



Mines at Capelton, Quebec. Old shafts and dumps.

CANADA
DEPARTMENT OF MINES
MINES BRANCH

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EUGENE HAANEL, PH.D., DIRECTOR.

PYRITES IN CANADA

ITS OCCURRENCE, EXPLOITATION, DRESSING, AND USES

BY

Alfred W. G. Wilson, Ph.D.

CHIEF OF THE METAL MINES DIVISION



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No. 167

LETTER OF TRANSMITTAL.

TO DR. EUGENE HAANEL,
Director of the Mines Branch,
Department of Mines,
Ottawa.

SIR,—I beg to transmit, herewith, a report on Canadian Pyrites: Its Occurrence, Exploitation, Dressing, and Uses.

I have the honour to be,
Sir,
Your obedient servant,

(Signed) Alfred W. G. Wilson.

OTTAWA,
May 10, 1912.

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List of Abbreviations.

- G. S. C.—Report of the Geological Survey of Canada.
O. B. M.—Report of the Ontario Bureau of Mines.
Eng. and Min. Jour.—Engineering and Mining Journal of New York.
Trans. A. I. M. E.—Transactions of the American Institute of Mining Engineers, New
York.
Can. Min. Jour.—Canadian Mining Journal.
Jour. Can. Min. Inst.—Journal of the Canadian Mining Institute.
C. P. R.—Canadian Pacific Railway.
G. T. P.—Grand Trunk Pacific Railway.

PYRITES IN CANADA:

ITS OCCURRENCES, EXPLOITATION, DRESSING, AND USES,

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Alfred W. G. Wilson, Ph. D.

INTRODUCTORY.

Sulphur is a chemical element which plays a most important part in our arts and manufacturing industries. Directly or indirectly, either as the element sulphur, or as a compound with other elements, it is associated with the manufacture of most chemicals, synthetic dyes, kerosene, explosives, sugar, starch, breakfast foods, textiles and fabrics of many kinds, paper, rubber goods, and so on through a long list of commodities, many of which are articles of everyday use. It also finds a place in medicine, and in agriculture it is used as a fungicide and in the manufacture of fertilizers. Among the compounds which sulphur forms with the other elements, the one which stands pre-eminent is that with oxygen, sulphur dioxide, SO_2 . From this compound is made sulphuric acid, individually one of the most important chemical compounds made by civilized man. The aqueous solution of the gas also forms the liquor which is used in the process of manufacturing sulphite pulp for paper making. By far the greater portion of the world's annual consumption of sulphur is utilized in the preparation of either of these two substances, they and their products being subsequently utilized in other manufacturing processes.

Sulphur dioxide gas is made in two ways, by burning sulphur in air, and by the burning or roasting of pyrites—a compound of iron and sulphur—in air. Nearly one half the sulphur consumed annually is obtained by roasting pyrites.

Native sulphur is not known to occur in Canada in commercial quantities; pyrites has been found in many localities, but it is mined only at a few points. The present rapid expansion of our manufacturing industries, and the projection of a number of large sulphide pulp mills, have started many inquiries regarding our supplies of this ore. Moreover, some of the industries in the adjacent republic, especially those located in the region of the Great Lakes, are also in need of additional supplies of ore. If pyrites ore of a suitable grade can be produced in Canada, with the assurance of a reasonably steady output, there is a large and immediate market for this product now available.

The present bulletin has been prepared in response to numerous inquiries respecting the pyrites resources of Canada. The writer has had a two-fold object in view—to supply practical information that will be of immediate value either to the producer or to the consumer, and to present a general outline of the methods employed for utilizing the sulphur contents of these ores that will be of interest and possibly of some value to non-technical men who may desire to become interested in the industry. For the property owner and prospective producer, it attempts to outline the present market requirements and to indicate where that market now exists; for the purchaser and manufacturer it provides the best available information with respect to our known deposits of pyrites. It does not purport to be an exhaustive treatise on the geology and mining of pyrites, nor on the methods of recovering the sulphur content from ores of this class. Technically-trained men and others interested in this information will usually be able to obtain it by referring to some of the many treatises which discuss the various phases of this subject.

The descriptions of the pyrites properties in Canada which are presented in this bulletin have either been obtained by corresponding directly with the owners of these properties, or by compiling the information from the best available reports. The writer's other duties have made it impossible, except in a few instances, for him to make a personal visit to each of the properties in question. An attempt has been made to assemble within the covers of a single volume, all the data which could be obtained with respect to pyrites properties in the various provinces of the Dominion of Canada. Such information as has hitherto been available is, for the most part, scattered through numerous public and private reports, many of which are difficult of access. The writer has attempted to collect and sift this information and in the present volume he has reproduced all that appeared to be of permanent value.

The bulletin also attempts to place before the owners of prospects, and others interested in mining, as reliable information as possible with respect to the present market conditions. Careful and direct inquiries of practically all the consumers of pyrites within two hundred miles of the international boundary have elicited the information that if Canada can produce suitable pyrites ore, there is a large and immediate market which requires more than four times her present annual production. The existence of this market justifies extensive exploration of properties which may possibly contain ore bodies of value. Owners of such properties can be assured of a market for their product, *provided they develop the property to a stage where steady shipments of a uniform grade of ore can be maintained*. Inasmuch as the large market which exists is for the most part in a foreign country, the author wishes to point out that he regards the development of a larger export industry in pyrites ore merely as a preliminary step to the development of associated manufacturing industries in Canada. The exportation of materials in a raw state is always to be deplored. Where the narrowness of the home market retards the development of natural resources and renders the establish-

ment of manufacturing industries impracticable, exportation of raw materials may usually be justified as a temporary expedient leading to the better development of our own resources. At the present time the market in Canada for sulphuric acid is a comparatively limited one. A reference to the annual reports of the Department of Customs shows that only an insignificant quantity of acid is imported. From this it may be inferred that practically all the sulphuric acid required, at present, for Canadian consumption is manufactured in Canada. On the other hand, a study of these same returns indicates that Canada imports from foreign countries many chemicals for whose manufacture sulphuric acid is required. Some of these might well be made in this country, and certainly will be, if the market shows further expansion. The development of scientific farming and the increasing use of artificial fertilizers will also tend to enlarge the market for many products for whose manufacture sulphuric acid is an important constituent.

The enlargement of the market for the products of sulphuric acid, together with an increased production of the acid, will encourage the pyrites mining industry in this country. At present, the very high cost of the acid on the open market tends to curb the development of allied industries.

In connection with the possibility of enlarging the home market for pyrites, considerable space has been devoted to a discussion of the possibility of using pyrites as a source of sulphur for the manufacture of sulphite pulp. At present it is a matter of regret that much of our annual production of pulp wood is exported in an unmanufactured condition. This also is true of the surplus pyrites ore, over and above that required for home consumption. The wages, manufacturer's profits, and other increments in value, which accrue through subjecting raw materials to manufacturing processes, are lost to this country. Moreover the industrial population which is supported by such industries as these is, of necessity, located where the manufacturing takes place. Their location in the country of production would mean also an increased market for food and textile products.

The pulp manufacturing industry in Canada has been expanding rapidly in recent years. Where sulphite pulp is made imported sulphur is used exclusively.¹ European mills, on the other hand, almost without exception, find it profitable to use pyrites as a source of sulphur. That this is so is not due solely to the fact that European labor is cheaper, but because pyrites is cheaper than sulphur. Several experimental plants have been erected for this purpose in America; but the process is not yet well established. That pyrites can be used for this purpose, and that the process is more economical than when sulphur is used (*at the present relative market prices*) is an established fact. The development of a sulphite pulp industry in Canada, in which pyrites will be used, depends upon the technical skill of our sulphite pulp makers on the one hand, and on our pyrites miners on the other. If a regular supply of suitable ore could be assured for a term of years, some of our pulp mills, which are favorably located with respect to the mines,

¹ One large mill is now projected in which pyrites will be used in place of sulphur.

would be warranted in installing suitable roasting plants. Under existing conditions, when no guarantee can be given that plenty of suitable ore is available at a reasonable price, our mill owners naturally hesitate to assume the heavy capital expenditure necessary to install the roasting plants.

It may be pointed out that mills located in the valley of the St. Lawrence river are particularly favored in regard to a guarantee of suitable ore. There are two operating pyrites mines in the province of Quebec producing suitable ores and with good shipping facilities. There is every reason to believe that these properties have large ore reserves, and, in addition, there are some excellent prospects in the neighborhood of the working mines. Any manufacturer so located that he could obtain ore from these mines at a reasonable rate should have little hesitation in experimenting with a view to installing the necessary pyrites roasting plant. Such a manufacturer, because of his location, is always in a position to procure foreign ores, especially Spanish ores, at current seaboard prices and the supply of these ores is very large. He therefore has the assurance that if, for any reason, his Canadian ores fail, he will not have to permit an expensive plant to lie idle. On the other hand, if the mine owners and others interested in the development of the district were sure of a good and steady nearby market for their ore, they would, for their own protection and advantage, put themselves in a position to accept long-time contracts and to maintain a constant and regular output of ore. The possibility of the competition of foreign ores will have a steadying effect on the contract prices for the sulphur content of the native ore.

Sulphite pulp mills in the vicinity of the Great Lakes would not find conditions quite so favorable as those on the St. Lawrence. There will probably be an abundant supply of ore available in the future, since the existence of a number of large ore bodies north of the Great Lakes is known. The grade of the ore is not, on the average, so high as that of the Quebec ores, but it usually roasts cleaner. The competition of United States buyers, who even now are not able to obtain all the ore they require, will tend to increase the cost. Even here, however, the market is influenced by the cost of Spanish ores, and prices as a rule will not tend to fluctuate seriously, and the saving in contrast with sulphur costs will be very large. Where the sulphite pulp mill owners take the precaution to mine their own ore as well as to cut their own pulp wood, their sulphur costs will be independent of the market and will represent only the costs of mining, dressing and delivering the ore from their own properties.

Chapters on the manufacture of sulphuric acid and on the burning of sulphur have been included in response to requests for general information of this character. There are available many technical works dealing with the manufacture of sulphuric acid. The technical expert or prospective manufacturer will naturally consult these works when in search of detailed technical information. The descriptions of the processes which are given in this report are intended, rather for the non-technical man who may be interested in the pyrites industry and in learning of the industrial processes for which pyrites is a raw material.

The various types of roasting furnaces described in the text are those now in use in chemical works in America or Europe, for the purpose of preparing sulphur dioxide gas. The subject of roasting ore for the sole purpose of driving off a portion of the sulphur content, does not come within the scope of this bulletin. Therefore it will be found that no descriptions are given of many types of roasting furnaces which are usually used solely for this purpose, and not primarily intended to recover the sulphur content of the ore. The writer is indebted either to the designers or to the manufacturers of the various types of furnaces described, for drawings and photographs from which the plates, which accompany this bulletin, have been prepared. In many instances the original patent specifications have also been consulted.

The author has been privileged to inspect either the whole plant or those portions of the plant in which he was interested, at about twenty-five different chemical works and sulphite pulp mills in Canada, the United States and Newfoundland, where sulphur or pyrites are utilized in manufacturing processes. In practically every instance, valuable information and suggestions have been placed at his disposal by officers of these corporations. It has not been possible to individually acknowledge these courtesies in the accompanying bulletin—indeed in many instances, the author was requested not to do so. It has been thought best to refrain from making any specific reference to any individual plant. The writer wishes, however, to express his sincere thanks to the many gentlemen who received him so courteously, and to acknowledge his indebtedness to them for much valuable information.

It is a matter of regret that the author has not had the opportunity of studying the operation of pyrites burning plants and the gas purifying systems of some of the sulphite pulp mills in Scandinavia and in Germany, where pyrites is used as the source of sulphur. It is considered that such first hand information might have furnished valuable data to those who are interested in the installation of similar equipment in this country.

CHAPTER I.

SULPHUR AND ITS COMPOUNDS.

Sulphur

Sulphur, which occurs native or in the free state, has been known to mankind since very early times. The ancients employed it for fumigating purposes and also in certain religious rites. It appears, also, to have been used for destroying fungus growths in vineyards and orchards, for treating skin diseases, for lighting fires and preparing torches, for cementing glass, for bleaching, for "mello" work in metals, and for many other purposes in a manner similar to the uses to which it is applied at the present day.¹ It was formerly termed brimstone and was considered by the alchemists to be the principle of combustibility.

The compounds of this element occur in nature in much larger quantities and are much more widely distributed than free sulphur itself. The compounds of sulphur with the metals, termed *Sulphides*, and those with the metals and oxygen, termed *Sulphates*, are found in large quantities in some localities. The more important compounds of sulphur which occur as natural products are:—

(1) *Sulphides*.—Iron Pyrites FeS_2 ; Pyrrhotite, Fe_7S_8 ; Copper Pyrites or Chalcopyrite, CuFeS_2 ; Bornite, Cu_3FeS_3 ; Galena, PbS ; Sphalerite or Zinc Blende, ZnS ; Cinnabar, HgS ; Stibnite or Grey Antimony, Sb_2S_3 ; Realgar, As_2S_2 ; Orpiment, As_2S_3 .

(2) *Sulphates*.—Gypsum, $\text{CaSO}_4 + 2 \text{H}_2\text{O}$; Anhydrite, CaSO_4 ; Heavy Spar, BaSO_4 ; Kieserite, $\text{MgSO}_4 + \text{H}_2\text{O}$; Epsom Salt or Epsomite, $\text{MgSO}_4 + 7 \text{H}_2\text{O}$; Glauber Salt or Mirabilite, $\text{Na}_2\text{SO}_4 + \text{H}_2\text{O}$; Green Vitriol or Melanterite, $\text{FeSO}_4 + 7 \text{H}_2\text{O}$.

Physical and chemical properties of sulphur. Sulphur occurs in nature in the form of crystals and also massive, in spherical or reniform shapes incrusting stalactitic and stalagmitic forms, and in powder. In colour it is canary yellow, straw and honey yellow, yellowish brown, greenish, reddish to yellowish grey. The streak is white, the lustre, resinous adamantine. It is transparent to translucent; as usually occurring, it is semi-transparent at the edges and of the well-known bright canary-yellow colour, which darkens with an increase in temperature; at -50°C ., it is nearly colourless; it is practically tasteless and without odour, does not conduct electricity but becomes negatively electrified by friction. It is brittle, and has a hardness between 1.5 and 2.5. The specific gravity is 2.07 and the atomic weight 32.06. (Oxygen 16).

¹ See Lunge, Sulphuric Acid and Alkali, 3rd Edn., Vol. I, Part 1, p. 14 et seq.

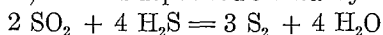
Sulphur melts at 110.5° C. and forms a thin, light yellow liquid, which on being more strongly heated becomes darker and thicker; between 250° – 260° C. it is nearly black and so viscid that it will not flow or pour; as the temperature is raised further it becomes thinner, and is of a brownish colour; at 440° C. it boils, forming a brownish-red vapour. It begins to volatilize before the boiling temperature is reached.

Sulphur exists in a number of allotropic modifications; it can be obtained in a number of different crystalline forms and in at least two amorphous varieties, one of which is soluble and the other insoluble in carbon bisulphide. A form is also known which is soluble in water.¹

Foreign.—Occurrence of sulphur

Native sulphur occurs in many parts of the world either in beds of gypsum and associated rocks or in the regions of active and extinct volcanoes. It occurs in Sicily in the valley of Noto and Mazzaro; on the Italian mainland, it occurs in Romagna and Marche in Central Italy.² It also occurs in the Apennines between Forli and Macerata. In the south of Italy it occurs in the province of Avellino, in the Sabato valley, and in Calabria, in the region of Cottona. A small quantity has been found in the solfatara near Naples. It is deposited from hot springs in Iceland, Savoy, Switzerland, Hanover, and in other countries. Deposits occur in Upper Egypt and large deposits are reported from Russia in Kyrk-Tschulva in the Transcaspian district of Aschabad near Schjich.

Sulphur associated with solfatara has been found near many of the world's volcanoes. Volcanic gases almost always contain sulphur dioxide, SO_2 , and sulphuretted hydrogen, H_2S , and when these two gases come into contact in the presence of water vapor, they mutually decompose with the liberation of sulphur, which is deposited on nearby surfaces when sufficiently cool.



Sulphur of this type is abundant in the Chilian Andes in South America, and it has been obtained from China, India, the Philippine Islands and Sandwich Islands.

In Mexico, it is found in several localities, in the crater of Popocatepetl, at Los Cerritos, San Luis Potosi, at Los Conejos, Durango, near Torreon, in Tamanlipas, in Lower California, at El Promentorio and Las Virgines.

In the United States, it is found:—in Wyoming, in the Unita Mountains, 30 miles southeast of Evanston, near Thermopolis, Tremont county, in the upper part of Sunlight Basin, Park county; in the Yellowstone park in deposits and about fumaroles; in Idaho, near Soda Springs; in Colorado, in Mineral county; in Nevada, near Humboldt House, and at Rabbit Hole Springs, Humboldt county, Steamboat Springs, Washoe county, Columbus, Esmerala county; in southern Utah in large deposits (once mined at Cove

¹ See Dana, Mineralogy; Roscoe and Schorlemmer, Treatise on Chemistry; Lunge, Sulphuric Acid and Alkali.

² See "The Sulphur Industry of Italy," Mineral Industry, Vol. VIII, 1899, pp. 592-616. and Mineral Resources of the United States, 1910, Part II, page 785.

creek, Millard county, now mined in Black Rock district) in California at the geysers of Napa valley, Sonoma county, in Santa Barbara, near Clear Lake, Lake county; also on the west slope of Mount Lassen, 55 miles from Red Bluff, Tehama county; in Texas, at several points, Bryan Heights, Brazoria county, Matagorda, Liberty, and the west side of Brazos river; in Louisiana, in Calcasieu parish and other localities where the so-called "dome" formations occur.

Occurrence of Canadian sulphur.—In Canada native sulphur has been noted, in the reports of the Geological Survey, as occurring in many different localities. In every instance; however, the finds were only of interest as mineralogical occurrences and *none of economic importance are known.* In several of the occurrences, the sulphur found was formed by the decomposition of pyrites; the other occurrences are associated with springs of mineral water charged with sulphuretted hydrogen, or with gypsum deposits.

Native sulphur has been found in scattered crystals in a gypsum quarry in Colchester county, Nova Scotia.¹ In Ontario, at Clinton, Huron county, there is a deposit affording masses of pure yellow compact or fine grained sulphur, together with small transparent crystals of the same.²

The deposits associated with mineral springs are all small and are too numerous for all to be mentioned in detail.

Numerous springs, the water of which is impregnated with sulphuretted hydrogen, occur in Ontario, in Manitoba and in western Canada—especially in the Rocky mountain region. McConnell reports mineral springs of large volume at Sulphur point, on the southeast shore of Great Slave lake and at the tar springs north of Point Brule on the north shore of the same lake. In both cases, small quantities of sulphur are deposited in the basins of the springs and along the channels of the streamlets which drain them.³

An interesting occurrence, which is worthy of further investigation, was reported by Selwyn from the Smoky river, Alberta.⁴ The river is named from the fact that at a number of places, white, sulphurous fumes, having the appearance of smoke, are emitted from the ground. These "bocannes," as they are called, are found along the valley of the river. "The banks of the river are high and steep, and the strata are well exposed in the great slides which have taken place in the soft, dark grey or black shales of which they are composed. Where the fires have burnt out, the cliffs present a variety of shades of red, yellow and white, and where the smoke or vapour is still issuing from the ground, there are large patches, which at a distance look like snow and sulphur—lead white and brilliant yellow." Some of this material, brought back by Selwyn, was analyzed by Hoffman and he gives the following composition:⁵—

¹ C. G. S., Vol. IV, Part T, p. 61.

² C. G. S., Vol. IV, Part T, p. 61.

³ G. S. C., Vol. IV, Part D, p. 31.

⁴ G. S. C., 1875, 76, pp. 58, 73.

⁵ C. G. S., 1875-76, p. 420.

Sulphur.	46.517
Ammonium chloride	50.422
Ammonium sulphate.	1.807
Potassium sulphate.	0.035
Sodium sulphate	0.274
Calcium sulphate.	0.146
Sulphuric acid (SO ₄), probably pertaining to the traces of iron and magnesium.	0.014
Extraneous matter	0.922

100.137

The phenomena observed here were formerly attributed to the combustion of beds of lignite. Selwyn notes that neither coal nor lignite beds are to be seen in the locality and states that the beds (seen by him) do not contain much pyrites. Dawson, who visited the Smoky river in 1879, records the finding, by Hoffmann, of a large quantity of very finely divided pyrites with carbonaceous matter in these shales. He considers that "these together are quite sufficient to account for the slow combustion observed, and that the pyrites may, under certain circumstances, spontaneously initiate the phenomena by the heat evolved during its decomposition."¹

Sulphur for the Canadian Market

Sulphur sold on the Canadian market comes almost wholly from three sources; in the east and in the region of the Great Lakes both Sicilian and Louisiana sulphur are used; in British Columbia, the sulphur used nearly all comes from Japan. A small quantity of English recovered sulphur is also occasionally imported into eastern Canada.

Descriptions of the methods employed in Sicily to mine sulphur ores and to recover the sulphur will be found in various articles in the "Mineral Industry," and in Lunge, "Sulphuric Acid and Alkali." A more complete description of the present status of the industry, together with some suggestions as to a new method of utilizing crude sulphur, was published in the *Bollettino Ufficiale del Ministero d' Agricoltura, Industria, Rome 1908, Anno. VII, Vol. 1, Fasc., 3, pp. 361—400, and 1909, Anno. VIII, Vol. II, Serie C, Fasc. 9, by Prof. Guisepppe Oddo of the University of Pavia.* Abstracts of these articles were published in English in the *Mining Journal, London, Vol. 89, pp. 544, 545, and pp. 582—583, 1910.*

The Louisiana sulphur deposits are described in several articles in the *Mineral Industry*. A theory of the origin of the deposits was discussed by Lee Hager in the *Engineering and Mining Journal, "The Mounds of the Southern Oil Fields," Vol. 78, pp. 137—139 and pp. 180—183, 1904.* The deposits are described and their origin discussed by Prof. G. D. Harris, in *Bulletin No. 7, Geological Survey of Louisiana, on "Rock Salt, its Origin, Geological Occurrences and Economic Importance in the State of Louisiana"*

¹ C. G. S., 1879-80, Part B, p. 57 and p. 123.

1908—the sulphur and salt deposits being associated. Prof. Harris also discusses the subject in *Economic Geology*, Vol. IV, pp. 12–34, 1909, under the title “The Geological Occurrence of Rock Salt in Louisiana and Texas.” A description of the Frasch process for recovering sulphur, as applied in the Louisiana field, will be found in the *Mineral Industry*, Vol. V, 1896, p. 514.

In Japan, with one exception, all the sulphur mines of Hokkaido and the northern mainland are volcanic deposits. The principal mine is located at Oshino in the prefecture of Hokkaido. There are also important mines at Furutakei, Yuwaoto, Shikabe and Furano in Hokkaido. Sulphur is also obtained at a number of other localities, notably at Numajiri in Fukushima. The larger portion of the Japanese sulphur is simply congealed from sulphur springs which occur in the volcanic regions. The sulphur from Hokkaido, when obtained in the solid state, is simply melted in large boilers and sorted into several grades.

Compounds of Sulphur

The compounds of sulphur which form the principal sources of supply of this material are Pyrites, Chalcopyrite, and to a less degree, Bornite, Galena and Sphalerite. The first three of these, only, are important in the present discussion. In the following paragraphs, brief notes on the mineralogy of each of these substances are given; descriptions of two minerals, closely related to Pyrites, Marcasite and Pyrrhotite are also included.¹

Pyrites

Composition—Iron bisulphide, FeS_2 —Sulphur 53.34%, Fe 46.66%.

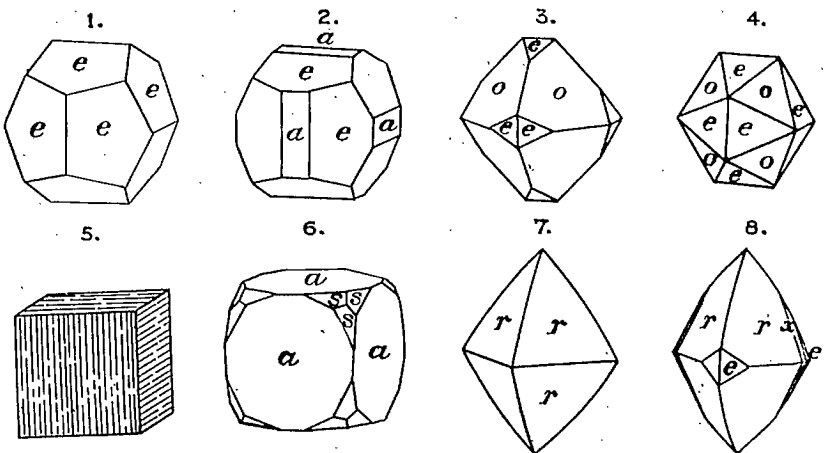


Fig. 1. Crystal forms of pyrites. (After Dana.) 1-6. Simple forms. 7, 8. French Creek.

¹ See Dana, *System of Mineralogy*; Miers, *Mineralogy*; Hintze, *Handbuch der Mineralogie*; or other standard works on mineralogy.

Synonyms—Pyrites, Iron Pyrites, Mundic, Fool's gold, (English), Schwefelkies, Eisenkis, Pyrit (German), Pyrite, Fer sulfuré, (French), Svafvelkis (Swedish), Pirite (Italian), Pirita, Pirita amarilla, Bronce (Spanish).

Forms.—Pyrites when in crystal form, crystallizes in the isometric or cubic system. The commonest forms are the cube (Fig. 1-5), the pentagonal dodecahedron (or pyrito-hedron) (Fig. 1-1), and the octahedron (Fig. 1-7); often the faces of crystals are striated in one direction. Pyrites also occurs in massive, granular, radial reniform or globular forms.

Cleavage.—An indistinct cleavage occurs parallel to the faces of the cube, and another parallel to the octahedron.

Fracture.—Conchoidal and irregular.

Hardness.—Brittle, H = 6 — 6.5.

Specific Gravity.—4.95 — 5.10.

Lustre.—Metallic, splendent to glistening.

Colour.—A pale brass-yellow, nearly uniform.

Streak, Powder.—Greenish black or brownish black.

Aspect.—Opaque.

Notes.—Thermo-electrically both positive and negative varieties occur. A part of the iron is sometimes replaced by nickel, cobalt, thalium or copper in very small quantities; copper in the form of the sulphide (chalcopyrite, bornite, etc.) also occurs as a mixture with pyrite. Gold is sometimes present, distributed invisibly through it, auriferous pyrite being an important source of gold. Small quantities of arsenic, silica or selenium, and occasionally zinc blende or galena may also occur.

Determination.—In a closed tube a sublimate of sulphur is formed and the residue is magnetic. Before the blowpipe it gives off sulphur which burns with a blue flame and exhibits the characteristic odor of sulphur dioxide. It is insoluble in hydrochloric acid, but is decomposed by nitric acid. It can usually be readily recognized by its color and other physical properties.

The mineral derives its name from the Greek word $\pi\upsilon\rho$ —fire—in allusion to the sparks which are thrown off when the ore is struck with a hammer, or other hard, blunt instrument. The sparks can be readily produced by rubbing over a coarse file, and the odor of burning sulphur can be detected.

Occurrence.—Pyrites occurs abundantly in rocks of all ages. In the crystal form it usually occurs in small cubes, pyrito-hedra, octohedra or less common forms. It also occurs in irregular or spheroidal nodules, and in veins. It is frequently found in clay slates, argillaceous sandstones and in other rocks of the coal formations.

Ores of commercial value usually occur in huge, lenticular masses, less frequently in veins; they most frequently appear to be associated with basic intrusive rocks—though the deposits themselves may occur in rocks of any kind. Enormous deposits of massive pyrites, the most important at present known, occur in Spain and Portugal (Rio-Tinto, Tharsis, Santo Domingo). Others are known in Italy, France, Germany, Norway, Russia, Japan, South America, Mexico, United States and Canada.

The nodular masses of pyrites which occur in coal seams, "coal brasses" of the miners, are in some localities an important source of commercial pyrites.

Alterations.—Pyrites readily changes to an iron sulphate by oxidation, some sulphur being set free. On its surface, it may often be altered to limonite and subsequently from limonite to red oxide of iron. Green vitriol, limonite, göthite, hematite, quartz, graphite, and ochreous clay all occur as pseudomorphs after pyrite.

The alteration of the upper portion of pyrites and kindred deposits to limonite and hematite gives rise to the "gossan" caps which are characteristic of the surface exposures of all large pyrites deposits.

Marcasite

Composition.—Iron bisulphide, $\text{FeS}_2 = \text{Sulphur } 53.34\%, \text{ Fe } 46.66\%$.

Synonyms.—Cockscomb, Spear, Cellular, White Pyrites (English); Wasserkies, Kammkies, Speerkies, Strahlkies, Zellkies (German); Fer sulfuré blanc, Pyrite bland, Marcassite (French); Pirite bianca (Italian); Marcasita, Pirita blanca (Spanish).

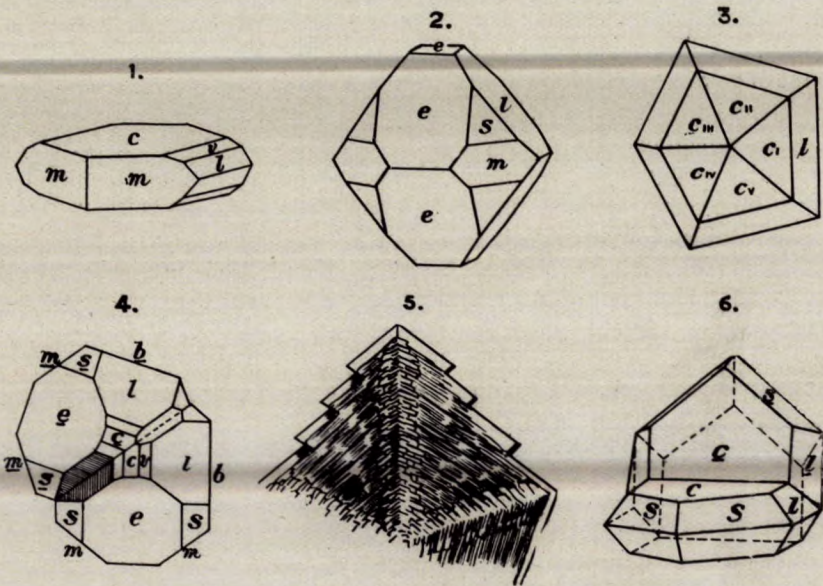


FIG. 2. Crystal forms of marcasite. (After Dana.) 1. Common form. 3. Schemnitz. 3. Freiberg. 4. Galena, Ill. 5. Folkestone. 6. Freiberg.

Form.—It crystallizes in the orthrhombic system. The crystals are commonly tabular and also pyramidal, frequently striated. It is not found in simple crystals, but owing to its multiple twinning, presents a great variety of shapes with jagged outlines and re-entrant angles—hence the colloquial names "Cockscomb pyrites," "Spear Pyrites," etc. Marcasite occurs in

stalactites with radiating internal structure and the exterior covered with projecting crystals. It also occurs in reniform, globular and discoidal shapes.

Cleavage.—Distinct parallel to the prism faces.

Fracture.—Uneven.

Hardness.—Brittle, $H = 6-6.5$.

Specific gravity.—4.85–4.90.

Lustre.—Metallic.

Colour.—Pale bronze-yellow, deepening on exposure.

Streak, Powder.—Grayish or brownish black.

Aspect.—Opaque.

Determination.—Is like pyrite, but is more liable to decomposition. It is distinguished from pyrite by its crystalline structure, and usually by its lighter colour.

Occurrence—It occurs under much the same conditions as pyrite but is not so common a mineral in crystalline rocks or in metalliferous veins; it is more common than pyrites in the form of nodules and concretions of organic origin in sedimentary rocks. The spear variety occurs very abundantly in the plastic clay of the brown coal formation at Littmitz and Altsattell, near Carlsbad in Bohemia, and is extensively mined for its sulphur or for use in the manufacture of ferrous sulphate. Crystals and crystallized material have been reported from many places both in Europe and in America. It does not occur massive, and is not an important ore of sulphur.

Alterations—Marcasite is very liable to decomposition; it is often altered to brown limonite on the surface; many specimens fall to pieces, especially when exposed to a moist atmosphere. Limonite and pyrite occur as pseudomorphs after marcasite, also bournonite, chalcopyrite, magnetite, and sphalerite.

Pyrrhotite

Composition—This mineral is of somewhat doubtful composition, the analyses indicating considerable variation. Different formulae ranging from Fe_5S_6 to $Fe_{11}S_{12}$ have been given; they all conform to the general formula Fe_nS_{n+1} . Some of the purest specimens approach very closely to the monosulphide FeS in composition and the ore is often referred to as the mono-sulphide.

The percentage composition varies with the formula:

$Fe_7S_8 =$ Sulphur 39.6%, Iron 60.4%

$Fe_8S_9 =$ Sulphur 39.2% Iron 60.8%

$Fe_{11}S_{12} =$ " 38.4% " 61.6%

Pyrrhotite often contains cobalt, nickel, or copper (as chalcopyrite or bornite), occasionally arsenic, and sometimes silver, gold, platinum and some of the rarer metals.

Synonyms.—Magnetic pyrites (English); Mangetkies, Leberkies, (German); Pyrite magnetique, Fer sulfuré magnétique (French); Magnetkis (Swedish), Pirrotina (Italian), Pirita magnética (Spanish).

Form.—Usually classed as hexagonal; pyrrhotite generally occurs massive with a granular structure.

Cleavage.—A distinct basal cleavage is sometimes exhibited by crystals, which are usually hexagonal plates.

Fracture.—Uneven to subconchoidal.

Hardness.—Brittle, $H = 3.5-4.5$

Specific gravity.— $4.58-4.64$

Lustre.—Metallic.

Colour.—Between bronze-yellow and copper red, and subject to speedy tarnish.

Streak, powder.—Dark grayish black.

Aspect.—Opaque.

Notes.—Pyrrhotite is magnetic, the magnetism varying much in intensity. Sometimes it possesses polarity.

Determination.—Its peculiar bronze colour and magnetic properties serve to distinguish pyrrhotite from iron and copper pyrites. It remains unchanged when heated in the closed tube. In the open tube it gives off sulphurous fumes, and becomes more strongly magnetic. It is decomposed by hydrochloric acid with the evolution of hydrogen sulphide.

Occurrence.—Pyrrhotites occur in Norway, Sweden, Germany (Harz, Bavaria, Saxony), Austria (Bohemia) and elsewhere in Europe. They are reported from Brazil and from many states of the United States—notably Maine, Vermont, Massachusetts, New York, New Jersey, Pennsylvania, Virginia and Tennessee. Pyrrhotite ores containing copper are an important source of copper and sulphur in the vicinity of Copperhill and Isabella, Tennessee. In Canada, several deposits are known in the Maritime provinces, in Quebec, in Ontario and in British Columbia. The most important of these at the present time are those of the Sudbury district, Ontario—the ores being mined and treated for their copper and nickel content. Many of these pyrrhotites do not contain nickel in economic quantities.

Pyrrhotites, when of economic importance, usually occur in lenticular masses or pipes of massive ore associated with a basic igneous rock. The nickeliferous pyrrhotites of the Sudbury district are nearly all associated with a characteristic rock called norite—soda-calcic feldspar, with enstatite or hypersthene.

Chalcopyrite

Composition.—A sulphide of copper and iron, $CuFeS_2$ or $Cu_2SFe_2S_3 =$ Sulphur 35.0, copper 34.5 iron 30.5.

Analyses often show variations from the formula, due in most cases to the mechanical admixture of pyrite. Chalcopyrite sometimes contains small amounts of silver or gold; thallium is also present at times.

Synonyms.—Copper pyrites, Peacock ore in part (when tarnished), (English); Kupperkies, Chalkopyrit (German); Chalcopyrite, Cuivre py-

riteux (French), Kopparkis (Swedish), Calcopyrite, Rame giallo, Pirite di rame (Italian), Cobre amarillo, Bronze amarillo, Bronze de cuivre (Spanish).

Form.—Crystallizes in the tetragonal system. Crystals are commonly tetrahedral in aspect, the faces large, dull in lustre or oxidized, and diagonally striated. It often occurs massive and compact.

Cleavage.—Distinct parallel to certain faces.

Fracture.—Uneven.

Hardness.—Brittle, $H = 3.5-4$.

Specific Gravity.— $4.1-4.3$.

Lustre.—Metallic.

Colour.—Brass-yellow, often tarnished or iridescent.

Streak Powder.—Greenish black.

Aspect.—Opaque.

Determination.—In the closed tube decrepitates and gives a sublimate of sulphur. In the open tube gives off sulphur dioxide. Upon charcoal fuses to a magnetic globule; with soda gives a globule of copper containing iron. The roasted mineral gives reactions for copper and iron. Dissolves in nitric acid with the liberation of the sulphur forming a green solution; the addition of ammonia to neutralize the solution will precipitate the iron as brown ferric hydroxide and the resulting solution will be of a deep blue colour.

It can be distinguished from pyrites by its colour and hardness. The iridescent purplish tarnish is very characteristic, but must be distinguished from the colour of bornite (which see).

Occurrence.—Chalcopyrite constitutes one of the principal sources of copper; possibly three-fourths of the world's annual production is derived from ores of this mineral. It occurs in masses, in veins, and disseminated through gangue materials of various kinds, often quartz. The country rocks may be gneisses, crystalline schists, or igneous rocks of various kinds. Other sulphides are usually found associated with the chalcopyrite. The commonest of these are pyrite, galena and spalerite, bornite, pyrrhotite, chalcocite, tetrahedrite, and even cassiterite are also found in association with it. Silver and gold sometimes occur, and more rarely nickel and cobalt.

Deposits containing chalcopyrite occur in many of the countries of Europe, in South Africa, Australia, South and North America. In Canada, small quantities have been mined in the Maritime provinces. A considerable output has been obtained from Quebec mines; it is widespread in Ontario in the country north of lake Huron, though no important mines are now in operation for the chalcopyrite alone. The copper content of the nickeliferous pyrrhotites of the Sudbury district probably occurs in chalcopyrite. Numerous localities in British Columbia and in Northern Canada are known to exhibit this mineral.

Chalcopyrite is not normally an ore of sulphur. Incidentally it may happen that its sulphur content can be recovered. Many pyrite ores, however, contain chalcopyrite in small amount, and after roasting the pyrites

to recover the sulphur, it is often desirable to treat the cinder to recover their copper content. The presence of copper decreases the amount of sulphur recoverable from the ore.

Alteration.—Chalcopyrite becomes oxidized under atmospheric influence; the copper becomes converted into the soluble sulphate and may be removed by natural leaching leaving a residue of hydroxide of iron or limonite. Secondary products formed by the decomposition of chalcopyrite are malachite, covellite, chrysocolla, melaconite, chalcocite, and occasionally tetrahedrite.

Bornite

Composition.—A sulphide of copper and iron, but varying in the proportions of these metals. The crystallized mineral agrees with the formula $\text{Cu}_3\text{FeS}_3 = \text{Sulphur } 28.1\%$, copper, 55.5% , iron $16.4\% = 3 \text{ Cu}_2\text{S} \cdot \text{Fe}_2\text{S}_3$ (Groth) or $\text{Cu}_2\text{S} \cdot \text{CuS} \cdot \text{FeS}$. The massive varieties give from 50% to 70% copper and 15% to 6.5% of iron, this variation being due in part at least to the mechanical admixture of other sulphides.

Synonyms.—Erubescite, Purple Copper Ore, Variegated Copper Ore, Peacock Ore, (English), Buntkuppererz, Kupperkies. (in part), Kupperlazul (German); Bornite, cuivre panaché (French); Brokig Kopparmalm (Swedish).

Form.—Crystallizes in the regular system. Common form is cubes, faces often rough or curved. It also occurs massive, with a granular or compact structure.

Cleavage.—Imperfect, in traces only.

Fracture.—Conchoidal, uneven.

Hardness.—Brittle, $H = 3$.

Specific gravity.— $4.9-5.4$.

Lustre.—Metallic.

Colour.—Between copper red and pinchbeck-brown on fresh fracture, speedily iridescent from tarnish.

Streak, Powder.—Pale grayish black.

Aspect.—Opaque.

Determination.—It is very similar to chalcopyrite. In the closed tube it gives a faint sublimate of sulphur. In the open tube yields sulphur dioxide, but no sublimate. On charcoal it fuses to a brittle magnetic bead. The roasted ore gives reactions for copper and iron. It is soluble in nitric acid forming a green solution with the separation of sulphur; the addition of ammonia will precipitate the iron as the reddish brown hydroxide, and will change the colour of the solution to a characteristic blue. The mineral is distinguished from chalcopyrite by its purple colour.

Occurrence.—This mineral comes second to chalcopyrite as an important source of the metal copper. It occurs usually associated with the other copper minerals in veins and disseminated through crystalline schists. Occurrences are reported from Germany, Hungary, Norway, Sweden, Spain, England, and other countries in Europe; from Chili, Peru, and other places

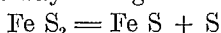
in South America; from Mexico and from many states of the United States. In Canada, it was once an important ore in the eastern townships of Quebec. It also occurs in Ontario and in British Columbia.

The ore is valuable for its copper content. It occasionally occurs associated with pyrite, but in itself is not an ore of sulphur. An ore which contains much copper, say above 6% or 7%, due to the presence of either bornite or chalcopyrite, will not usually be considered as a sulphur ore, and will not be treated as such.

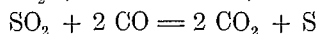
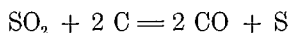
Artificial Production of Sulphur

The problem of producing sulphur artificially from sulphides of the metals is one of considerable practical as well as theoretical interest.¹

It has long been known that pyrite or chalcopyrite when heated in the absence of oxygen (or air) will yield sulphur. The residue from heating pyrites in this way is magnetic and is a variety of pyrrhotite.



Sulphur dioxide can be decomposed in a variety of ways. If passed over heated carbon, sulphur is liberated and the oxygen unites with carbon to form either the dioxide or the monoxide or both, dependent upon the conditions of the experiment.



Sulphur is also freed from the dioxide in the presence of hydrogen.



If sulphur dioxide is passed over sulphides of the alkalies heated to a red heat, sulphur is liberated. Where calcium sulphide is used the sulphide at first absorbs the gas; afterwards sulphur distils over and the sulphide becomes converted into the sulphate. The latter can again be reduced to the sulphide by heating it red hot and passing coal gas over it.

Sulphuretted hydrogen also can be decomposed by oxidation with the liberation of sulphur.

At some time or other each of these reactions has been utilized in an attempt to develop a commercial process for the manufacture of sulphur. In the majority of cases these processes do not appear to have been successful on a commercial scale.² An important exception is the Chance-Claus process for preparing sulphur from soda waste from the Leblanc process. In England about 30,000 tons of sulphur per annum are recovered in this way.³

The discovery or invention of a process whereby the sulphur content of the sulphur dioxide gases, that are discharged from smelters, can be recovered economically would be of great value *in some localities*. Some smelters are located so far from any possible market for any sulphur they might recover

¹ See Lunge, Sulphuric Acid and Alkali, 3rd Ed., Vol. I, Part I, pp. 25-30.

Also Schnabel, Handbook of Metallurgy, 2nd Ed., Vol. II, pp. 104-106.

² Compare Lunge, Sulphuric Acid and Alkali, 3rd Ed., Vol. II, Part II, p. 904.

³ Lunge, op. cit., pp. 943-959.

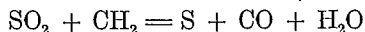
that it is doubtful if such a process would be of benefit to them. Others, however, are within reach of a market for sulphur if it could be economically recovered from the waste gases. Attempts have been made, from time to time, to convert this waste sulphur dioxide into sulphuric acid at the smelter. This is being done successfully at the smelter of the Tennessee Copper Company at Copperhill, Tennessee, and at the plant of the Ducktown Sulphur, Copper and Iron Company at Isabella, Tennessee. Both of these smelters are located in a district where there is a heavy demand for acid for the manufacture of artificial fertilizers, and hence their opportunity was exceptional.

Sulphur recovered from these waste gases would be more easily handled than sulphuric acid, and could reach a broader market than that available for the acid. It is very doubtful if any of the smelters in Canada could recover their sulphur by manufacturing sulphuric acid and *make it pay*. In some cases, if the sulphur in the waste gases could be *recovered as sulphur* it could probably be marketed readily. The daily output of sulphur in the waste gases from some of our smelters is very large. A process to recover the sulphur might easily be so *successful technically* that its *success commercially* at certain plants would be negated. The very large output of sulphur that would result from a recovery of even 50% of that now lost at these smelters would very quickly overload the Canadian market and would greatly reduce the price of sulphur. Where the radius of profitable distribution is large enough and reaches to the broader market in the adjacent United States, this cheapening might not be detrimental to the commercial success of the process. The whole question, however, is a deeply involved problem in economics that will require very careful consideration before any process that is a technical success can be put into operation on a commercial scale.

A process designed for this purpose has been recently tried experimentally at Campo Seco, California, and the results obtained are very encouraging. The following notes are compiled from two articles, descriptive of the process, which were published in the Mining and Scientific Press of San Francisco.¹

The Thiogen Process for the recovery of Sulphur from Sulphur Dioxide.

The principle involved in the reactions utilized in the Thiogen process is the reduction of the gas by means of a hydrocarbon. Assuming for simplicity's sake, a hydrocarbon of the formula CH_2 , the reduction should proceed as follows:—



Since the conversion of sulphur dioxide into free sulphur and free oxygen is a reaction that involves an absorption of energy, such reaction cannot be accomplished without supplying such energy. This energy must therefore be supplied in any process which is successful.

¹The Thiogen Process for Reduction of SO_2 in Smelter Fume, by Stewart W. Young, Min. & Sci. Press, Vol. CIII, pp. 386-387, Sept. 23rd, 1911.

Experiments with the Thiogen Process, by Frank L. Wilson, Min. & Sci. Press, Vol. CIV, pp. 497-498, April 6, 1912.

In practice very serious difficulties stand in the way of a solution of this problem; these are partly chemical and partly mechanical. Young states the more important of these difficulties as follow:—

(1) The presence of free oxygen in the gases to be treated, bringing about a serious waste of hydrocarbon.

(2) The slowness and incompleteness of the reactions even when oxygen is not present.

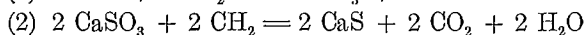
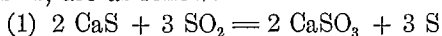
(3) The fact that all the available energy of the hydrocarbon is not utilized, since carbon burns to monoxide instead of dioxide.

These difficulties have been met and solved in the laboratory; the experiments at Campo Seco, described below, were conducted while attempting to develop a commercial process. Young goes on to say:—

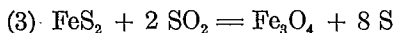
“The Thiogen process has been put into practical form by carrying out the above reaction in an indirect way. The sulphur dioxide is first absorbed by means of a basic sulphide, either in the wet or dry state, the one chosen for most work being calcium sulphide. The reaction which takes place here results in the formation of calcium sulphite and free sulphur. The presence of oxygen in the gases does not interfere in this reaction to any appreciable extent. That is, the reaction with sulphur dioxide is very rapid, while that with oxygen is very slow.”

“The second step in the process consists in removing the free sulphur from the calcium sulphite, which may be accomplished by distillation or other suitable means. The third step consists in the reduction of the calcium sulphite by means of hydrocarbons. This reaction results in the regeneration of calcium sulphide which again enters into the reaction in its first stage, that is, it is used for the further absorption of sulphur dioxide. Under ordinary conditions the reduction of the calcium sulphite to sulphide is a matter of considerable difficulty, the reaction being rather slow, even at high temperatures, and resulting in the conversion of the carbon into monoxide instead of dioxide as is desirable. A method has, however, been devised whereby the reaction takes place readily even at relatively low temperatures, and whereby the complete combustion of the hydrocarbon is assured. An adaptation of the process has also been devised whereby gases which are free, or nearly free, from oxygen may be handled with a much increased mechanical efficiency. In fact, the fundamental principles upon which the process depends offer very considerable possibilities of adaptation to suit special conditions. Incidentally, considerable progress has been made towards adapting the process to the recovery of flue dust.”

“The reactions involved in the indirect method, expressed in chemical symbols, are as follow:



Another reaction which is made use of to some extent depends upon the fact that when sulphur dioxide is passed over a heated sulphide ore, the sulphide ore is roasted, and that almost as completely as if air were used. Expressed chemically, this reaction is as follows:



In laboratory experiments the reactions described above are rapid, especially so when iron salts are present in the catalyzer. No CO is formed and all of the carbon combines with the oxygen to form CO_2 directly. The mixture of CH_2 and SO_2 may be passed over almost any calcium compound, as CaCO_3 or CaSO_4 , and the resultant compound is CaS. In case the gases contain free oxygen, this must be removed before the CH_2 will displace the oxygen in the SO_2 , and this difficulty is the most serious drawback to the process from an engineering standpoint. The catalytic agent must also be maintained at a suitable temperature while the gases are passing over.

The gases should be cleaned as thoroughly as possible before passing into the combustion chamber. At Campo Seco this was accomplished by passing the gas from one roaster through a large settling drum, and thence through a second furnace. The resultant gas contained about 8% SO_2 . This gas from the second furnace was passed directly to the apparatus.

The general arrangement of the apparatus is shown in the drawing (figure 3).

The vaporization of the oil is accomplished by the use of steam injected burners (figure 3, a). This spray of oil is directed into the combustion chamber, which consists of a checkerwork of brick. A temperature of about 800°C . is obtained. Beyond the combustion chamber is a reaction chamber similarly filled with brick checker work. This second chamber is square in cross section, 4.5' to a side, and 30' in length. Its capacity is more than enough to handle the gases from the two roasters used.

The spaces in the checker work of this chamber are nearly filled with a mixture of equal volumes of plaster of Paris and sawdust wetted with water, to which a small amount of iron salts has been added. Such a mixture is advantageous because it gives a porous mass and decreases the amount of plaster of Paris used. The sawdust burns out on heating the chamber, and the CaSO_4 is quickly reduced to CaS, the mass shrinking so as to fill about half the space between the bricks.

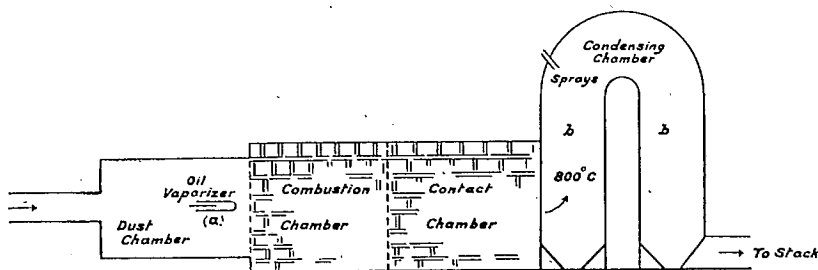


FIG. 3. Sketch of Young sulphur reduction apparatus at Campo Seco, California.

Beyond the contact chamber a condensing chamber is placed to collect the liberated sulphur. In the experiments at Campo Seco cast-iron condensers were found to be too leaky, and at present an inverted V-shaped

pipe is used (figure 3, b), each condenser having a sloping floor with a trap-door. In the experiments difficulties were experienced in this chamber. The selenium, arsenic, or antimony content of the ores passes into the furnace gases and these substances were condensed with the sulphur. A separation can probably be obtained by using a low, broad, slightly inclined condensing chamber in which the gas is cooled by water sprays to a temperature below the boiling point of selenium and arsenic (about 750° C), or about 500° C.: the selenium, arsenic, and antimony will then be deposited on projecting tiles placed in the walls of the chamber for that purpose and finally drawn off through traps in the lower corners. The sulphur, having a lower boiling point, will pass on and be caught in the regular condensing chamber.

Tight construction is required throughout and difficulties have been experienced with the experimental plant because of the porous character of the brick walls, and because of their expansion when heated.

On the second trial at Campo Seco there was a considerable leakage of air and consequently considerable oxygen came in contact with the free sulphur and combined with it. Heat was generated by this combustion and the temperature at the condenser was raised to slightly over 950° C. Analysis of the gas showed 5.6% SO_2 at the inlet and 0.2% at the condensing chamber, a decrease of 5.4% or above 97% of the sulphur dioxide present.

CHAPTER II.

MINING AND MARKETING OF PYRITES.

Requirements of Pyrites Deposits.

The conditions which any deposit of pyrites must fulfil that it may be utilized for manufacturing purposes are of two kinds, commercial and technical.

The commercial conditions are:—

1. The deposit must be large enough to warrant the expense of development to a condition where a constant output can be maintained.

2. It must be large enough to produce a tonnage of ore that shall return to the operators within a reasonable time the full cost of the work of prospecting and development, together with a profit on their investment.

3. It must be favorably situated with reference to transportation facilities, either by water or rail. Owing to the nature of the material it must be situated as near to its market as possible.

4. It must be so situated that the ore can be mined and marketed at a cost reasonably below the market value.

The technical conditions are:—

1. The ore should be practically free from gangue material since the presence of foreign substances lowers the percentage of sulphur in the ore and necessitates the handling of worthless material. For the same reason the presence of any other sulphides than the bisulphide of iron, which forms the ore proper, is disadvantageous because no other compound of sulphur contains either so high a percentage of sulphur or parts with it so freely. Even copper pyrites, which in some of our ores forms the principal valuable constituent of the ore, is detrimental to the manufacture of sulphuric acid, both because it contains less sulphur than pyrite and because its greater degree of fusibility makes it more difficult to regulate the temperature of roasting. Pyrites carrying more than eight per cent copper cannot be profitably employed in the manufacture of sulphuric acid.

2. It must be free from such elements as lead, zinc, arsenic, antimony, or selenium. The presence of arsenic or antimony has a deleterious effect on the quality of the resulting acid. Lead increases the fusibility of the charge and wastes sulphur by forming lead sulphate. Impure ores, because of the sulphur losses which the impurities cause, are heavily penalized; they can however be utilized for certain purposes, and some of the impurities can be removed.

3. The sulphur content of the ore should be as high as possible. Good lump ore will contain as much as 50% of sulphur. Ore containing 40% sul-

phur, not otherwise undesirable, would be considered a good ore. Owing to the scarcity of pyrites at the present time, ore containing between 35 and 40 per cent sulphur, if of good roasting quality, would be marketable. The value on the market would be less in the case of richer ores because of the increased amount of useless material that must be handled.

4. The ore must be of good roasting quality. Cinder from a good burning pyrites will not contain more than one per cent of sulphur. If the gangue is easily fusible or if it contains elements which unite with the sulphur to form sulphates, there will be difficulty in roasting and sulphur losses will ensue. Where lump ore is to be prepared for market, the pyrites should be strong enough to stand crushing without producing a large amount of fines. A granular ore, or one soft and easily disintegrated, will increase the proportion of fines and makes the roasting more difficult.

Certain varieties of fine textured pyrite have good crushing qualities but are extremely undesirable for use in lump burners because they decrepitate in the kilns—often with explosive effect. Sometimes the decrepitation is so extensive as to entirely choke the draft, leading to numerous furnace difficulties. Such decrepitating ores have to be reduced to fines and roasted in shelf burners.

Prospecting for Pyrites

All the known pyrites deposits in Canada have been found by prospectors when in search of other minerals than sulphur, usually gold, copper, or iron. In nearly every case it was only on development that the true nature of the deposit was discovered. In some few instances development was continued to a shipping stage; in the majority of cases as soon as it was known that the prospect did not contain sufficient values in gold or copper, or (when an iron prospect) that it contained too much sulphur, work was stopped. As a consequence there are many prospects which contain pyrites; but in most instances, it is not known whether there is enough ore in the deposit to make it commercially valuable.

Pyrites deposits may occur as replacements in association with either acid or basic igneous rocks—quartz, porphyry, diabase, gabbro and similar rocks. These rocks may have undergone metamorphism—appearing now as chloritic or talc schists or even as amphibolites—or they may be partly decomposed, forming (if basic) the types of rock known collectively as green stones. The deposits are often associated with zones of fracture and shearing presumably because the solutions from which the ore was deposited found less resistance to their passage along these zones of weakness.

In shape the ore bodies are usually lenticular, that is, they are thin on the margins and bulge near the middle of the deposit. Rarely will the dimensions in three directions, or even in two, be the same. If the horizontal dimension along the strike is elongated so that the opposite sides are parallel, the ore body will simulate a vein. If the vertical dimension parallel to the pitch is greatly elongated, the ore body will assume the shape of a pipe.

In prospecting a deposit it is well to determine its probable shape as soon as possible. It is also desirable to know what portion of the original ore body has been left in place by erosion. It must be remembered that the ore was probably deposited in its present position at a time when the present surface lay far below the surface of that time. Erosion has removed the overlying cover and exposed the ore.

The present surface may happen to section the ore body at any point above, or below or at its middle.¹ If the surface intersects the ore near the upper edge of the lens, the ore body will widen as we go down. If the intersection takes place at or near the middle, the sides will at first be nearly parallel; in depth it will narrow downwards, and at last will pinch out. If the intersection takes place near the bottom of a lens, the ore body will be shallow and will pinch out almost immediately.

Lenses are found in all positions with respect to the present surface. Lenses occur which have no surface outcrop at all; others occur with only a small portion removed, while in some cases only the lower portions have been left in place by erosion. Remnants of lenses of this last type are apt to be deceptive. The surface sections may show good ore over a considerable area, but as soon as deep exploration is attempted the ore will be found to pinch out. It is therefore desirable to prove the ore at depth as soon as possible, for without a good body of ore extensive work is unwarranted. Deeper work may also disclose other lenses which have no surface outcrop.

Pyrites oxidizes easily with the formation of sulphuric acid and limonite. The sulphuric acid is removed by soil waters and the limonite usually remains forming the deposit known as gossan. In appearance gossan is a dark brown or reddish material often somewhat porous in texture, and comparatively light in weight when lifted. Pyrrhotites also form gossan caps; their gossan is somewhat denser than that formed by pyrites, though it is usually impossible to distinguish between them. Pyrite itself can easily be distinguished from pyrrhotite by the absence of magnetic properties. In colour pyrites usually is slightly yellower in tone than pyrrhotite. An analysis will readily distinguish between them, especially if pure material is obtained, since pyrrhotite contains less sulphur than pyrite.

Pyrites usually weathers more easily than the surrounding rocks, so that the deposits usually lie below depressions in the surface. Soil will wash into the depressions from the adjacent higher land, often in sufficient quantity to completely cover the deposit. The soil becomes stained reddish with iron rust from the gossan. The presence of sulphides will sometimes be indicated by rust-stained rocks along the sides of the depression.

In prospecting, then, careful attention should be given to belts of dark basic igneous rocks, especially those which show evidence of fracturing. The margins of the rock outcrops should be closely watched for iron rust

¹ For purposes of discussion it is assumed that the ore body is a typical lens, thin at the margins, and thick in the middle.

stains. Depressions should be examined for reddish soil and lumps of gossan. Both soil and gossan will sometimes be found down-hill below the actual deposit itself.

Where the soil indications are favorable, test pits should be sunk. Occasionally, in attempting to trace gossan to its source, trenching will be necessary. In test pitting over a typical deposit, the digger will usually pass through the following distinctive layers of material:—

Loam (including black muck and soil).

More or less sandy soil (grading into)

Red coloured soil.

Gossan, (loose above, cemented below).

Impure Sulphate of Iron (whitish colour, bitter astringent to taste).

Pyritic sand (partially decomposed)

Pyrite (undecomposed.)

The thickness of the soil cover overlying the gossan and the thickness of the gossan will vary greatly according to local conditions. Gossan caps vary in thickness from a few feet to more than fifty feet. Just below the gossan there are often found a few inches of whitish material which consists of impure sulphate of iron mixed with gossan, and occasionally partly decomposed pyrite. Immediately above the massive pyrite there is often a layer of more or less granular pyrites, varying in thickness from a few inches to several feet. This granular pyrites grades into solid undecomposed ore.

The gossan caps overlying pyrites deposits are usually limonite. In many localities these deposits have been converted into hematite. How far this difference in the character of the gossan is due to a mere accident of location resulting in better drainage in one locality than the other is largely a matter of conjecture at present. It is possible that some of the hematite caps are due to the metamorphic alteration of limonite. In any event, in Central Ontario at least, hematite deposits often overlie pyrites ores and are therefore indicators of possible pyrites deposits.

Developing a Prospect

A pyrites deposit, once discovered, must be systematically studied to determine whether there is sufficient ore present to be commercially available.

So much depends upon the location of the deposit and its relation to its surroundings that no general course of procedure can be laid down. The purpose of the work, at this stage of the proceedings, is to determine as expeditiously and as cheaply as possible if ore is present in quantity. It is also desirable to determine the shape of the ore body and the position it occupies with respect to the adjacent rocks.

The nature of the topography of the immediate surroundings will often give some indication of the position of the ore body, and of its length and breadth at the surface. Where the soil cover and gossan cap are not too thick to make the expense prohibitive, the boundaries of the ore body can be determined by digging prospecting trenches across the ore body at regular

intervals. The location of the trenches will be determined by local topography; the distance apart of the trenches will also be governed by local conditions in each case. An interval of 50 feet, or even 100 feet in some cases will be found sufficient. It will not be necessary to sink the trenches through to the unaltered pyrite in every case. If the boundaries of the gossan cap are determined systematically by trenching, the extension of the unaltered pyrite can be confirmed by a series of test pits in the trenches at the boundaries.

Where the cover above the deposit is so heavy that trenching becomes too expensive the prospecting will have to be carried on either by drilling or by shaft sinking. In the majority of cases it will be found more economical in the long run to explore the locality thoroughly by drilling, before a shaft is put down. Information obtained by drilling will enable an engineer to properly locate the shaft with respect to the ore body, so that the ore may be mined in the cheapest way. Shafts located before the size and position of the ore body are known, are almost always put in wrong places, and are always a source of troubles and delays.

Where the boundaries of the ore body can be laid down approximately by trenching, it will usually be found advisable to locate a few drill holes to prove the ore at depth. From these holes the position of the ore body can be determined, and an approximate estimate of its size can be reached. With these data it will usually be possible to choose the best location for the shaft and also to determine the pitch at which the shaft should be sunk. If the dip and pitch of the ore body are not located prior to shaft sinking, it very frequently happens that the first shaft has to be abandoned, or it becomes necessary to turn the lower part of the shaft at an angle to keep it in or near the ore. Shafts of this character are constantly a source of additional and unnecessary expense, both when sinking and in upkeep when in operation.

Where the boundaries of the ore body have to be located by drilling, the methods employed will differ according to the locality and convenience of the prospectors. In some cases churn drilling by hand, with the use of a spring pole will be found both cheap and satisfactory. Where the deposits are deeply covered it may be found necessary to employ an ordinary power driven churn drill, such as is used for sinking gas and oil wells.

Where the drill holes have to pass through hard rocks, some form of rotary core drill must be employed. In some cases a calyx or a shot drill will serve; but the machine most widely used is the diamond core drill.

The drill holes should be located systematically. The methods to be employed will depend upon local conditions. The holes should be located as nearly as possible so as to cut the ore body at right angles to its dip. A single line of holes, especially where it has been possible to approximately locate the boundaries on the surface, will often be found sufficient. In some cases two or more rows of holes will be required.

Where preliminary exploration by trenching or churn-drilling is not possible, it may be advisable to sink a series of drill holes systematically from the corners of squares.

The distance apart of the holes will be determined by local conditions, taking into consideration also the depth to which it is necessary to sink the holes. In practice this distance varies from 25 to about 100 feet, but may extend to 500 feet or more.

Normally the machine will be set up on the hanging wall side of the deposit. To avoid moving the machine a set of three holes, two inclined and one vertical, can often be put down from a single station. Only one of these will be normal to the ore body.

Where an exploratory shaft is required a hand windlass is often used for the preliminary work. It will usually be found to be more expeditious to erect a small tripod from which a sheave can be hung. The hoisting rope passes through this sheave; one end of the rope is attached to the bucket, the other passes under an anchored pulley and is attached to a whiffle tree. A horse is used for power. A *whip* of this character will be found sufficient to sink a small prospecting shaft 100 feet in depth.

For shafts of more than one compartment and for deeper shafts a small head frame will usually be required, and a power hoist driven by steam or electricity will probably be most economical for sinking.

During the sinking of the preliminary shaft, care should be taken to keep ore and waste rock separate from each other. In this way it is possible to form some idea of the relative proportions of each in the section made by the shaft. It is also possible to determine the character of the ore.

Developing a Mine

When the existence of a good ore body has been shown, and its position has been determined, the next step is to develop the ore body in such a way that a regular and constant output can be maintained. Owing to the great variation which will maintain in different localities it is possible only to discuss this question in a general way. The methods here discussed are applicable chiefly to narrow ore bodies. Huge lenses of ore, such as sometimes occur, would require somewhat different methods, though the preliminary work would be similar to that outlined here. *The development work should always be performed under the direction of an experienced and competent engineer, who should be held responsible for the method employed.*

The size and position of the ore body and the character of the ore, if known at least approximately, will make it possible to determine the method of mining which is to be employed. In many cases, especially where there are a series of deposits of different sizes and shapes, different methods may have to be employed in different parts of the same mine. The methods employed should be such that as much of the ore as possible can be removed before abandoning the mine.

In locating the shaft care should be taken to place it where there will be ample room to dump waste rock, and where the ore can be handled most expeditiously. Should the natural ground not permit of this, room must be obtained by making the head frame high enough to give room for an ample dump and to handle everything by gravity.

The size of the shaft will be determined by local conditions, by the size of the body of ore to be mined, and by the daily output which it has been decided to maintain. At least two compartments should be used, one for hoisting; the other for a ladder and pipe way. The use of two compartments also aids in ventilating the shaft and mine. The shaft may be sunk in the ore, or it may be located in the foot wall just below the ore body. As far as possible it should be kept parallel to the ore body. Where this is not done, and the shaft runs out into the rock, it will be necessary to perform a lot of dead work to reach the ore.

Levels should be run from both sides of the shaft sufficiently long to determine the length of the ore body. Where the ore body is wide, cross cuts should be run on the levels at regular intervals (50 or 100 feet) apart and the full width of the ore. When more than one set of levels is run, they are usually connected by winzes, thus blocking out masses of ore on four sides. The standard distance between levels is 100 feet. Practice varies greatly in different localities, and the distance between levels may vary from 40 to about 250 feet, according to local conditions and the methods of mining employed.

At regular intervals along the levels raises are put up, chutes are set in the foot wall, and stopes are developed above the levels. The distance between the chutes will vary from 25 to about 50 feet. One or more of the raises are usually put through to the level above as soon as possible, to assist in the ventilation of the stope.

In some cases, on narrow ore bodies, instead of developing a series of stopes the practice is to take a second cut or slice about 6 feet high, the full length of the level. Then a row of heavy stulls is put in and covered with lagging, and the ore is broken down to the stulls by slicing. Chutes are built into the foot wall at regular intervals and provision is made for a manway by which entrance can be had to the stope. As the ore is broken down from above, enough loose ore is drawn off from below, from time to time, to leave working room between the top of the broken ore and the top of the stope. When the stope has been raised through to the floor above, the balance of the loose ore is drawn off as required. When all has been removed the stope is abandoned.

In some cases it has been found advantageous to use a double row of stulls with a space about 5 feet high between. The chutes are placed in the foot wall below the lowest set of lagged stulls. Openings are left in the upper set of stulls, alternate with the chutes of the lower set, and the loose ore drops through these openings to the lagging on the lower stulls. It is said that the

chutes choke less frequently when this method is employed. Also it is always possible to get in behind the chutes when it is necessary to loosen the broken ore or to clear the chute.

In practice it is not customary to wait until the shaft and levels have been completed before the stopes are laid out. In some cases the preliminary work, if carried on in ore, will produce enough ore to maintain a steady output. In these cases, the stopes are laid out and started but are only used to supplement the ore supply from development work.

Stoping also can go on in one part of a mine while development is being carried forward elsewhere. In short, after preliminary development, all kinds of work can be carried forward simultaneously.

Development should always be kept far enough in advance of mining, that the future of the mine can be determined for some time ahead. The mine owner who can maintain a steady and uniform output of ore of good quality will have no difficulty in securing contracts for his ore. If deliveries are irregular and if the sulphur content is not kept up to standard, endless trouble will ensue and it will be difficult to renew contracts. The owner with small quantities of ore to market at irregular intervals will always have difficulty in selling his product, and will usually have to accept a price somewhat below the market.

Market Requirements

Pyrites suitable for acid making should contain as much sulphur as possible. Pure pyrites contains 53.4% sulphur. The greater number of acid makers demand a product containing not less than 42% sulphur; there are, however, a few large consumers who purchase ore as low as 37% sulphur. Many purchasers demand that the ore be free from arsenic, though in certain fertilizer works, ore otherwise desirable, will be accepted if the arsenic content does not exceed one per cent. The presence of copper, zinc and lead, antimony, calcium and magnesium, fluorine, chlorine and selenium are undesirable. Ore containing pyrrhotite as well as pyrite is also undesirable, though it will be purchased by some consumers, if the sulphur content is not too low.

Market Quotations.—The present price on the New York market for domestic non-arsenical pyrites is about 12 cents per unit of sulphur, f.o.b. railroad, for furnace size. Domestic non-arsenical fines are quoted between 10 and 12 cents per unit. Arsenical ore brings a slightly lower rate, while non-arsenical Spanish and Portuguese ore usually command a higher price.

The following review of the market conditions in 1910—the latest available—is taken from *Mineral Industry*.¹

“Market Prices and Conditions”.—There was a gradual upward tendency of prices in the pyrites market in 1910. Quotations for domestic non-arsenical furnace size opened the year at 11½ cents per unit of sulphur per long ton,

¹ Volume XIX, p. 624.

closing in December at $11\frac{1}{2}$ and 12 cents, and domestic fines advanced from 10 and $10\frac{1}{2}$ cents to $10\frac{3}{4}$ and 11 cents. Imported non-arsenical furnace also advanced from $12\frac{1}{2}$ to 13 cents during the year. Imported arsenical furnace exhibited a rise from $11\frac{1}{2}$ and 12 cents to $12\frac{1}{2}$ cents, and arsenical fines advanced from $10\frac{1}{2}$ and 11 cents, to 11 and $11\frac{1}{2}$ cents per unit. As a result of the decline in the domestic production, importers of Spanish pyrites were able to raise on their ores to keep pace with the rising price of the domestic product."

Available Sulphur

A pyrites ore is valuable only for the available sulphur which it contains, and the value of any given ore will be determined solely by the ease with which that sulphur may be recovered. The presence of deleterious elements necessitates the use of special apparatus for their elimination and increases manufacturing costs. The amount of sulphur that can be recovered from an ore depends first upon the chemical composition of the ore and secondly upon the care and skill of the burner operator. It is possible to produce a cinder from pure ores that will contain less than one half per cent of sulphur. In practice, the sulphur loss in this way is not often less than one per cent.

The following extract from Mineral Industry discusses this question from the standpoint of the purchaser.¹

"When ores contain, among others of minor importance, the following minerals, these will, at the ordinary temperatures of burners used by sulphuric acid manufacturers, retain in chemical combination the following proportions of sulphur, which will therefore not be available for making acid:

For each per ct. of There will be found.....	Zn.	ZnO.	Cu.	CuO.	Pb.	PbO.	CaO.	MgO.	Fe ₂ O ₃ .
	0.50% S.	0.39% S.	0.50% S.	0.40% S.	15% S.	0.14% S.	0.57% S.	0.80% S.	0.60% S.

This on the assumption that all the sulphides are converted to sulphates, which is by no means the case.

An ore, therefore, which assays 43% sulphur, but also contains, say, 5% zinc, 2% copper, and 1% lime, would really contain $43 - 4.07 = 38.93\%$ available sulphur, and as even ores which practically contain nothing but iron and sulphur are rarely burnt down on an average much under 1%, an additional 1% would have to be deducted for ordinary loss in burning, making the available sulphur in this ore: $43 - 5.07 = 37.93\%$.

Moreover, since the only sulphur which an acid manufacturer recovers is the "available sulphur," and since pyrites is usually sold at a price per unit of sulphur by assay, it is necessary to remember that the unit price is greater than it seems. Take, for instance, the above ore at a unit price of 10c.:

¹ Falding, F. J., "The Manufacture of Sulphuric Acid, Mineral Industry, Vol. VII, 1898, pp. 653-4.

44% sulphur at 10c. = \$4.40 per ton of 2,240 lb.; but as the manufacturer can only recover 37.93% S, he is really paying more than 11.5c. per unit for all the sulphur he can possibly expect to recover. Or, if he has the choice between an ore containing only 42% S, but no impurities, and an ore of 44% S, with 4% unavailable on account of impurities, deducting at least 1% more for loss in burning, then the ores compare not as 42: 44, but as 41 : 39.

It is also necessary to consider the proportional value of the 48% and 38% grades of sulphides, and, for the sake of convenience, these ores will also be compared with brimstone containing say 98% S. One ton (2,240 lb.) of brimstone containing 98% S is equal to 2.042 tons of sulphide ore containing 48% available sulphur, or to 2.579 tons of sulphide ore containing 38% available sulphur. (If the sulphide ores contain 49 and 40% available sulphur, then the proportion is 1 : 2 : 2.45 respectively.) Therefore, 1 ton (2,240 lb.) of brimstone (98% S) has available 2,195 lb. of sulphur; 2.042 tons (4,574 lb.) of sulphide ore (48% S) have 2,195 lb. of sulphur, and 2.579 tons (5,779 lb.) of sulphide ore (38% S) have 2,195 lb. of sulphur. Or one ton (2,240 lb.) of available sulphur will be produced by 1.02 tons of 98% brimstone, costing at seaboard \$20. per ton = \$20.40; 2.084 tons of 48% sulphide ore, costing at seaboard, \$5.50 per ton = \$11.46; or 2.632 tons of 38% sulphide ore, costing at mines \$3 per ton = \$7.90. (These prices are approximate only and *pro forma*).

From these figures it is evident that the cheapest source of supply depends directly on the location of the works or, in other words, on the freights. For instance, a freight rate of \$1.25 per ton on a 38% ore from the mines to the seaboard would make such ore cost $\$1.25 \times 2.632 + \$7.90 = \$11.19$, or almost as much as the high grade 48% ore would cost at works located on the seaboard.

The proportional weight of one ton of actual available sulphur having been established, therefore, as a ratio of 1.02 for 98% brimstone, 2.084 for 48% ore, and 2.632 for 38% ore, the same ratio holds good for each of these raw materials as regards labor at the works, including loading, storing, breaking, burning and in the case of cinder which has no value, of removing the same.

As Lunge points out (Vol. I., p. 51,) also "under conditions otherwise equal the unburnt sulphur in the cinders is the same by weight. If, for instance, 5% of sulphur is left in the cinders, this amounts with a 35% ore to $5 \div 35 = 1/7$; with a 45% ore to only $5 \div 45 = 1/9$; the proportion to be kept in view is accordingly not 35 : 45 = 7 : 9, but 30 : 40 = 3 : 4."

* * * * *

So far as the chemical condition of the sulphide ore is concerned, therefore, the intending purchaser in any given locality, in order to decide on the cheapest source of supply, must consider, at the prices quoted to him, (1) the amount of sulphur in any ore which will be actually available for his use; (2) what the freight on that actually available sulphur will be, and what the cost of handling the material necessary to obtain such available sulphur at his works, and (3) whether the ore contains arsenic, selenium or other im-

purities which he is not prepared to eliminate, but which may unfit the acid produced for his purposes.

Suppose we have two ores, one with 44% S; 42 Fe; 4.5 Zn; 0.5 Pb; 1.2 Cu; 0.01 As, and 7.3 insoluble residue; and the other 51.5% S; 46.0 Fe; 0.15 Pb; 0.4 Cu; 0.1 CaO; 0.15 MgO; 0.12 As, and 1.45 insoluble; from analysis I. we must deduct the sulphur which will be bound by the zinc, lead and copper, or 2.92%, and add 1% for loss in burning, or 3.92% S, making the available sulphur 40.08%; from analysis II. we have to deduct the sulphur bound by the lead, copper, lime and magnesia, or 0.4%, and add 1% S = 1.4, making the available sulphur 50.1%; consequently the two ores will bear the ratio of 40 to 50. For each ton of actual available sulphur purchased by sample I., 2.5 tons of the ore must be bought, and of sample II., 2 tons. Freights will cost, therefore, 25% more on ore I., than on ore II., and works' expenses in the same proportion. Ore II., however, has the disadvantage to some purchasers of a rather large content of arsenic. For each locality, and for each manufacturer, the equation has to be solved between prime cost and cost of actual available sulphur."

TABLE I.
Sulphur Contents of Pyrites Ores

Percentage sulphur content.	Sulphur in pounds per ton of 2,000 lbs.	Sulphur in pounds per ton of 2,240 lbs.
53.34%.....	1,066.80	1,194.81
52.	1,040.	1,164.80
51.	1,020.	1,142.40
50.	1,000.	1,120.00
49.	980.	1,097.60
48.	960.	1,075.20
47.	940.	1,052.80
46.	920.	1,030.40
45.	900.	1,008.00
44.	880.	985.60
43.	860.	963.20
42.	840.	940.80
41.	820.	918.40
40.	800.	896.00
39.	780.	873.60
38.	760.	851.20
37.	740.	828.80
36.	720.	806.40
35.	700.	784.00
34.	680.	761.60
33.	660.	739.20
32.	640.	716.80
31.	620.	694.40
30.	600.	672.00

Contracts for Ore

Contracts with consumers are usually made for periods varying from two to five years; a minimum sulphur content and a minimum tonnage delivery per month are usually specified. Clauses relating to labor difficulties, mine accidents, and similar troubles are usually inserted to protect the mine owner in case matters of this kind should interfere with his deliveries.

Irregular deliveries and the delivery of ore that is below the contract minimum in sulphur are to be avoided if an operator hopes to retain or renew contracts.

An acceptance of a contract for delivery of ore before there is reasonable assurance that the mine contains sufficient ore, and that it can be mined out and delivered on contract terms is reprehensible and will ultimately lead to difficulties and losses.

The very small margin, which remains for the producer between mining costs and receipts for a low grade ore such as pyrites, often makes it difficult for some owners to carry development work far enough in advance of mining to insure a regular output. The mining of pyrites will be profitable in itself, only where large tonnages are produced and marketed. The small producer, who places his product on the market instead of utilizing it in a plant of his own, not only has to be content with a smaller margin of profit, but he will have greater difficulty in keeping his ore up to grade; under such conditions it also will usually be difficult to maintain a uniform output. Consequently the small producer must expect to have difficulty in marketing his product, and he should also exercise great caution in entering into contracts for deliveries.

Preparation of Pyrites Ore for Market

Pyrites ore, as it comes from the mine is not generally in a condition in which it can at once be used in the furnaces. It will usually contain a certain amount of waste rock from the mine and in addition, much of the ore will be in lumps too large to be economically utilized in this condition. It must therefore be subject to treatment which will remove the useless material as thoroughly as possible, thereby increasing the percentage sulphur content of the ore, and at the same time it must be reduced to a size suitable for the market. The amount of dressing and sizing to which an ore is subjected will vary greatly according to the nature and purity of the deposit and in accordance with contract requirements. Coarse waste rock can usually be left in the mine. At the surface during the process of dressing, much waste can also be removed either by hand picking or by mechanical treatment. There does not appear to be any recognized standard scheme of sizing pyrites ores. "Kiln" or "lump" ore may vary from lumps that will not pass a 4" ring down to material that is about 0.5 inches in diameter, while "fines" or "smalls" includes all below the minimum size given above. Many buyers purchase ore as *run of mine* and do their own sizing. Plants whose equipment is not

adapted to handle all sizes of ore find it necessary to purchase ore suitable for their furnaces. A miner producing ore for the pyrites market will usually be governed by his contracts in the matter of the preparation of his ore. Where contracts call for "lump" ore, a certain percentage of fines is permissible, and naturally, unless other contracts call for "smalls", he will dispose of as much of his fine ore as possible in this way.

The process of separating pyrites from the gangue material such as quartz, calcite, and fragments of country rock is a relatively simple one, owing to the difference of specific gravity between the ore and waste. Where pyrites is associated with copper, zinc and lead ores, the problem becomes much more complicated. In these cases the pyrites saved is usually the least valuable of the constituents, and a discussion of the methods of concentration belongs rather to the metallurgy of these ores. Ores from different mines differ greatly in character, and, where more than simple crushing and sizing is required, a scheme of treatment should in each case be designed to suit the particular ore which is to be treated. In general the scheme of treatment will be somewhat as follows:—

1. Preliminary sizing over a grizzly, hand spalling and removal of some coarse waste.
2. Hand sorting on a table or belt.
3. Crushing to smaller sizes.
4. Screening.
5. Crushing, sizing, water concentration.

As illustrations of the methods which are employed in practice, the flow sheets of four mills are given herewith. The mine where the first of these was installed is not now in operation. The flow sheet of the mill of the

FIG. 4. FLOW SHEET, MILL OF COLE MINE, ST. LAWRENCE CO., N. Y.

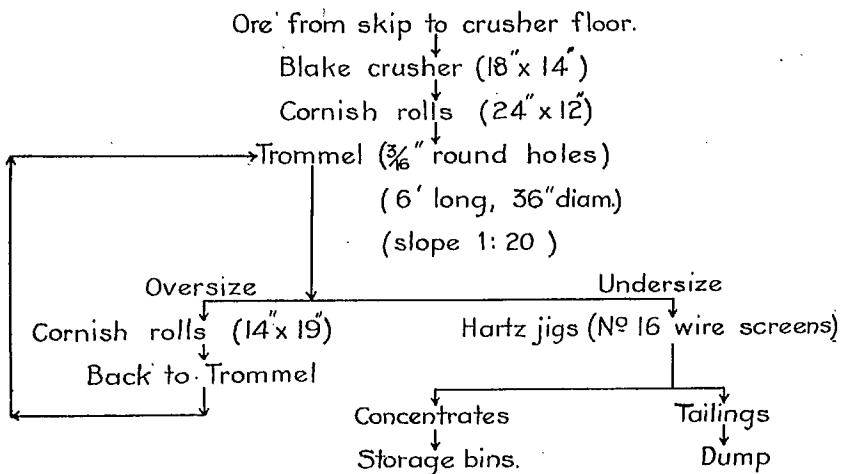
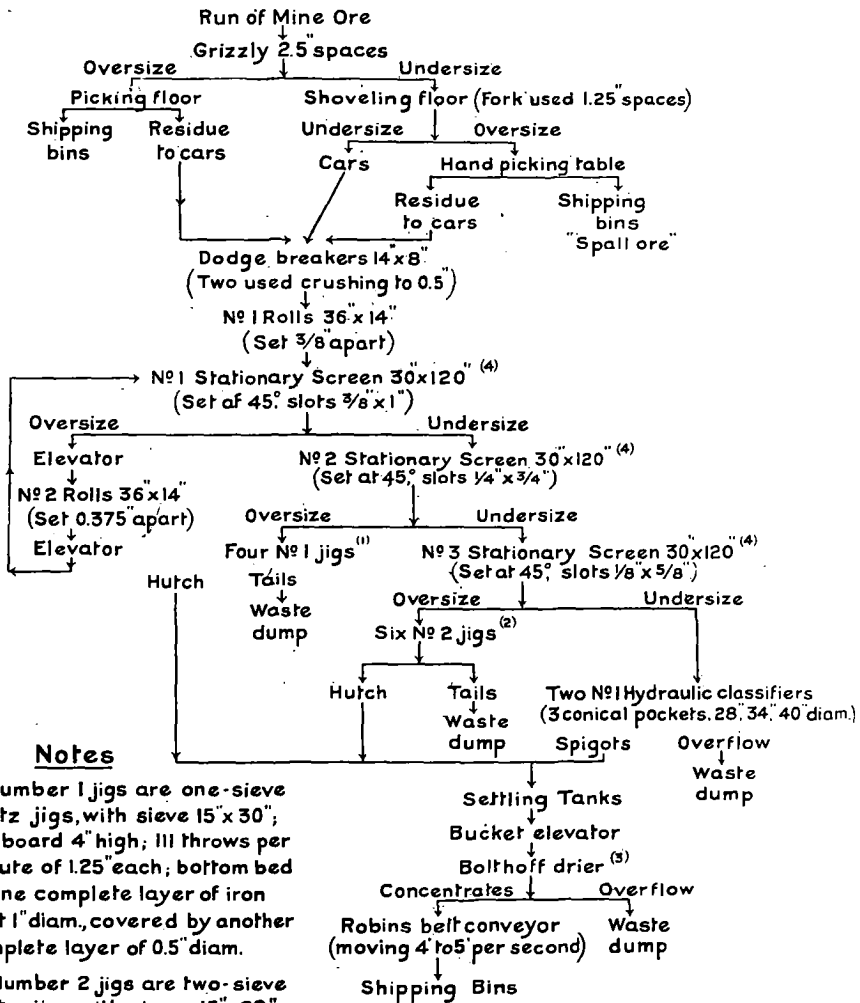


FIG. 5. FLOW SHEET, SULPHUR MINES AND RAILROAD COMPANY,
SULPHUR MINES, VIRGINIA.



Notes

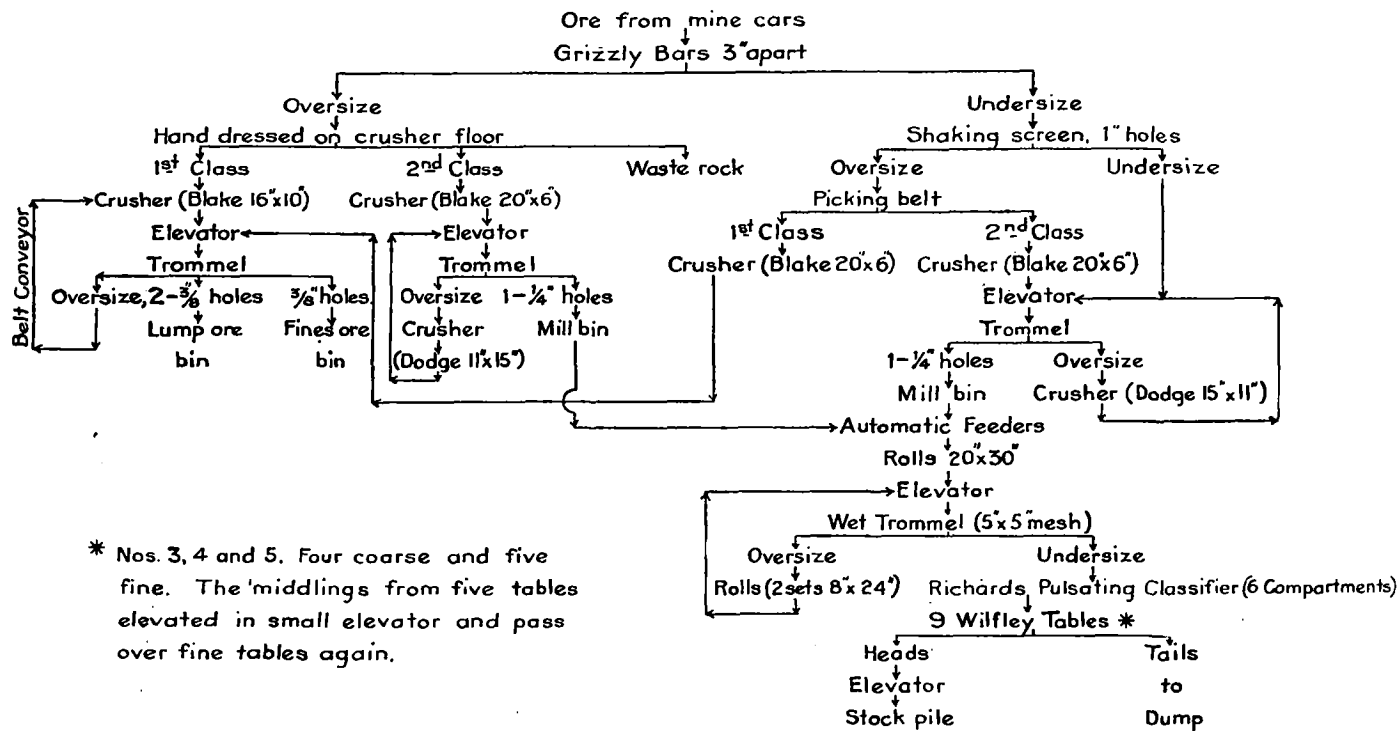
1. Number 1 jigs are one-sieve Hartz jigs, with sieve 15" x 30"; tail board 4" high; 111 throws per minute of 1.25" each; bottom bed of one complete layer of iron shot 1" diam., covered by another complete layer of 0.5" diam.

2. Number 2 jigs are two-sieve Hartz jigs, with sieves 15" x 28" and throw of $\frac{5}{8}$ ", otherwise like number 1.

3. The Bolthoff drier is 6'x42' in size, with cast iron plates travelling about 2' per second.

4. Screens are run dry. Acid water would eat them out in about 48 hours.

FIG. 6. FLOW SHEET, MILL OF EUSTIS MINING COMPANY.



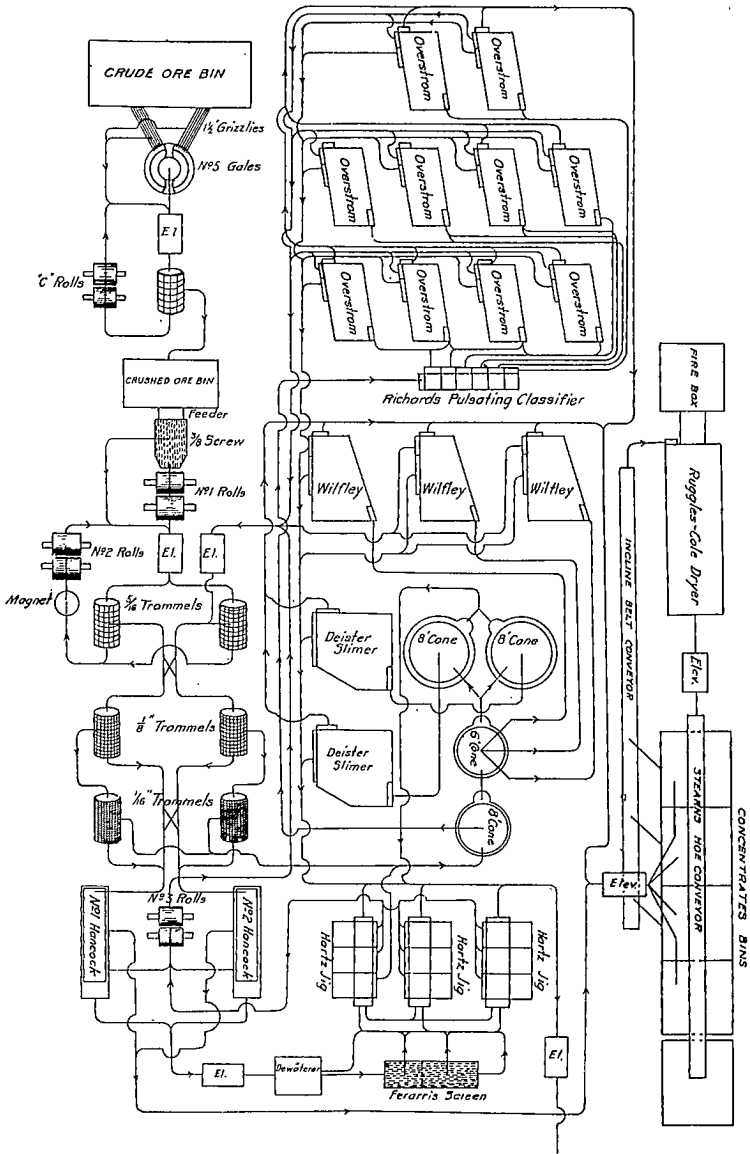


FIG. 7. Flow diagram, mill of St. Lawrence Pyrites Company.

Sulphur Mines and Railroad Company was compiled from Richards' data.¹ At this mine the ore runs 28-33% sulphur and 13% silica; the lump shipping ore runs 40% sulphur or more, and 5.5-5% silica; the fine concentrates run 42% sulphur and 5.5-5% silica; the tailings run 11% sulphur. One hundred tons of mine ore yield about 44 tons of lump shipping ore, 44 tons of fine concentrates, and 12 tons of tailings. The capacity of the mill is 130 tons per day of 10 hours. Both the other plants whose flow sheets are given are in operation, and the flow sheets are published through the courtesy of the managers of the properties in question.

The Available Market for Canadian Ores

On another page is given a list of twenty firms whose acid and fertilizer plants are located within reach of some Canadian pyrites mines or prospects. The combined annual requirements of these works is in excess of 350,000 tons of ore. The ore now used in these plants is in part domestic; a large portion is imported from Spain or Portugal; only a very small part is mined in Canada.

The consumers' requirements in the vicinity of the Great Lakes alone, including also some points that can be reached from lake ports, is in excess of 200,000 tons of ore suitable for acid making. From the reports of the Canadian Department of Customs we find that more than half the Canadian pyrites which is exported finds its way to the eastern market; hence the tonnage which reaches the Great Lakes market is very small. On the other hand, we find that Spanish ore is transported to lake points by rail from the Atlantic seaboard.

Inasmuch as freight rates to ports on the south shores of the Great Lakes are comparatively low from many Ontario points at which pyrites deposits occur, it would appear as if this section of the United States market offers great possibilities to owners of pyrites deposits in that province.

In the lake market Canadian pyrites of suitable quality should command a price slightly higher than in the New York market. This difference in price at any given point will approximately represent the difference in freight rates between certain Atlantic ports and the Ontario point of origin. According to the last report of the Ontario Bureau of Mines, the average price, *at the mine*, for Ontario pyrites, during the year 1910, was \$2.90 per ton. The average sulphur content of this ore is not given and hence the average value, per unit of sulphur, cannot be ascertained.

¹ For additional information consult Richards, *Ore Dressing*, Volume II, p. 893, and pp. 904-6.

CHAPTER III.

STATISTICS OF PRODUCTION OF PYRITES

Mining of pyrites in Canada began, as far as the author has been able to learn, about the year 1880. No statistics of production prior to that date are available. Statistics were collected annually by the Mines Division of the Geological Survey Department from 1886 until 1907. Since 1907 this work has been performed by the Division of Mineral Resources and Statistics of the Mines Branch, Department of Mines.

The Department of Customs records the exportation to the United States in the 5 fiscal years 1881-1885 of 120,126 tons of pyrites on which a duty of about \$245,023 was paid. This probably represents the production of those years. These ore were obtained from the Sherbrooke district, Quebec, and appear to have been the first pyrites ores used in the United States for the manufacture of sulphuric acid.

TABLE II.

Exports of Canadian Pyrites to the United States from 1881 to 1885¹

Fiscal Year.	Tons (2,000 lbs.)	Duty.
1881.....	10,812	\$ 29,786
1882.....	23,980	47,754
1883.....	25,211	39,879
1884.....	26,000	about 53,870
1885.....	34,123	73,734
	120,126	about \$245,023

The following tables have been compiled by Mr. John McLeish, Chief of the Division of Mineral Resources and Statistics. The values given are the values at the mine or point of production. In the table of exports, the values given are those entered at the Customs. A comparison of the two valuations will frequently show a considerable discrepancy between the value at the mine and that entered for export. This difference is in part due to the fact that the export valuation sometimes includes the value of the copper content of certain of the ores. There are, however, other differences that cannot be accounted for in this way.

¹ Geol. Surv. Can., Report for 1886, Part S, p. 61.

TABLE III.

Annual Production of Pyrites from 1886 to 1911.

Calendar Year.	Tons, 2,000 lbs.	Value.	Calendar Year.	Tons, 2,000 lbs.	Value.
1886.....	42,906	\$193,077	1899.....	27,687	110,748
1887.....	38,043	171,194	1900.....	40,031	155,164
1888.....	63,479	285,656	1901.....	35,261	130,544
1889.....	72,225	307,292	1902.....	35,616	138,939
1890.....	49,227	123,067	1903.....	33,982	127,713
1891.....	67,731	203,193	1904.....	37,180	134,033
1892.....	59,770	179,310	1905.....	33,339	125,486
1893.....	58,542	175,626	1906.....	42,743	169,990
1894.....	40,527	121,581	1907.....	46,243	212,491
1895.....	34,198	102,594	1908.....	47,336	224,824
1896.....	33,715	101,155	1909.....	64,644	222,812
1897.....	38,910	116,730	1910.....	53,870	187,064
1898.....	32,218	128,872	1911.....	82,666	365,820

The following table shows the tonnage of pyrites entered for export between the years 1894 and 1911.

TABLE IV.

Exports of Pyrites 1894-1911.

Calendar Year.	Tons.	Value.	Calendar Year.	Tons.	Value.
1894.....	8,532	\$33,205	1903.....	21,067	\$59,604
1895.....	7,705	38,298	1904.....	18,279	49,911
1896.....	15,002	33,837	1905.....	19,755	55,767
1897.....	15,096	30,812	1906.....	26,050	65,349
1898.....	9,804	26,387	1907.....	25,056	80,139
1899.....	15,599	34,084	1908.....	17,283	96,600
1900.....	17,620	41,182	1909.....	35,798	156,644
1901.....	24,971	57,263	1910.....	30,434	110,071
1902.....	18,584	50,178	1911.....	32,102	120,585

There are no records of the amount of pyrites imported into Canada in recent years. The following table, compiled from the returns of the Department of Customs shows the quantity of brimstone and crude sulphur imported into Canada between the years 1880 and 1911.

TABLE V.

Imports of Brimstone and Crude Sulphur, 1880-1911.

Fiscal Year.	Lbs.	Value.	Fiscal Year.	Lbs.	Value.
1880.....	1,775,489	\$27,401	1896.....	6,934,190	\$63,973
1881.....	2,118,720	33,956	1897.....	8,672,751	87,719
1882.....	2,375,821	40,329	1898.....	38,026,798	373,786
1883.....	2,336,085	36,737	1899.....	24,517,026	265,799
1884.....	2,195,735	37,463	1900.....	21,128,656	215,433
1885.....	2,248,986	35,043	1901.....	23,856,651	270,608
1886.....	2,922,043	43,651	1902.....	24,640,735	325,307
1887.....	3,103,644	38,750	1903.....	24,412,737	259,123
1888.....	2,048,812	25,318	1904.....	19,364,730	204,663
1889.....	2,427,510	34,006	1905.....	23,435,140	242,251
1890.....	4,440,799	44,276	1906.....	43,047,672	436,156
1891.....	3,601,748	46,351	1907 (9 months)...	25,854,615	277,439
1892.....	4,769,759	67,095	1908.....	51,806,739	517,249
1893.....	6,381,203	77,216	1909 ¹	44,049,172	426,569
1894.....	5,845,463	61,558	1910.....	42,943,340	430,632
1895.....	4,900,225	56,965	1911 ¹	50,562,547	524,473

The consumption of pyrites in Canada is not easily determined. The records of the Department of Customs do not keep separate account of any importations of pyrites ores, and no independent statistics are available. The amount imported annually is, however, very small, and in some years there are no importations whatever. The following table, which represents the difference between the production, as compiled from returns furnished by individual mines, and the total quantities exported gives only an approximation of the home consumption of domestic ores. The difference between production and exports in any one year must necessarily include both the quantity used in Canada and the quantity remaining in stock at the mines. This latter is usually very small.

¹ Brimstone, crude or in roll or flour, or sulphur in roll or flour.

TABLE VI.

Approximate Canadian Consumption of Domestic Pyrites, 1894-1911

Calendar Year.	Tons (2,000 lbs.)	Calendar Year.	Tons (2,000 lbs.)
1894.....	31,995	1903.....	12,915
1895.....	26,493	1904.....	18,901
1896.....	18,713	1905.....	13,584
1897.....	23,814	1906.....	16,693
1898.....	22,414	1907.....	21,187
1899.....	12,086	1908.....	30,053
1900.....	22,411	1909.....	28,846
1901.....	10,290	1910.....	23,436
1902.....	17,032	1911.....	50,564

TABLE VII.

Recoverable Sulphur in Canadian Pyrites

Assuming average recovery of 41%

Calendar Year.	FROM ALL ORE PRODUCED.			FROM ALL ORE EXPORTED.		
	Tonnage (2,000 lbs.)	Value.	Average Value per Ton.	Tonnage (2,000 lbs.)	Value.	Average Value per Ton.
1894.....	16,616	\$121,581	\$ 7.31	3,498	\$ 33,205	\$ 9.49
1895.....	14,021	102,594	7.32	3,159	38,298	12.12
1896.....	13,823	101,155	7.32	6,151	33,837	5.50
1897.....	15,953	116,730	7.32	6,189	30,812	4.98
1898.....	13,209	128,872	9.76	4,020	26,337	6.56
1899.....	11,352	110,748	9.76	6,396	34,084	5.33
1900.....	16,413	155,164	9.45	7,224	41,182	5.70
1901.....	14,457	130,544	9.03	10,238	57,263	5.59
1902.....	14,603	138,939	9.45	7,719	50,178	6.50
1903.....	13,933	127,713	9.17	8,637	59,604	6.90
1904.....	15,244	134,033	8.79	7,494	49,911	6.66
1905.....	13,669	125,486	9.18	8,100	55,767	6.88
1906.....	17,525	169,990	9.70	10,681	65,349	6.12
1907.....	18,960	212,491	11.21	10,273	80,139	7.80
1908.....	19,408	224,824	11.58	7,086	96,600	10.81
1909.....	26,504	222,812	8.41	14,677	156,644	16.72
1910.....	22,087	187,064	8.47	12,478	110,071	8.90
1911.....	33,893	365,820	10.79	13,162	120,585	9.16

The following table showing the imports of sulphuric acid into Canada since 1885, has been compiled from the returns published by the Department of Customs.

TABLE VIII.

Sulphuric Acid entered for Home Consumption, 1885-1912.

Fiscal Year. Ends March 31.	Quantity in pounds.	Value \$	Fiscal Year.	Quantity in pounds.	Value \$
1885.....	774,764	10,791	1899.....	165,637	2,427
1886.....	507,927	7,930	1900.....	740,858	7,066
1887.....	678,603	8,468	1901.....	448,608	5,272
1888.....	2,494,648	35,415	1902.....	420,731	4,626
1889.....	181,652	2,606	1903.....	102,314	2,332
1890.....	211,871	2,927	1904.....	113,407	2,563
1891.....	177,627	2,466	1905.....	920,804	8,227
1892.....	222,623	2,837	1906.....	(a) 822,585	8,588
1893.....	172,422	2,367	1907.....	(b) 733,151	6,901
1894.....	107,520	1,648	1908.....	(c) 650,095	7,582
1895.....	174,605	2,481	1909.....	241,388	3,298
1896.....	114,137	1,430	1910.....	914,058	8,466
1897.....	977,446	8,033	1911.....	2,486,992	21,855
1898.....	665,344	5,536	1912.....	1,615,180	15,027

(a) For 12 months ending June 30th.

(b) For 9 " " March 31st.

(c) For 12 " " March 31st.

The chief foreign market for Canadian pyrites is the United States. The following tables show the United States production and consumption of both pyrites and sulphur.¹

¹ Mineral Resources of the United States, 1910, Part II, pp. 795-798. Also advance chapter on Sulphur and Pyrite, from Mineral Resources, 1911.

TABLE IX.

Production of Pyrites in the United States, 1882-1911.

Year.	Quantity Tons of 2,240 lbs.	Value.	Year.	Quantity Tons of 2,240 lbs.	Value.
1882.....	12,000	72,000	1897.....	143,201	391,541
1883.....	25,000	137,500	1898.....	193,364	593,801
1884.....	35,000	175,000	1899.....	174,734	543,249
1885.....	49,000	220,500	1900.....	204,615	749,991
1886.....	55,000	220,000	1901.....	(a) 241,691	1,257,879
1887.....	52,000	210,000	1902.....	(a) 207,874	947,089
1888.....	54,331	167,658	1903.....	(a) 233,127	1,109,818
1889.....	93,705	202,119	1904.....	207,081	814,808
1890.....	99,854	273,745	1905.....	253,000	938,492
1891.....	106,536	338,880	1906.....	261,422	931,305
1892.....	109,788	305,191	1907.....	247,387	794,949
1893.....	75,777	256,552	1908.....	222,598	857,113
1894.....	105,940	363,134	1909.....	247,070	1,028,157
1895.....	99,549	322,845	1910.....	241,612	977,978
1896.....	115,483	320,163	1911.....	299,904	1,162,261

a Includes production of natural sulphur.

TABLE X.

Production of Sulphur in the United States, 1880-1911.

Year.	Quantity. Tons of 2,240 lbs.	Value.	Year.	Quantity. Tons of 2,240 lbs.	Value.
1880.....	536	21,000	1896.....	4,696	87,200
1881.....	536	21,000	1897.....	2,031	45,590
1882.....	536	21,000	1898.....	1,071	32,960
1883.....	893	27,000	1899.....	4,313	107,500
1884.....	446	12,000	1900.....	3,147	88,100
1885.....	638	17,875	1901.....	(a) 241,691	1,257,879
1886.....	2,232	75,000	1902.....	(a) 207,874	947,089
1887.....	2,679	100,000	1903.....	(a) 233,127	1,109,818
1888.....			1904.....	127,292	2,663,760
1889.....	402	7,850	1905.....	181,677	3,706,560
1890.....			1906.....	294,153	5,096,678
1891.....	1,071	39,600	1907.....	293,106	5,142,850
1892.....	2,400	80,640	1908.....	369,444	6,668,215
1893.....	1,071	42,000	1909.....	239,312	4,432,066
1894.....	446	20,000	1910.....	255,534	4,605,112
1895.....	1,607	42,000	1911.....	265,664	4,787,049

a Includes the production of pyrite.

TABLE XI.

Sulphur imported and entered for consumption in the United States for the calendar years 1906-1911,
by kinds, in long tons.

Year.	Crude.		Flowers of sulphur.		Refined.		All other. ¹		Total
	Quantity.	Value. \$	Quantity.	Value. \$	Quantity.	Value. \$	Quantity.	Value. \$	Value. \$
1906.....	72,404	1,282,873	1,100	29,565	709	17,918	28	3,224	1,333,580
1907.....	20,399	355,944	1,458	41,216	606	14,589	60	8,426	420,175
1908.....	19,620	318,577	793	22,562	693	17,227	30	4,013	362,379
1909.....	28,800	492,962	770	23,084	966	26,021	53	7,565	549,632
1910.....	28,656	496,073	1,024	30,180	1,106	25,869	47	6,489	558,611
1911.....	24,200	434,796	3,891	83,491	985	24,906	68	9,643	552,836

¹ Includes sulphur lac and other grades not otherwise provided for, but not pyrite.

TABLE XII.

Statement, by Countries and by Customs Districts, showing the imports into the United States of Crude Sulphur or Brimstone, each calendar year 1908-1911, in long tons.

Countries whence exported and Customs district through which imported.	1908		1909		1910		1911	
	Quantity.	Value. \$	Quantity.	Value. \$	Quantity.	Value. \$	Quantity.	Value. \$
Canada.....	26	485	297	7,235	5	160	.....	.....
United Kingdom.....	.....	13	2	58	7	199	11	248
Italy.....	12,950	197,203	10,369	194,834	10,704	201,993	8,031	156,157
Japan.....	7,055	119,457	15,800	250,639	17,377	283,232	16,185	279,991
Other countries.....	87	1,419	446	6,188	554	10,404	23	329
	20,118	318,577	26,914	458,954	28,647	495,988	24,250	436,725
Customs District.								
Baltimore, Md.....	.....	.....	5,586	105,436	4,312	80,756	1,500	28,209
Boston and Charlestown, Mass....	1	18	.....	.....	5	121	20	480
New York, N.Y.....	7,366	114,939	4,601	85,059	6,817	128,794	6,531	127,948
Los Angeles, Cal.....	.....	.....	608	9,711	754	12,424	700	11,330
San Francisco, Cal.....	10,231	157,847	10,132	158,588	7,310	116,595	9,664	85,928
Willamette, Oregon.....	1,978	35,691	4,342	68,780	7,623	124,643	4,661	19,274
Hawaii.....	.....	.....	.....	.....	1,200	21,160	1,100	161,720
All other.....	542	10,082	1,645	31,380	626	11,495	74	1,836
	20,118	318,577	26,914	458,954	28,647	495,988	24,250	436,725

TABLE XIII.
Consumption of Sulphur in the United States
From Mineral Industry, 1910, p. 623. In Tons of 2240 lbs.

Source.	1903	1904	1905	1906	1907	1908	1909	1910
Sulphur: Domestic production...	35,098	193,492	215,000	294,000	307,806	307,761	303,000	300,000
Imports	190,931	130,421	84,579	64,646	20,318	20,118	26,914	26,647
Total	226,029	323,913	299,579	358,646	328,124	327,879	329,914	328,647
Exports	967	2,493	1,713	14,419	35,925	27,894	37,152	30,742
Consumption.....	225,062	321,420	297,866	344,227	292,199	299,985	292,762	297,905
(a) Sulphur contents.....	220,560	314,992	291,909	337,342	286,355	293,985	286,906	291,905
Pyrites: Domestic production...	199,387	173,221	224,980	225,045	261,871	206,471	210,000	200,000
Imports	427,319	413,585	515,722	533,346	627,985	668,115	692,385	806,590
Total.....	626,706	586,806	740,702	758,391	889,856	874,587	902,385	1,006,590
Exports.....	1,330	.....	.....	.....	.....	.....	.....	.....
Consumption.....	625,376	586,806	740,702	758,391	889,856	874,587	902,385	1,006,590
(b) Sulphur in domestic....	87,730	76,217	98,991	99,020	115,223	90,847	92,400	88,000
(c) Sulphur in foreign.	200,215	194,385	242,389	250,673	295,153	314,015	325,420	379,097
Total sulphuric content.....	287,945	270,602	341,380	349,693	410,376	404,862	417,820	467,097
Grand total sulphur consumption.	508,505	585,594	633,289	687,035	(d)696,731	(d)698,847	704,726	759,002

(a) Includes crude and refined sulphur. Sulphur content of crude is computed at 98 per cent.

(b) Computed at 44 per cent.

(c) Computed at 47 per cent.

(d) This figure is in excess of the true consumption as a large percentage of the domestic output of sulphur was stored.

The market price of pyrites in the United States is practically controlled by the price of Spanish pyrites. The following table, from Mineral Industry, 1910,¹ shows the exportations of Spanish-Portuguese pyrites to the United States since 1905.

TABLE XIV.

United States Imports of Spanish Pyrites.

Year.	Quantity (2,240 lbs. to ton).	Value.	Average Value. per Ton.
1905.	477,171	1,694,562	3.55
1906.	558,129	1,954,517	3.50
1907.	628,625	2,492,608	3.96
1908.	713,788	2,687,626	3.76
1909.	661,269	2,462,213	3.72
1910.	729,502	2,626,705	3.60

The world's production of pyrites and sulphur since 1896 is shown on the two following tables from Mineral Industry 1910.²

¹ Page 627.

² Page 626 and 621.

TABLE XV.

World's Production of Pyrites
*In Metric Tons*¹

Year.	Belgium.	Bosnia.	Canada.	England.	France.	Germany.	Hungary.	Italy. (a)
1896.....	2,560	.....	30,580	10,177	282,064	129,168	52,697	45,728
1897.....	1,828	.....	35,291	10,752	303,488	133,302	44,454	58,320
1898.....	147	3,670	29,223	12,302	310,972	136,849	58,079	67,191
1899.....	283	.....	25,112	12,426	318,832	144,623	79,519	76,538
1900.....	400	1,700	36,308	12,484	305,073	169,447	87,000	71,616
1901.....	560	4,570	31,982	10,405	307,447	157,433	93,907	89,376
1902.....	710	5,170	32,304	9,315	318,235	165,225	106,490	93,177
1903.....	720	6,589	30,822	9,794	322,118	170,867	96,619	101,455
1904.....	1,075	10,421	29,980	10,452	271,544	174,782	97,148	112,004
1905.....	976	19,045	29,713	12,381	267,114	185,368	106,848	117,667
1906.....	908	13,474	35,927	11,318	265,261	196,971	112,623	122,364
1907.....	397	3,671	35,494	10,357	283,000	196,320	99,503	126,925
1908.....	357	5,000	42,934	9,599	284,717	219,455	95,824	131,721
1909.....	214	(b)	58,645	8,564	273,221	198,688	(b)	149,084
1910.....	213	.....	50,735	10,393	.....	215,708	.....	.....

¹ The metric ton weighs 2,204.6 pounds.

TABLE XVI.
World's Production of Sulphur. (a)
*In Metric Tons.*¹

Year.	Austria. (b) (e)	Chile.	France. (b)	Germany.	Greece.	Italy. (b)	Japan.	Spain.	United States.	Total.
1895	932	.....	4,213	2,061	1,480	370,766	15,557	2,231	1,676	398,916
1896	781	940	9,720	2,263	1,540	426,353	12,540	1,800	3,861	459,798
1897	642	664	10,723	2,317	358	496,658	12,013	(b)3,500	1,717	528,592
1898	589	1,256	9,818	1,954	135	502,351	10,339	3,100	2,770	532,312
1899	671	989	11,744	1,663	1,150	563,697	10,241	1,100	1,590	592,290
1900	985	2,472	11,551	1,445	891	544,119	14,439	750	4,630	581,282
1901	5,048	2,516	6,836	963	2,336	563,096	16,548	610	6,977	604,930
1902	3,826	2,636	8,021	487	1,391	510,333	18,287	450	7,565	552,996
1903	4,610	3,560	7,375	219	1,266	553,751	22,914	1,680	35,660	631,035
1904	6,410	3,594	5,447	209	1,225	527,563	25,587	605	196,588	767,249
1905	8,542	3,470	4,637	205	1,126	568,927	24,652	610	218,440	830,609
1906	15,258	4,598	2,713	178	(d) 1,000	499,814	27,589	700	298,704	845,956
1907	24,199	2,905	2,000	176	(d) 1,000	426,972	33,329	3,612	312,731	801,911
1908	17,429	2,705	2,189	811	(d) 1,000	455,312	33,419	13,872	312,700	829,437
1909	12,725	4,508	2,900	1,185	(d) 1,000	435,060	35,480	21,750	303,000	817,608
1910	(c)	(c)	(c)	1,272	(d) 1,000	395,836	(c)	(c)	300,000	.....

(a) From the official reports of the respective governments. The sulphur recovered as a by-product by the Chance-Claus process in the United Kingdom, amounting to between 20,000 and 30,000 long tons annually, is not included.

(b) Crude mineral; limestone impregnated with sulphur.

(c) Not yet reported.

(d) Estimated.

(e) Includes such production from Hungary.

¹ The metric ton weighs 2,204.6 pounds.

TABLE XVI. (Continued.)

Year.	Japan.	Newfound- land.	Norway. (c).	Portugal. (c).	Russia.	Spain.	Sweden.	United States.	Total.
1896.....	(b)	27,267	60,507	207,440	11,550	100,000	1,009	111,031	1,071,778
1897.....	7,626	32,790	94,484	276,738	19,380	100,000	517	133,502	11,252,472
1898.....	8,726	32,335	89,763	302,686	24,570	70,265	386	194,219	1,341,383
1899.....	8,376	26,154	95,636	347,234	23,250	107,386	150	181,263	1,446,782
1900.....	16,166	Nil.	98,945	402,870	23,154	34,638	179	204,538	1,464,512
1901.....	17,589	7,532	101,894	443,397	30,732	33,953	Nil.	238,582	1,568,999
1902.....	18,580	26,000	121,247	413,714	26,465	145,173	Nil.	231,849	1,713,654
1903.....	16,149	42,674	129,939	376,177	22,780	155,739	7,793	202,577	1,692,812
1904.....	24,886	61,166	133,603	383,581	31,667	161,841	15,957	175,992	1,696,099
1905.....	25,569	51,534	162,012	352,479	30,689	179,079	20,762	228,580	1,789,816
1906.....	36,038	28,583	197,886	350,746	20,660	189,243	21,872	228,646	1,832,475
1907.....	56,166	28,000	236,038	365,164	18,316	225,830	27,000	266,061	1,978,242
1908.....	33,867	(b)	269,129	105,939	56,345	263,457	29,569	209,774	(d) 1,757,687
1909.....	27,066	.....	(b)	(b)	(b)	236,000	16,104	213,371	.....
1910.....	.....	.....	.....	.....	.....	.....	.....	203,200	.....

- (a) Cupriferous in part.
 (b) Reports not yet available.
 (c) Both iron and copper pyrites.
 (d) Not including Newfoundland.



CHAPTER IV.

OCCURRENCE OF PYRITES

The Occurrence of Pyrites in Canada.

GENERAL STATEMENT

The following notes on the recorded occurrences of pyrites ores in Canada have been compiled from various sources, chiefly, however, from published reports of the Federal and Provincial Departments of Mines. Personally the author has been able to visit all but two of the localities mentioned as occurring in the Maritime Provinces and in Quebec. In Ontario four of the producing mines have been visited and also several prospects; where possible, application has been made to the owners or operators for the most recent information. In British Columbia the two properties mentioned have been visited.

The greatest amount of work in prospecting for Pyrites has been done in Ontario. In the year 1906, Mr. E. L. Fraleek was commissioned by the Department of Mines of Ontario to prepare a special report on Iron Pyrites in Ontario. This report, the only one of its kind in relation to Canadian pyrite deposits, is now long out of print and copies are difficult to obtain. The matter contained in Mr. Fraleek's report, is however, the best available information with respect to many prospects in Ontario, and these, with an increased demand for pyrites, may be of future value. The author has consequently made copious extracts from Mr. Fraleek's report. Occasionally it has been deemed advisable to paraphrase certain of the extracts; in view of this acknowledgment it was not considered necessary always to employ quotation marks, where portions of the report have been printed unchanged. Where possible, additional notes have been added to bring the information up to date. The sections of the present report which relate to Ontario have also been submitted to the Department of Mines of Ontario for revision and correction.

Data relating to British Columbia have been obtained from the Provincial Department of Mines and from other sources.

PYRITES IN THE MARITIME PROVINCES

Provincial reports and the reports of the Geological Survey of Canada contain many references to occurrences of the mineral pyrites in various localities in the provinces of Nova Scotia and New Brunswick. The writer has not been able to find any record of the mining of pyrites on a commercial

scale at any locality in either of these provinces. In a few instances sample shipments have been made, but these were made many years ago, and the ore was valued for its copper content only.

The pyrites occurrences in the Province of Nova Scotia, so far as the writer is aware, are not known to be large enough to be of commercial importance.

In the Province of New Brunswick, in the parishes of St. Stephen and St. David there are a number of localities in which both pyrites and pyrrhotite occur. No detailed description of these deposits appear to be available. Dr. Matthew, reporting on the district in 1876, states that they may be of commercial importance in the future. A verbal communication to the writer by a resident of St. Stephen confirmed this view. Exploratory work is needed to determine if any of those deposits are of commercial importance.

When visiting some supposed occurrences of copper ores in New Brunswick, the writer was informed that a large deposit of pyrites was known to occur on the northwest Miramichi river above Red Bank. Direct inquiries of the alleged owners have elicited the information that no such occurrence is known to them.

In conclusion it may be said that geologically one would expect that pyrites deposits would occur in certain localities in these provinces, since the conditions are very similar to those which prevail in Newfoundland and in several of the states to the south and west where these ores are mined. Much of the country is very difficult to prospect on account of the cover of loose waste, and so little is known of the country that it should not be said that such deposits do not occur. The most that can be said is that at present no deposits have been discovered and sufficiently exploited to show that pyrites ore can be obtained on a commercial scale.

PYRITES IN QUEBEC

The pyrites deposits of the province of Quebec have been, until recently the most important known to occur in Canada. Many of the ore bodies which have been mined for pyrites were discovered during the decade 1860-1870. The first claims were located as gold prospects: subsequently development showed that the ore contained an important amount of copper, and the claims were therefore operated as copper properties. A little later it was found that the high sulphur content of these ores rendered them valuable for acid making. The total output of the province during the last thirty-five years has probably exceeded one million tons of ore carrying 40% of sulphur or more.¹

At the present time there are only two properties in active operation. These are the Eustis, formerly the Crown mine, located about 7 miles south of Sherbrooke, and the McDonald mine located about 7 miles from Weedon station on the Quebec Central Railway. The property adjacent to the

¹ No accurate statistics are available.

Eustis mine, the Capelton mines of the Nichols Chemical Company, was operated between the years 1863–1908. In addition, a considerable amount of pyrites was mined at the Howard mine, formerly the Cillis, and at Moulton Hill northeast of Sherbrooke. Important deposits of pyrites are known to occur at the King mine, adjacent to the Howard, and on a property near lake Coulombre north of Garthby station on the Quebec Central Railway. Brief descriptions of these properties are given in subsequent paragraphs.

The occurrence of copper sulphides and of pyrite has been reported from a number of other localities in the province of Quebec. Where exploratory work has been undertaken it has almost invariably been for the purpose of discovering copper or gold ores. Occurrences of this type are particularly numerous in the belt of altered igneous rocks which runs in a southwesterly direction past the city of Sherbrooke. The district for about ten miles northeast of Sherbrooke and for about the same distance towards the southwest is worthy of very careful exploration, especially in the neighborhood of some of the old prospect openings. As the available information with respect to these prospects relates rather to their possibilities as sources of copper ore, detailed descriptions are reserved for the report on the Copper Resources of Canada.

Copper bearing pyrites minerals occur on almost every lot of the eighth and ninth ranges of the township of Ascot, south of Sherbrooke. A number of prospects also occur on the eleventh range and there are scattered prospects on other ranges.

Eustis mine.—This property is located on lots 2 and 3, Concession IX, township of Ascot, about seven miles south of the city of Sherbrooke. It is owned and operated by the Eustis Mining Co.¹

The discovery, which was made about 1865, was located on lot 4 of the ninth range. The ore body was followed down from the outcrop, and the main mass of ore was found to occur on the lot to the south. The ore body consisted of a series of sulphide lenses, dipping approximately at an angle of 35° towards the southeast. The bottom of the present shaft is about 3,200 feet below the old sills. The largest of the lenses was nearly 800 in length along the dip; the horizontal width, parallel to the strike of the rock structures, varies to about 250 feet, while the thickness varies from a few inches to over 70 feet at the widest points. The other lenses were of the same general shape, though somewhat smaller.

The total output of the mine, since it was opened, has probably been in excess of half a million tons of ore. At present, development work is well in advance of mining and there is said to be more than two years' supply ready for stoping. The ore is a particularly pure pyrites with which is associated chalcopyrite. The shipping ore contains 40–45% sulphur, some of the lump ore occasionally running as high as 50% sulphur. It usually contains less than 2% of copper, and very small values in gold and in silver. The ore

¹ Head office, Boston, Mass., P.O. Box 1422.

from the upper portion of the mine is said to have contained a higher percentage of copper.

The ore is free from arsenic and is an excellent ore for acid making. It is said that ore from this mine was the first pyrites used in America for making sulphuric acid. It is also probable that it will be found very suitable for sulphite pulp manufacture.

The mine is operated by electric power generated on the Coaticook river. It is also provided with an auxiliary steam plant to operate the mill at times of low water.

There is a dressing mill on the property equipped to treat about one hundred tons of ore per day. The flow sheet of the mill is given on page 36 of this report.

The dumps of waste which have accumulated during the earlier mining operations contain much good ore. They are now being sorted over and the concentrating ore is being sent to the mill for treatment.

A small portion of the Eustis ore is utilized at the chemical works at Capelton. The greater part of the ore is shipped out of Canada to various chemical works in the United States. The copper and other values in the ore are recovered from the cinder at the smelter at Norfolk, Virginia, belonging to the principal owners of the Eustic company.

McDonald mine.—This property is located on lot 22, range I, township of Weedon, about 7 miles south and east of Weedon station on the Quebec Central railway.

Exploration work was begun in the summer of 1909, by the sinking of small prospecting shafts. The preliminary work showed the existence of a promising body of ore, and more extensive operations were begun, including the sinking of what is now the number one shaft. During the last two years, development and exploration has been carried on systematically, and a considerable tonnage of ore carrying about 5% copper in addition to the sulphur has been shipped.

There are now two shafts on the property, number one, having a depth of 110', and number two, which in January (1912) had a depth of 260 feet. The total amount of drifting, in January 1912, was 900 feet, all in ore. In addition a considerable amount of upraising had been done to block out ore in preparation for stoping. The development work is regarded as having proved the ore body to a depth of 300', and for a distance along the strike of 530'. Development work is still being pressed forward, sinking at the rate of about 35' per month, and drifting at the rate of 100' per month.

The mine is now equipped with a boiler plant having a total capacity of 200 H.P. The air compressor plant is capable of supplying 600 cubic feet of free air per minute. In addition, each shaft is supplied with hoists, that at number two shaft having a capacity of 20 H.P.

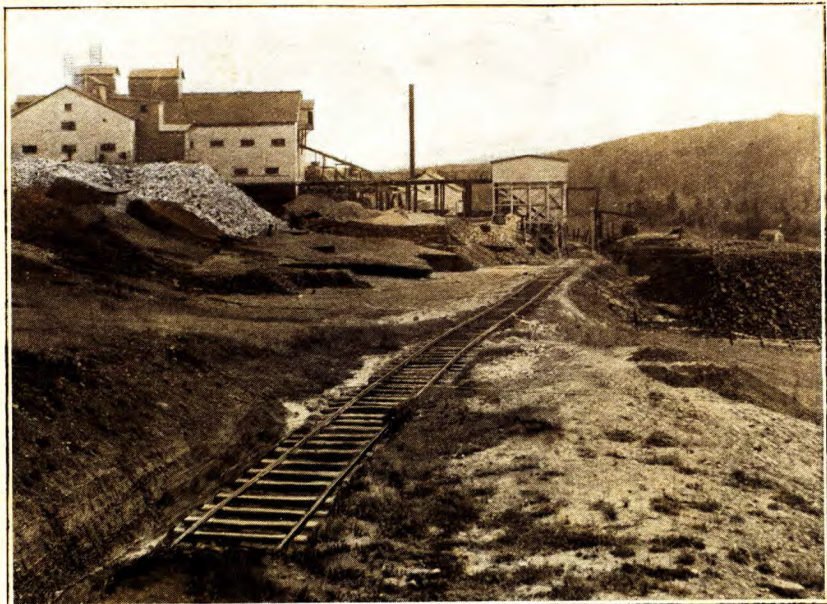
An aerial tramway is now being installed to transport the ore from the mine to loading bins at the railway.

At present most of the ore is shipped to the works of the Nichols Chemical Company at Capelton. Smaller shipments have been made to United States points.



Eustis mine. Showing dumps and tram line to mill.

PLATE III



Eustis mill. Loading bins and stock pile of fines ore.



Eustis mine. East side of large empty stope.



Eustis mine. Mining ore, main stope near 21st level.

The property is operated by the East Canada Smelting Company, Limited.¹

Capelton Mines.—The group of mines which may collectively be named the Capelton mines are located on lots 3 and 4, range VIII, township of Ascot. The original mines were Albert mine on lot 3, range VIII and the Capel mine on the S. E. $\frac{1}{4}$ of lot 4, range VIII. With this group should also be included the old Crown mine on lot 4, range IX. As indicated in the reference to the Eustis mine, the ore bodies, first discovered on the Crown property, extend across the boundary towards the southeast, and it is on these ore bodies that the Eustis company is operating.

The first discoveries were made on the Capelton properties about 1863. They were first exploited as gold prospects, but development work soon demonstrated that there was a considerable quantity of cupiferous pyrite available. In the early days of their operation unsuccessful attempts were made to extract the copper by the Henderson process, and the mines were closed. Subsequently the properties passed into the control of G. H. Nichols & Co. This firm at first shipped most of the ore to sulphuric acid works near New York. Subsequently large acid works were established at Capelton, and later a small smelting plant, to treat the richer copper ores and cinder.

The mines were operated, practically continuously for about thirty years, and were finally closed in 1908, the deepest shaft having reach a depth of about 1,800 feet.

Several ore bodies occurred on the property on a strike approximately northeast, all having an inclination towards the southeast. The ore bodies varied in dimensions; in general the form appears to have been lenticular. The width of the several ore bodies varied considerably from narrow vein-like bodies to masses over 50 feet across. A considerable portion of the ore carried over 5% copper, and on one occasion an ore body of considerable size containing over 15% copper was encountered.

The deposits on the Capelton properties are doubtless associated with big deposit of cupiferous pyrites on the Eustis property. They appear, however, to have carried more copper and to have been more irregular in their distribution.

The known ore bodies appear to have been exhausted and the mines were closed down in 1908. The closing of the mines is said to have been due chiefly to the difficulty of handling the water. Much of the plant has since been removed.

Howard mine.—This mine is located on lot 5, range XI, township of Ascot. The property, formerly known as the Cillis, was reopened by the same company² as that which operated the Moulton Hill mine, and at the same time. The ore body was developed through a single shaft from which levels were driven along the strike. It is known that the operations followed the ore to a depth of over 200 feet. No data are available as to the maximum

¹ President, Chas. E. Force, 49 Wall St., New York.

² Grasselli Chemical Company of Cleveland.

depth to which exploration was carried. Mining operations ceased when the ore crossed the boundary to the adjacent property, known as the King mine.

The ore appears to have been a nearly pure pyrite carrying a low percentage of copper. No returns are available showing the tonnage which was shipped.

The experience obtained in mining at Capelton and at Eustis would suggest the possibility of the occurrence of other lenses of similar ore at depth below the ore body which has been discovered and mined.

Moulton Hill.—This property is located on lots 23 and 24, range III, township of Ascot. The surrounding country is well covered with soil and prospecting in the neighborhood would have to be done by drilling. The original discovery is said to have been made by the uprooting of a tree. The country rock is a sercitic schist carrying quartz veins and stringers and a good deal of pyrite. The ore body, which lay approximately parallel with the rock structures dipped in a southeasterly direction at an angle of about 50°. The reported thickness is said to have been between 4 and 6 feet at the surface. At a depth of 70 feet it is said to have had a width of nearly 50 feet. The mining operations appear to have been carried out through a three compartment shaft, 6' × 15' in section, inclined parallel to the dip of the ore body. There is also a smaller vertical shaft on the property. Both shafts are caved; the mine is full of water, and no data could be obtained as to the extent of the underground workings.

The ore was apparently a mixture of pyrite and chalcopyrite, the former predominating.

The mining operations were carried on by the same United States company that operated the Howard mine, and the ore was shipped to the United States for use in acid works.

It has been stated that during the last year of its operation the production reached about 1,000 tons per month. No further data are now available.

Garthby prospect.—The road which runs northwest from Garthby station on the Quebec Central railway crosses directly over a lens of pyrites on lots 22 of the first ranges north and south, of the township of Garthby. Prospecting pits occur on both sides of the road, about five miles from the railway, and within a few hundred yards of lake Coulombre. At present the old pits are full of water and little can be learned about the nature of the deposit. The old work appears to have been chiefly in ore, and there is a small amount of nearly pure pyrites piled beside the road. This ore appears to be of good quality. A sample gave the following analysis:—¹

Al ₂ O ₃	·24%
CaO	·20
MgO	·30
Cu	·36

¹ H. A. Leverin, Analyst.



Albert mine. Shaft house, dumps, and tailings.

S.	45.32%
Fe.	40.45
Insoluble.	11.00

The surrounding country is covered with soil and bush. The extent of the ore body could not be ascertained from the surface exposures. No records of the old mining operations are available.

King mine.—This property is located on lot 4, range XI, township of Ascot. The property belongs to Mr. A. O. Norton, Coaticook, Quebec, who carried on development work for a number of years. Active development ceased in 1910, and the workings have been allowed to become filled with water.

The ore body, which was mined on the Howard property, extends into this property. It has been developed by an inclined shaft, and lateral drifts along the ore, but only some small trial shipments have been made. Portions of the ore are rich in copper, assays running as high as 12%, and the property has been explored as a copper prospect, rather than as a source of pyrites. A small amount of pyrites containing considerable copper has already been developed ready for stoping.

As in the case of the Howard property, the size and nature of the ore lens already discovered would suggest that it might be profitable to search for other ore bodies below the present one. On which property they would occur is largely a matter of conjecture. Similar ore bodies have been found to a depth of over 3,000 feet on the Eustis property, and to over 1,800 feet at the Capelton mines; these mines are only a few miles away.

Victoria prospect.—It has been known for sometime that pyrites occurs on the N. E. $\frac{1}{4}$ of lot 4, range VIII Ascot. This is the property immediately adjacent to the Capelton mines towards the east. Only a very small amount of surface prospecting has been done and the occurrence of ore bodies of value is problematical.

The strike of the ore-bearing zone in which the Eustis and Capelton ore bodies were found lies across this property, from which one would infer, that careful prospecting work would be warranted.

Other prospects.—Pyrites ore carrying copper values is reported to have been mined on the following properties in the township of Ascot:—

Clark mine, lot 11, range VII.

Sherbrooke mine, lot 12, range VII.

Hepburn mine, lot 7, range IX.

Suffield mine, lot 3, range XI.

Copper ores have also been mined in small quantities from a number of other properties in the township of Ascot. No data as to the sulphur content of the ores are available. The information that is on record with respect to these properties is very meagre. Practically nothing can be learned as to the value of the prospects by inspecting the surface, and their value as pyrites prospects is purely problematical. For this reason such data as have been collected are reserved for the report on the Copper Resources of Canada.

PYRITES IN ONTARIO

Brockville District

Brockville Chemical Company.—In 1868, John Cowan and J. B. I. Robertson began mining for pyrite on lot 19, concession II, Elizabethtown township, Leeds county. The pyrite occurred in a series of lenses conformable to the lamination of a highly foliated pink granite gneiss. A series of irregular cavities, probably caused by folding, had occurred; in these were deposited calcite and iron pyrites in parallel bands, and mining took the form of gouging out the richer shoots of ore, irrespective of any other consideration. No timbering was done, and when a part of the pit became unsafe, work at that point was abandoned. The main pit was sunk to a depth of 250'. The strike of the deposits was northeast, and the dip to the southeast. Mining operations ceased in 1879.

The ore from this property was used for making sulphuric acid in Brockville. After the mine was closed, pyrites was obtained from near DeKalb junction in New Hampshire. In a report of the Geological Survey of Canada,¹ the acid works are thus described:—

“The Brockville Chemical Company’s mine in the township of Elizabethtown has been closed since 1879. The chemical works are, however, still in operation. The pyrite at present used by the Company is being brought from New Hampshire at the rate of a carload a day. There are 16 kilns in operation each having a capacity for 300 pounds of ore. The kilns are charged every hour and produce about 85 carboys of sulphuric acid a day. In the distillery there are 24 glass retorts attached to glass receivers for redistilling the crude acid. Besides the above, about 15 carboys of nitric and hydrochloric acids can be produced per day. In this case iron retorts and earthen receivers are used. The company employ 26 men.”

A portion of the sulphuric acid was used at a fertilizer works in Brockville. Mixed acid was also supplied to two dynamite works in that neighborhood. One of these was started by C. W. Volney, the inventor of the Volney blasting powders, who afterwards sold out to one Griffin; and the other by Smith and Nelson, who were succeeded by Abbott and Harrison. Operations of all kinds ceased in 1880, and to-day not a vestige of these industries remains.

The cause of the decline and obliteration of these, at one time, flourishing industries was the prohibitive price of raw material. To the cost of mining near DeKalb Junction must be added hauling to the railroad and loading, freight to Ogdensburg, unloading, re-loading into barges, water transportation to Brockville, unloading, reloading on wagons and hauling three miles to the acid works. Working on imported ore, the plant could not successfully meet competitors. The evidence of men who worked in the old pits is to the effect that they were never completely exhausted.

¹ C. G. S., 1883, Part L, p. 10.

Sloan Prospect.—Lot 18, concession II, Elizabethtown township, adjoining the old Billings mine on the east. A band of gossan strikes in a northeast direction along the edge of a swamp. On this deposit a shaft has been sunk to a depth of 19·5'. The gossan cap is from 6' to 8' in depth. The shaft is on the foot wall and dips quite strongly to the southeast. The cross-section of the shaft is 10' × 10' and it is all in vein matter. There is a width of 3' of solid pyrites along the footwall and the remainder is composed of alternate bands of pyrite and crystallized calcite, locally called spar—about one half pyrite to one half spar. The pyrite is high grade, the only impurity being the calcite that gets intermixed in the course of mining. The method of mining consisted in drilling, shooting, and mucking the pyrite and calcite separately. They break from each other quite freely. Two carloads, 80 tons, were shipped to Buffalo and Capelton. The returns were 40% sulphur.

The prospect lies half a mile from the Brockville and Westport railway and two miles from the St. Lawrence river.

Shipman Prospect.—About 6 miles to the west is another occurrence of pyrite in gneiss. The deposit lies on the northern flank of a rocky hill about 60' in height. Pyrite has been mined from an irregular pit 40' long and 30' wide. Small stringers leading out from this pit have been followed, making irregular surface workings to the extent of 100 square feet. The pyrite is high grade, but very much intermixed with pyrrhotite and country rock. The prospect is one half mile from the Grand Trunk railway and one mile from the St. Lawrence river.

McIlwraith mine.—Lot 5, Concession IV, Darling township, Lanark county. The vein strikes slightly north of east along a contact between diorite on the south and crystalline limestone on the north. It was first opened up many years ago by W. H. Wylie of Almonte, and Wm. Hall of Darling, when prospecting for gold. They sank a shaft to a depth of 35'. The Nichols Chemical Company instituted mining operations under an option in September 1899. The old shaft was deepened to 75' and from the bottom a drift run 8' to the east. A tunnel 150' long, with an outside approach of 50' was driven along the strike of the vein. This discloses a length of over 90' of workable ore, clean high grade pyrite enclosing lenses of quartz. A cross cut of 12' to the south failed to pierce the width of the deposit. The lens dips to the south at an angle of 60°, and pitches to the east away from the shaft which passed through it. It is claimed that it was caught again by the drift at a lower level. Work ceased at the expiration of the option, the end of April, 1900. Three carloads of ore were shipped. The mining was all done by hand. The gossan cap is 14' deep.

In a line of weakness caused by the contact of the diorite with the crystalline limestone, pyrite-bearing solutions have eaten out cavities and lenses in the limestone, depositing in them, pyrite and quartz. These break quite freely from each other, and the only impurity in the pyrite is small intermixed particles of quartz. Allowing for reasonable culling, an average sample from the tunnel, assayed by A. G. Burrows, yielded 42·6% sulphur,

and a sample from a dump of 300 tons removed from the property to an adjoining lot, and which had been exposed to weather for 6 years, yielded 38.86 per cent sulphur.

The property is 10 miles by winter haul from Clyde Forks on the Kingston and Pembroke railway.

Hastings District

Bannockburn Pyrite Mine.—Lot 25, Concession VI, Madoc township, Hastings county, about a mile southeast of the village of Bannockburn. In 1898, openings were made for iron ore, and Stephen Wellington of Madoc, shipped eleven carloads of bog iron ore or limonite to the Hamilton Iron and Steel Company. This ore, which ran upwards of 38% metallic iron and low in sulphur, was merely the gossan capping of iron pyrites deposits. These were further prospected by Thomas Burnside and William Coe of Cleveland. In the summer of 1900, they transferred their lease to the American Madoc Mining Company, who abandoned operations at the McIlwraith in favour of the more accessible deposit. The gossan capping at the Bannockburn mine varied in depth from 8' to 15'. A pit about 80' in diameter and 90' deep was sunk, but at this stage had to be abandoned. Through the oxidation of low grade ore, large masses began to scale off the sides of the pit, necessitating either an expensive system of square set timbering or cessation of the work. In the meantime a new lens had been opened up about 500' south of the open pit. A shaft was sunk here, levels run every 60', overhand stoping adopted, and a skipway with guard rail provided. A battery of boilers and a five-drill, straight-line air compressor were installed, which supplied the drills, steam being used for the pumps. In later years this method of working was abandoned for the following practice. A pit or trench 8' or 10' in depth was sunk and this was followed by underhand stoping back the full length of the lens. For convenience in mucking, the skip was replaced by a bucket; the lens pitched to the north and was penetrated by the shaft so that the operation of the skip had become impossible. The skids at the top of the rock house were inclined to the horizontal. As the loaded bucket was hoisted into this position, a chain was hooked into a ring in its bottom, the skids were pulled apart, and the bucket was dumped by lowering it slightly. The bucket was then hoisted, the chain unhooked, and it was then thrown back on the skids and lowered. The bucket loads were dumped on steel bars, placed 6" apart above a series of grizzlies spaced to one-half inch. The fines from the grizzlies discharged through the rock house floor and the culled lump ore was wheeled out to a loading dock, whence wagons drew it half a mile to the siding on the Central Ontario railway.

Some shipments from the open pit graded from 46% to 48% of sulphur, and some from the south lens did not run higher than 37%. A fair average of the property would be 40% of sulphur. The ore is hard and makes very little fines.

The country rock is a chlorite schist, showing talcose or micaceous alteration in the vicinity of the ore bodies. The south lens and enclosing schist strike slightly west of north until west of the open pit, when a fold of a 90° angle turns the strike to a little north of east. The south lens dips to the country rock to the east, and the open pit in a similar manner dips to the south. Unfortunately the surface of the schist at the apex of the fold was covered by a deposit of limestone, which was subsequently metamorphosed to a calc schist, but there is no evidence whatsoever of faulting. Folding, whether of a simple nature or a pitched anticlinal subsequently eroded, produced the lines of weakness through which the pyrite-bearing solutions seeped, the deposits being formed by replacement. The ore separates readily from the fairly good foot wall, but towards the hanging, the grade lowers, and it shades gradually into the schist. It is impossible to obtain fresh specimens of the schist. Originally it was probably hornblende; at present it is chloritic, due probably to surface weathering and the influence of the mineral bearing solutions from the adjacent vein. The south lens is 160' in length, and varies from 8' to 15' in width. The mine employed from 35 to 40 men and shipped during its 6 years of operation about 580 tons per month. All the ore went to the works of the General Chemical Company at Buffalo.

Although the ore fell off neither in grade nor quantity with depth, yet on account of the open pit method of mining (the south lens being stoped out to a depth of 275'), and the tendency of the walls to scale, mining became so hazardous that the operations were abandoned in August, 1906.

The Hungerford Fahlbund.—The Hungerford fahlband lies about 5 miles east of the village of Tweed north of the Canadian Pacific railway. It strikes north 65° east, and is easily traceable for two miles. Level farm land to the south is underlain by garnetiferous crystalline schist cut by massive diorite. About 500 yards north of the deposits, the schists have been invaded by a pink hornblende granite that now rises above the surrounding country, forming a series of rugged hills (locally called the Bald mountains); this granite has protected the ore bodies from erosion. The deposits are strung along the contact of the diorite and the schist, the strike of the lenses, the contact, the fahlband, and the schists being identical.

Hungerford mine.—Lot 23, Concession XII, Hungerford township, Hastings county. This mine was opened 30 years ago, by the American Madoc Mining Company, as a gold property, and a smelter was erected to extract gold from the barren pyrite. The present operators, the Nichols Chemical Company, re-opened the mine in June, 1903. Owing to some difficulty about the title, the mine was closed down in August, 1904, but operations were resumed in August, 1905, and have since been continuous.

The first shaft, with cross section 8' × 14', was sunk in the diorite foot-wall to a depth of 300', and levels were run every 100'. Two other ore bodies were discovered, one from surface outcrops, the other during the

progress of underground work. On each level cross cuts were made to catch these ore bodies, known respectively as the middle and north lodes. There are now 2 shafts on the property, and about 3,500' of drifting has been done on the ore bodies on 5 levels, exclusive of cross cuts, and the sixth level is now being opened up.

In exploitation work winzes are usually carried down in advance of shaft sinking. At present the main shaft is being sunk from the 5th to the 6th level.

The middle lode has no visible outcrop on the surface. It lies 85' to the north of the south lode, and was found when drifting towards the north lode on the first level. Cross cuts have also been run through this lode on the 2nd and 3rd levels, and considerable exploratory work has been done upon it. It carries ore on the 1st and 3rd levels, but not on the 2nd. This lode, on the first level, has a width of about 6' of high grade ore, but on the 2nd level it contains a very large quantity of calcite.

The north lode lies 45' farther north. When first cut, it was 22' wide, 17' being through massive pyrite. The length of this lode, as indicated on the surface, is over 500'. On the 3rd level, drifts have been run along the lode 370' east and 250' west of the cross cut that runs to the south lode. The width varies between 6' and 22'.

The mine is fairly dry, very little water being encountered, and that chiefly on the north lode.

Much of the ore that has been hoisted has been secured during development work. Some stoping has also been done on the three upper levels. At present the bulk of the ore hoisted is obtained during the development work.

The ore is coarsely granular and makes a large percentage of fines. The main impurity is calcite, though there is also some quartz present. A small quantity of pyrrhotite occasionally occurs, mainly in the north lode next the footwall.

A new head frame, built entirely of 12" × 12" yellow and red pine, has been erected at the No. 2 shaft, the only one in use. This frame is 62'-10" in height, measured on a 59° slope to the sheave axle. In the upper part of the frame two grizzlies are located, one above the other, and the skip dumps directly upon the upper grizzly. The bars on this grizzly are spaced 2.5" apart, and the oversize falls on the sorting floor. The undersize falls on the second grizzly—bars spaced 1" apart—and is divided into two products, "spalls" and "fines."

In the lower part of the head frame, four bins have been built to hold the three grades of ore—lump, spalls, and fines—and the rock. The bins are raised above the ground level, and are provided with chutes and gates, so arranged that carts may drive beneath to be loaded. All ore is carted from the bins to the works. The rock is run into a mine car, which is pushed by hand over rails to the edge of the dump. (Plate VII, B.)

At the present time only fines burners are used at the works. Hence no lump ore is required. In preparing the ore for the Herreshoff burners, the lump and spalls are passed through a No. 3 McCully crusher (capacity about 150 tons per day) and a set of Buchanan rolls, 24" × 14". The lump and spalls are dry enough to be used at once. The fines from the mine are dried in a wood fired rotary dryer before being fed to the furnaces.

In shaft sinking, two machines are used, in drifting only one—both Ingersoll and Holman drills are in use. For stoping both Rand and Hartzog hammer drills are employed.

Overhand stoping is employed throughout the mine. The main drifts are run the length of the ore body. Chutes are placed about 20' apart, and an 8' ore pillar is left above the drift. The stopes are raised to within 8' of the level above, just enough ore being drawn off during stoping to give working room above the broken ore in the stope.

The drifts are 5' wide and 6'-6" high. Both the ore and rock break hard, and usually 19 or 20 holes are required to square a cut. Most of the drifting is done on contract.

Power is obtained from the Seymour Power and Electric Company, the generating station being at Campbellford, 40 miles away. The current is received at a voltage of 44,000, and is stepped down to 240 volts for use in the plant and mine.

The air compressor is a motor-driven Rand, type DD-2E, cross compound compressor, direct connected to a 150 H.P. Westinghouse synchronous motor. The stroke is 16", the low pressure cylinder is 16" in diameter, and the high, 9" in diameter. The capacity of the machine is 833 c.f. per minute; free air at a speed of 225 r.v.m. The operating pressure is 100 pounds. This compressor is located in the main power house at the plant, and the air is run to the mine by a 4" line.

For the protection of the works and mine a 3-stage, centrifugal Alberger motor driven fire pump, of a capacity of 750 gals. per minute at 125 pounds pressure, has been installed.

The hoist is an Allis-Chalmers single drum electric hoist, 42" × 28", capacity 4500 pounds at 450' per minute. It is connected with a 75 H. P. Allis-Chalmers motor; a one-inch plow steel hoisting cable is used. The skip is of one ton capacity.

In the shaft, 30 pound rails are used, and in the mine, 20 pound rails.

For pumping water out of the mine a 3-stage motor driven centrifugal pump has been located at the third level. This pump has a capacity of 250 gallons per minute, and elevates the water to the surface. A similar pump will be installed on the 6th level. At present water from the lower levels is raised to the main pumping level by small air pumps.

Sheet steel, side-dumping, rotary mine cars of one ton or 18 cubic feet capacity are used in the mine. These run to the shaft and are dumped directly into the skip.

All the ore mined is used directly in the acid works which has been erected on the property at Sulphide station by the Nichols Chemical Company. The average percentage of run of mine ore will be about 35%, the fines being much higher.

The Canadian Pacific railway main line between Montreal and Toronto crosses the southern end of the property, a little more than a quarter of a mile from the mine.

*Canada mine.*¹—Lot 26, concession XII, Hungerford township.

This prospect is located on the same fahlband as the Hungerford mine. A lead of gossan can be traced across this lot along the side of a depression. In 1907, a trial shaft was put down on this property to a depth of 110'. The shaft followed the lode on an incline of about 50°. Some drifting has been done on the 85' level. The lode strikes east and west; the property adjoins the mine operated by the Nichols Chemical Company.

The width of the lode varied from 4' to 7'. The ore on the dump is pyrite with a little calcite and pyrrhotite, and will grade upwards of 40% in sulphur according to Fraleek.

The prospect lies about 125 yards north of the Canadian Pacific Railway.

It was prospected by New York capital, and W. A. Hungerford of Madoc, was in charge of the work.

Hungerford Western Extension.—Lots 21, 22, concession XII, Hungerford township. This property, in 1906, had been fairly well prospected by means of surface trenches at regular intervals along the strike of the fahlband.

The western lens had been exploited by surface trenches to a length of 500' and exhibits in the trenches, near the line between the lots, a width varying from 16' to 18' of ore, which will grade from 42% to 44% sulphur. The only impurity consists of small included lenses of calcite.

The eastern lenses had not been prospected in 1906, but they are presumably continuations of the Hungerford mine ore bodies.

Pyrite has also been located to the south of the railway. The gossan is about 40' wide, but not enough work had been done to determine the extent of the ore.

The Canadian Pacific railway crosses the southern end of the property, about 300 yards distant.

*Ontario Sulphur Mines, Limited.*²—The property of this company comprises the northwest quarter and the east half of lot 21, concession XI, township of Hungerford, Hastings county, having a superficial area of 150 acres. Work on the property commenced in March 1908, and has been carried on continuously, save for a shut-down of two months in the summer of 1910. The pyrites deposit on which work has been done is located about half a

¹ Formerly the Oliver prospect.

² Managing Director, B. A. C. Craig, National Club, Toronto; Mine Office, Tweed, Ont.



A. Head frames at the Sulphide mine, Nichols Chemical Company.



B. Head frame and shaft house, No. 2 shaft, Sulphide mine.



C. General view of the acid works, Sulphide, Ontario.
Views at Sulphide, Ontario.

mile west of the Hungerford mine. It appears to be a lens pitching towards the southeast.

The main shaft (14' × 7') has been sunk to the 100 foot level. Below this it was narrowed to 10' × 7' and was carried down to 250' below the collar. On the 100' level drifts have been carried 84' west and 98' east along the lode. On the 200' level the west drift runs 17' and the east drift has been carried 170' from the shaft.¹ A cross cut has been run for 30' from the east drift on the 100' level; for 12' from the west drift on the 200' level; and for 27' from the east drift on the 200' level.

The work which is being carried on at present is largely for exploration and development.

The present plant consists of two upright boilers with a capacity of about 65 H.P. The mine is provided with one 3-drill Clayton air compressor operating 2 Corkill and 3 hammer drills. The hoist is capable of hoisting 1,200 pounds 300 feet. The pumping equipment consists of a duplex steam pump for the boilers and one Cameron sinking pump.

It is proposed to install electric power by extending the power line of the Seymour Power Company from the plant of the Nichols Chemical Company less than three quarters of a mile to the east. The shaft is to be straightened and a skip track installed. The new equipment will include a 2 ton electric hoist, and a 12 drill air compressor. A shaft house will be erected with ore sorting floor and bins. An aerial tramway will be run to the Canadian Pacific Railway where it crosses the Company's lot about 1800 feet from the mine, and loading bins will be provided at the siding.

The company are also considering the erection of a concentrating plant, but this will not be erected this year.²

The total shipments from the property up to the first of May, 1911, have been 4,821 long tons of ore averaging 36½% sulphur.

The Queensboro Fahlbund.—This fahlband, which is near the eastern boundary of Madoc township, strikes in a general north-of-east direction, and can be readily followed for a distance of two miles, stained, rusty and decomposed schists being discernible throughout that distance.

Queensboro mine.—Lot 11, concession XI, Madoc township, Hastings county. This property is located about one mile southwest of the village of Queensboro, and one half mile west of the Bay of Quinte railway.

The deposit lies in a depression at the contact of a garnetiferous crystalline schist to the south, resembling that at Hungerford, and an intrusion of light grey granite to the north.

A small spring creek ran through the depression over a part of the deposit. This it was necessary to divert, and a shaft was sunk at the edge of the old creek bed, to a depth of 85'. At 50' in depth water came in to such an extent that a drift was driven to the east for 30' and a cistern was

¹ In July, 1911.

² 1911. The mine was closed near the end of this year.

constructed into which the water was trapped by means of wall plates and troughs. At the bottom of the shaft, a drift has been run to the west for 25', and a cross cut made 20' to the north. A drift was also driven to the west on the 50' level.

One hundred and fifty feet to the west another shaft has been sunk to a depth of 30'.

About 100' southwest of the main shaft, a zone of highly pyritous rock was worked. Through this ran several lenses, up to 4'-5' in thickness, of medium grade pyrite, shading off into leaner ore. One lens contains disseminated copper pyrites, which was worked by an open pit.

The mine was operated by the British American Development Company of Toronto.

The plant consisted of 2 boilers, one 65 H.P., and one 50 H.P., both locomotive type and asbestos covered; also one McEwan Drill Co., of New York 4-drill, straight-line air compressor with cylinder 12" x 18", and one steam hoist 10" x 12". There are likewise a blacksmith shop, storehouse and an office building.

The pumps comprise one Knowles with 6" suction and 5" discharge, and two vertical plunger Cameron pumps 2.5" x 2" and 3" x 2.5" respectively.

The pyrite was hauled by teams to Queensboro station and there shipped to the Contact Process Company at Buffalo. The first 21 cars shipped averaged 47% sulphur, and shipments up to the fall of 1906 amounted to 65 carloads.

The highest grade ore comes from a series of lenses close to the granite contact. That on which the main shaft is sunk has, at the shaft, a width of 15' and a length of about 50', thinning out towards the ends. To the west is a similar lens, which shows a width, in a surface trench, of 20' of very high grade pyrite. The iron pyrites in these lenses is a hard, heavy, dense ore resembling a massive magnetite, the only impurity being thin veinlets of quartz. To the south is an extensive area of more or less imperfect impregnation, showing places from which a 35% sulphur ore can be quarried.

A noteworthy feature of this deposit is a small vein to the west of the workings which has a northwest strike and is about 2' wide. It has been opened by a trench 16' long and 4' deep. It cuts the formation at an angle of 45°, and appears to possess well defined walls. The vein is composed of quartz, pyrite, copper pyrite and argentiferous jamesonite. This vein is of later age than the pyrite deposit. The jamesonite fills the interstices and is formed around crystals of pyrite. This vein possesses an interest on account of the rare occurrence of jamesonite in this country, and the present high price of antimony.

*Canadian Sulphur Ore Company's Property.*¹—N. $\frac{1}{2}$ Lot 9, Concession X, Madoc. When this property was investigated by Mr. Fraleck in 1906, a series of pits and trenches had disclosed a belt of gossan over 500' in length, about 200' in width, and about 12' in depth. The gossan was mainly con-

¹ Formerly Wellington prospect.

glomerate with iron oxide as a cementing material; certain portions were a fairly good limonite. Here and there throughout the gossan, were found pyrite boulders up to 12' in diameter, but the ore body had not been located.

Subsequent prospecting and development has disclosed pyrite ore in a series of lenses in a fahlband, occurring in rocks of pre-cambrian age. The lenses vary in width up to 20'. The ore is high grade, very little cobbing, if any, having to be done, and cars have been shipped running 40%-48% sulphur. The ore is free from arsenic, zinc, lead, copper and calcium. It burns very satisfactorily, and is in good demand by sulphuric acid makers. The output goes mainly to Sulphide, Ontario, and to Buffalo, N.Y.

The main shaft is now down 135', and a second shaft 400' west is down 50'. The property is equipped with an 80 H.P. steam boiler, 3-drill air compressor, steam hoist, air drills, pumps, and other necessary machinery. There is a comfortable boarding house for the men, and an office building. The property is still in the early stages of development, but the company expect to ship, shortly, at the rate of 30 tons a day.

The operating company is the Canadian Sulphur Ore Company, Limited, of which Mr. A. Longwell is president, and A. B. Willmott, secretary and treasurer. The head office is 404 Lumsden Building, Toronto, and the mine address is Queensboro, Ontario. Mr. S. N. Graham is the superintendent in charge of the mine.

Davis prospect.—South half of Lot 10, Concession IX, Madoc. This prospect corners on the property of the Canadian Sulphur Ore Company. To the northwest a test pit about 10' deep has been sunk on pyrite somewhat intermixed with crystalline limestone. At another point on the same lot a heavy band of gossan was being prospected in 1906. The results of this prospecting work are not known to the author.

Farrell prospect.—Lot 9, Concession VII, Madoc township. This prospect is situated on the Farrell farm about 2 miles northeast of Madoc village, Hastings county.

The country rock of the deposit is a calc schist with a northwest strike to which the deposit conforms. Test pits for a distance of 200' show either gossan or pyrite. A shaft has been sunk to a depth of about 25'. About 40 tons of ore lie on the dump. A sample representing an average of 75% of this material yielded 40.64% of sulphur. The deposit maintains a uniform width of 5'. The only impurity in the ore is crystalline limestone.

McKenty prospect.—Lot 6, Concession VII, Madoc township. This prospect lies on the McKenty farm at Mullet's Corners, 2 miles east of the village of Madoc. Hematite was shipped from this property 35 years ago, and iron mining has been carried on in a desultory manner ever since.

A pit, at one time 60' deep, has caved. An examination of the cull dump reveals the fact that all large lumps of apparent hematite have, when broken, a core of pyrite. In Mr. Fraleck's opinion, this is one of many instances throughout Eastern Ontario where hematite constitutes the gossan capping of a sulphide ore body.

An interesting feature is a talus breccia to the south of the deposit, composed of sharp angular fragments of hematite cemented with a sandstone bond.

Little Salmon Lake prospect.—Lot 23, concession VII, Cashel township, Hastings county. This prospect is located on the shore of Little Salmon lake. A hill rises sharply above the level of the lake to a height of 80'. Half way up the hill, a trench 40' long has exposed a deposit of pyrites. In the north end of the trench, the pyrite uncovered is 15' wide. An average of 75% of pyritous material yielded 38.83% of sulphur. The country rock of the deposit is a chlorite schist and the strike is east and west.

The Central Ontario railway is 9 miles distant by winter road to Gilmour, and 6 miles by winter road across Big Salmon lake to the gravel pit.

Gunter prospect.—Lot 23, concession IV, Cashel. On this prospect, a shaft has been sunk on the lead to a depth of 23' on bands of alternate quartz and pyrite. The work was performed while prospecting for gold. The soil on the surface is quite unaltered, and no gossan, fahlband or other indications of a pyrite deposit are visible. The pyrites in the shaft, however, uniformly increased with depth. A sample representing two thirds of the dump yielded 39.50% of sulphur. The total width of the vein is 5'.

The Central Ontario railway is 7 miles distant by summer road and 6 miles by winter haul.

Other Eastern Ontario Prospects

Snooks prospect.—Lot 7, concession XIV, Loughborough township, Frontenac county. On this property a fahlband strikes northeast through a coarse, impure crystalline limestone. At the only opening, massive pyrite shows to a width of 7', and mixed with crystalline limestone, to a width of 25'. This is on the road allowance and was uncovered in obtaining material for the road. The fahlband can be easily traced across lot 6, concession XIV, to the shore of Desert lake. It is 9 miles distant by rough wagon road to Hartington on the Kingston & Pembroke railway.

Ladore prospect.—Comprises a portion of the E. $\frac{1}{2}$ lot 19, concession VII. Dalhousie township, Lanark county. A heavy fahlband strikes north of east along the contact of a coarse amphibolite and a fine grained, gray granite. Nearly every trench in the marshes and depressions exposes gossan in the form of a good grade of bog iron ore. Two pits 100 yards apart have been sunk to a depth of 20' and 22' respectively in gossan and decomposed rock matter. The south pit is noticeable for quantities of delicate cellular silica. Seams up to a foot in thickness have been found but pyrite in quantity has not yet been located.

The same fahlband continues across lot 19, concession VI, along a contact of crystalline limestone and granite. Here are a series of interesting caverns in the limestone, which have been caused by solvent action of acid solutions, followed by deposition of pyrite in the cavities and subsequent oxidation.

The property is 7 miles by winter road from Wilbur siding on the Kingston & Pembroke railway, and was prospected by Wellington & Henderson of Madoc.

Stalker prospect.—Lot 42, concession VI, Clarendon township, Frontenac county, about 2 miles east of the village of Plevna. A well defined fahlband strikes across this property in an east and west direction. A small test pit has been sunk on a lens of pyrite, which shows at that point a width of 6'. A quartz vein 1' in width lies along a hanging wall of clay slate, the footwall consisting of crystalline limestone. At 6' in depth the gossan shades into hematite as the fahlband crosses on lot 42, concession V.

Foley prospect.—This property is situated 5.5 miles by a fairly good wagon road, north from Enterprise station on the Bay of Quinte railway. The work consists of a pit 80' long, 40' wide, and 10'–15' deep, sunk in pyrite and pyrrhotite, the two sulphides occurring in about equal proportions, intermixed with pyroxene, calcite, mica, and molybdenite. A sample treated at the laboratory of the Kingston School of Mines was successfully separated by combined washing and magnetic concentration. The pyrite consists of small masses occurring in the rock and in pyrrhotite, and the deposit is irregular. The occurrence is in an outlier of crystalline limestone, surrounded at a short distance by granite.

Northern Ontario Occurrences

*Northland Pyrites Mine.*¹—This property is located on the shore of James lake, about three-quarters of a mile west of the Timiskaming and Northern Ontario railway at the 83rd mile post. The discovery was made in 1903, but active development was not commenced until December 1906.

The main shaft has a depth of 300', with levels at 100', 175', and 275'. A winze was sunk from the second level, 75' north of the shaft, a depth of 100', a drift running to the shaft, and then a raise was put up to connect with the shaft at the second level. Some of the ore north of the shaft has been removed by open cut workings, and a considerable amount of ore has also been stoped out on the second and third levels.

The main shaft on the deposit dips with the schist at an angle of about 70° to the west. The lens-shaped ore body lies in a soft green schist about 100' east of the contact with a grey hornblende granite. The only impurity in the ore consists of small veinlets of quartz and massive pyrrhotite on each wall of the lenses. Occasionally, pyrrhotite is also finely disseminated through the pyrite. The ore breaks nicely, making very little fines in the course of mining.

The ore is usually mined by underhand stoping. It is hoisted to the shaft house, where it is broken and cobbled. It is then dumped directly from the storage bin to the cars, a siding from the Timiskaming and Northern Ontario railway having been built to pass under the ore bin. The greater part of the ore was shipped to Buffalo, N. Y.

¹ Formerly Rib lake mine, James lake mine, Harris mine.

The mine is equipped with two 100 H.P. boilers, a 12-drill air compressor, and a hoist.

The property is at present closed down.

In 1909, Mr. L. Hanna was manager. The head office of the operating company is at London, Ontario, and Mr. John Smallman is Treasurer.

Western Ontario Occurrences

Helen Iron mine pyrites deposits.—Located in the Michipicoten Mining Division, about 15 miles northeast of Michipicoten harbour, Lake Superior.

The Helen iron mine has been fully described in various reports of the Ontario Bureau of Mines.¹ Underground working has revealed the existence of pyrites in large quantities. The pyrite and hematite deposits lie in a roughly elliptical rock-rimmed amphitheatre bounded on the east by a steep hill of iron carbonate, on the north by cherty carbonate and quartz porphyry schists, on the south by quartz-porphyry schist, and on the west by pyritous and cherty iron carbonates. The rock structures are almost vertical.

The Helen iron mine occupies the eastern end of a great pit-like depression. The ore body, as shown by the plans of the several levels, is elliptical in outline with an east and west axis about 500' in length, and a width of about 300'.

Lenses of pyrite occur throughout the hematite deposit, and the sulphide also occurs to the east, north, and west of the hematite ore body. The pyrite consists almost entirely of granular ore. Lumps of hard ore are occasionally found, but the greater portion of the sulphide is in a fine granular condition resembling very clean concentrates. Occasionally, small veins of a clear, white quartz sand occur. Samples of ore will assay over 50% sulphur. Mine shipments will grade about 42% or better, dependent upon the amount of hematite that may become mixed with the ore.

The pyrite in the lenses or pockets, being closely confined by the hematite and of a saccharoidal structure, flows readily, like hot dry sand, wherever the pressure is relieved. Therefore, if an opening happens to be made in one of the lenses, it is necessary to take prompt measures to prevent the flow and to regulate it, if necessary. Special timbering is necessary, and even then the pressure is so great that openings into the pyrite can only be maintained with difficulty and for a short time.

Arrangements are being made to maintain a steady annual output of pyrites from this mine, which will probably be one of the largest pyrite producers in Ontario.

Conmee township.—Thunder Bay district, Lot B, Concession V. Some work has been done on a deposit which lies on this lot about a quarter of a mile west of Bridge 31A, on the Canadian Northern railway, some distance below Mokoman station.

¹ O. B. M. Reports for 1898, 1901, 1902, 1903, 1904, 1905.

The deposit strikes northeast near the contact of conglomerate and the Mattawin Iron range. A deep covering of bouldery gravel obscures the surface, and the deposit can only be examined where a small pit has been sunk on the bank of Beaver creek. The bottom of the test pit is 5' below the level of the creek, and about 80 tons of ore have been thrown on the dump. The pyrite-bearing zone appears to be about 30' wide.

The occurrence is one of replacement, in part, or wholly, the conglomerate being replaced by pyrite, which even when massive, retains the rock structure. The more soluble pebbles have been completely replaced by pure pyritic nodules with a roughly spherical outline. In the other portions of the conglomerate, the substitution is more or less incomplete, the pebbles of pure silica being entirely unchanged. An average sample of ore on the dump yielded 29.20% sulphur.

Tip-Top Copper mine.—This property is situated 9 miles by trail southwest of the Canadian Northern railway at Kashaboive station. The main shaft is 200' deep, dipping 70° to the north, and four levels, 50' apart, have been driven. The following is a synopsis of the work done in the various levels:—

1st level.	Drift to East.	80' in length.
" "	" " West.	40' " "
2nd	" " East.	70' " "
" "	" " West.	40' " "
3rd	" " East.	60' " "
" "	" " West.	40' " "
4th	" " East.	65' " "

Cross cuts:—

1st level to the South.	60' in length.
" " " " North.	140' " "
4th " " " "	130' " "

Stopes:—

" " East.	40' long	25' high	8' wide
" " West.	30' "	15' "	10' "
2nd " East.	40' "	10' "	10' "
" " West.	30' "	10' "	8' "

Shaft No. 2, about 600' north of east from No. 1, is 50' deep.

Shaft No. 3, about 500' east from No. 2, is 20' deep.

The plant consists of 2 boilers, one 70 H.P. return tubular, and one 30 H.P. marine; one hoist, cylinders 6" × 8", one Ingersoll-Sergeant 4-drill air compressor.

The associated rocks, according to Miller,¹ are a series of talc and green schists. Diabase occurs as a dyke rock and also felsite. The ore consists

¹ Ontario Bureau of Mines 1903, p. 102.

of copper pyrites, pyrrhotite and iron pyrites. It carries values in gold in addition to the copper.

The Tip-Top is essentially a copper prospect. Massive pyritic lenses in the mine would run upward of 40% sulphur, but there are extensive associated bodies of leaner and very highly siliceous ore.¹

Steep Rock Lake deposits.—The deposits in the vicinity of this lake were very thoroughly prospected for iron ore. They lie north from Atikokan station on the Canadian Northern railway.

Three-quarters of a mile west from the shore of the lake, the Mackenzie and Mann locations AL 461 and 462 have been prospected by four diamond drill holes. These are said to have disclosed a deposit of pyrites, but details are not available. The country rock on the surface is interbanded silica and highly altered green schist.

A very large deposit of iron pyrites has been uncovered at the southern extremity of Straw Hat lake. This is reached by a trail to the westward from the southern part of the eastern arm of Steep Rock lake. The work done comprises trenching, test pitting, and 4 diamond drill holes on locations 857 X and 858 X. The south trench shows a width of pyrite of over 140', the eastern 60' of which would be quite high grade at shallow depth, as the only impurity was gossan. The ore showed unequal banding and nodular weathering. The eastern portion of the ore shown in the trench is somewhat siliceous, and would not run more than 38%-40% sulphur. A test pit 100 yards to the north near the camps, shows very fair pyrites under a heavy capping of limonite and hematite. The hill, on which the south trench is located, is 30' high, and the whole gully to the west appears to be underlain with pyrite. Diamond drilling disclosed the pyrite in the form of a vast crescent, between the horns of which lies a deposit of hematite, an occurrence resembling very much that of the Helen iron mine.

The country rock to the west is an eruptive greenstone, and to the east it is a green schist. These, along the trail to Steep Rock lake, show at times a curious ellipsoidal weathering.

The deposit is 4 miles level draw from the Canadian Northern Railway to the south-west.

Other Rainy River Prospects

The sulphides of Nickel lake, or Turtle river, and of the Pipestone lake range have been very little prospected, and whether several of these great gossan ranges are underlain with pyrite or pyrrhotite is as yet unknown. Work has been done at certain points on pyrrhotite, in the belief that it was nickeliferous, but except for diamond drilling on one location, the pyrite has been ignored.

¹Since going to press E. S. Moore has published "Report on the Tip-Top Copper Mine," Ontario Bureau of Mines, Report Vol. XX, part I, 1911, pp. 209-213.

"Iron pyrites is found in quantities that may prove important in the future on the shore of Nickel lake between Grassy Portage and Rice bays. On 577 P and 580 P, under a thick gossan of brown iron ore, one finds masses of solid pyrites several square yards in extent, and more than a foot in thickness. As little or no stripping has been done, one can hardly form an idea of the extent of these deposits. The mineral exists as a rather coarse granular mass in which the usual cubes may be seen. As it is common iron pyrites and not pyrrhotite, the name Nickel lake is misleading, and it is probable that the locations were taken up there under a misapprehension."¹

This range extends for a considerable distance along the valley on the Little Turtle river, but as no work had been done, and as the reports of timber rangers and others were exceedingly vague, a personal examination was not made.² No prospectors of that district were met who knew the distinction between pyrite and pyrrhotite.

"On the south side of Nickel lake in Watten township, a few miles farther west, the railway cuts through a considerable stretch of the Iron range, here of a somewhat unusual character, consisting largely of granular silica, occasionally banded with magnetite, but more often heavily charged with sulphides, especially pyrrhotite. In places, the sulphides become massive, hardly anything else being present. One band of pyrites 15' thick just at the shore of Nickel lake may in future be of importance as a source of sulphur."³

The Pipestone iron range was not examined, but from its similarity to the other western ranges, associated deposits of iron pyrites may reasonably be expected.

North of Riddell Siding.—Locations A 274, A 257, and A273 are situated about 1.5 miles north of Riddell siding on the Canadian Pacific railway. Here a heavy fahlband strikes in a northeast direction along a range of bare hills. In all the valleys and depressions along the range, high grade limonite is found. Some of this may have resulted from the decomposition of pyrites in place, but for the most part it has been derived from oxidation of disseminated iron-containing minerals along the ridges, and subsequent deposition of the hydroxide in the depressions. It was impossible to determine the depth of the limonite, but the surface area was quite extensive. No high grade gossan was observed in place on the ridges, and the fahlband was in the main low grade. A small test pit, however, near the shore of a lake, disclosed promising gossan and very fair pyrite. The country rock is a felsitic schist cut by numerous pegmatite dykes. It is said that a 20' shaft has since been sunk with good results, and that later operations have disclosed a considerable body of mixed pyrite and pyrrhotite running about 45% sulphur.

Vermilion Pyrites mine.—This property formerly the Vermilion Pyrites mine, and still earlier the Michie Pyrite mine, is now operated by the Northern Pyrites Company, 25 Broad St., New York. The Mining locations, H. W.

¹ Coleman, A. P., O. B. M. 1894, p. 74.

² By Mr. Fraleck.

³ Coleman, O. B. M. 1902, p. 134.

715 and H. W. 716, are situated on the shore of Big Vermilion lake, about 35 miles northeast of Dinorwic on the Canadian Pacific railway, and about 4 miles from Graham on the Grand Trunk Pacific railway.

The deposit lies in a depression between a rocky ridge which strikes somewhat north of east, and the shore of Big Vermilion lake. It runs into the lake towards the west end. The surface is covered by a heavy blanket of boulder clay varying from 8' to 20' in thickness. The only place where the gossan cap was exposed was on the shore of the lake where wave action had removed the clay cover. The lake derives its name from the discoloring of the water by iron oxide from this gossan cap, and the discovery was made by a prospector when searching for gold ores.

Two shafts have been sunk on the ore body. Number 1 shaft is vertical, 8' x 10' in section and is used only as a manway and for pipe lines and ventilation. It is 260 feet in depth. This shaft is equipped with a standard 41" Lidgerwood single drum hoisting engine. Number 2, the working shaft, is a 3-compartment shaft sunk in the foot wall at an angle of 58°. The hoisting compartments are each 4' x 6', and the shaft is 260 feet in depth. It is equipped with a 30 H.P. Flory double cylinder standard friction hoist, and Stephens-Adamson automatic mine skips.

The power plant at Number 1 shaft consists of three 100 H.P. 66" x 16' Jenckes horizontal tubular boilers, class B. Air is supplied by one Canadian Rand cross-compound Corliss compressor (RR3) of 1000 cubic feet capacity, and one half a Duplex Allis-Chalmers-Bullock Class GC air compressor. There is also a high pressure, Type A, 4 $\frac{3}{4}$ " x 4 $\frac{1}{2}$ " American Blower vertical engine and a 6 K.W., Type B, 116-120 volt Bullock generator. The mine is also supplied with such accessory appliances as feed water heater, supply and fire pumps, etc.

Over number 2 shaft a headframe 50' high has been erected. This contains a 50-ton ore pocket into which the skips will dump and from which the ore will be delivered to the crushers in the adjoining rock house. The rock house is equipped with one number 3, and one number 5 Austin gyratory crushers, and the necessary grizzlies for screening the ore to furnace size. The crushed ore is raised by bucket elevator and delivered through the screens to the ore bins over the aerial tramway. Power is supplied by a 16" x 18" Regal automatic engine.

The aerial tramway, which was constructed two years ago to convey the crushed ore from the rock house to the spur from the G. T. P. Ry., about 3 miles distant, has been furnished with new equipment and a new terminal erected at the spur where the ore may be either delivered direct to railway cars or stocked in piles for subsequent loading by means of a 10-ton locomotive crane alongside.

The mine has been equipped with new rock drills of both the piston and hammer styles as well as with new mine cars, air piping, tracks, etc. Overhead stopes have been opened preparatory to the resumption of shipments during the coming season.

A new office and warehouse, dry house for the underground men, powder magazine, machine shop, water lines, mess and bunk house, as well as several cottages have been provided.

About a year and a half ago, some 6000 tons of ore were shipped, but since then there have been no shipments. The ore mined during development work was stock-piled. It is hoped that about 25,000 tons will be sent out this season (1911), if transportation facilities will permit; this will include ore mined in development work.

The ore body has been developed for 800 feet on the 2nd. level. In addition, there is considerable drifting on the 1st. and 3rd. levels; the total amount of drifting in December 1911, exclusive of cross cuts, was 1500 feet. The width of the ore body varies from 30 to 63 feet.

According to Fraleck the interbanded pyrite and rock near the hanging wall side, as disclosed by the shaft and crosscut is suggestive of vein filling, especially as some tourmaline was observed along the northern edge of the deposit. The laminated structure of the ore, however, renders it more probable that the deposit is of the replacement type, and that the banded pyrite and rock along the northern edge represent incomplete replacement of the schist. The country rock along the hanging wall side is composed of a greenish highly calciferous schist. The gangue matter of the ore is quartz. The ore body strikes northeast and southwest, and dips to the northwest at an angle of about 61°.

The ore consists of pyrites (with some pyrrhotite) which apparently runs about 40% sulphur; this also being the proportion of sulphur in the lot of ore already shipped. The ore is a hard and fine grained pyrite and will be mostly lump ore, with some fines. It has proved to be an excellent ore for acid making, the residual sulphur lost in the cinder being often less than one per cent, although this will be increased by any admixture of pyrrhotite.

The mine is operated for the Northern Pyrites Company¹, by Robert K. Painter of Benson Mines, New York, as Consulting Engineer and H. V. Smythe, local Superintendent at the mine.²

The Fanning prospect.—This prospect is situated on the shore of Big Vermilion lake, 8 miles west of the Vermilion mine. Some trenching through a blanket of boulder clay about 4' in thickness has been done at the extreme end of a point. High grade pyrite in seams from 2' to 6' in thickness is interbanded with graphitic shale. The deposit strikes east and west, and dips toward the shore to the north. It is said that borings in the lake out from the shore disclosed high grade pyrite to a width of 20'. The deposit dips towards the shore and could be very readily prospected with a diamond drill.

The Morley prospect.—This prospect is situated about 3 miles southeast of Schreiber on the Canadian Pacific railway, and about 2 miles from the

¹ 25 Broad St., New York.

² Since going to press E. S. Moore has published "Vermilion Lake Pyrite Deposits," Ontario Bureau of Mines, Report Vol. XX, Part I, 1911, pp. 199-209.

north shore of Lake Superior. The work in 1906 consisted of a trench 36 paces in length and 8' deep, running north and south along the strike of the deposit, which lies between trap to the east and quartzite to the west. The pyrite is practically pure on the east side, but towards the west becomes mixed with pyrrhotite, and across a width of 6' is changed almost entirely to the latter mineral. Twenty-five feet to the east and farther down the hill a shaft has been sunk on a parallel lens. The shaft was filled with water, but judging from the quantity of material on the dump, would be about 60' in depth. The pyrite runs almost the theoretical percentage, but the major part of the dump is composed of pyrrhotite and intermixed pyrrhotite rock. One hundred feet below towards the bottom of the gully, a tunnel 20' in length has been driven into the hill to the east, with a cross-cut 30' in length, disclosing a very lean mixture of pyrrhotite and rock. One quarter of a mile to the north, test pits have been sunk on some stringers of pyrite, the extent of which it was not possible to ascertain, owing to the thoroughness of the weathering.

The Otisse prospect.—This location, 776 X, lies about 1.5 miles north of Schreiber at the north end of Cook lake. A heavy fahlband strikes east and west for about a mile. The gossan capping had been removed in several places and test pits sunk. The largest of these was about 12' deep and 12' long across the strike of the deposit, which is here seen to consist of a very fine grained mixture of pyrite, pyrrhotite and silica. An average sample of the dump yielded 32.26% sulphur.

Goudreau Lake deposits.—These extensive pyrite ranges, lie about 18 miles in a straight line to the southwest of Missanabie on the Canadian Pacific railway, and about 3 miles by trail west of the western end of Goudreau lake.

The country between Dog lake and Goudreau lake is composed of green schists cut by felsitic and greenstone intrusions. At the outlet of the more northerly lake of the Two Sisters, the formation consists of a fine grained conglomerate with pebbles the size of a small pea in a soft green cementing material. Three miles to the north, this shades into a very coarse conglomerate, with light coloured boulders upwards of 12" in diameter. Proceeding from this point up the creek flowing out of Goudreau lake, considerable disturbance has given the conglomerate a foliated structure, and the boulders are very flatly compressed, with the longer axes parallel to the schistosity. West of Goudreau lake, however, the conglomerate has shaded into a green schist.

For convenience, the ranges will be roughly described as the North range, comprising deposits "A", "C", and the "Bear claim", and the south range comprising deposits "B", "D", and "E"; True's trail runs north of east between the ranges.

Approaching the deposits from the east, the trail passes to the south of the Bear claim and along the northern edge of two small lakes. At the western end of the second lake, True's trail proceeds in a westerly direction. Another trail runs north to deposit C and another to deposit B in a southwest direction.

The prevailing rock at the lakes is a green schist. This has, however, been metamorphosed in places to a vitreous hornstone schist by the intrusion of a greenstone to the north. A well defined contact occurs a short distance to the north of the western end of the lake.

Deposit "C."—For about 400 paces north of True's trail, the path to deposit "C" passes over low ridges of rusty schist, and then through a depression underlain by limonite. Parallel with this, and striking east and west, runs a low ridge of pyrite, with green schist to the north. A surface cross-cut here discloses a width of 50' of fairly high grade pyrite except for some bands of green schist, which could easily be culled out, and fine intermixed silica. The pyrite on the side of the ridge is covered with a thin scale of gossan which deepens towards the depressions. The total length of deposit "C" as disclosed by 16 pits is about 600'.

Deposit "A."—A short distance to the north and slightly east of "C" is deposit "A." In the vicinity of the hill on which the camps are situated, all of the depressions are underlain with limonite. Except for a few trenches, the exploratory work here was done with a diamond drill. Coleman describes the locality¹:—"A section across the low hill near its west end shows green schist, to the south, then limestone with some pyritous schist, 30' of pyrite, 12' of green schist, 9' of pyrite, and green schist to the north. There seems to be little continuity in the structure, however, and sections at different points vary greatly among themselves. Pyrites or gossan extends about 400' from east to west, with a width of about 150'; but it is greatly mixed with other materials, especially schist and limestone. It is stated that a diamond drill hole on "A" claim showed pyrite to a depth of 169' averaging about 35% sulphur.

Deposit "B."—This deposit is reached by a trail about one quarter of a mile long in a southwest direction from the outlet of the second lake. The central portion of this trail passes along a light colored siliceous schist, studded with small broken crystals of hornblende, suggesting a sheared granite. Deposit "B" lies on the northern flank of a rocky ridge striking east and west and forming the southern shore of a small lake. Along the side hill, trenches reveal a length of 900' of either pyrite or gossan, and the lake bottom on that side appears to consist of limonite. The pyrite here, although somewhat interbanded with green schist, is of fair grade. On the side hill where drainage is good, the capping is very thin, and laminated, but becomes a considerable body of limonite in the lake and the depression at the eastern extremity.

Deposit "D."—Along the south end of a hill, a short distance west of the lake is deposit "D." The exposed pyrite has here weathered in a very peculiar manner, fresh fractures showing an ore of much lower grade than the surface would indicate. This deposit is the smallest and lowest in grade of the series.

¹ O. B. M., 15th Report, 1906, p. 186.

Deposit "E."—A short distance to the west, across a small muskeg, lies deposit "E." Coleman's description is as follows¹:—

"The first outcrop toward the west, named "E" by the prospectors who explored it, runs east and west for about 100', and in cross section shows from south to north:

Pyrite with some green schist.....	8 paces.
Limestone (mostly hidden by debris).....	6 "
Pyrite.....	4 "
Green schist (strike 100°, dip 60° S.).....	33 "
Pyrite with some cellular silica.....	29 "
Very rusty banded silica (dip 25° S.).....	19 "
Width of section.....	98 "

"Just to the west of the hill top on which the section was measured, the limestone and much of the pyrites have been dissolved out as a narrow ravine, and here a shaft 25' deep has been sunk. The materials on the dump are mainly limestone, but with some bands and knots of green schist and many masses of pyrite—sometimes interbanded with the limestone."

"The limestone is exactly like that of the Grenville series, but the silica at the north end of the section is unmistakably iron formation, though with little interbanded magnetite. The pyrites often has a porphyritic look, large crystals being embedded in a finer ground mass."

"A short distance to the north of this lake, along the path from outcrop "E," a nearly straight band of crystalline limestone was followed for 410 paces. In some places it is 35' wide, though generally less than that, and parallel to it on the north runs a long depression sometimes showing gossan on its north side and perhaps representing a band of pyrites. The limestone is white or grey, and dips about 80° to the south with a strike nearly east and west. After the 410 paces diorite seems to cut off the limestone, but 160 paces to the east there are 2 sink holes running east and west as narrow trenches. The largest is 15' long, and 8' or 10' deep with 6' of partly decomposed pyrite at the bottom."

Bear Claim.—This claim was not visited by Mr. Fraleek; Coleman's description is as follows:² The most easterly deposit, called the Bear claim, displays many interesting features, and has the largest extent of all the outcrop crops seen, with a length from east to west of 1200' and a width of nearly 300'. To the west, there is low peaty ground with small pools containing a foot or more of ochre or bog ore probably leached from the deposit, and much of the deposit itself is gossan covered or hidden beneath drift."

"A stripping near the middle shows gossan or pyrite at several point across the strike over a width of 150', but no stripping crosses the full width. Towards the east, walls of green schist or schistose hornblende porphyrite,

¹ O. B. M., 1906, pp. 184-5.

² O. B. M., 1906, pp. 186.

rise on both sides, and at the east end of the deposit, the appearance is that of an amphitheatre with walls 50' or 75' high. Here pyrites seems to dip in all directions under the hornblende porphyrite, as if it was a dome with the top removed. The pyrites was weathered out near the top of the wall of the amphitheatre, leaving the schist projecting over it like an eave. Whether the valley was formed by the destruction of pyrites is uncertain, but the arrangement suggests this. The pyrites of the Bear clearing seems more mixed with rock matter than in most of the deposits, but it covers a far larger area than any of the others."

The above descriptions show that there is a very considerable pyrite-bearing area near Goudreau lake, and indicate that only a meagre amount of exploratory work has been done, in proportion to that necessary for arriving at any adequate estimate of quantity and grade of the available ore. A large extent of gossan and bog-ore covered depressions has not as yet been prospected. It is not unreasonable to expect that in some of these, deposits of pyrite, higher in grade than those of the hilly outcrops, may be found. Deposits "B" and "C" are higher in grade than the others, and, with very little culling, their product should run approximately 40% sulphur. In the other ore bodies workable lenses of 40% ore doubtless occur. The remaining material running between 25% and 35% in sulphur could readily be concentrated to a 48% or a 50% product. The plant is quite simple, and the operating cost in a country replete with water-power, should not exceed 60 cents per ton. The over burden of limonite is by no means insignificant economically, and will repay removal, especially if taken away before it becomes contaminated during the mining of the pyrite.

Some of the deposits are associated with outliers of the Iron formation, but the proximity of the eruptive greenstone to the north is suggestive of some of the Eastern Ontario occurrences.

Further exploration work has been carried out on the prospects by the Lake Superior Corporation, but the results of this exploration are not yet available to the public.

Pyrites south of Chelmsford—Clark prospect.—Lot 9, Concession VI, Creighton township, Algoma district. On this property a trench 50' long and 3' to 12' deep, across the strike, which is easterly, shows gossan all the way. The gossan towards the north has clearly been formed by seepage from the deposit, which appears to lie along the side of a rocky ridge. Owing to the small amount of work done, and to the rapidity of oxidation, no pyrite could be observed in place, but some pieces in the dump were very high in grade.

The country rock to the south is a mottled crystalline schist, quite massive in structure.

Craig and Hamilton prospect.—The adjoining lot to the west has been prospected for copper. The work consists of several trenches, test pits, and a 60' shaft which has been sunk through interbanded iron pyrites, chalcopyrite, bornite, schist and graphitic shale, the last being present in quantity.

The appearance of the dump indicates that if properly culled, the ore would grade high enough in sulphur content to be available for acid-making purposes.

These prospects are 7 miles by good wagon road from Chelmsford station on the Canadian Pacific railway, and 4 miles across level country from the track.

Deposits elsewhere.—In the vicinity of Rossport and Jackfish on the Canadian Pacific railway, north of lake Superior, locations have been taken up for gold, that seem to carry pyrite in sufficient quantity to warrant the expectation that they may develop into pyrite mines. Mr. Fraleck was not able to obtain authentic data as to the exact localities and was unable to visit all the prospects.

In other districts, especially in the Sudbury region, prospectors appear to have at times opened up deposits of pyrite which were abandoned when nickel was not found to be present.

S. F. Miller in his report¹ on the Iron Ores of Nipissing District, discovered extensive belts of pyritous rocks paralleling with iron ranges. He suggests that they form with the jaspilite ranges alternate legs of an eroded anticline. It is possible that these may form a source of pyrite, soon as the districts in which they are found are provided with transportation facilities.

Pyrites North of the Hudson Bay Watershed

Island portage on Mattagami river.—On an island portage on the Mattagami river, between its junction with the Kakozhish and Kapuskasing rivers, is an iron pyrite deposit that was noted both by A. G. Burrows and E. L. Fraleck in 1900.²

The former writer mentions the occurrence of a vein of quartz impregnated with pyrite and garnets. This vein is about 30' wide, and showed for 40' along its length. A sample of the vein material, nearly all pyrites, showed a gold assay of \$1.40 per ton. No trenching has been done and the quantity and quality of the ore is not known.

Big River deposit.—In the Report of the Bureau of Mines, for 1895,³ Mr. E. B. Borron quotes John Driver's description of a large pyrite deposit on Big river, a tributary of the Opasatika river. John Driver, who started out from Brunswick Post, states: "We followed the Missinabi down to the Opasatika portage, which is a straight line, northeast 40 miles, and thence crossed over to Opasatika lake, which is 3.5 miles south of Missinabi river. From the west end of Opasatika lake to the junction of the southwest end of Missinabi lake is 91 miles, including 5.5 miles up the Big river to the pyrites bed or vein. Having looked over the vein, which I had no trouble to find, the next work was to cut out a path or road on the south

¹ O. B. M., 10th Annual Report, 1901, p. 173.

² Report of the Survey and Exploration of Northern Ontario, 1900, pp. 66 and 77.

³ Page 255.

bank down to the camp, a distance of 1.5 miles. . . . We uncovered the rock along the south bank the full width of the bed of pyrites, which is 35' from wall to wall. I put in shots, which broke up the vein rock 2' deep, from which I got specimens. I then uncovered the rock 100' back from the bank, and found the vein covered over with a foot of sandy loam. My men uncovered the vein from wall to wall, and I found it to be 35' wide. The course is northwest 2° west, and (the rock dips) at an angle of 65° east. In tracing the vein south, I found it to be deeply covered with soil. The rock gradually rises in going back from the river and at 300 yards is about 20' above water level of the river."

"When Mr. Borron explored Big river in 1886, he thought that the rock in the river was a boulder from which he got his specimen, but I found it to be part of the vein, 15' wide and 2' above the water. It crosses one third of the river on the south side about 200 yards up stream. The river here takes a bend to the south, and comes back on itself, so that in following the course of the vein on the north side, it cuts across this point of land, which is a drift soil However, in the following up the course, I found the vein to crop out at the foot of the rapid on the south side of the west branch of the forks of the river, half a mile northwest from the place where I had been working. Here the rock is deeply covered with stiff clay. I got the men to clean off the part of the vein, and took what specimens I could break off with my pick hammer. From the surface, the pyrites at this place does not look as good as at the lower place, although I am quite sure it is the same vein. The rock is so deeply covered with a clay soil that I could not follow it any farther, but no doubt it continues on for a much farther distance northward. In following up some 300 to 400 yards. I found that the country rock took a change, being on the west side of the vein Laurentian, while on the east side and all the way down the river to the first rapid, it is a slate, what I take to be a Huronian."

Lower Island portage, Mattagami river.—E. L. Fraleck states that at this portage there is every indication of a considerable body of iron pyrites ore.¹

Pyrite under Hematite

The iron ores of eastern Ontario are characterized by a high sulphur content. In several localities, they are known to be underlain by pyrite. In some cases, properties were operated until the sulphur content, due to the presence of pyrite, became too high for shipment, and the mine was abandoned. The workable depth, as an iron ore deposit, varied from 25' to about 80'. Pieces of ore containing pyrite cores can be found on the old dumps. There seems to be no doubt but that these hematite deposits were the gossan capping of sulphide ore bodies, subsequently altered from limonite to hematite.

In only one instance, that of the Eldorado Copper mine, has development work been continued after the hematite suitable for the iron ore market

¹ Exploration in Northern Ontario, 1900, p. 81.

had been removed. This property was operated for a short time as a copper mine, a small matting furnace having been erected to smelt the ore obtained. The property was closed in 1907 after the ore body had been followed to a depth of about 300'. It does not appear to have been successfully operated as a copper producer, but as a sulphur property it may still prove to be of value.

In the following list are given the lot and range numbers of localities in Eastern Ontario from which hematite has been reported. Many of these localities are unexplored prospects, others are abandoned iron mines:—

	Range	Lot
Hastings county, Marmora township .	IX	6, 12, 13, 14
	X	13, 14, 16
	XI	16
Hastings county, Madoc township . . .	I	18, 19
	II	2, 18
	V	11, 12, 13, 15, 17, 18
	VI	4, 7, 9, 10, 12, 13
	VII	6, 8, 9
Hastings county, Huntingdon	XIV	9
Hastings county, Faraday	X	21
	XI	21
Frontenac county, Portland township.	IX	6, 7
	X	7
	XII	5
Leeds county, Crosby township.	VI	5
	IX	24
Bastard township.	IX	24
	IV	4
Lanark county, Bathurst township.	X	22, 23
	XI	21
" " North Sherbrooke . . .	XII	21
	XI	11
" " Dalhousie	XII	11
	IV	1
	XI	11
" " Darling.	XII	11
	III	22
	IV	16, 22
	IV	16, 22
	XI	22, 23, 24, 26, 27
	XII	26, 27

Geological Relationships

In discussing the geological relationships of the pyrite occurrences in Ontario, Fraleck states that pyrite deposits have been found throughout an

area of approximately 170,000 square miles, including eastern, northern and western Ontario.

On the basis of their rock associates, he divides the deposits into three classes as follows:—

1. The Gneissoid, comprising the Brockville and Mattagami deposits. In both cases basic dykes are in close proximity.
2. Those of the Iron formation, comprising the Helen, Straw Hat lake, and probably the Goudreau lake deposits; those in the crystalline limestone of Eastern Ontario are similar in origin, if not in age.
3. The remainder are associated with the crystalline schists with, in almost every instance, an eruptive greenstone close by.

PYRITES IN BRITISH COLUMBIA

The mineral pyrites is reported from many localities in this province. For the most part these occurrences are associated with gold or copper ores, and the deposits are not valuable because of the sulphur content of the ore. At the present time no pyrites is mined in British Columbia for its sulphur, nor, so far as the writer was able to learn, is any imported. The sulphides which are mined are smelted to recover copper and the precious metals, and the sulphur is burned off. It is possible that in the future, with the development of manufacturing industries, there may be a market for the sulphur content of suitable ores. Present needs are satisfied by the importation of Japanese raw sulphur, which costs between \$17–\$18, per ton, in cargo lots at sea board points.

There are two localities, at which pyrites deposits occur that are worthy of special mention, viz.—the Hidden Creek property of the Granby Consolidated Mining and Smelting Company, and an occurrence on the Ecstall river about thirty-five miles above Port Essington, owned by the British Columbia Pyrites Company.

Hidden Creek.—¹This property is located about three quarters of a mile from tide water, on Goose Bay at the head of Observatory Inlet. It is now controlled by the Granby Consolidated Mining and Smelting Company, which owns 14 claims and has mining rights in several others. This Company has been exploring and developing this prospect as a copper property for about two years, and it is probable that a smelter will be erected in the near future.

A large body of sulphide ore has been developed by a system of tunnels and supplementary diamond drilling. A tonnage estimated at about 6,000,000 tons of 2% (copper) ore, or about 12,000,000 tons of 1.65% ore has been shown to be present. In addition, development work has shown a very considerable tonnage of ore of a higher grade—above 5%—and a large tonnage of low grade. A large force is now employed in preparing the property for operation on a large scale as a copper mine.

¹ Granby Consolidated Mining and Smelting Company, Grand Forks, B.C.

Much of the ore which occurs on this property is almost pure sulphides with high sulphur content, and a large tonnage occurs that is nearly pure pyrite.

Under present conditions there is no market for the sulphur content of the ore, and as a consequence, the sulphur will be burned off and discharged into the air in the process of smelting. Should it be warranted by market conditions at any time before the deposit is exhausted, a large tonnage of pyrites with a low copper content will be available from this mine. As the mine is practically at tide water, it would be comparatively easy to deliver the ore very cheaply at any point on the coast. After treatment in a roasting furnace to recover the sulphur content, the cinder could easily be subjected to treatment to recover the copper and other values which it would contain.

*Ecstall river.*¹ This property is situated on Red Gulch creek, a tributary of the Ecstall river, at the head of tide water, and about 35 miles above Port Essington. The portal of a prospecting tunnel, which is driven into the ore, is about 2,400 feet from the river. There is said to be an iron stained band on the west side of the creek, presumably pyrites, traceable for several thousand feet, and varying in width from 12' to 200'.

The writer visited the prospect tunnel on Red Gulch creek but was not able to visit the outcrop on account of the weather conditions. The sill of the tunnel portal stands only a few feet above the creek and the tunnel is driven into the side of the gulch. At about 50' from the entry it cuts an ore body of almost pure pyrite about 15' in width. Ore has been stoped out on each side of the tunnel for about 20' and the full width of the ore chute.

Outcroppings showing pyrite are said to occur in a number of other places further up the creek, and on the side of the valley. These were not visited. Exploratory work has been confined to the opening of this tunnel.

A sample shipment of ore from the tunnel, said to be about 100 tons, is reported to have been made to the Chemical Works at Victoria. The test of the trial shipment of ore showed that it is a very satisfactory ore for acid making.

Samples which were assayed show small values in gold, silver and copper. The sulphur content varies from 40 to 48%.

Further exploratory work is required to definitely determine if the pyrites ore bodies on this property are large enough to be operated economically. At present there is no market on the coast for ore of this character and no work is being done on the ore bodies.

PYRRHOTITE IN ONTARIO

Pyrrhotites are not usually considered to be sulphur ores, since a pure pyrrhotite contains only 39.2% sulphur, which can only be recovered with difficulty, while pure pyrite assays 53.4% sulphur. Pyrrhotites have, however been successfully roasted in several types of fines burners, without sup-

¹ British Columbia Pyrites Co., care of Swinerton and Musgrave, Victoria, B.C.

plying additional heat from an external source; the gas produced contains a lower percentage of sulphur dioxide than that made from pyrites. Conditions might easily arise whereby it would be economical to employ ores of this kind for acid making.

Ores of this class have been found at a few localities in Eastern Ontario, but the most important known deposits are the nickel-copper-bearing pyrrhotites of the Sudbury district. Exploration work has shown that there are probably nearly 50,000,000 tons of this ore available in the district. Much of it will contain above 25% sulphur, some of it will run above 30%. Present practice is to roast the ore in open heaps, driving off slightly more than one half the sulphur. It does not appear to be commercially practicable to save this sulphur at the present time, i.e., the cost of recovering and marketing the sulphur would be greater than the value of the sulphur recovered. The expansion of the market for sulphur dioxide and the introduction of improved processes may, in the future, so modify conditions that it may be practicable to recover and market some of the sulphur which is now valueless and is thrown away under present practice.

Notes on some Foreign Occurrences of Pyrites

Pyrites for the United States market, apart from the domestic supply, comes chiefly from Spain and Portugal. Small quantities are also imported from Norway, Newfoundland, Mexico, Canada, and other countries.¹ The value of pyrites on the United States market is practically determined by the value of the Spanish ores.

The ore bodies which occur in Spain are the largest in the world and their annual output is also the largest. As the nature of these occurrences is interesting for comparative purposes, a description of these deposits has been included in this report. Some notes on occurrences in Norway and Japan have also been included, the latter because Japanese pyrites would be readily available did a market exist on the west coast of America.

The Pyritic Deposits of Huelva, Spain²

The pyrites deposits of the province of Huelva, Spain, are probably the most important known deposits of this mineral. They have been known and exploited since very ancient times. The following general description of the region is an abstract of an article by Mr. A. Monerieff Finlayson. A much more detailed discussion, including a description of some of the individual deposits will be found in the original paper; numerous references to the literature of the district will also be found in Mr. Finlayson's article.

The pyritic deposits occupy a belt extending from Aznalcollar in Sevilla, through Huelva, to Aljustrel in Alemtejo (Portugal). Their apparent dis-

¹ See Chapter III, Table 15.

² Abstract, article of same title by A. Monerieff Finlayson, *Economic Geology*, Vol. V., pp. 357-372 and 403-437, 1910; compare also P. Truchot, "Les Pyrites," pp. 32-64, 1907.

tribution in long belts is purely fortuitous, and is due to the tectonics of the district, but, on a smaller scale, well-marked lines of mineralization are evident extending over two or three miles and including several detached lodes.

In form the lodes are lenticular, both in plan and in section, but their dimensions are variable, and there are all gradations from very elongated lenses to short wide masses. A type sometimes met with is wedge-shaped in plan, with one broad and one tapering end. As a rule, however, both ends of a lode feather out along the strike. "Rolls" may occur along the walls, and the rolls frequently divide up into stringers, both at their terminations in strike and vertically. Their lower ends generally taper to a point in cross-section, accompanied often by a decrease in length at successive levels, but occasionally they have a broad base, especially when, like the north lodes of Rio Tinto, they are enclosed in porphyry. A pitch along the strike of the lodes is occasionally seen.

The deposits show great variations in size, but there is a general tendency towards proportional dimensions in individual lodes. The longest masses include the San Dionisio and South Lodes of Rio Tinto, which have a combined length of over 4.5 miles. La Zarza is 1,360 yards in length, and the lodes of Sotiel cover a length of over 1,100 yards. The great majority of the lodes, however, vary between 300 and 750 yards, and a few are shorter than 200 yards. The width, *i.e.*, maximum width, of lodes is generally proportional to their length, but there is considerable irregularity. San Dionisio, probably the largest single lode in the field, reaches a width of 270 yards, but the majority of the large lodes range between 50 and 160 yards in width, and the smaller ones between 16 and 32 yards.

The depth or vertical extent of lodes is, in the first place, roughly proportional to their other dimensions. Thus San Dionisio is opened up to a depth of 1640', and is known to extend still deeper. This is, however, an exceptional figure. The vertical range of ore deposition has undoubtedly been very restricted, and has probably in no cases exceeded 3370'. Few of the lodes appear to have exceeded an original depth of 1600', and as a result of denudation, very few now attain to 1000'. The smaller lodes invariably taper out at a much less depth than this. The factor of denudation has, however, been the all-important cause in determining the present vertical extent of lodes in the field. This is strikingly seen where two or more parallel lodes occur *en echelon*. In such cases, one lode may feather out a short distance below its outcrop, while its neighbor has no outcrop, but dies out before reaching the surface. The extreme effect of denudation occasionally seen has been the erosion of a lode to such an extent that the residual portion has been completely converted into gossan, with no sulphide ore beneath. On the other hand, many lodes taper near the surface, and have an insignificant outcrop, thus indicating that but little has been removed by erosion.

The lode walls are generally well-defined and smooth, and marked by clay selvages or gouge. Slickensides are common and the walls are in all

respects similar to those of veins of the normal type. They clearly mark planes of former movement. The adjoining slates are frequently much crushed and contorted, especially along the continuation of the lode channel, and brecciation of the rocks, with a cement of quartz and massive pyrite, is sometimes seen, especially where the lodes adjoin porphyry, as at Rio Tinto, or diabase, as at Santo Domingo.

It is characteristic of the lodes that they are invariably found along planes or zones of weakness, such as the contact of porphyry and slate, or quartzite and slate. The lode zone of Cabezas del Pasto, for example, is in a belt of soft crushed slates, some 165' wide, with quartzites to the south of it, and greywacke to the north. The position of the lodes throughout the area has clearly been determined in each case by structural features, *i.e.*, by natural lines of weakness which gave way under strain, and permitted shearing or overthrusting.

The Country Rock.—Of the 33 chief lodes or groups of lodes in the district, 4 are practically enclosed in porphyry, 2 are at the junction between slate and diabase, 11 are at the junction of slate and porphyry, and 16 are enclosed wholly in slates or associated sedimentaries. A consideration of their structural relations, indeed, at once suggests that the lodes cannot be regarded as genetically related to any one group of igneous rocks *per se*.

Beyond the walls, the country rock is impregnated with pyrites to a distance of from 30' to 45', according to the size of the ore body, and the effect is commonly greater on the hanging wall side. The adjoining rocks further show the effects of hydrothermal action to a marked degree, forming the zone of "salbanda." At San Dionisio, Rio Tinto, the porphyry has been altered, over a distance of 30' to 60' from the wall to an earthy porous rock full of unaltered quartz phenocrysts.

Lode Structure.—The typical lodes are composed of massive, homogeneous pyrite. The ore is remarkably free from admixed country rock. Enclosed "horses" of country rock occur, but they are unimportant in comparison with the width of the lodes. At other times, the lodes are frequently split up into legs or strings by intercalated seams of country rock. Later faults are not common, except in the case of some small lodes where considerable displacement and even severance of the lode has occurred. That movement has occurred since lode formation is, however, clearly shown by the abundant and often characteristic joints which traverse the mass of the ore. Thus a set of vertical joints is commonly seen running parallel with the strike of the lode, and frequently a second vertical set, running from wall to wall and passing into the country rock may occur. Finally, horizontal joints or "floors" and irregular diagonal jointing are sometimes present. The joint planes are nearly always well slickensided, and often lined with quartz. The comparative absence of faults in the lodes is probably due to their massive and resistant nature."

"The typical ore is seldom conspicuously banded in structure, but highly banded ores occur as local seams in parts of the lodes, alternating with and

sometimes passing insensibly into the massive ore. A faint banding can, however, generally be discerned, parallel with the lode walls.

The Ores. The Gossan.—The essential ore of the oxidized zone is a massive hematite, containing over 50% of iron, and from 10% to 15% of siliceous and argillaceous matter. Its depth varies from 80' to 160', the average being about 100'. The depth of oxidation has clearly been determined, in all cases, by the topographic level of ground water, though it is dependent also, in a minor degree, on the relative porosity of the enclosing rocks. The appearance of the outcrop is often somewhat deceptive; thus, in the case of lodes whose upper termination does not reach the present surface, the line of outcrop may be marked only by ferruginous slates, or there may even be no surface indication whatever of ore beneath.

The lower limit of the gossan is sharp and well defined and the line of contact between gossan and sulphide ore is sometimes marked by an earthy zone carrying considerable values in gold and silver.

Zone of Enriched Sulphides.—The top portion of the sulphide zone for a thickness of 3' or more is generally composed of leached or impoverished pyrite, containing only traces of copper. Beneath this commences the zone of enriched sulphides, in which the ore assays from 3% to 12% of copper, the average being from 4% to 7%. The enriched pyrite which is softer and more porous than the lean ore beneath, carries chalcopyrite and chalcocite as the chief products of enrichment. Both chalcopyrite and chalcocite are abundant in the upper part of the zone, as veins filling cracks in the ore and in the adjoining country rock. Bornite is not very characteristic, but stringers of argentiferous galena, with occasional tetrahedrite and other silver-bearing ores, have been abundant as secondary products in some lodes. Gypsum and barytes occur with the secondary ores, filling fissures and joints. Native copper occurs in small quantities, in arborescent form and also deposited on old mine timbers.

Owing to the imperceptible transition from enriched to lean ore, the depth of the zone of enrichment cannot be very exactly stated, and, where faults or fissures occur in or adjacent to the lodes, there may result local enrichment at much more than the usual depth. The average depth of enrichment may, however, be placed at 160' to 200' below the gossan or 260' to 325' below the outcrop. To this depth the ore will in most cases, be found to assay 3% or more in copper.

Zone of Primary and Lean Sulphides.—With increasing depth the copper content, first of the enriched ore and later of the primary ore, progressively decreases. The bulk of the primary ores vary between 0.8% and 2% of copper, while some, such as those of El Perruval and La Zarza, assay 0.5% or less. The rate of decrease in depth varies greatly. In the low-grade masses, there may be comparatively little change to considerable depths. While the general law of decrease in depth holds good, there are local exceptions. In several mines there have been found patches of rich primary ore (chalcopyrite) at or near the lower terminations of the lodes.

The inclination of all the Huelva lodes is generally pretty steep and varies but little in different parts of the field. Differences in the rate of decrease due to this cause, if they exist, are consequently not easily detected, and in any case are not likely to be of economic significance.

The primary ore may be considered under four classes, namely massive ore, banded and complex ore, pyritous slates and magnetic ore. The massive ore, in which, it should be noted, a faint trace of banding is very frequently discernible, constitutes the greater portion of the lodes. It has a specific gravity of 4.5 to 4.8 and carries from 48% to 50% of sulphur. As the copper content decreases, the ore becomes harder and whiter. The total amount of silica alumina and earths seldom exceeds 3% or 4%, except in local siliceous ores. Lead and zinc occur in small quantities. Arsenic varies from 0.25% to 1%, and traces of bismuth, selenium, tellurium and other metals are present. Silver occurs in quantities up to 1 or 1.5 ozs. per ton and the gold amounts to 1% or 2% of the silver present.

Pyrites in Norway

The great cupriferous pyrite deposits of Norway are found along the degraded mountain range which forms the backbone of Scandinavia, between 59° and 70° north latitude. Ores are mined in the Sulitjelma region in Nordland, north of the Arctic Circle in the Trondhjem district, and at several points along the central and west coasts. The deposits at Sulitjelma are the largest producers in the kingdom.

The Norwegian deposits are typically lenticular in form, and are conformably intercalated between the layers of a crystalline schist belonging to the lower Silurian. They are usually closely associated with intrusive masses of gabbro or an associated soda granite. The ore bodies consist of iron pyrites and disseminated chalcopyrite in a siliceous gangue—mostly quartz. The thickness of the lenses varies from a few feet to more than 60'; their horizontal length on the surface is not much greater than their width, but they extend downward to very considerable depths, forming ore bodies of small cross section, but of great length.

The gangue which accompanies the ores is usually quartz. With the quartz are associated less amounts of hornblende mica, diopside and garnet; feldspar, epidote, titanite, chlorite, talc, and fluorspar are also present as accessory minerals; zinc blende, pyrrhotite, galena and arsenopyrite sometimes occur in small amounts.

At Sulitjelma, the presence of these gangue minerals makes it necessary to concentrate the ores. Two products are made—one containing 4-8% copper for smelting, and the other containing 1-4% copper, 45% sulphur, 34-36% iron, 2-2.5% silica and alumina, for export.

There are a number of pyrites ore bodies known to occur in Norway which are not exploited at the present time because of the difficulties of transportation.

*Pyrites in Japan*¹

Japan contains 38 out of the 250 greatest copper mines of the world according to Weed.² The copper ores occur in veins, impregnations or stockworks in acid volcanic rocks and in lenses of cupriferous pyrite in crystalline schists.

These deposits are operated chiefly for the copper content of the ores, the sulphur being lost; ore from deposits of the last type mentioned could, however, be utilized for its sulphur content. According to the Mineral Industry, slightly over 27,000 tons of pyrites were mined in Japan in 1909—a small output when the number and size of the lenticular deposits of cupriferous pyrites is considered. Data are not at present available indicating from what mine or mines this output of pyrites was obtained. As, however, there are undoubtedly abundant supplies of cupriferous pyrites available, and as Japanese pyrites might readily become an important factor in the market situation along the Pacific Coast in competition with native ores, the subjoined sketch of two of the more important deposits in Japan is given.³

The largest and most important of the deposits of cupriferous pyrites is the Besshi mine. The mine is situated on the watershed range of Shikoku, near Kyoto in southern Japan, and lies between 3000' and 4000' above sea level. It is connected by railway with Niihama on the coast, which is a port of call for steamers.

The rocks of the district are chloritic and graphitic schists, which, near the mines, contain bands of piedmontite schist. Quartz schist runs along both sides of the deposit, and in places grades into sericite or piedmontite schist. Amphibolite schists, eklogite and several dykes of serpentine containing chromite outcrop on the hanging wall side at some distance from the deposit.

The deposit itself is described as a bed of cupriferous iron pyrite striking at 120° and dipping northward in the upper level at 45° and at 60° in the lower levels. The bed is over 5000' long, 2'-30' wide, and the present (1909) deepest part is 2150' deep along the dip. In the bed two swells seem to course from the upper west part to the lower east corner, sloping at about 45°. There are several step faults in the eastern part.

The ore may be classified into three kinds:

- (a) Massive pyrite containing about 3% Cu, and 2% SiO₂.
- (b) Banded ore with the country-rock containing 4% Cu and 30% SiO₂.
- (c) Enriched ore.

The average tenor of the ore during a three month period in 1909 was 3.8% Cu, 33.3% S, and 35.3% Fe.

¹ See "Mining in Japan, Past and Present," published by the Bureau of Mines, The Department of Agriculture and Commerce of Japan, 1909.

² "Copper Mines of the World," W. H. Weed, 1908, p. 149.

³ Abstract, "Mining in Japan," p. 220.

At present all the ore is smelted, about two-thirds of it being first roasted in stalls to reduce the sulphur content; it is then treated in blast furnaces; the balance of the ore is subjected to pyritic smelting.

Other ore bodies of a similar type occur at the Kune mine which is situated in a forested mountainous region, on the left side of the upper course of the Tenryû river, 36 miles north of Hamamatsu station on the Tokaidô railway. The most important deposit forms an irregular massive ore body extending about 1000' with an average width of 45', being 100' wide at its greatest breadth. Several other beds occur in lenticular masses of small size varying in width from 3' to 25'.

The ore assays 4.5% Cu, 42% Fe, 45% S, and 4.5% Si. The best ore contains more than 20% Cu. At present the ore is used only for its copper content.

A number of other deposits of this type occur in Japan, some of them of considerable importance. Such are the Hibira, Hyuga and Itsuki pyrite ore bodies, which occur in carboniferous slates near intrusive bodies of quartz porphyry.

CHAPTER V.

THE ROASTING OF PYRITES

In practice, sulphides of the metals are subjected to a roasting process, either for the purpose of removing a part or all of the sulphur with the object of recovering the metallic portion only—usually copper or zinc—or for the purpose of recovering the sulphur contents of the ore. In the latter case it is usually desirable to remove the sulphur as completely as possible, though in the case of ores containing copper, it may be necessary to so regulate the roasting process that a sufficient quantity of sulphur may be left in the ore to permit of as perfect a recovery of the copper contents as possible.

Pyrites ores, as they come from the mine, are not usually suitable for charging into furnaces immediately. It is almost always necessary to break up the larger lumps in order to burn the pyrites completely. This is sometimes done at the mine, but more frequently at the works. At the mines the ore is usually passed directly over a grizzly from the skip or hoisting bucket. The oversize passes through some form of crusher, the large lumps being spalled. Gangue and rock matter are picked out by hand on the crusher floor. The crushed ore and the undersize pass through trommels or screens, to separate the lump ore from the fines. In some mills, where finer crushing is required, a second set of jaw crushers may be employed, or rolls, or both. The finely crushed ore will then be treated on tables. At many chemical works, run of mine ore is purchased. At these works the ore is often broken by hand and then screened to separate the fines from the lump.

Where the lumps of ore are too large, they do not burn completely; if cinder from such lumps is broken, cores of green ore will be found. Large lumps tend to become too hot when burning, and may form slag. On the other hand, ore that is too fine tends to pack, and prevents access of the proper amount of air. In burning pyrites, it thus becomes indispensable to separate the lump ore from the fines and to treat each separately. Pyrites burners can be worked to full advantage only if the pieces of ore are of uniform size, and where practicable, it is advisable to make a number of sizes. In practice the majority of plants seem to treat but two sizes "lump" (ore that will pass a $2\frac{1}{2}$ " ring, sometimes a 3" ring) and "fines" (ore that will pass a $\frac{3}{8}$ " screen, sometimes a $\frac{1}{4}$ " screen). In some plants an intermediate grade ("pea") is made; it constitutes that portion of the ore which will pass a 1" screen, but which is retained on the $\frac{3}{8}$ ".

Lump ores, in America at least, are used almost exclusively in acid works. Attempts to use them in the manufacture of sulphite liquors for

paper making were not very successful and have been abandoned.¹ In Europe, lump burners have found a place in paper mills for many years, but are now being gradually replaced by other forms of burners.

Fines ore is burned in furnaces of a special type—usually arranged so that the burning ore may be stirred intermittently, either by hand or by mechanical means, to promote combustion and to prevent undue heating and slagging. The gas obtained from these burners, especially some of the more improved forms, is richer in sulphur than the gas from lump burners, and can be made practically free from sulphur trioxide. Fines burners are largely used in acid works in conjunction with lump burners, and, in Europe, they have been installed in a great many paper mills.

Types of Pyrites Roasting Furnaces.

LUMP BURNERS

Lump burners are usually erected in the form of batteries of 16 to 32 furnaces, each rectangular in horizontal section, arranged with the units in two rows, back to back, with a common central wall. This arrangement insures the delivery of a fairly uniform supply of sulphur dioxide, economizes in space and material, conserves heat, and greatly reduces first costs. In construction details, the types of lump burners in use among the different acid makers vary greatly. The following may be considered as a generalized description of a typical set of burners of modern construction.²

Batteries of furnaces are usually built of brick, red brick being used for the lower portions and for the outer walls and arches. Falding introduces a layer of hollow clay brick behind the front plates; these tend to keep the furnace room cooler and to conserve the heat.³ The inside walls above the grates, the arches, and the gas flues are made of fire brick. Fire clay mortar is used, or, especially for the cooler parts of the furnace, boiled down tar and sand, it being necessary that all joints shall be gas proof.

The front walls are usually one brick thick, and vertical inside, while the back or centre wall between each two furnaces of a battery is usually two bricks wide. The side walls between adjacent burners are 1.5 or 2 bricks thick to a little above the level of the feed door, and one brick thick in the upper part. The arch below the gas flue is 4.5 inches thick, and the upper arch is of the same thickness. The top of the furnace is usually covered with finely crushed cinder to several inches in depth. Below the grate bars,

¹ Except in one case where experimental work, now in progress, is reported to have been successful.

² For detailed descriptions and drawings see:—

Lunge, George, *Sulphuric Acid and Alkali*, 3rd Ed., Vol. I, Part II, pp. 291 et seq.

Falding, F. J., "The Manufacture of Chamber Sulphuric Acid," *Mineral Industry*, 1899, pp. 665-468.

Hoffmann, Carl, *Handbuch der Paper Fabrikation*, Band II, pp. 1462 et seq.

³ Falding, *op. cit.*, p. 665.

the cinder pits may be made narrower than the grate area by widening the base of the centre wall and sloping it forward on both sides, and by sloping the side walls inward. The end walls of the battery are usually about 18" thick.

The brick work is faced with cast iron plates, one for each unit in the battery, each plate being provided with the necessary openings for operating the furnace. The end plates are solid. The whole is bound together by vertical buckstaves—steel rails, "I" beams or special castings—held with horizontal tie-rods (1½" round iron rods) above and below. The tie-rods are attached to the stays by stirrups, and are provided either with turn buckles or with threads and nuts, so arranged that the tension may be adjusted to suit the condition of the furnace.

The interior of each unit is divided into two portions by the grate bars, that portion below the grate bars constituting the cinder pit, while the space above the bars constitutes the furnace proper.

The top of the furnace is arched over with fire brick, leaving a small (5"-8" square) central opening, which leads to the space above. These spaces above the furnaces are connected together forming a gas flue, one on each side, leading to a dust chamber at one end of the battery of furnaces. On some furnaces a common central gas flue is used instead of two flues. In a continental type of burner, the flue is entirely omitted; the side walls between adjacent furnaces act as bridges, and the space above the bridges, being uninterrupted, acts as a flue. In this type of burner, the expense of a fire brick arch, twice the length of the battery, is saved at apparently no loss in efficiency.

The grate area varies from about 18 to 33 square feet, the usual width being about 5', and the depth from front to back 5·5'. The cinder pit varies from 18" to 24" in height. The sill of the charging door is placed about 30" above the grate bars—the height varies between 20" and 30". The height of the abutment of the arch above the grate bars is about 42", and the spring of the arch is between 8" and 10". On some furnaces, the arch is sprung from side to side over each furnace; on others an arch is sprung from each side wall to the median wall, thus running lengthwise of the furnaces. The upper part of the gas flue is made by a second arch rising from 8" to 12" above the furnace arch, and running the length of the battery. On some burners, this arch reaches across the whole battery and is carried by the side walls, which are made high enough.

The grate bars are sometimes made of bar iron, oblong in cross section, but more frequently bars with a square cross section are used. Two inch square iron is a standard size.¹ The grate bars rest on cast iron bearings, of which there are 2; where the furnace is deep, 3 bearing bars are used. Bearings are turned on the grate bars, the diameter of the cylinder at the bearing being that of the bar. The ends of the bars, which project beyond the first bearing, are left square, and a key is provided to facilitate turning and

¹ Some furnace designers use 1·5" square iron.

shaking. The grate bars are placed about 4" apart, from centre to centre. With square bars it thus becomes possible to have three standard widths of openings between the bars. If the bars are all set with a flat side horizontal, the width of this opening will be 2". If alternate bars are set with one diagonal of the square section horizontal, the openings will be 1.6": if all the bars are set with one diagonal of the square section horizontal, the openings will be 1.17" wide. Usually the bars stand with the diagonals horizontal, i.e., with the smallest possible openings between them. When it becomes necessary to remove a portion of the cinder, the furnace man adjusts his key to the end of the grate bars, each in turn, and rocks them a few times from side to side. This movement momentarily enlarges the opening between the bars and at the same time exercises a crushing force on the cinder next the moving bar. The tendency is to force the cinder between the bars downward. The movement of the bar also tends to loosen the pyrites for some distance above the grate. By moving the bars in succession, or by shaking alternate bars, cinder may be drawn off from the whole bottom of the grate as required.

The cast iron furnace fronts are usually from 1" to 1.5" in thickness. They are provided with suitable openings to give access to the gas flue, the furnace above the grate, the ends of the grate bars and the cinder pit. Less frequently a poke hole is provided between the feed door and the grate bar door. Door-frame flanges are cast on the front of the plate, so arranged that the lower part of the door lies a little farther from the vertical furnace front than the top. The fronts of these flanges are planed and the faces of the doors which rest on the flanges are also planed, to make a gas tight joint, and rendering the use of luting unnecessary. The effect of the wider bottom flange is to cause the doors to slope inward at the top, and thus to be pressed by their own weight against the planned bearing on which they rest. In most furnaces, the doors run in grooves, but in some cases, they are hinged to lugs cast on the plates. Occasionally they are fastened shut by the use of a swing bolt and wrench nut. Usually two doors are provided over the grate bar ends, hinged to turn up, while a single door, sliding in a groove, is found suitable for each of the other openings.

FINES BURNERS

Burners for pyrites fines all consist of one or more hearths of fire brick each covered by an arch a short distance above it, and so arranged that the heat is confined to the space between the hearths and the arches. Two general types of these furnaces may be recognized: (1) Single hearth furnaces and (2) Multiple hearth furnaces.

(1) *Single hearth furnaces.*—The commonest form of single hearth furnace consists of an oblong hearth of moderate width and considerable length. The ore is fed at one end of the hearth, and is moved forward continuously and is discharged at the other end, when burnt out. When the forward movement is produced by rakes operated by hand, suitable doors are provided along both sides of the hearth, which is usually between 8' and 10' in width.

In a more efficient style of furnace, the ore is mechanically stirred and moved forward by rakes operated by an endless chain, or carried on a travelling arm. That the cinder may be practically free from sulphur, it is necessary to make these single hearth furnaces of considerable length (120'-150') or even more. The gas produced in such a furnace is relatively free from dust. The furnaces are simple in construction and easily repaired.

Certain types of mechanically operated furnace are also built with a single circular hearth of considerable breadth (up to 36'). Such furnaces are usually muffle fired or direct fired, and the ore is stirred by rakes carried on rotating arms, moved automatically by power. Such furnaces are used only for special purposes, and are not usually employed expressly for the manufacturing of sulphur dioxide.

(2) *Multiple hearth furnaces.*—These furnaces are constructed with two or more hearths, one above the other. The hearths may be either oblong or circular in plan. In both types of multiple hearth furnace, the ore is fed at the top of the furnace and travels slowly back and forth over the hearths, dropping from hearth to hearth at alternate ends, until it is discharged at the bottom. The air for combustion enters the furnace at the bottom and travels in an opposite direction. Furnaces of this type are more complicated in construction, more difficult to keep in repair, and more expensive, while the dust causes greater trouble. On the other hand, the furnaces are more compact, conserve the heat, and are more efficient.

Falding¹ classifies fines roasting furnaces for acid making as follows:

1. Single hearth straight line, mechanical furnace. (Holthoff-Wetthey).²
2. Single hearth, circular, mechanical furnace (Pearce turrett).³
3. Double hearth modifications of both the preceding furnaces are built. They are intended to use with self-burning sulphides, and arranged as muffles for burning base sulphides such as zinc blende, etc., besides being built for burning ores with auxiliary fuel where the gas is wasted or not used for sulphuric acid.
4. Multiple hearth, straight line, hand-worked furnaces (Falding's modification of the Malétra-Shaffner type).
5. Multiple hearth, straight line, hand worked muffle furnaces for zinc blende and base sulphides (Rhenania furnace).
6. Multiple hearth, straight line mechanical furnaces (Spence hurners).
7. Multiple hearth, straight line, mechanical furnaces, muffled for base sulphides (Hegeier's modification of the Eichhorn-Liebig furnace).
8. Multiple hearth, circular, mechanical furnaces, air cooled (Herreshoff's modification of the MacDougall type).⁴
9. Multiple hearth, circular, mechanical furnaces, water cooled (Frasch's modification of the MacDougall type):

¹ Mineral Industry, 1899, p. 670.

² Mineral Industry, Vol. VI, pp. 449-450.

³ Ibid., Vol. III, pp. 205-211, and Vol. V, pp. 267-268.

⁴ Ibid., Vol. VI, p. 237.

10. Multiple hearth, circular, mechanical, muffed furnaces for base sulphides (Haas-MacDougall type).

There are many different types of multiple hearth furnaces in operation. As a general rule, it may be stated that the furnaces with oblong hearths are usually of large size and very considerable capacity. They are employed only in the largest works and, where the preparation of sulphur dioxide is the object in view, only for the manufacture of sulphuric acid.

In the majority of acid works, multiple hearth furnaces of the circular type are installed to burn fines, and, where large capacity is required, a number of units may be arranged to form a battery of furnaces.

In the following pages, descriptions are given of several types of furnaces, which are more commonly installed in acid works and which are beginning to be installed in sulphite pulp mills.

The Malétra type of roasting furnace

In the majority of acid plants in America, pyrites fines are roasted in some form of mechanical roaster. In some European plants, including also a few paper mills, some type of hand operated shelf burner is still employed. In European acid works, something more than fifty years ago, pyrites fines were burned by utilizing a portion of the heat from lump burners. M. Malétra, owner of the works near Petit Quevilly, near Rouen, conceived the idea of burning the dust by its own heat of combustion, without any aid from a lump burner. This idea was worked out, with the aid of M. Tinel, about 1867, and proved entirely successful. A number of modifications of the original Malétra burner, have, from time to time, been erected. For the most part, these burners are now obsolete, but the following description of the original Malétra burners may be of some interest.¹

The general arrangement of the hearths can be seen by reference to the accompanying drawings (Plates VIII and IX.). The furnace is built with brick walls and fire-clay shelves. The furnaces shown in the diagram have flat shelves. In the newer types, the shelves are arched for greater stability, especially in the case of wide shelves. On the original burners, the shelves are 8' long and 5' wide. They consist of 8 plates in 2 rows of 4 each; they rest, at the sides, in the walls of the burner, in the middle on fire-clay bearers, s.s. On some burners, the shelves are nowhere enclosed within the brick-work of the walls; they are then more easily replaced when broken. On an improved form of burner, the middle bearers have been omitted and the width of shelves reduced to 3'-3" — 3'-7". The shelves are not equidistant, the upper shelves, where more gas is evolved, being wider apart than the lower ones, where the radiant heat of the shelves is all the more useful. The best distance for the upper shelves is 4.5".

¹ Abstract, Lunge, Sulphuric Acid and Alkali, 3rd Ed., Vol. I, Part I, pp. 334-338. See also Truchot, Les Pyrites, p. 124-127.

Usually a set of burners is built in a single row. In order to start the burner a coal grate, a, and fire-door, b, are provided which are walled up when the burner has been brought up to a white heat. During this time, the top working-door remains open. Then the five plates, c, d, e, f, g, are charged with small ore through doors h, i, k, whereupon the pyrites takes fire at once. The air enters through l and is regulated at will. The gas travels over all the plates in a serpentine manner, indicated by the arrows, escapes through m into the dust-chamber, n, and through, o, into the acid-chamber or into another dust-chamber. Where used in an acid works, the chamber, n, is covered by a metal plate, p, upon which lead pans, r, r, are placed, in which all chamber-acid can be concentrated from 112° to 144° Tw.

In order to burn large quantities of pyrites, the ore must be moved. This is accomplished in the following way:—Every four hours, the contents of the lowest plate, g, are drawn through the door, k, on the arch, t, (which is level at the top but slopes behind), after the ore lying on the arch has first been pushed through the door, k, to the opening into the pit u. Then through the door, i, the contents of f are pushed down to the plate, g, and there levelled.

Thus the higher plates are successively treated, till the highest plate, c, is emptied and can be charged with fresh ore. If four furnaces go together, one of them is on turn every hour. The contents of the pit, u, are removed once a day by the door v. The movement of the ore by the removal from one shelf to another causes its thorough combustion, and thus also raises the heat. Four furnaces of the above dimensions burn daily 3 tons of pyrites. From 6.5 to 7 lbs. of ore are calculated for each superficial foot of shelving.

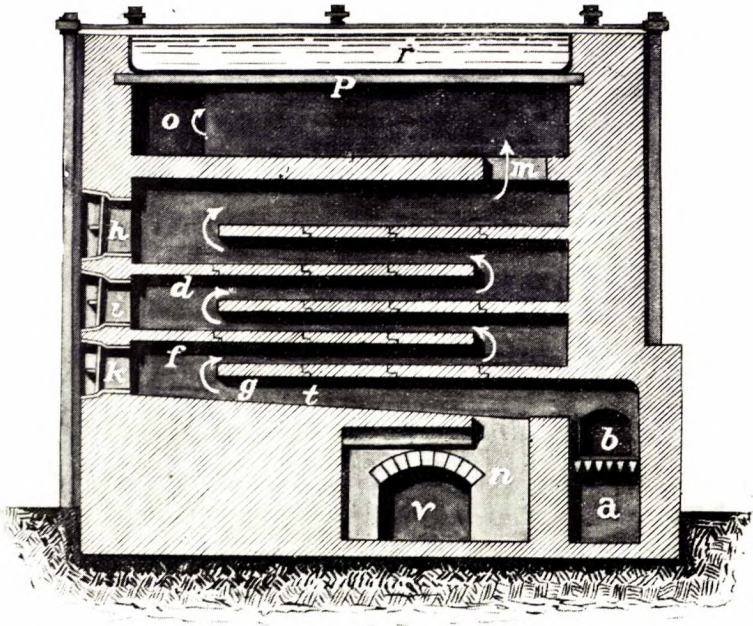
An improved form of the Malétra burner was designed by Dr. Max Schaffner, of Assig. Descriptions and drawings of these furnaces will be found in the second edition of Lunge's work on Sulphuric Acid and Alkali, pp. 255, 256. Drawings and a brief description of a similar Hand Shelf Burner are given by Falding in the Mineral Industry, Vol. VII, 1899, p. 669.

Practice has shown that burners worked from both sides allow too much false air to enter, and most builders prefer to arrange two rows back to back. In the third edition of his work on Sulphuric Acid, Lunge gives full drawings of the most modern dust-burners from the designs of Mr. H. H. Niedenföhr.¹ The accompanying plate shows a cross section of this furnace, showing the arrangement of the shelves and doors and the location of the cinder pit and gas flues. Plates X and XI are sections of two furnaces showing the arrangement of the hearths. The original drawing given by Lunge shows a battery of 16 furnaces arranged in two rows of 8 each.

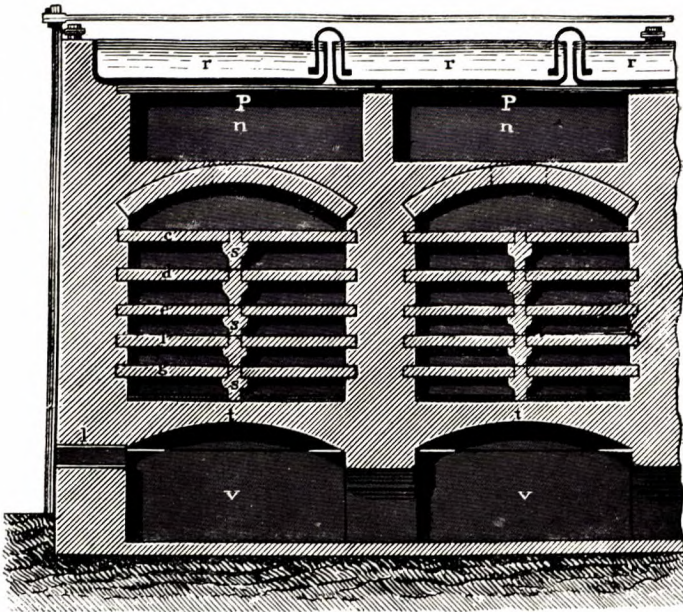
Furnaces of the MacDougall Type

The furnaces described below, with one exception, are all vertical cylindrical in form, and consist of a series of superposed annular hearths, centrally pierced by a hollow, vertical shaft. Projecting radially at right angles from

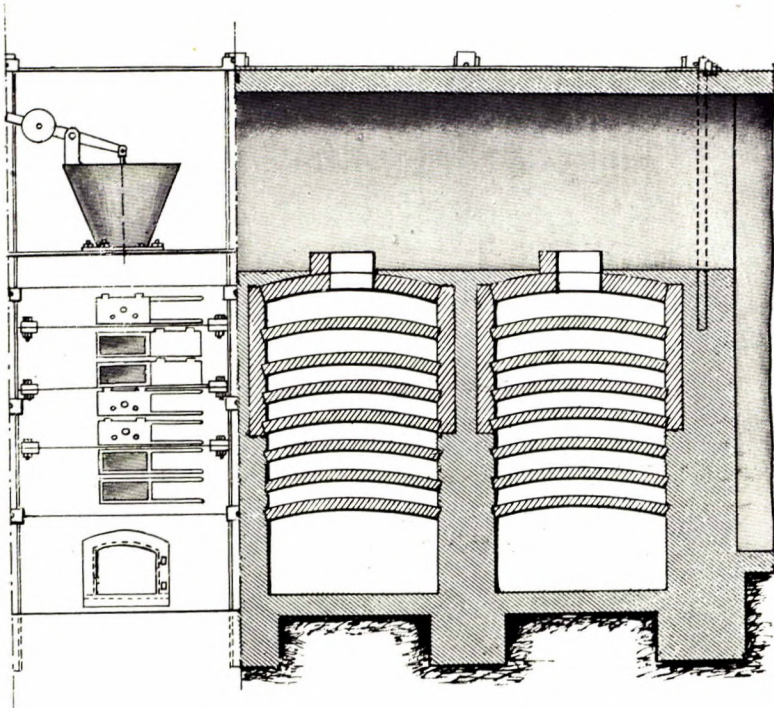
¹ Lunge, Sulphuric Acid and Alkali, 3rd Ed., Vol. I, Part I, pp. 338.



Malétra shelf roaster, longitudinal section (Lunge).

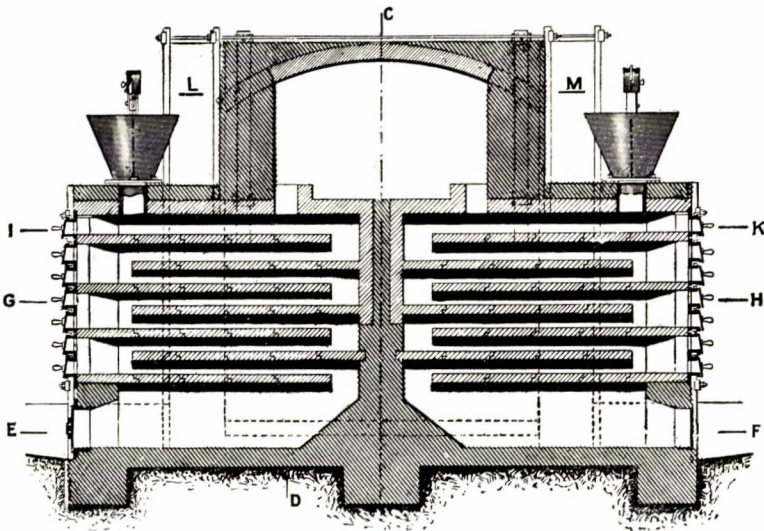


Malétra shelf roaster, cross section (Lunge).



Niedenführ design, Malétra shelf roaster, cross section showing two furnaces and front of a third (Lunge).

PLATE XI



Niedenführ design, Malétra shelf roaster, longitudinal section showing two furnaces, back to back (Lunge).

the shaft, over each hearth, are two arms provided with fixed or movable teeth (rabblers or rakes) attached to the under side and placed at an angle to the arm. The central shaft is caused to revolve by power applied through gear wheels, and the rabble arms and rakes are thus made to rotate slowly in a horizontal plane above the hearth. The pairs of arms provided for each shelf, being attached on opposite sides of the rotating, vertical shaft, are faced in opposite directions.

The ore is fed into these furnaces from the top, and is distributed over the hearths by the rabblers. The rabblers on the arms are so disposed that the material on the different shelves is plowed alternately outward from the shaft and inward towards it, special openings being provided on the periphery of one set of hearths, and at the centre of the other set, whereby the ore may pass from shelf to shelf. The cinder is discharged at the bottom of the furnace.

The air supply for the combustion of the sulphur of the ore enters the furnaces at the bottom hearth and travels upward over the hearths. Air can also be admitted on other hearths, if necessary. The products of combustion pass through the same openings as the ore, but in the opposite direction these openings being made sufficiently large to accommodate them. The space above the upper hearth acts as a gas chamber from which the gases are drawn off to the portion of the plant where they are required.

All furnaces of this type are built of brick; sometimes the furnace is also enclosed in steel plate. Usually, fire bricks are used for the interior portions of the furnace, which are exposed to a high heat, and hard-burned, red brick are used elsewhere. Some makers employ specially shaped fire brick for the hearths.

These burners differ greatly among themselves in many details of construction, such as number and construction of hearths, character of central shaft, method of attaching rabble arms and rabblers, cooling devices, method of applying power to the central shaft.

*MacDougall Roasting Furnace.*¹ These furnaces were patented by the MacDougall Brothers early in the seventies. The original plant was used for burning pyrites to furnish sulphur dioxide for the manufacture of sulphuric acid. The burner consisted of a cast iron cylinder 6' in diameter and 12' high, formed of 7 rings bolted together and provided with a solid bottom, but open at the top. The rings were cast so that the lower inner edge of each served as an abutment for a flat, brick arch, which divided the inner space of the cylinder into 7 chambers, the uppermost of which was open at the top. A central cast iron shaft, 6" thick, which passed through central openings in each of the hearths, was used. At the top and bottom, lutes and cups were employed to make a hydraulic joint to prevent the escape of gas. To the cast iron shaft, cast iron arms, provided with teeth along their lower margin, were attached. The teeth were placed alternately in opposite directions on each hearth, so that the ore was moved from the centre to the periphery, and from the periphery to the centre on alternate hearths. Corresponding to this,

¹ See Lunge, Sulphuric Acid and Alkali, Vol. I, Part I, pp. 343, et seq.

perforations were provided in the arches at suitable points, that the ore might drop from shelf to shelf. The power required was about 2 H.P.

The ore burned in this furnace would all pass through a one inch screen. It was fed to the first closed chamber from the open top chamber, by a plunger, whose rate of delivery could be regulated.

The furnace roasted $3\frac{1}{2}$ tons of ore in 24 hours. With 8 chambers instead of 6, it can burn 5 tons. The cinder contains about 2% sulphur, and the capacity amounts to about 0.02 tons per square foot of hearth area.

The original MacDougall furnaces had to be given up because the quantity of flue-dust was so great that it seriously interfered with the working of the acid chambers; many mechanical difficulties were also encountered. A number of modifications were subsequently introduced to overcome these difficulties. The newer form of MacDougall furnace is now employed at many metallurgical works for roasting concentrates preparatory to smelting.

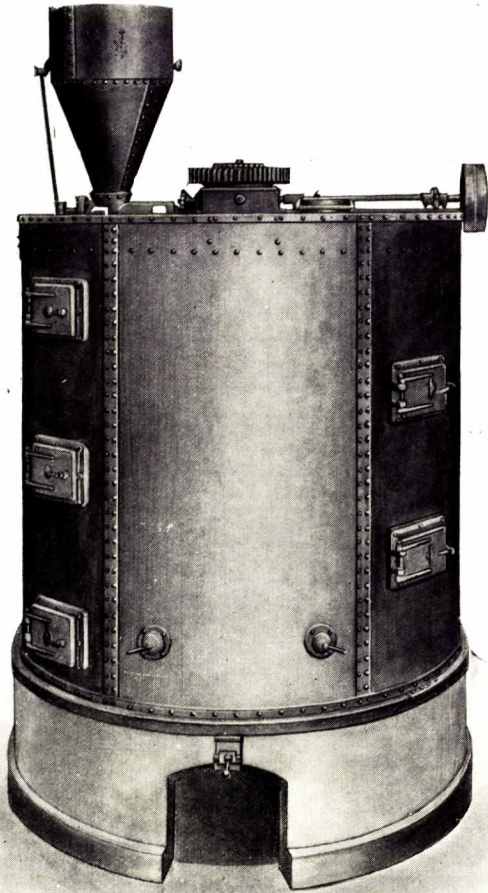
*Kauffmann's Roasting Furnace.*¹ This is a cylindrical furnace with five superposed brick hearths. (Plates XII-XIII). The raw ore is introduced into a charging hopper above the furnace by manual labor or by a mechanical elevator. A regulated quantity of ore is fed continuously to the upper hearth of the furnace, either by a worm conveyor or by a reciprocating piston. The charge is spread by the revolving stirrer arm, and gradually travels towards the outer edge of the hearth, where it feeds through channels to the hearth below. On this hearth it is moved towards the centre, the rables being sloped in a direction opposite to those on the hearth above. At the centre, next the shaft, the ore drops to the hearth below. Similarly it passes from the third to the second hearth and from the second to the first or lowest hearth. From the lowest hearth, the cinder is discharged through a sloping cast-iron chute. This chute is provided, at the outer end, with an automatic valve which prevents the entrance of air, while at the same time, it permits the cinder to escape.

The air necessary for the roasting process enters the furnace at the lowest hearth, through four inlets that are distributed around the furnace, and are fitted with adjustable valves, that the quantity of air admitted may be under control.

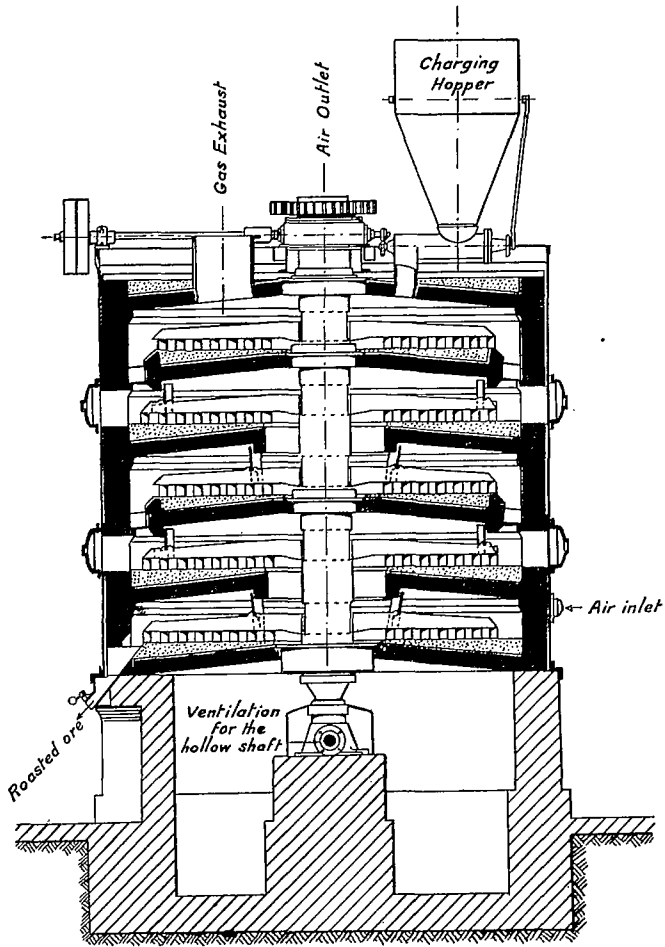
As the air travels through the furnace in a direction opposed to that in which the ore travels, there is a tendency for the gas to become loaded with dust at the openings between the hearths. One of the features of the Kauffman patent was the introduction of a series of asbestos screens, which arrest the ascending stream of gas at points where the ore falls down. These screens were said to preclude any excessive loading of the gases with dust. On the later furnaces, these screens have been omitted, as being unnecessary.

The chief characteristic of the Kauffmann furnace is the construction of the stirrer arm and the method employed to attach it to the vertical shaft. As shown in the accompanying drawings (Plate XIV and figure 8), the arm socket in the vertical shaft is rectangular in section, and passes directly

¹ Manufactured by the Erzröst-Gesellschaft, Cologne, Germany.

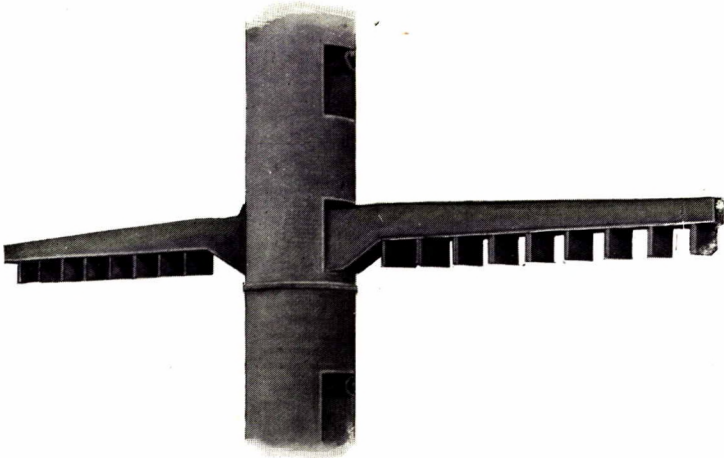


Kauffmann roasting furnace, outside.



Kauffmann roasting furnace, cross section.

PLATE XIV



Kauffmann roasting furnace, showing rabble arm and shaft attachment.

through it. The arms for each hearth are cast in a single piece, shoulders being provided with lugs which lock into corresponding pockets in the shaft socket, and prevent the accidental shifting or removal of the arm, once it has been put in place. These arms can be easily and quickly removed and replaced when worn or broken, without cooling down the furnace, and no bolts or wedges are employed to hold them in place.

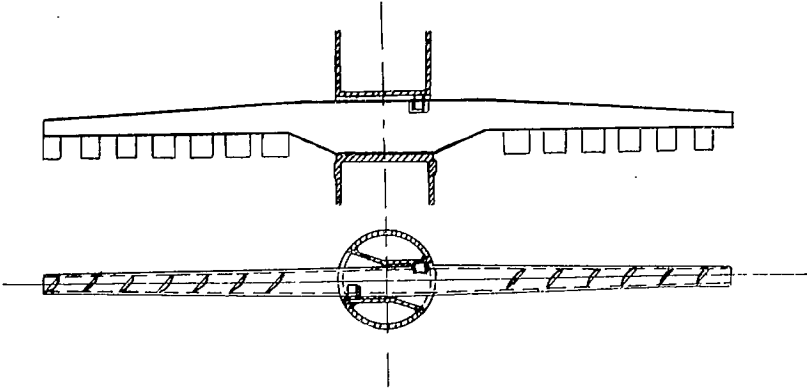


FIG. 8. Section showing method of attaching the rabble arms employed in the Kauffmann roasting furnace.

The hollow shaft is cooled by air which is forced by a fan into the shaft through the hollow bottom bearing. This air under pressure keeps the shaft and the junctions between the shaft and the arms from becoming unduly heated.

On the newer type of Kauffmann furnace, the arms are rotated by a driving mechanism placed at the upper end of the central shaft. Power is transmitted by pinions and a worm wheel, mounted in a cast iron casing filled with oil. The worm engaging with the worm wheel is activated by a belt pulley, which in turn is moved by any convenient intermediate gear. Each furnace can be driven independently of the others in a battery. On furnaces provided with the top drive, the custom is to replace the four pillars, on which the earlier types of this furnace were carried, by a ring of brickwork. The closing in of the bottom of the furnace makes it easier to prevent the cooling of the bottom hearth, and is said to increase the efficiency of the furnace. The shaft takes between 3.5 and 4 minutes to make one complete rotation.

The capacity of the furnace is from 2,800 to 3,000 kilos (approximately 3 tons) of pyrites, containing 50% sulphur, per 24 hours. The power consumed lies between 0.3 and 0.5 H.P. per furnace. Little attendance is required apart from the labour needed to bring pyrites to the furnace and to remove the cinder. The metal portions of the furnace weigh about 5,500 kilos (16,535 lbs), and the refractory materials about 25,000 kilos (65,100 lbs.).

The cost of the furnace at the works is 5,500 marks (\$1,300); the erection cost in Germany amounts to about 400 marks (\$100.).

Under the Kauffmann patent there is also manufactured a three hearth furnace especially intended for use in sulphite pulp mills, and designed to burn either pyrites or the residues from purifying gas. This furnace differs from the ordinary type of furnace in the rapidity of rotation of the arms, and in the fact that the roasting pyrites is displaced in opposite directions by the two arms. The rabbles and arms are cast in one piece as in the other furnace. The amount of dust produced in this furnace is somewhat greater than in the 5-hearth furnace, but this usually causes no difficulty in the manufacture of sulphite pulp, because the gas is washed before it enters the towers.

The metal portions of this furnace weigh 6,000 kilos (13,228 lbs.), and the refractory materials 15,000 kilos (33,000 lbs.). The cost is the same as the 5-hearth furnace.

Furnaces built under the Kauffmann patents are in operation at many fertilizer and chemical works, and at several paper mills on the continent of Europe.

*Herkules Roasting Furnace.*¹ Another calcining furnace that has been installed in several chemical works and paper mills in Europe is named the "Herkules" mechanical roaster. The general construction of this furnace can be seen from the accompanying diagram (Plate XV). There are 6 hearths, each built of fire brick, and slightly arched. The rabble arms are bolted to the central shaft at a slight angle, so that the rabbles will lie close to the hearth at all points. The central shaft and the arms are water cooled to prevent over-heating and breaking. The air for combustion is under control and enters on the lower hearth. Rosette dampers are also provided on the two working doors on each hearth through which an additional air supply can be admitted, if required.

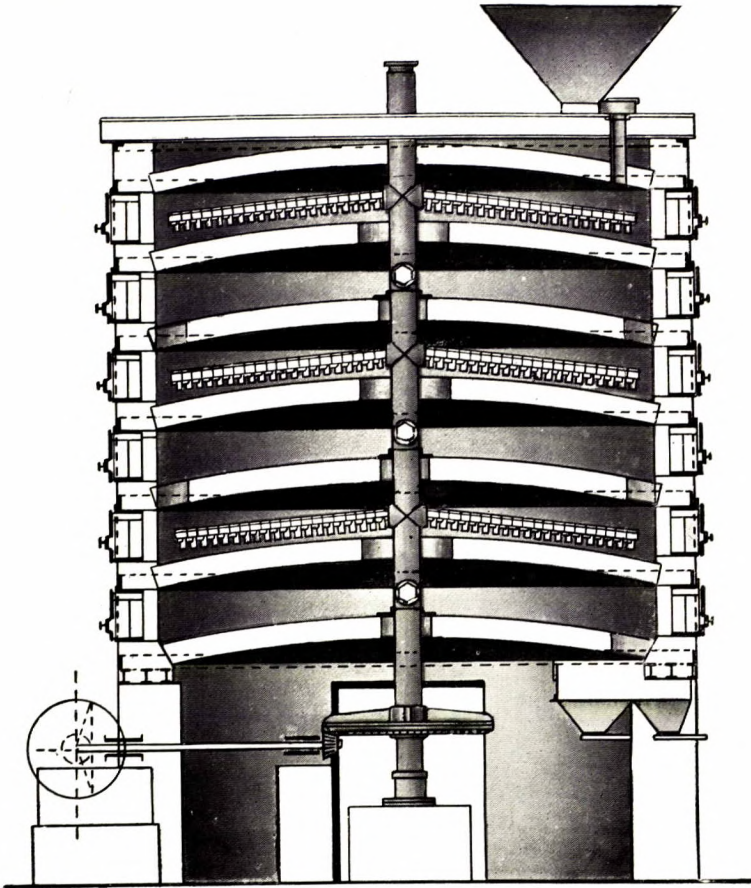
The total hearth area is 110 square metres (1,184 square feet), and a capacity of 12-15 tons of pyrites, 42%-50% sulphur, per 24 hours, is claimed for this furnace. When in charge of skillful operators and forced, 20 tons per 24 hours can be roasted. The power required is about 0.5 H.P. A concentration of 10-11% sulphur dioxide is claimed for the gas without any special difficulties.

The iron parts of this furnace weigh between 18,000 and 19,000 kilos (41,000 lbs.), not including the mechanical elevator, and its attachments. The complete cost of the installation is 21,000-23,000 marks (\$5,000-\$5,475), with about 2,000 marks (\$475.00) additional for an elevator.

*Herreshoff Roasting Furnace.*² This well known furnace is widely used in acid works throughout both America and Europe for the manufacture of sulphur dioxide; furnaces of this type have also been installed in a number

¹ Information with respect to this machine can be obtained from Dr. J. Lutjens, Chemist and Engineer, Hanover, Germany.

² General Chemical Company, Mechanical Furnace Department, 25 Broad St., New York. The furnace is also built in Canada and can be purchased through the Nichols Chemical Co., Montreal.



Herkules roasting furnace, cross section.

of European sulphite mills. They are employed in some metallurgical works for preliminary roasting of sulphide ores, and have been used with success in the roasting of ore containing pyrites and sphalerite, in preparation for magnetic separation. Pyrrhotite has also been successfully roasted in furnaces of this type. (See Plate XVI.)

The furnace is made in several sizes, the main features of which are given in the following table:—

TABLE XVII.

Outside Diameter	Number of Hearths.	Area of Hearths Square Feet.	Square ft. Floor space required for installation of 4 roasters.	Height to lower chord building truss.	Weight Metal Parts.	Weight Fire Bricks.	Lbs. Sulphur 24 Hours.
11' 7½"	5	381	979	18' 1½"	16,000	16,000	3,000 to 6,000
11' 7½"	7	548	979	22'	25,000	32,000	4,500 to 9,000
15' 9¾"	6	912	2,192	25' 9"	43,000	79,000	8,000 to 16,000
20'	5	1,308			68,000	132,000	12,000 to 30,000
20'	7	1,810			82,000	168,000	16,000 to 42,000

Construction.—The following description of the 15'-9¾" diameter standard furnace gives the main features involved. This furnace consists of a double riveted steel shell lined with hard burned red brick. The hearths, six in number, are built of special fire brick and are arched. The central shaft is composed of two hollow cast iron pipes, the smaller within the larger, which allows of a 2" annular space through which a constant circulation of air is maintained. The arms are hollow, with a partition running nearly their full length inside, and dividing them into two parts, the arm being so connected to the hollow shaft that cooling air circulates through it at all times. The arms are fitted to slots in the central shaft to which they are also bolted, these bolts being surrounded by air-cooled metal and covered with insulating material. A bayonet-lock type of arm is sometimes employed in place of the bolted arm. The rables, which are movable, are made in five sections with from one to five teeth to a section, and any one of these sections can be slipped off or on an arm in a few minutes. The teeth are set at different angles according to their location on the arm, to equalize the quantity of ore moved forward by each blade per revolution. Any tooth can be taken out of the section and replaced without disturbing the remaining rables.

The entire furnace is mounted on six cast iron columns, each five feet in height. The central shaft rests in oil thrust-bearings at the base, where power is applied by means of gears. A shear pin is provided in the driving mechanism which acts as a safety device in case of undue strain.

Several different types of feed are adopted in different installations, dependent on the nature of the operation. One method of feeding is by spreading the ore on top of the roaster with rabbles similar to those in the furnace, the ore being dried in this way and at the same time fed gradually to the hearth below. Screw feeds and reciprocating plunger feeds are also employed.

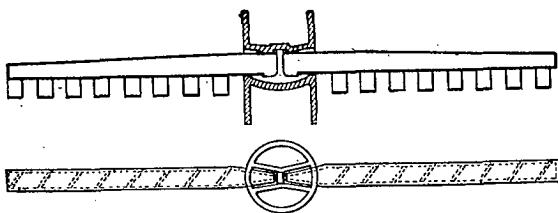


FIG. 9. Movable rabble arm for small Herreshoff furnace.

The older 5-hearth furnace consists of a steel casing $\frac{1}{4}$ " thick, lined with hard burned red brick 8" thick. The hearths are made of special fire brick and are 4.5" thick, 12"-13" apart, and the pitch of the arch is 4.5". The central shaft is 14" in diameter, is hollow, and is connected with a light sheet iron stack about 10' in height that extends above the top of the furnace. At each hearth, there are cross channels passing directly through the shaft normal to its axis. These transverse channels are about 4" wide and 5" high, and allow ample space around them for the passage of the ascending cooling air. They also form the sockets into which the rabble arms are inserted (Figure 9). On each arm, on the inner edge, is cast a small rib; in each socket in the top, and at the centre of the vertical shaft is a pocket running across the channel. When an arm is forced into its proper position, the rib on the arm locks into the pocket in the shaft socket and the weight of the arm always keeps it properly locked in the channel. By raising the outer end of the arm about 3", the top edge of the rib is brought below the pocket, and the arm can easily be pulled out. Practice has shown that these arms, weighing 100 pounds, can be unlocked, removed from the furnace, and new ones inserted and locked into place in about one minute.

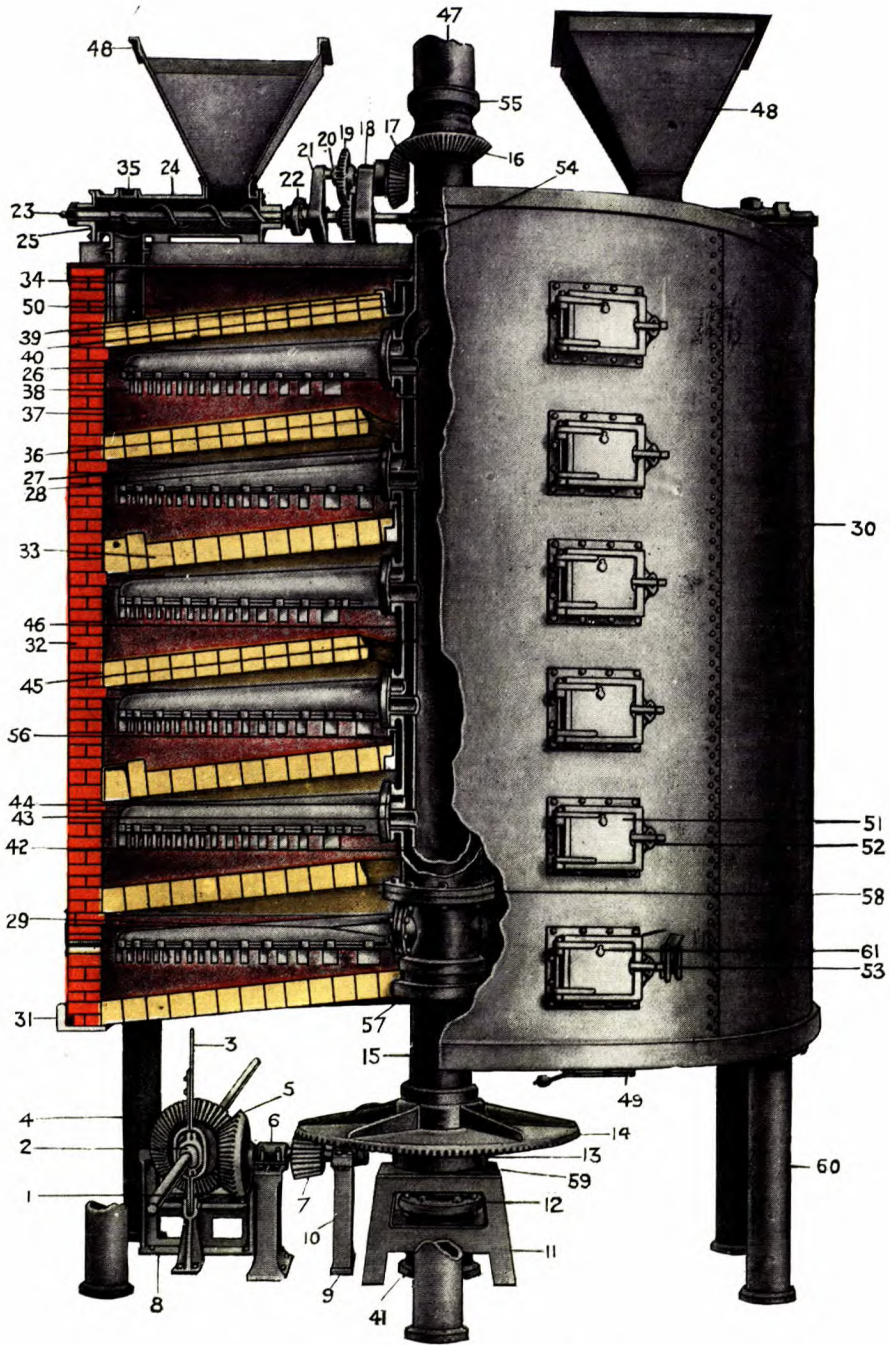
The hollow arms for this furnace are each cast in one piece, and are provided with 7 and 8 teeth respectively. A special grade of iron is used that has been found best to withstand the heat. The portion of the arm which enters the socket in the shaft, is kept below a red heat by the air current in the central shaft and does not become overheated.

The entire furnace is mounted upon eight columns, each about 4' high, and power is applied to the central shaft by driving gear below the furnace. A shear pin is provided in the driving mechanism for safety.

THE HERESHOFF, MECHANICAL ROASTING FURNACE

Descriptive Legends for Plate XVI.

1. Main driving shaft
2. Starting clutch.
3. Starting lever.
4. Main driving gear.
5. Transmission gear.
6. Pillow block.
7. Pinion wheel.
8. Floor stand.
9. Pedestal.
10. Pillow block or pedestal.
11. Main shaft floor stand.
12. Stuffing box and gland.
13. Ball bearing collar.
14. Driving rack or spur wheel.
15. Main revolving shaft.
- 16 21. Feed drive.
22. Flange coupling.
23. Worm gear bearing.
24. Worm gear housing.
25. Worm feed.
26. Rabble arm or rake arm.
27. Arm flange shaft.
28. Shaft flange for arm.
29. Flange bolts.
30. Boiler plate casing.
31. Base flange or base plate ring.
32. Red brick.
33. Fire brick.
34. Outer drop hole or feed spout.
35. Poke hole.
36. Inner drop hole shelves, 2-4 and 6.
37. Cinder bed.
38. Removable blades or plows.
- 39-40. Seal lutes.
41. Cool air intake.
42. Central hollow shaft.
43. Cool air tube-out.
44. Warm air tube-return.
45. Annular air chamber.
46. Outer shell of central shaft.
47. Hot air stack.
48. Feed hopper.
49. Cinder outlet with damper.
50. Sulphur-dioxide chamber.
51. Inspection door, brick-lined.
52. Door latch.
53. Combustion air inlet with adjustable slide.
54. Top bearing.
55. Stack seal (lute).
56. Shelf seal (lute) (3) and (5).
57. Bottom seal (lute) (1).
58. Flange connecting outer and inner shaft.
59. Ball bearing (bearing plate).
60. Columns.
61. Peep hole in inspection door.



Herreshoff, mechanical roasting furnace.

In colder districts, it has been found an advantage to substitute an extra course of brick, bound with iron bands, for the steel sheathing which surrounds the furnace, thus further reducing the heat losses.

Operation.—When in operation, the floors of each hearth, which follow the curve of the arch, are levelled by introducing a sufficient quantity of cinder or other similar material. Where the top of the furnace is not used as a dryer, the arch above the highest hearth is also covered to a depth of several inches with cinder or sand to retain the heat.

Ore is brought to the feed hopper at the top of the furnace either in barrows or by elevators or conveyors. From the hopper it is fed automatically into the furnace and is then stirred and distributed by the rabblers on the revolving rabble arms—the feed being driven by gears attached to the central shaft.

The angles at which the rabble teeth are set are so calculated that the ore is propelled in the direction of the radius as well as in a circle, one rabble acting in the above manner while the next following rabble takes the same ore and simply turns it over. This causes each individual piece of ore to travel on a path which might be termed a zigzag spiral, and is a most perfect method to insure the exposure of a large quantity of ore surface to the oxidizing action of the air.

In the 15'-9 $\frac{3}{4}$ " furnace the ore drops from the top shelf of the furnace to the outer edge of the hearth below; it is then rabbled inward and drops to the inner edge (centre of furnace) of the second hearth; from there it is rabbled onward and drops on the outer edge of the third hearth, and so on alternately to the two cinder-discharge ports on the periphery of the bottom hearth.

The air for oxidizing is admitted through ports around the sides of the furnace over the bottom hearth. It circulates through the furnace by the openings on the inner and outer edges respectively of each hearth, these openings being made large enough to give a free passage to the upward current of gases as well as to the downward moving stream of ore. The space above the topmost shelf acts as a gas chamber.

When this furnace is in operation, and when the top of the furnace is not used as a dryer, the drying is done on the first hearth. Roasting starts on the second hearth, continues freely on the third and fourth, while on the fifth it is nearly complete. On the sixth the ore appears dark, and the roasting is complete.

For dead roasting, under ordinary circumstances, the shaft makes one revolution in 150 seconds; for metallurgical work, one revolution in 70 seconds.

According to Hofman¹ a Herreshoff furnace (old style, 5 hearths) with its shaft making 50 revolutions per hour roasts in 24 hours, 5-6 tons of wet concentrates with about 35% sulphur, or 0.015 tons per square foot of hearth

¹ Hofman, H. O., "Notes on the Metallurgy of Copper of Montana," Trans. A. I. M. E., Albany meeting, 1903, Vol. XXXIV, p. 277.

area, reducing the sulphur to 6%. Seventy furnaces make 4 to 5 tons, or 6.4% of flue-dust. This roasting was for metallurgical purposes, not for the manufacture of sulphur dioxide.

In acid plants, the same furnace treats 3-4 tons of pyrites, 44% sulphur, or 0.0098 tons per square foot of hearth area, reducing the sulphur to 2.5-3.5%; the shaft makes 30 revolutions per hour. The larger (15' 9 $\frac{3}{4}$ ") furnace will roast about 18,000 pounds per 24 hours. The capacity of the furnaces will vary with the chemical composition and physical character of the ore used, together with the kind of roast required (dead, magnetic, or metallurgical) and would have to be determined for each particular case before definite capacities can be estimated. In general it can be assumed that capacities are lowest for dead roasting and greatest in metallurgical work.

The operation of the furnace can be regulated by any of the following methods, so as to produce the result desired.

1. Changing speed of rotation of central shaft and rabblers.
2. Changing rate of feed.
3. Changing draft.
4. Changing amount of cooling air by which the temperature inside the furnace is controlled.

In practice it is found that the principal cost for repairs to the small type of furnace is due to the burning out of the rabble arms. According to the makers, about 6 arms per year have to be renewed at a cost of between \$20 and \$30. With the furnace of new design, which has a more efficient system of cooling the movable arms, and in which individual rabblers or rabble teeth can be readily replaced, the life of the arms will be much greater. On the smaller and medium sized furnaces, the arms, which fit into sockets, can be easily renewed in a few minutes with very little disturbance of the furnace operations. The breaking down of a bolted arm in the newer large furnaces, although it may not occur frequently, will put the furnace out of commission for about one week, as the furnace will have first to be cooled sufficiently to enable the workmen to replace the arm, and will then have to be heated up again.

The most distinctive feature of the new type of this furnace is the effective control of temperature within the furnace, that is, by the mechanical circulation of more or less of the cooling air through the hollow shaft and arms a correspondingly greater or less amount of heat is withdrawn. This control of the temperatures within the furnace will tend to prevent scarring by enabling the operator to maintain the temperature of the ore below the sintering point in the zone of maximum heat generation.

A study of the accompanying drawing (Plate XVI) will give the reader a very good idea of the general construction of the latest design of the Herreshoff furnaces.

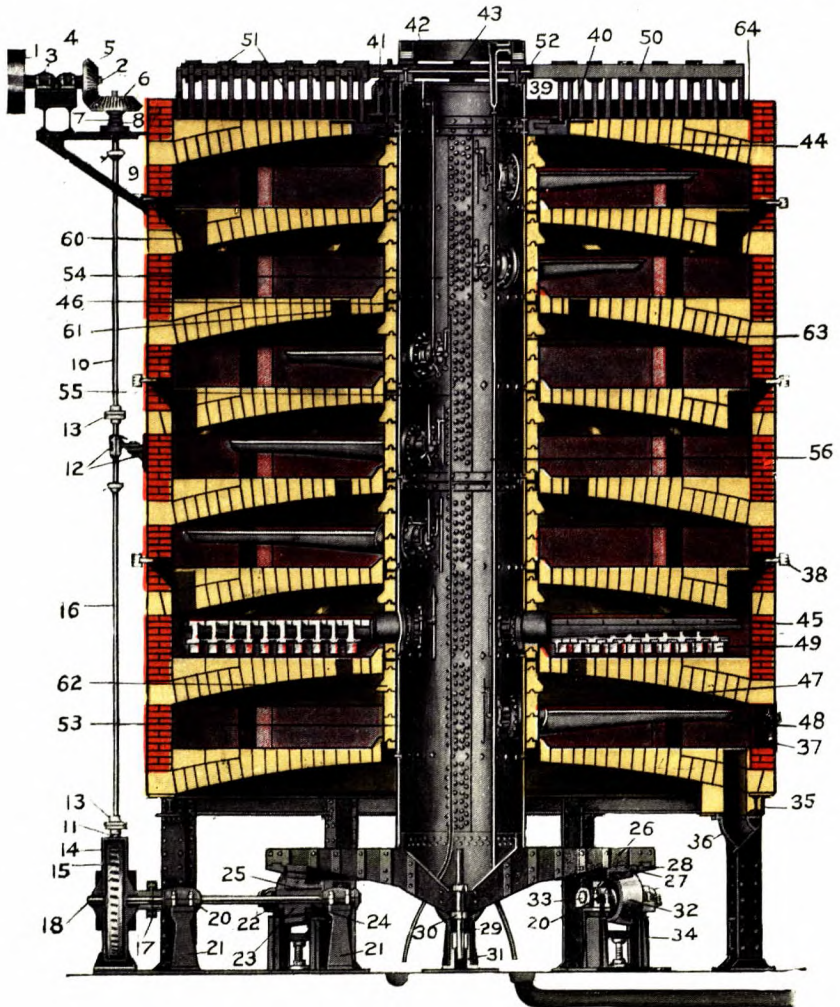
*Wedge Mechanical Roaster.*¹ This furnace is built with one, three, five,

¹ Wedge Mechanical Furnace Company, 115 Chestnut St., Philadelphia.

WEDGE, MECHANICAL ROASTING FURNACE

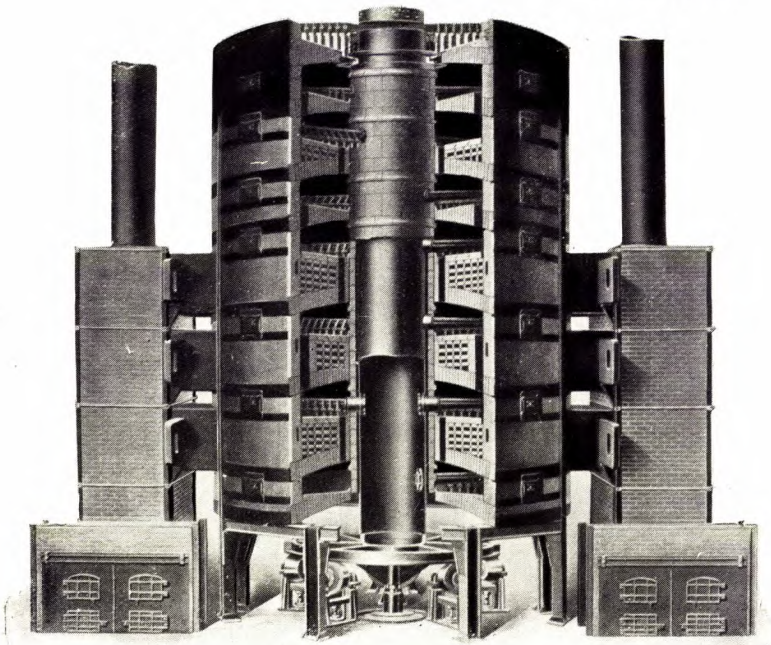
Descriptive Legends for Plate XVII.

- | | |
|-----------------------------------|---|
| 1. Driving pulley | 33. Supporting roller shaft |
| 2. Top horizontal shaft | 34. Supporting roller adjustable stand |
| 3. Pillow block | 35. Cinder outlet support plate |
| 4. Pillow block—end thrust | 36. Cinder outlet elbow |
| 5. Bevel gear | 37. Door |
| 6. Bevel gear | 38. Poke hole and stopper |
| 7. Collar | 39. Upper feed plate |
| 8. Top flange bearing | 40. Lower feed plate |
| 9. Oil collar | 41. Feed box |
| 10. Upper vertical shaft | 42. Water pan |
| 11. Lower vertical shaft and worm | 43. Water pan support |
| 12. Bearing—with adjustable box | 44. Upper tile support |
| 13. Flange coupling | 45. Blade holders—R. H. and L. H. |
| 14. Worm gear housing | 46. Lower tile support |
| 15. Worm wheel | 47. Furnace arm holder |
| 16. Intermediate vertical shaft | 48. Furnace arm |
| 17. Flange coupling | 49. Removable blades |
| 18. Lower horizontal shaft | 50. Dryer arm |
| 20. Pillow block | 51. Dryer plows, plow bars and holders |
| 21. Floor stand | 52. Dryer arm saddle |
| 22. Collar | 53. Central shaft. |
| 23. Bevel pinion | 54. Water inlet pipe to arm |
| 24. Safety pin collar | 55. Water discharge pipe from arm |
| 25. Safety pin | 56. Overflow pipe from water pan |
| 26. Master gear | 60. Outer drop hole |
| 27. Gear segment | 61. Inner drop hole |
| 28. Race way segment | 62. Central shaft brick |
| 29. Center pin | 63. 1-inch space between central shaft
and central shaft brick |
| 30. Center pin collar | 64. Tile. |
| 31. Center pin guide bearing | |
| 32. Supporting roller | |

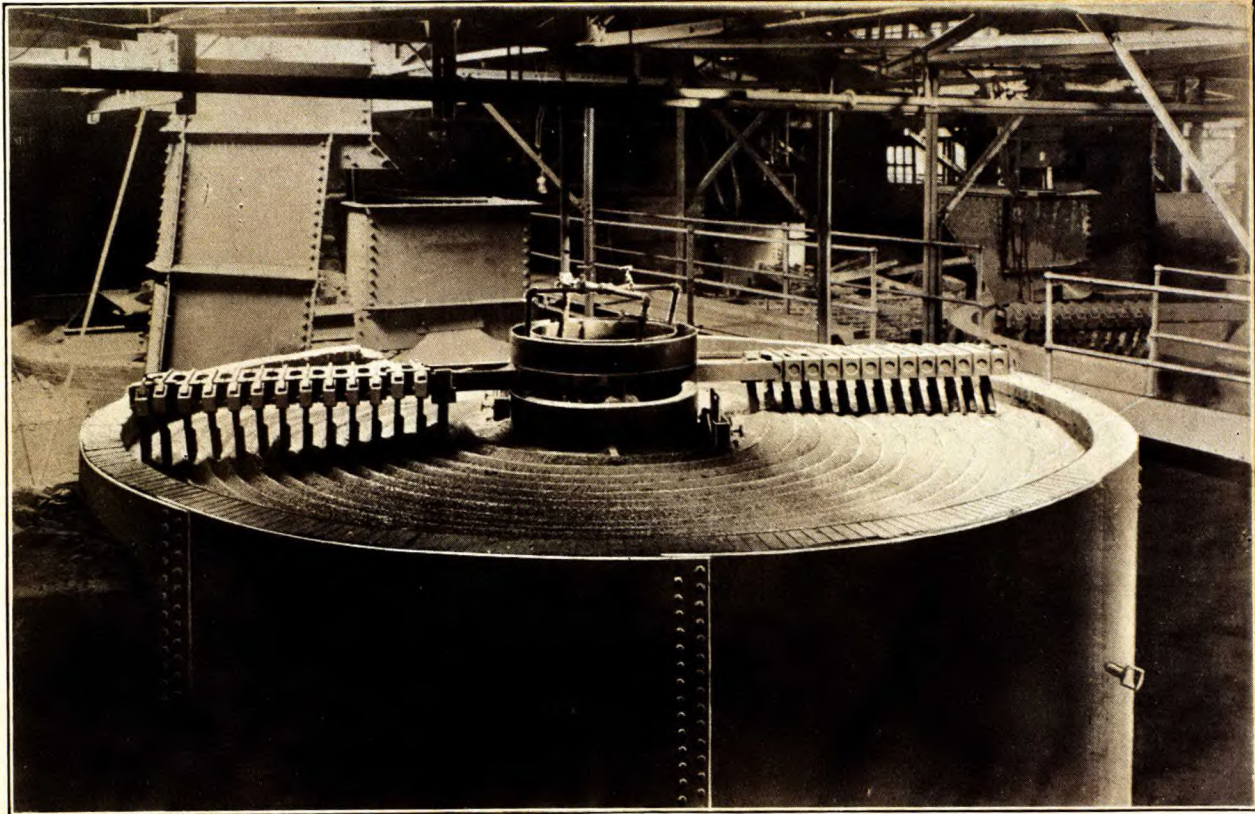


Wedge, mechanical roasting furnace.

PLATE XVIII



Wedge mechanical roaster. Three hearths muffle fired, air pre-heated.

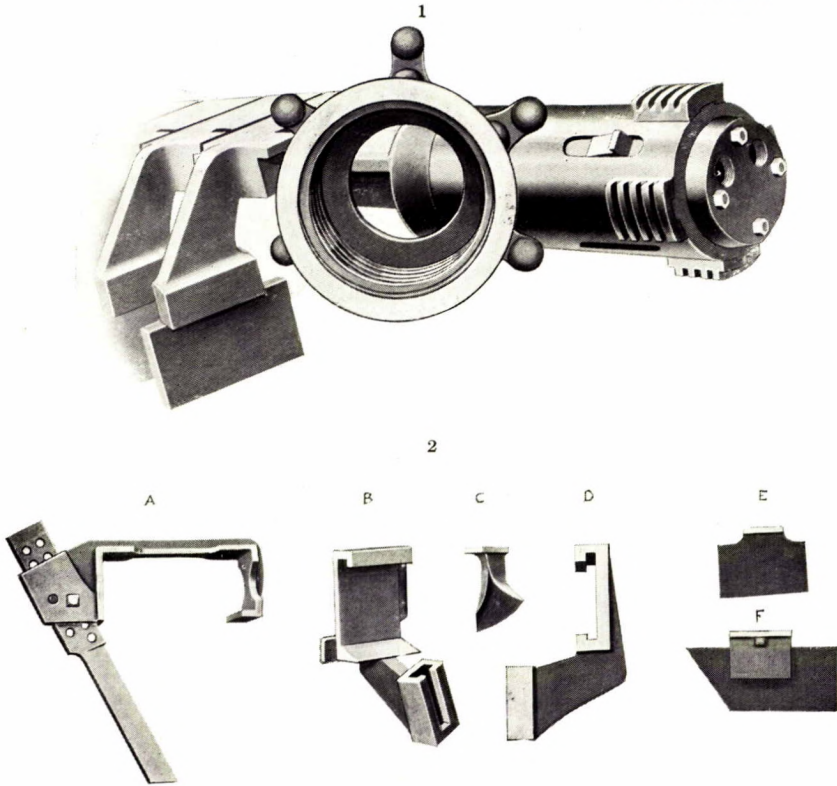


Wedge mechanical furnace. Top used as a dryer.



1. Rabble arm.
2. Arm dressed with rabble blade holders and blades.
3. Arm partly dressed with holders and breech block.

Wedge mechanical roaster.



Wedge mechanical roaster.

1. Inner end of arm with steel threads and keys in position.
 2. Rabble holders and rabbles.
- | | |
|--------------------------------------|-------------------------|
| A. Dryer plow holder and rabble. | D. Cutting blade holder |
| B. Interlocking rabble blade holder. | E. Rabble blade. |
| C. Cutting blade. | F. Rabble blade. |

or seven hearths, the different styles of furnaces being adapted to different problems. (Plates XVII–XXI).

Construction.—This furnace consists of a cylindrical riveted steel shell encasing walls of hard burned, red brick. The hearths are constructed of special shaped fire brick, and are made horizontal, each hearth, however, forming an arch above the one below.

The most characteristic feature of the Wedge furnace is the central shaft. This shaft is made of riveted steel plate. In the smaller sizes (9'-9" and 12' diameter), it is 2' 6" in diameter; in the larger sizes the diameter is 4'. The outside of the shaft is protected by fire brick, made in special shapes, which are attached to and revolve with it. This hollow shaft is open at both top and bottom and the natural draft of air through it keeps it sufficiently cool for a workman to enter at any time. The large shaft is employed to give access to the arms from the inside.

Each rabble arm is cast in one piece, and made hollow, with a web down the centre. (Plates XX–XXI). The rear end is machined and fitted with a plate bored for two waterpipes—one leading to each side of the median web, these two spaces being jointed at the tip of the arm. When in operation, the water pipes are connected with a water supply, and the shaft and arms are kept cool by the circulating water.

The butts of the rabble arms pass through the sides of the shaft, two for each hearth, and each is held in place by the use of interchangeable steel threads, keys, and a breech block. (Plate XX, 1). When it becomes necessary to change an arm, the power is shut off, a workman enters the shaft and removes the breech block, keys and threads. The arm, from which the rabbles have previously been removed, is then withdrawn by other workmen, operating from the outside, and the new arm is inserted. The workman in the shaft then replaces the thread blocks, keys and breech block, and the arm is in place, ready to receive the rabbles. An arm can be changed in about 40 minutes, provided everything is made ready before stopping the furnace. The accompanying plates (Plates XX and XXI) show a single rabble arm, and also illustrate the method employed to attach it to the shaft.

Several varieties of rabble blade holders and rabble blades are used in the Wedge furnaces, according to the purpose for which they are required. One style is shown in use in the plate illustrating the top of the furnace used as an ore dryer (Plate XIX). Another illustration shows the Wedge interlocking rabble blade holder. The rabble blade holders are not bound to the arm at the heel, and if they stick or bind on the arm and will not slide off easily, they can be tipped off as shown on the plate (Plate XXI, 2).

On Plate XXI, A shows the dryer-plow, holder, and rabble used on the top of the furnace. On the top of the furnace, the wear is on the bottom of the rabble blade, hence this is made with a series of staggered bolt holes that it may be lowered, when worn—to secure economy in castings. Figure B shows an interlocking rabble blade holder; it is cast to hook on one side of the arm, and is free at the heel; rabble blades E or F slide into the holder and are held in position by pressure against the material being roasted. Figure C

is a cutting blade, and D is a cutting blade holder. This holder is made to slide on the arm so that it may be held rigid. The cutting blade can be slid into position in the same manner as the rabble blade E or F, and the holders can be pushed from the outer end of the arm towards the centre. As the arm revolves, the hearth will be mechanically plowed up or milled. These blades will be employed only where there is a tendency for the roasting ore to bake or cake on the hearth.

Rabbles and rabble blade holders are simple castings, are not machined, and can be cast in a local foundry.

The furnace is mounted on a structural steel frame carried on steel columns. Power is applied by gears to the central shaft from a main shaft below. A shear pin is employed in the driving mechanism for safety.

Operation.—Ore is brought to the feeding hopper above the furnace either in barrows or automatically by conveyors, the latter being preferable on account of the capacity of the furnaces. Ore falls from the hopper upon the top of the furnace, where it is spread out and stirred by special rabbles. The heat received by the arch above the upper hearth is utilized in drying the ore before it is fed to the hearths. Ore containing 6%–8% moisture can be efficiently dried in this way.

The dried ore falls upon the first hearth near its centre; here the rabbles work it gradually outward in a spiral path to the periphery, where it falls upon the second hearth. On the first, third, fifth, and seventh hearths, the ore travels radially outward, and on the second, fourth, and sixth it travels in the opposite direction. The cinder is discharged through ports on the periphery of the lowest hearth, either into barrows, or to some form of conveyor.

The air for oxidizing is admitted through ports on the sides, usually on the lowest hearth.

The accompanying table 18 gives some data with respect to the styles of furnaces manufactured under the Wedge patents. It also gives the hearth area, and rated capacity of the different roasters.

TABLE XVIII.

Wedge Furnaces. Size and Capacity.¹

No.	Diameter Outside.	Diameter of Shaft.	Number of Hearths.	Hearth Area. Square Feet.	Weight of Metal Parts.	Maximum Capacity in 24 Hours. Tons of 2,000 Pounds. ²
0	9' 9"	2' 6"	3	130	17,450 lbs.	1.5
1	9' 9"	2' 6"	5	217	20,900 "	2.5
2	9' 9"	2' 6"	7	304	24,350 "	3.5
3	12' 0"	2' 6"	5	373	23,200 "	4.3
4	12' 0"	2' 6"	7	522	27,300 "	6.0
5	16' 0"	4'	5	725	73,100 "	8.3
5a	16' 0"	4'	5	725	Special	8.3
6	16' 0"	4'	7	1,015	87,700 lbs.	11.6
6a	16' 0"	4'	7	1,015	Special	11.6
7	20' 0"	4'	5	1,245	86,800 lbs.	14.3
8	20' 0"	4'	7	1,743	110,300 "	20.0
9	21' 6"	4'	5	1,470	95,500 "	16.9
10	21' 6"	4'	7	2,058	116,000 "	23.6
10a ³	21' 6"	4'	7	2,058	116,000 "	23.6
11	22' 6"	4'	3	978	80,000 "	11.2
12 ⁴	34' 0"	4'	1	787	154,400 "	70.0
13	24' 0"	4'	3	1,117	82,600 "	12.8

In addition to the standard Wedge furnaces, primarily designed for use in acid works, the same firm manufactures a series of muffle fired furnaces for special purposes. Plate XVIII shows a furnace with three hearths, muffle fired, and constructed for coal firing. A preheater is also constructed between the second and third hearths. The furnace is arranged that air may be admitted at this point, preheated and admitted to the muffles below.

Many variations can be introduced into the construction of these furnaces; muffles can be applied to all the hearths, preheated air can be supplied either to the muffles or the hearths, or both; other fuels than coal can be employed, according to the purpose for which the furnace is required.

¹ Information supplied by the makers.

² In the capacity column these figures are based on roasting pyrites containing 50% sulphur, and reducing the sulphur to 2% in the cinder.

³ For Sulphite Pulp manufacture.

⁴ No. 12 furnace is designed more especially for chloridizing purposes, and the capacity shown above has been demonstrated in this service.

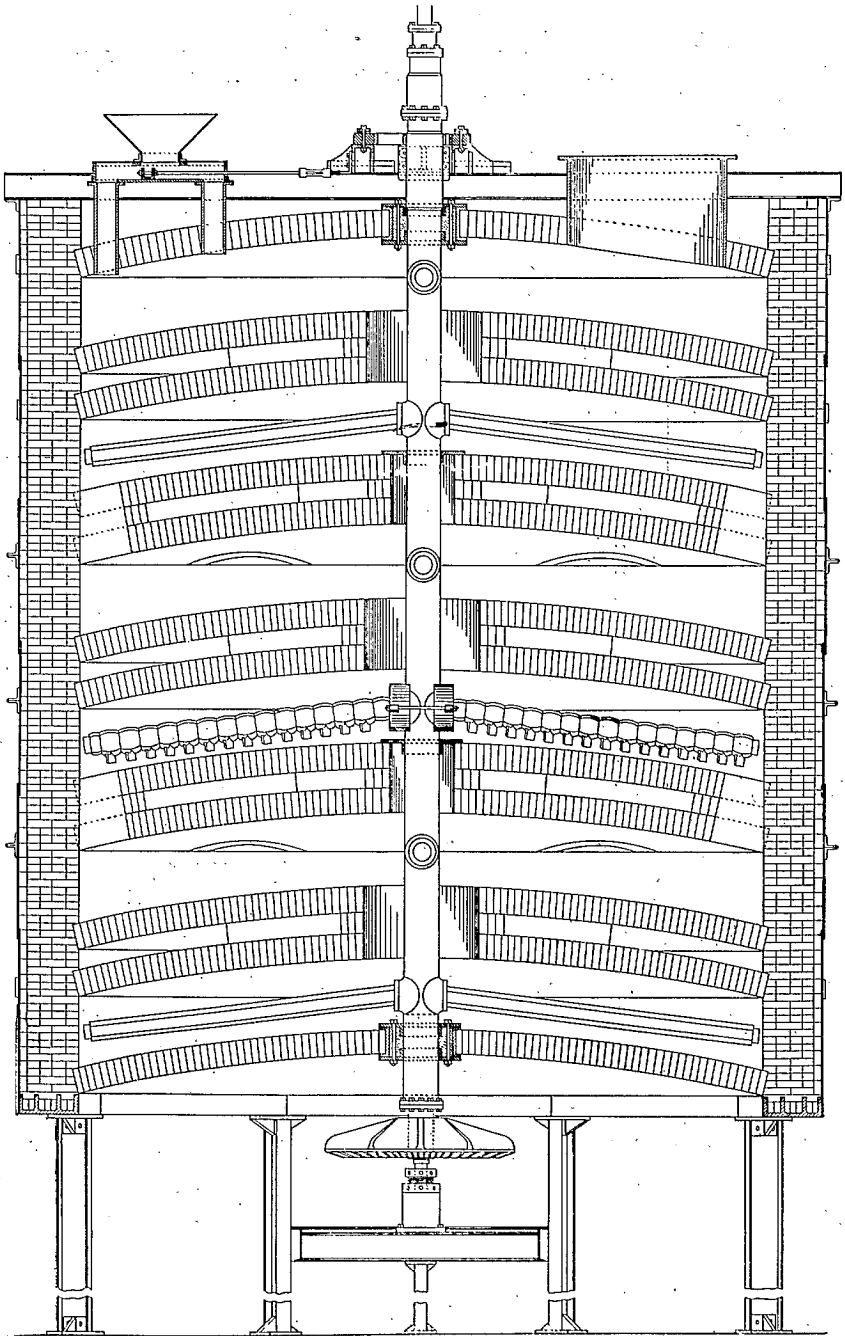


Fig. 10. Heinze-Freeland roasting furnace, Vertical cross section.

*Heinze-Freeland Roasting Furnace.*¹ A furnace, which has been erected at the works of the Ducktown Sulphur, Copper and Iron Company at Isabella, Tenn., presents a number of features which are of special interest. The following description and the accompanying plates are published through the courtesy of Mr. N. L. Heinz, and the Ducktown Sulphur, Copper, and Iron Company.

In general form and construction, it is similar to the other furnaces already described. It is a cylindrical six hearth furnace, with red brick sides and

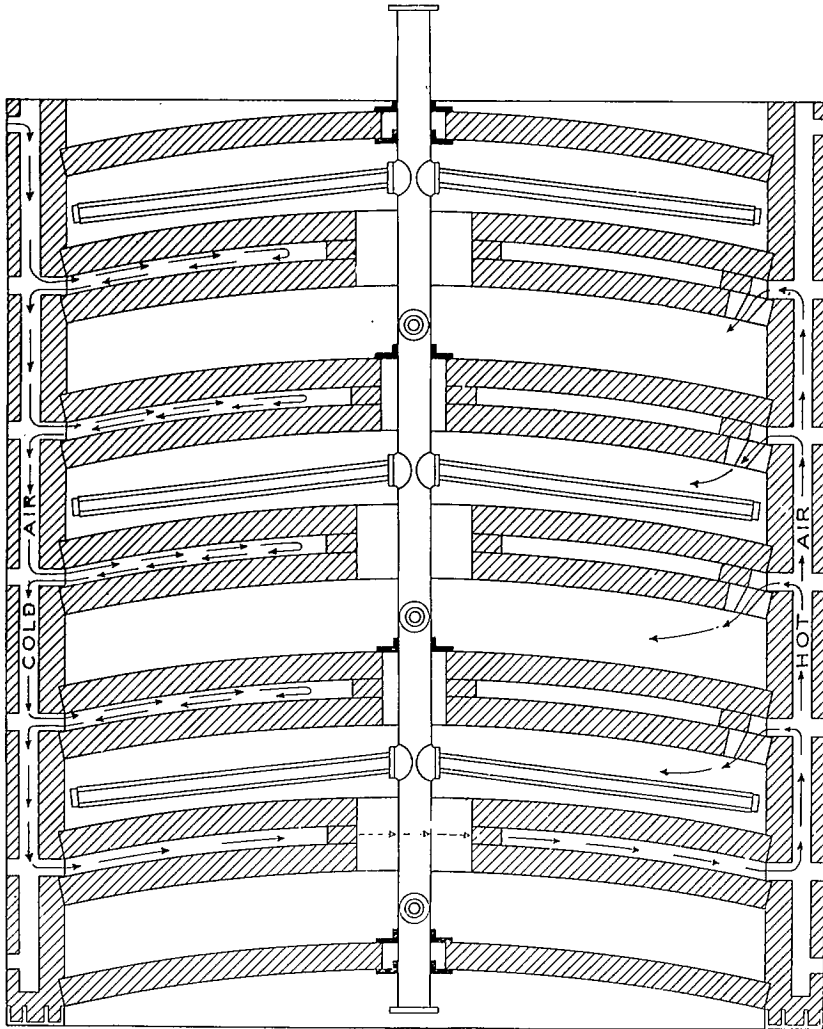


FIG. 11. Heinze-Freeland roasting furnace. Sectional elevation showing circulation of air.

¹ This furnace is controlled by the Patentees. Information may be obtained from the Wedge Mechanical Furnace Company, 115 Chestnut St., Philadelphia, or from N. L. Heinz, La Salle, Ill.

fire brick hearths. A central shaft carries rabble arms, two for each hearth. Both shaft and arms are cooled by circulating water. The novel feature is the introduction of a series of five muffles, one above each of the 5 lower hearths, and the thickening of the outer walls of the furnace for the purpose of introducing a series of air ducts. By means of doors in the outer wall, and suitably arranged plugs, which can be shifted at will, the air supply for the combustion of the sulphur in the ore on the hearths can be caused to first pass through any number of muffles. It becomes heated in the muffles and it can be admitted to any desired hearth. The general construction of the furnace, and the location of the air ducts with respect to the hearths are shown in the accompanying figures (Figures 10 to 13). It will be noted that the muffles are heated by the combustion of the ore on the hearth of the furnace. No auxiliary source of heat is necessary when ordinary pyrites is used in this furnace. The furnace seems specially adapted to the burning of ores which are low in sulphur.

In the installation at Isabella, an auxiliary dryer has been erected close to the furnace. The hot gases from the furnace are utilized as a source of heat for this dryer, and, when necessary, the ore to be roasted is first passed through the dryer.

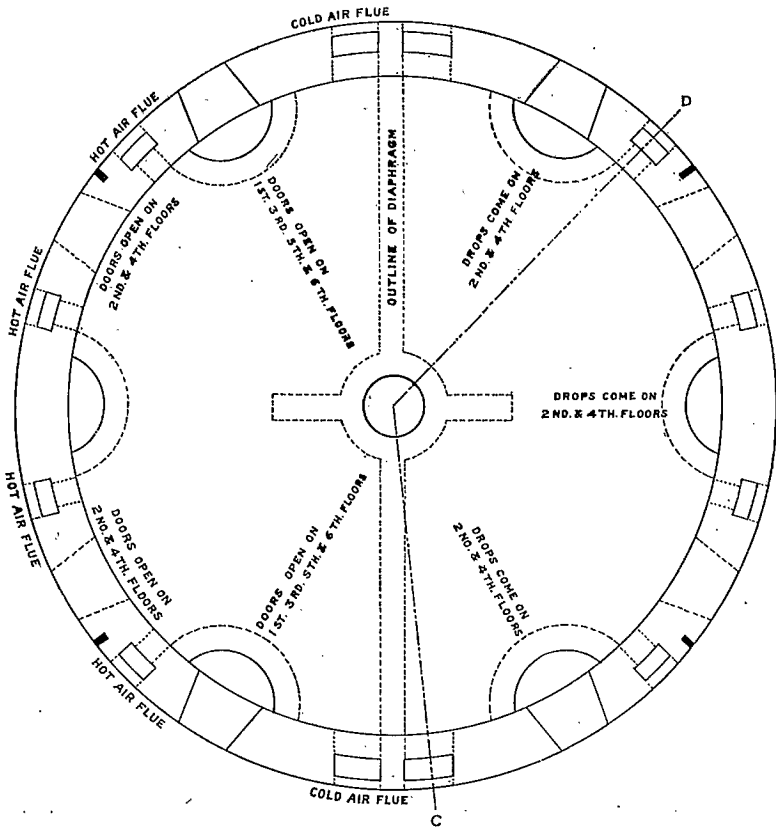
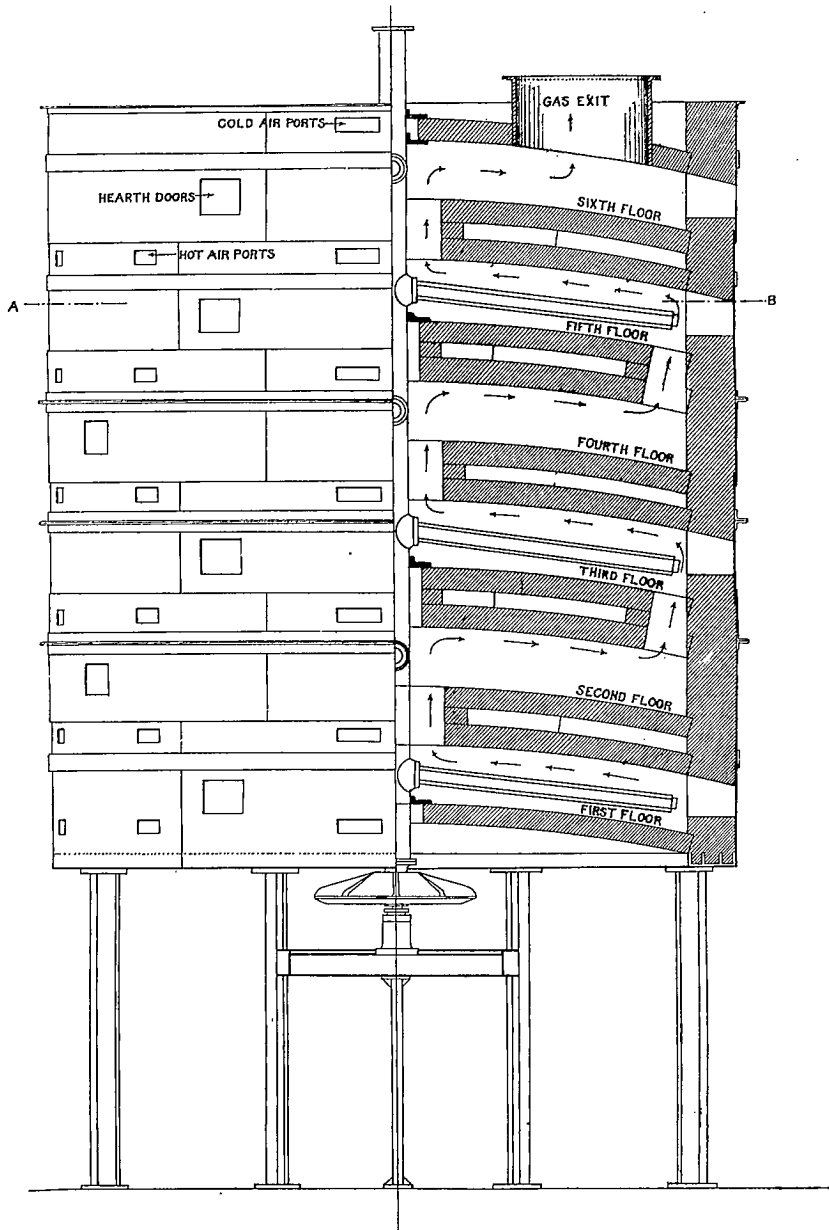


Fig. 12. Heinze-Freeland roasting furnace. Horizontal section diagram.

The furnace has only been in operation, intermittently, for a little more than one year, and complete data as to its capacity and efficiency are not available for publication. Mr. L. N. Heinze has, however, kindly supplied



Half End Elevation

Half Sectional Elevation

FIG. 13. Heinze-Freeland roasting furnace, showing air ports and hearths.

the subjoined memorandum with respect to two experimental runs which were made with this furnace.

"For 31 days the furnace was run *with the hot air* and the following capacity was obtained; crude ore charged 45,000 lbs. per day, with a total sulphur of 2.40% remaining in the cinder."

"For 30 days the furnace was run *without the hot air* and the following capacity was obtained; crude ore charged 29,300 lbs. per day with a total sulphur of 4.94% remaining in the cinder."

"The furnace is so arranged that it can be run with or without preheating the air. During the 31 day period, when the air was preheated to average 350 degrees C, no trouble with sintering was experienced."

"The ore charged averaged, S 26%, CaO 2.25%, MgO 3.15%, MnO 0.20%, Zn 0.45%, Cu 0.77%."

*Evans-Klepetko Furnace.*¹ The leading differences between this furnace and the Herreshoff furnace are in the size of the furnace and in the introduction of a water cooling system to protect the shaft and the stirring-arms. The first furnace built was 16' in diameter, was provided with 8 hearths, an air cooled shaft and 8 solid cast iron arms. The heat generated was sufficient to cause the arms to bend under their own weight. These difficulties were overcome by substituting water cooling for the air cooling, and by reducing the number of the hearths to 6. While primarily used only for roasting copper ores as a preliminary to smelting, the furnace can also be employed in acid making.

The furnace described by Hofman is 18'-3.5" high, 15'-10" in diameter; it is sheathed with $\frac{3}{8}$ " boiler iron and lined with a full course of red brick; it has 6 arched hearths with a 9" spring and 3' apart; each hearth has 2 stirring arms making 60 revolutions per hour. The furnace stands on columns 12' high, to allow the roasted ore to be collected in hoppers and discharged into cars. Six furnaces form a battery; they are placed from centre to centre 18' apart in one direction and 21' 3" in the other. Each furnace has 2 gas-flues, 2' in diameter and 12" apart passing out of the roof; the flues from 3 furnaces lead into 1 main, 6' in diameter, having openings along the top and bottom for removing the flue-dust; the bottom openings have vertical pipes which are connected directly with the calcine hoppers. The central shaft of a furnace is driven from below. Three furnaces receive their motive power from one main shaft, with which they are connected by friction clutches. A clutch can be thrown in or out from each of the 6 platforms surrounding a furnace. The cooling water is forced down to near the bottom of the revolving hollow shaft (9" inner diameter) through a 3" pipe and out to the ends of the horizontal stirring arms through 1" horizontal pipes. In its upward passage between shaft and pipe it takes up the return water from the stirring arm and discharges at the top through 2 spouts into a stationary launder. Shaft and arms are made up of flanged sections to permit easy

¹ Abstract from Hofman, H. O., "Notes on the Metallurgy of Copper of Montana," Trans. A. I. M. E., Albany meeting, 1903, Vol. XXXIV, pp. 258-316.

exchange. Running the overflow water at 80° C., 20 gallons of cooling water per minute are required by a furnace. Tests have shown that 10 H.P. is required for 6 furnaces. When ore, too low in sulphur to be self-burning, i.e., about 28%, is to be roasted, one auxiliary fireplace for 2 furnaces, placed on the level of the bottom floor and delivering the flame onto the fourth floor, furnished the additional heat required.

The moist concentrates arriving from the ore-dressing plant on an overhead track are dumped into the 2 feed-hoppers of a furnace. These are 10 feet apart and are 4'-6" in diameter for 9'-6" and then conical for 7'-6". At the bottom they are made 3'-6" by 1'-2", to fit into the openings in the roofs of the furnaces. The top of the hopper has a grating to break up any lumps and to keep out large pieces that may have accidentally gotten into the ore. The hopper holds 2 cars of concentrates, or 33 tons. This weight, pressing downward, prevents any hanging of the charge and thus solves the difficulty of feeding moist fine concentrates. The contents of the hopper is continuously discharged into the furnace by means of a feeding device of the form of an I, which passes to and fro under the mouth with a throw of about 10". The rods of the 2 feeders are joined by a cross piece which is pivoted in the centre and connected by a rod to one end of a link, while the other end is attached to the pitman of a crank and spur wheel; the spur wheel is geared to the central shaft of the furnace. The ore is spread on the top hearth to the thickness of 3" by the stirring arms. The tops of these arms are protected by cast iron caps against rapid wear at the places where they strike the ore column coming down through the feed openings. The outer half of a hearth is 9" thick, the inner 6". The reasons for the difference are, saving of brick, reducing of weight at centre, preventing contact with stirring-teeth when the hearth rises upon heating, and furnishing an offset to hold the loose working bottom (crushed limestone, sometimes flue dust and even coke dust), which is about 4" thick at the centre and 9" at the periphery. The 2 arms of a hearth have 7 and 8 cast iron teeth; these are 8" long by 6" wide by $\frac{5}{8}$ " thick; the lower 3" of the teeth, which come in contact with the ore, are chilled. There is no advantage in making the teeth thicker than $\frac{5}{8}$ ", as they wear off obliquely to the working surface and, consequently, would simply offer a larger wearing surface, but not lengthen the life. At the same rate that the teeth are worn off, the ore builds on the loose working-hearth. When they are to be renewed, they are removed and a plow is slipped over the stirrer arm and moved a little toward the centre after every circuit of the arm. Thus a crust is easily and surely broken up. The crusts on the second hearth are harder to break than those of the other hearths. The teeth on the top hearth last 25 to 34 days; those on the sixth 6 to 8 months. The shorter life of the former is attributed to mechanical wear caused by decrepitation of the ore. It cannot be due to chemical action, as the top hearth serves mainly for drying, unless the moisture should cause some sulphuric acid to form, but the temperature of the escaping gases is 315° C., and the draught is sufficiently strong to show a depression 0.3" of water.

Roasting begins on the second or third hearth, varying with the strength of the draught and the number of circuits that the stirring arms make. With a strong draught the heat creeps up; with 1 circuit in 55 seconds the roast begins on the second hearth, with 1 in 75 seconds on the third. As the ore passes from the first hearth through the annular opening at the centre of the roof of the second hearth (protected by a cast iron ring), it strikes a distributor which prevents any of it from passing down the shaft. During normal work 3 doors on the bottom hearth are left open for the admission of air. If the furnace becomes too hot, the doors on the third floor are opened more or less and thus the draught checked. While the ore drops from hearth to hearth, the upward gas current carries dust with it, and this striking the roof adheres to it in part and builds. In order to protect the arms from being worn out at these places, they are protected by cast iron caps. When the dust has grown to a thickness of 4", it is removed with chisel pointed bars. Experiments to protect the roof at weak spots with cast iron plates have proved successful, as the dust is easily pried off. The chunks of fritted dust go to the blast furnace as welcome lump ore; they contain only 6 per cent of silica with ore of 30 per cent silica, thus showing that light particles of ferric oxide are more easily carried away by the gas-currents than heavy gangue. The dust collected in the settling chamber runs higher in sulphur than the roasted ore.

In starting a furnace, crushed limestone is fed to form the working-bottom. Then a small fire of dry, soft, i.e., long flame, wood is started from the three side doors of the third and fifth hearths. A new furnace is brought to a dark red in 3 to 4 days, an old furnace requires only two days. Now, concentrates are fed. After charging for 5 to 6 hours, it sometimes happens that the furnace cools down too much, and this makes it necessary to start on the third and fifth floors a new fire for 1½ to 2 hours; occasionally, feeding of the ore is stopped and half a ton of coal is charged. When this has come to the third hearth, the machinery is stopped and the coal is allowed to burn out. The kindling of the coal may have to be assisted by placing dry wood on the hearth. Under normal conditions a furnace does its best work when the flue shows a depression in water of 0.3"; if it is less, the furnace gets cool. The normal ore mixture passes through the furnace in about 1½ hours. If the furnace gets too hot, more slimes are fed; if too cold, coarser concentrates are charged and the rate of feeding is reduced. As indicated above, the temperature is further regulated by the admission of air; closing the bottom door drives up the heat, opening them draws it down; opening doors higher up checks the draught. The rate of feed when once settled upon is usually not altered, and the number of circuits the arms make per hour remains, of course, constant.

The dust, which collects in the flue connecting three (resp. 4) furnaces and forms 4 to 5 per cent on the ore, is raked out every day, sometimes part of it is blown into the main flue of a battery, with a hose under a pressure of about 90 lbs. per square inch. The loss of weight in ore including flue dust is about 20 per cent.

A furnace treats, under normal conditions in 24 hours, 40 tons sulphide ore, with 35 per cent sulphur and 10 per cent copper, or 0.042 tons per square foot of hearth area, reducing the sulphur to 7 per cent; roasted ore, with 14 per cent copper treated in the same manner, retains about 10 per cent of sulphur. The product can, of course, be varied with the speed of travel of the stirring arms. Thus, with 1 circuit in 75 seconds it is reduced to 30 tons, with 1 in 50 seconds it is increased to 50 to 55 tons.

A section of six (resp. 8) furnaces is attended to in an 8 hour shift by $\frac{1}{2}$ foreman, 1 furnace man, 1 helper, $\frac{1}{8}$ oiler, $\frac{1}{8}$ repair man and 1 trimmer.

The following partial average analysis of roasted ore represents two determinations from the average day-and-night samples, taken during an experimental run of 15 days:—

SiO₂, 26.9 per cent.

Cu, 18.3 per cent, of which 9.9 was present as CuO.

Fe, 30.0 per cent, of which 17.9 was present as Fe.

S, 9.2 per cent, of which 0.81 was present as SO₂.

*Merton Roasting Furnace.*¹ This furnace, which is now coming into use in acid works in Great Britain, differs from the ordinary mechanical roasters in a number of important particulars. The accompanying figures 14 and 15 show a cross and longitudinal section respectively of the furnace for roasting pyrites ore. The furnace is constructed of brick with concrete blocks for the shaft pedestals. They are provided with three (several) hearths, rectangular in plan. As shown in the cross section, these hearths are arched to span the narrower dimension of the furnace. Two vertical shafts, carrying rabble arms are provided, the distance from centre to centre of the shafts being slightly less than the transverse dimension of the hearth. The shafts are rotated by means of machine cut worm gearing running in oil, and, wherever practicable, ball bearings are used to minimise friction. Both shafts and arms are water cooled throughout. The rabbles are moveable on the rabble arms, and can easily be renewed, being simply slipped on and off. They are arranged in two rows, on each arm, one being slightly in advance of, the other just behind, the rabble arm, so that the whole of the hearth is efficiently stirred.

The ore is fed through a hopper to the top floor of the furnace. It is worked along this floor by the rabbles, and on reaching the end, it drops through the ports to the floor beneath. Here it is worked along in a similar way, but in the opposite direction, until it reaches the ports at the other end of this second hearth, when it falls to the third hearth. It thus travels from hearth to hearth, and finally the desulphurised and oxidized cinder is withdrawn from the bottom floor. The air for combustion is admitted in the reverse direction to the progress of the ore, and the products of combustion

¹ Manufactured and sold by the Merton Furnace Company, 62 London Wall, London, E.C.

pass out by the furnace flue from the top floor close to the feed hopper. Working doors are provided to each floor, but they are only used for inspection purposes, or when the furnace is in need of repairs.

An auxiliary fire box is supplied to these furnaces, where an outside source of heat is required for oxidizing certain ores.

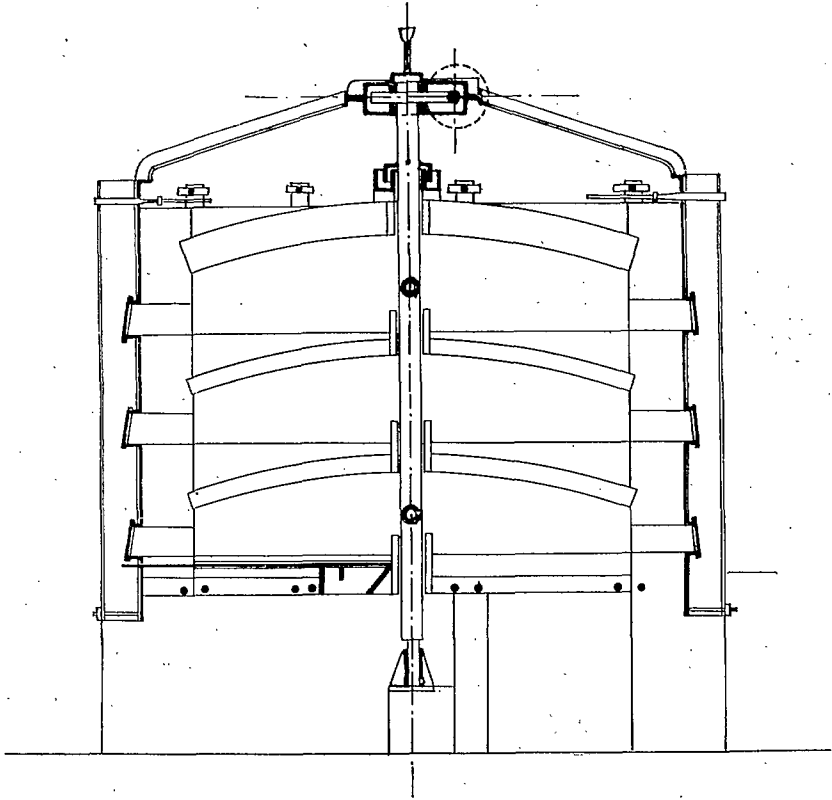


FIG. 14. Merton roasting furnace. Vertical cross section.

A standard furnace of this type will treat 5.5-6 tons of pyrites per day with a power consumption of 1.5 H.P.

It is claimed that a furnace of this type produces a minimum of dust, because the ore travels over the hearth area covered by the two rabble arms between each drop. Any dust produced has an opportunity of settling before passing from the furnace.

The repair bill is extremely small, renewals being practically confined to the rabblers.

The cost of this furnace is £480 or \$2,335.00.

This firm also construct a muffle furnace on the same general plan, but larger, specially designed for roasting lead and zinc ores, and for the recovery of the sulphur dioxide.

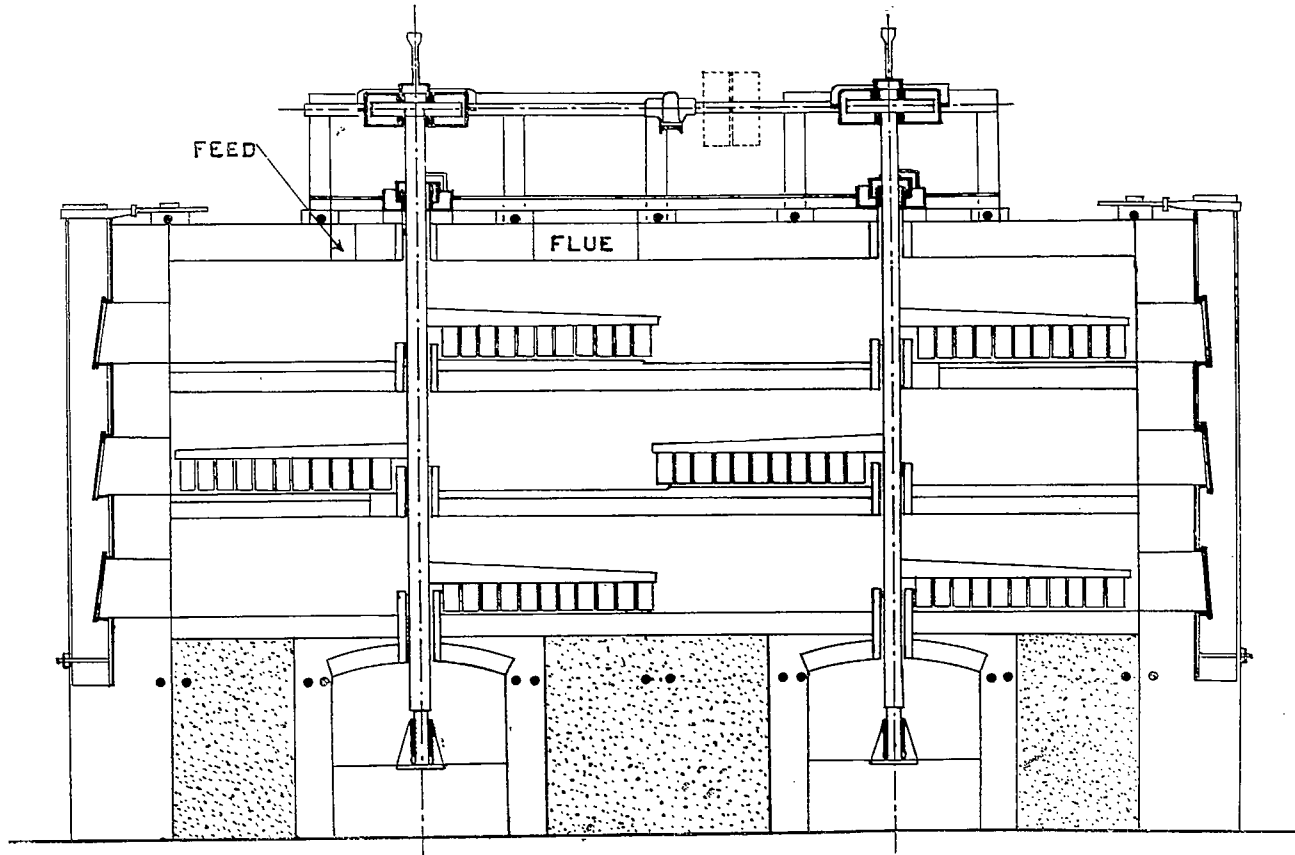


FIG. 15. Merton roasting furnace. Vertical longitudinal section.

O'Brien Roasting Furnace. This furnace is built with a cylindrical brick casing enclosed in a boiler plate shell, the whole supported on channel or angle iron columns. The furnace differs from others of the same type in the possession of a number of improvements in the details of construction. In the patent specifications, 26 separate claims are made for these improvements. The more notable modifications are as follow:—

The hearths are reinforced at the peripheries by annular bands which prevent their spreading when heated and exercising a pressure on the furnace casing. The rabble arms are detachable and fit into tapering sockets in the shaft, being held in place by lugs which interlock with corresponding projections on the shaft, when the arm after insertion in the socket is rotated upon its own axis through a short arc.

The shaft is made conical or tapering in form and is mounted with the smaller end down. Vertical chord-walls extend upward through the shaft forming three compartments. The rabble arms are made hollow, having two compartments, one for leading the air from one compartment of the shaft into the arm, the other for leading the air out of the arm into the other shaft compartment. The hollow rabble arms fit into a tapering socket, extending into the shaft through the chordwalls; the inner end of each arm is provided with openings which communicate with the respective compartments in the shaft. The shaft and arms are cooled by air forced into the hollow shaft from below.

The general construction of the furnace and its principal features are shown in Plate XXII. A single rabble arm with a cross section of the shaft, showing the chord-walls and air passages is shown in Plate XXIII A. An arm with rabbles attached is shown in Plate XXIII B. The connexions between the air channels in the arm and the shaft compartments are also shown in this figure.

*Sjöstedt Roasting Furnace.*¹ The special features embodied in this roaster are the following:—

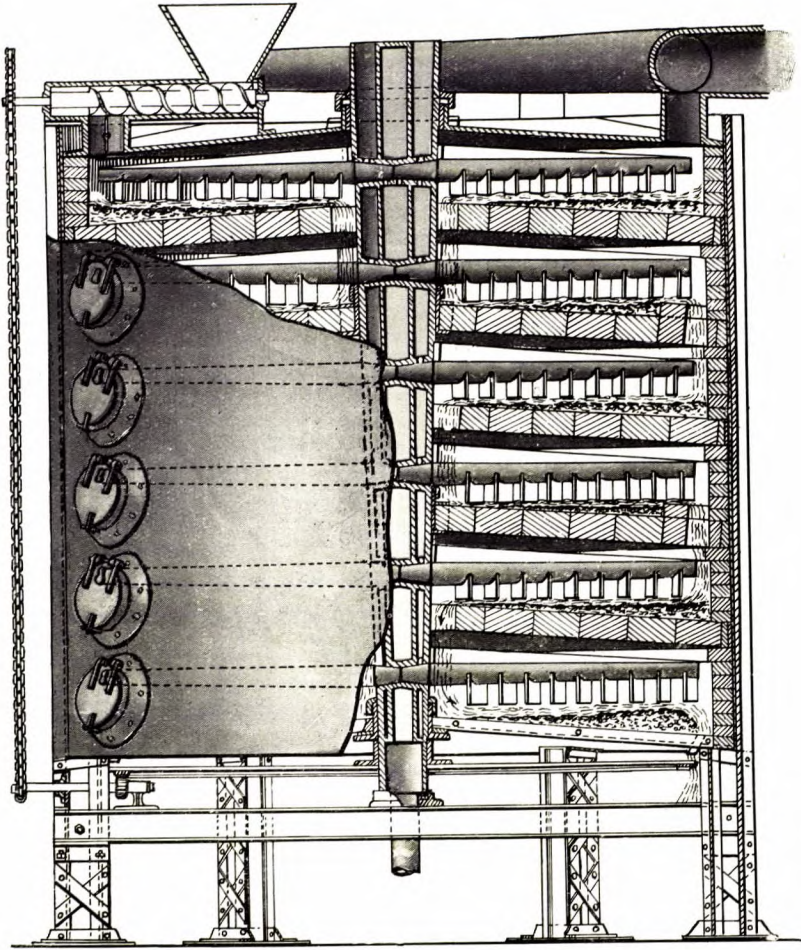
1. The combination of four single furnaces in one battery, disposed equi-distant from a common centre.

2. A minimum distance between the floor and roof arches of the roasting chambers, made possible by the construction of the arm, and the manner in which it is secured to the centre shaft (it being secured in position by a horizontal motion and a quarter turn).

3. A round rabble arm, with a perfectly secure locking device, having both ends closed so as to prevent any inflow of air from the centre shaft to roasting chamber, the air of combustion being admitted through special pipes, provided with valves for a perfect control of the same.

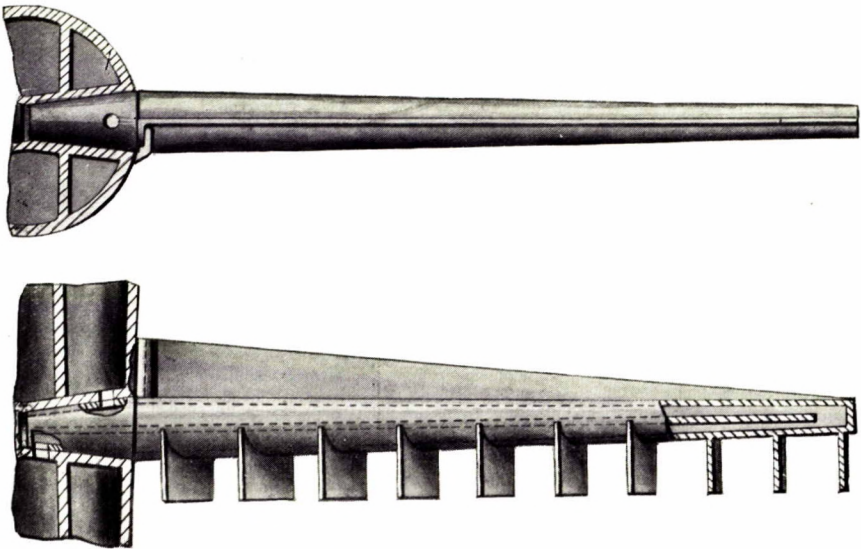
4. Separate muffle chambers for the application of an auxiliary heat, and having no connection with the roasting chambers, the one under the bottom hearth being a combustion chamber, and those under the second and

¹ Sjöstedt, Ernst A., "Acid Making from Pyrrhotite," Jour. Can. Min. Inst., Vol. VII, 1904, pp. 480-494, abstract.



O'Brien roasting furnace.

PLATE XXIII



O'Brien roasting furnace. Rabbles, rabble arm, and method of attachment.

top hearths being heating chambers, through which the combustibles of the extraneous fuel pass from the combustion chamber, and are thus utilized to advantage in heating the corresponding roasting floors.

5. A screw device for feeding the ore from the hopper to the roaster, the same being propelled by means of an endless chain from the main driving shaft.

Sections of this roaster are shown in figures 16 and 17.

Figure 17 presents a battery of four furnaces in horizontal cross section, on the broken line 1 1 and 1' 1' on figure 16, showing the combustion chamber a^5 , the lower and upper heating chambers a^4 and a^1 , and the lower, or discharging, hearth A^5 , figure 16 shows a sectional elevation of the battery on line 3 3, figure 17, being through the central columns of the furnaces, one side shown with the rabblers and one without. A^5 A^1 are five straight arched hearths; a^1 , a^4 and a^5 the combustion and heating chambers. The flow of the fuel gas and combustibles is indicated by arrows. The gas (or oil) entering from main F^3 through f^3 and a suitable burner into the combustion chamber at F and F^1 , strikes the hot baffle walls and is readily ignited, passes through the chamber and reaches the chimney flue D , which leads to the heating chamber a^1 , over the lower roasting hearth. This chamber is also provided

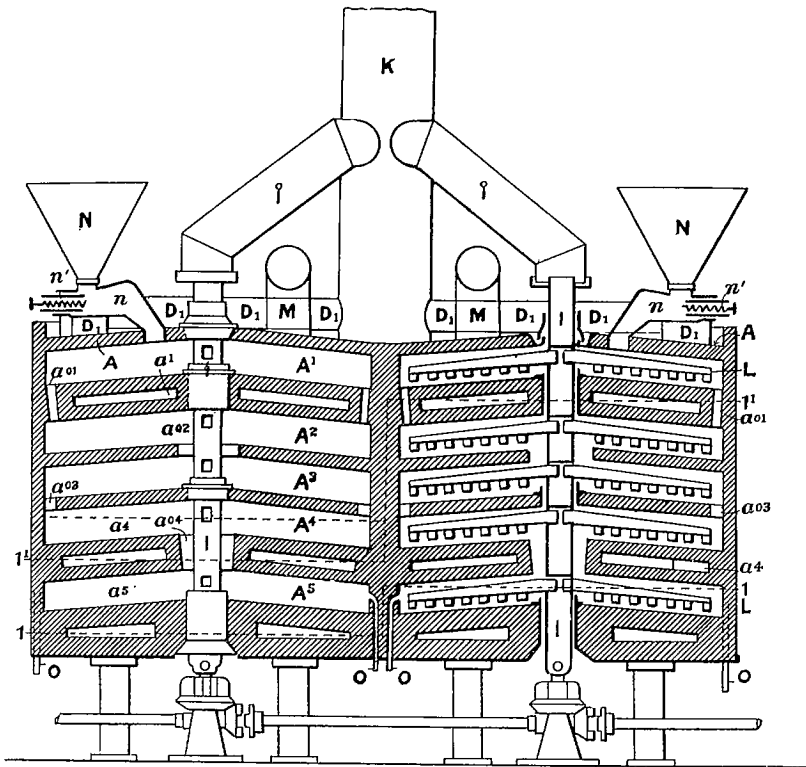


FIG. 16. Sjöstedt roasting furnace. Vertical section.

with a baffle wall, E, which extends to and surrounds the centre shaft I, separating the gas inlet from its outlet, and thus compelling the combustibles to make a full turn here before passing out and up through the upper section of chimney flue D to the heating chamber a^1 , under the upper roasting hearth. Here it makes a similar circuit before finally passing out through the last section of D and flue D^1 to stack K, which is common to the whole battery of four roasters. F^4 and F^5 are peep holes for inspecting the heat in the combustion and heating chambers. G is an air receiver ("hot blast") in the centre of the battery, into which the air of combustion is introduced under pressure from a Root blower and heated from the brick walls with which it is surrounded, and thence carried through blast pipes G^1 to the burners at F and F^1 . The ore, finely crushed, is introduced through an opening in the top of roof A of the upper roasting chamber to hearth A^1 , from hopper N, by feed tube n, provided with an automatic screw charging device, n^1 . Owing to the bottom heat furnished by heating chamber a^1 , the ore is soon dried while being moved toward the circumference by the teeth of arms L, fastened to the revolving centre shaft I, and drops finally down to hearth A^2 , through rim discharges a^{01} . The arms of this hearth, having their teeth placed in the

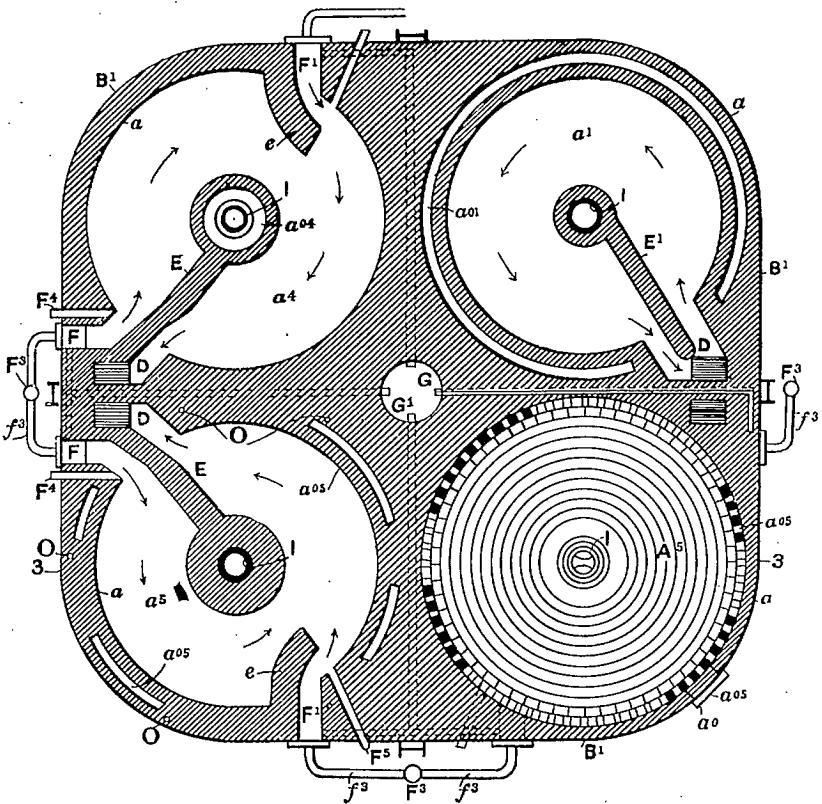


FIG. 17. Sjöstedt roasting furnace. Horizontal section.

reversed direction, now cause the ore to be moved toward the centre and discharge it through the centre openings a^2 onto hearth A^3 . By this time the sulphur has been largely removed, and the heat generated by the oxidation of the sulphur has diminished, but on reaching hearth A^4 , heated within, a temperature sufficient for a further oxidation is maintained; so also on the last hearth, A^5 , which is heated from within direct by the combustion chamber a^5 . The rabbles finally cause the now roasted ore to be discharged through openings a^6 and spout a^6 , leading to the ore conveyor. O are pipes admitting and controlling the air supply for roasting of the ore, and M a cast iron pipe leading from the top of arch A of each roaster, and through which the sulphurous gases pass out from the roaster to the main gas flue.

*Jones Cylindrical Roasting Furnace.*¹ This burner is designed to produce sulphur dioxide gas by roasting pyrites in a rotary kiln in an atmosphere containing air and sulphur dioxide gas made by burning commercial sulphur in an auxiliary sulphur burner. The earlier type of Jones burner (United States Patent No. 872,822) consisted of a rotary cylindrical kiln lined with fire brick; three rows of brick at equal distances apart, projecting beyond the others and forming three ridges running the length of the cylinder, acted as agitators as the kiln revolved. The more recent type of kiln (Canadian Patent No. 141,243) is divided into a number of compartments by a fire-brick lining as described below. In this type of kiln a central cylindrical passageway or tube is provided for the purpose of conducting vaporized sulphur or any other heat producing material to the combustion zone of the kiln. In practice the sulphur contained in the ore is ignited by the combustion of this vapor; afterward the heat developed may be sufficient to maintain the combustion of the ore without supplying additional fuel. Another feature of the process is the preheating of the ore to such a degree that the moment it enters the burning zone the sulphur of the ore will ignite and burn. A dust separator of special design is also employed with the Jones equipment.

The kiln is a rotary kiln mounted upon anti-friction rollers at a slight inclination (Figure 18 and Plate XXIV). A sulphur burning furnace or vaporizer is placed adjacent to the exit end of the kiln; this furnace is usually a concrete oven in which sulphur can be vaporized by burning, to be used for heating up the kiln and starting the combustion of the sulphur in the ore. Sulphur is fed into this oven through a suitable feed hopper. A pipe to conduct the vaporized sulphur to the kiln communicates between the oven and the discharge hood of the kiln, into which latter the cinder from the burnt ore falls in making exit from the furnace.

¹Description based on Canadian Patent Number 141243. Manufactured by the Pyrite Engineering Co., Carthage, New York.

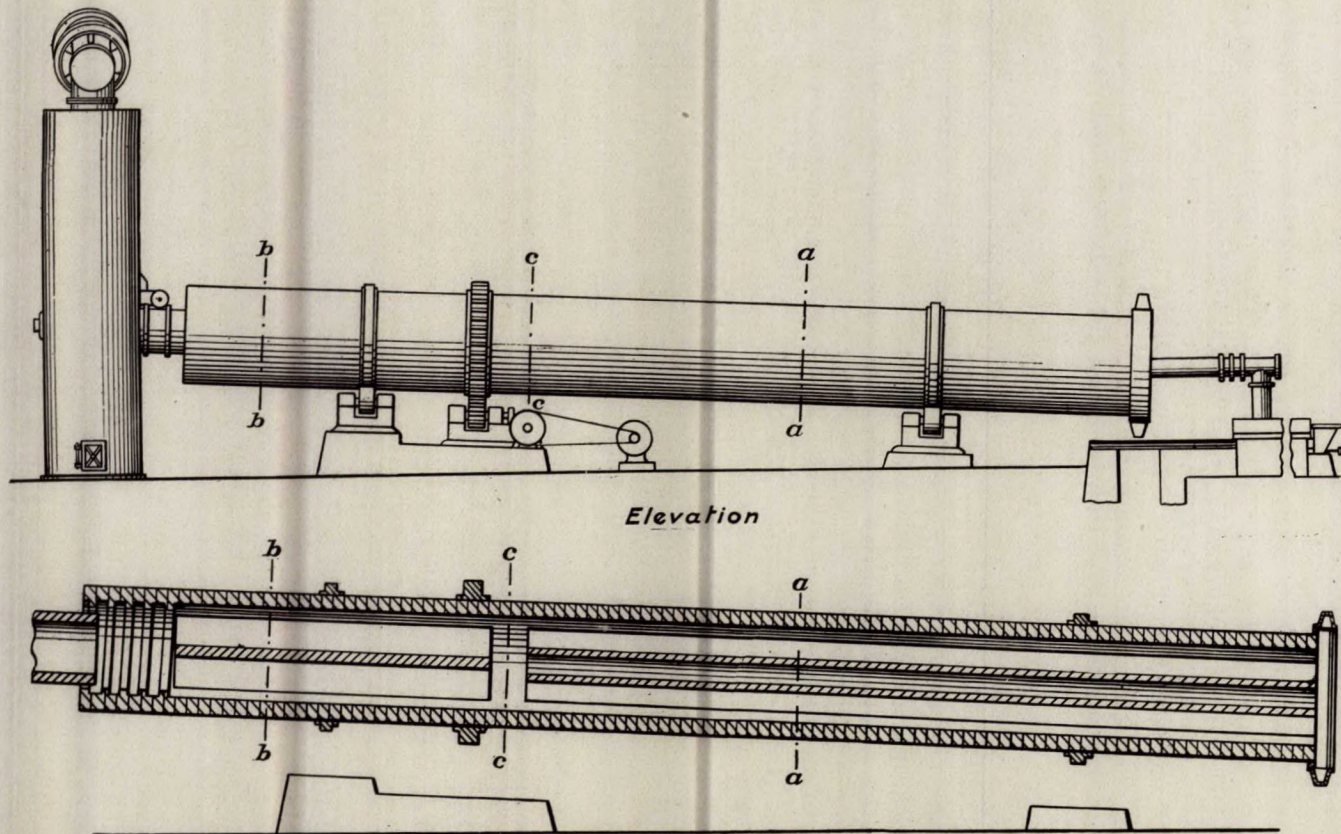
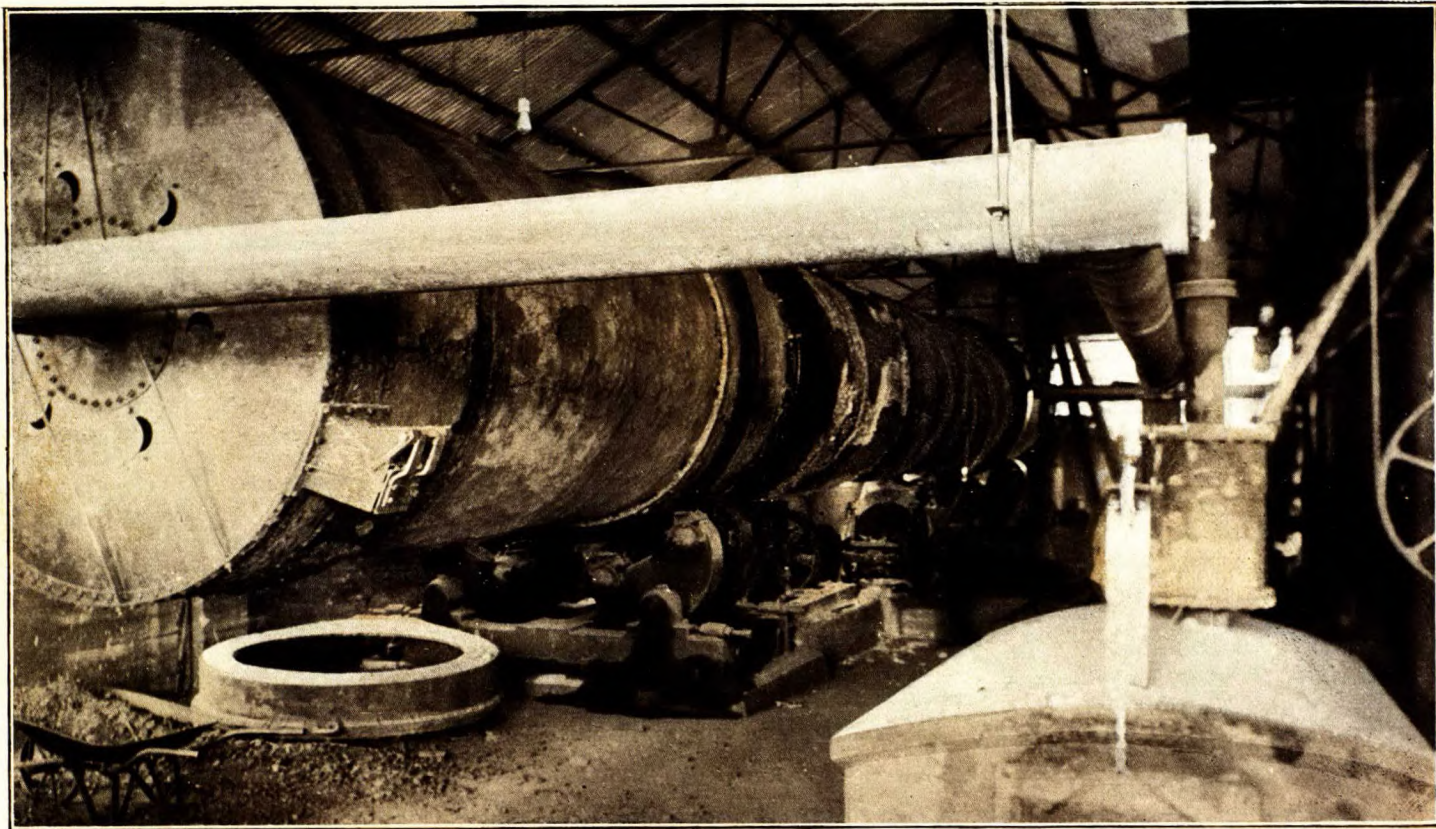


FIG. 18. Jones rotary kiln for roasting pyrites. Elevation and longitudinal section.



Jones rotary kiln, Hinckley Fibre Company's works, Hinckley, New York.

The kiln is lined with firebrick and is provided internally with a plurality of partitions, radially arranged between a central tubular duct and the inner circumference, (See Figures 18 and 19). These partitions and the tubular duct run from the exit end of the kiln to a small chamber near the anterior end where they terminate; this chamber forms part of the burning zone of the kiln. A second series of partitions is provided, without the central duct, intermediate between this chamber and the inlet end. Adjacent to the inlet

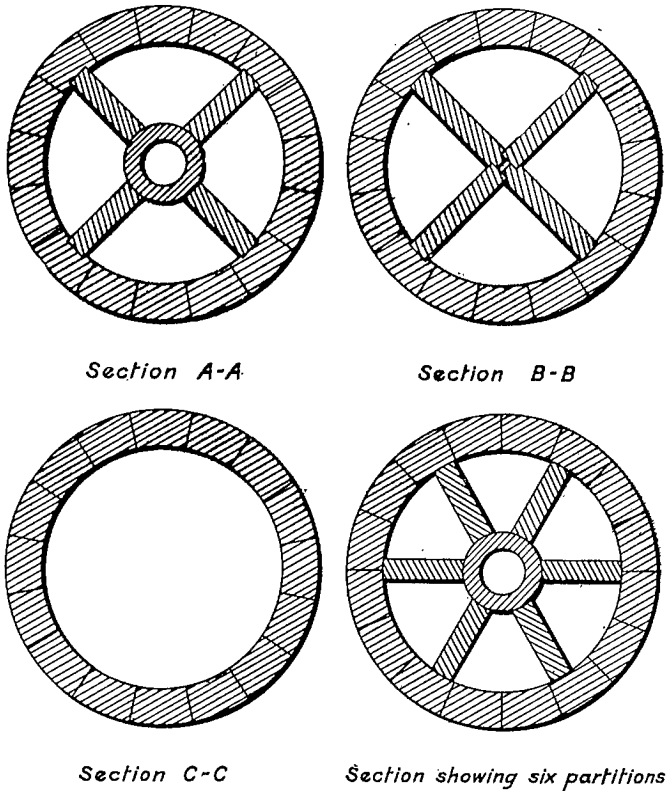


FIG. 19. Cross sections of Jones rotary kiln showing lining and partitions.

end of the kiln, and upon the inner surface of the latter, a worm screw is formed on the shell for the purpose of feeding the ore forward into the kiln as the latter enters the inlet end through the feed pipe. The number of partitions varies; four or six may be used. A discharge hood is provided at the exit end; this hood consists of an annular chamber having a closed end in which peep holes are placed. At points diametrically opposite each other two hoppers are attached to this hood; each hopper is fitted with a bracket arm to which a door is hinged opening outward. This door operates automatically as the cylinder revolves and allows the cinders to be dumped.

Adjacent to the inlet end of the cylinder is a stack into which the sulphur dioxide gas passes from the kiln through a suitable pipe connexion. Near the top of the stack and within it an ore hopper is placed (see Figure 20); the lower end of this hopper connects with an inclined pipe secured to the inner surface of the stack and about the marginal edge of an opening in the wall of the latter. Another inclined pipe, fastened to the outer surface of the stack in registration with this opening leads to the feeding cylinder in which a spiral feed screw is mounted. An inclined chute which passes through the inlet end of the kiln conducts the ore to the kiln.

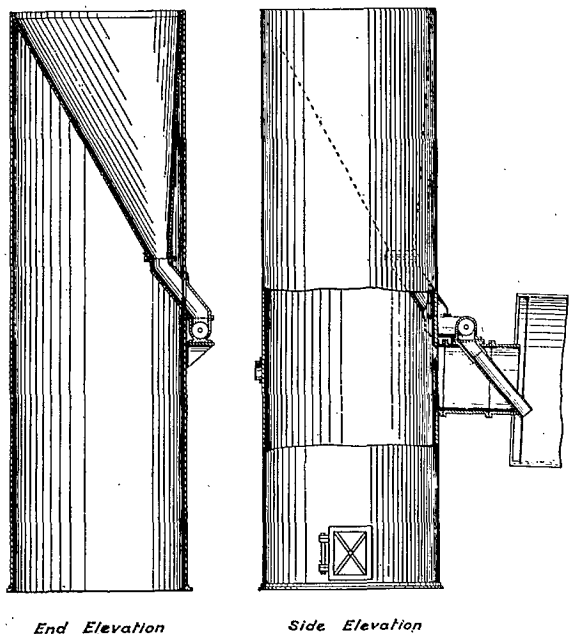


FIG. 20. Stack showing ore hopper and feed.

The hopper has an opening in its inclined wall to which a gas exit pipe is fitted. This pipe passes through the top of the stack to an elbow and thence through a slightly inclined pipe, about which an ore drying cylinder, capable of rotating, is mounted. Projecting from the inner surface of this cylinder are longitudinally disposed angle wings. These wings are provided for the purpose of lifting the ore and allowing it to drop as the dryer cylinder revolves about the hot central cylinder formed by the gas conduit. The ore is introduced into the drying cylinder through a chute, which passes through the gas conduit and delivers to the lower side of the rotating cylinder. The dryer cylinder is rotated in any suitable manner, and the feed can be made automatic.

A dust chamber or trap is placed adjacent to the kiln and is connected with the gas conduit that passes through the dryer, the connexion to the chamber being made through its top. (See Figures 21 and 22). The bottom

of the chamber is formed by two V shaped troughs running the length of the chamber; worm screws operate in the bottoms of these troughs to remove the dust as it accumulates. A series of transverse partitions, extending only partially to the height of the trap (about $\frac{1}{3}$) are provided within the chamber. Suspended vertically from the roof of the dust trap over each of the partitions

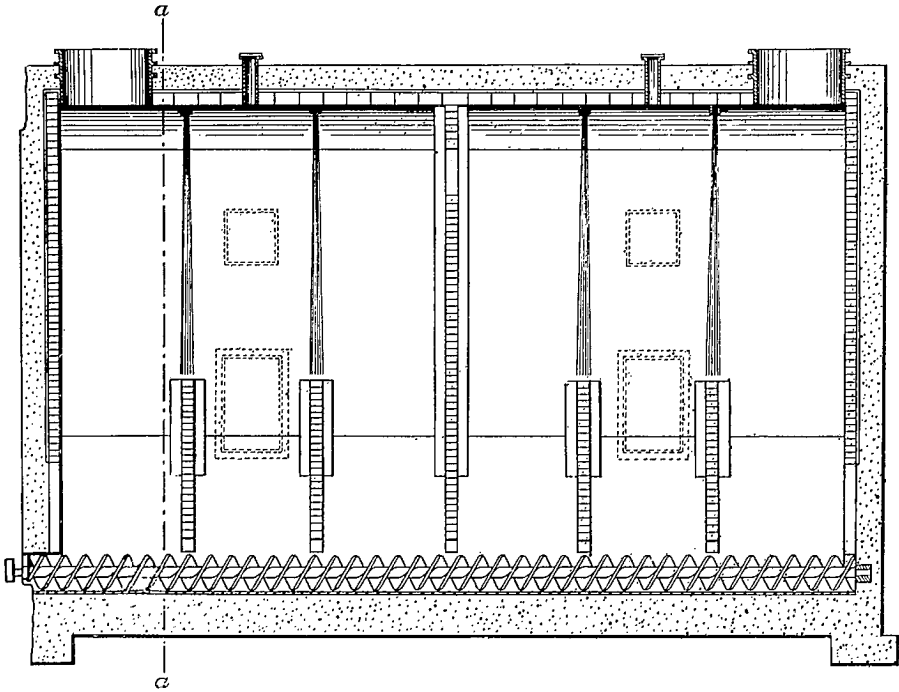


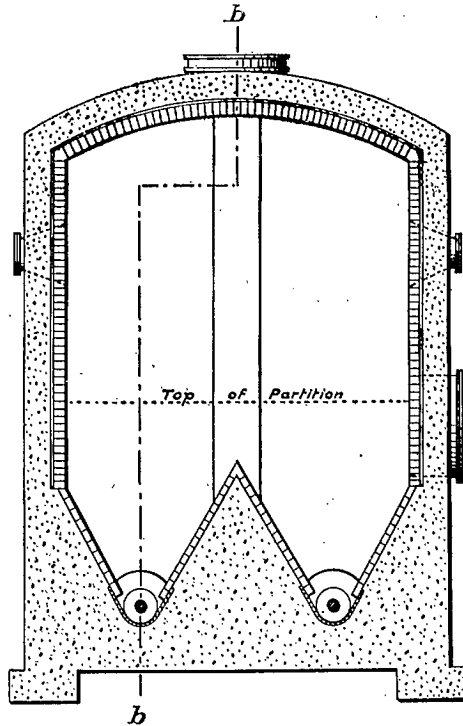
FIG. 21. Jones dust trap. Longitudinal section, on line b—b, figure 22.

are screens formed by bunches of piano wires. A central partition nearly divides the interior of the chamber into two compartments, there being an open space above the top of the partition provided for the purpose of allowing the gas to pass from one side of the partition to the other. Suitable sight openings are provided in the walls of the dust trap, and there are also doors through which access may be had to the chamber.

From the top of the dust chamber a conduit leads the gas which has been freed from dust to the cooling pipes which are placed within a tank designed to hold the cooling water. The cooling pipes course back and forth through the tank; they are provided with a quick flushing valve to clean them out when necessary. From the cooler the gas passes upward through a conduit to an expansion chamber where a further small quantity of dust may be detained. Thence it passes to the point of consumption.

In operating a plant of this type, combustion is started by burning a sufficient quantity of commercial sulphur or other heat producing agent within the sulphur furnace. The vaporized sulphur is conveyed through the

central duct in the kiln to the combustion chamber, where it ignites and heats the partitions within the kiln to incandescence. When the partitions are heated to the proper temperature, the kiln is ready to receive ore from the hopper. Pyrites ore, crushed preferably to about $\frac{3}{4}$ " size, is fed through a chute into the drying cylinder. Under the influence of heat from the gas conduit which forms the core of this cylinder and because of the agitation produced by the wings of the slowly revolving dryer, the moisture in the ore



Cross Section

FIG. 22. Jones dust trap. Cross section on line a—a, figure 21.

is driven off. This moisture may be conducted from the cylinder by any suitable stack. The ore passes forward in the dryer to the discharge opening and falls into the feed hopper in the stack. Drying has been found essential to prevent the formation of sulphuric acid when the sulphur dioxide gas is required for the manufacture of sulphide pulp. After the ore has been discharged into the hopper it again receives the heat of the gases from the kiln as these gases surround the ore hopper in the stack. The highly heated ore is fed into the kiln by a worm feed, and is pushed forward by the worm threads built on the inner walls of the kiln at the inlet end.

As the partitions have been heated to incandescence before the ore is admitted, it will begin to burn immediately, and sulphur dioxide will be

formed. If the ore be of sufficient richness it will burn of itself and the temperature maintained will be sufficient to burn out all the sulphur it contains; under these circumstances the vaporizing of the commercial sulphur in the furnace may be discontinued. The ore travels through the several compartments of the kiln, the cinder being discharged into the hood and hoppers connected thereto.

Tests have shown that the dividing of the interior of the kiln into compartments enables a large body of ore to be treated, and that this subdivision is essential to the successful working of the apparatus, affording a much larger capacity than would otherwise be the case.

The gas formed by the oxidation of the pyrite ores in the kiln is conducted by means of suction draught, into the dust trap, after passing about the hopper in the stack. The gas, containing a certain amount of dust, passes through the piano wire screens which are suspended from the roof of the dust trap. These cause the dust to settle. Tests have shown that the current of dust-laden gases causes the fine wires to vibrate and intercept the dust particles. From the dust chamber the gases are conducted into the cooler pipe where they circulate through pipes submerged in a cooling medium, usually water. From the cooler the gases pass into the expansion chamber, where any further particles of dust are precipitated. The cool and purified sulphur dioxide gas is now ready for use in making sulphurous or sulphuric acid.¹

Applications of Sulphur Dioxide

According to Lunge² the principal uses to which sulphur dioxide is applied are as follow: "The greatest quantity of SO_2 is produced for the manufacture of sulphuric acid. Next to this in importance comes its use for the manufacture of wood-pulp, mostly in the state of calcium bisulphite (or a solution of CaSO_3 in an excess of sulphurous acid). One of the oldest uses of sulphur dioxide, in the shape of burning sulphur, is as a disinfecting and antiseptic agent. For the former purpose it is not so much valued now as formerly, since it has been shown that many of the disease germs resist the action of SO_2 for a long time. The antiseptic function of SO_2 comes into play in the fumigation of wine casks, in the arresting of the fermentation of wort, in the manufacture of glue (where it acts also as a bleaching agent), and in many other cases.

In the textile industries sulphurous acid is largely used as a bleaching agent, especially for wool, silk, straw, etc. It is not quite certain in which way it acts in this case, possibly by forming a compound with the colouring matters contained in the fibres. Formerly it was generally assumed that the SO_2 in bleaching acted as a reducing agent, which indeed must be true

¹ See description of the installation at the Sulphite Mill of the Hinckley Fibre Company, Hinckley, N. Y., this report, p. 171.

² Lunge, Sulphuric Acid and Alkali, 3rd Ed., Vol. I, Part I, pp. 161-162.

in some cases, although probably not in all. The reducing functions of SO_2 are utilized in chemical and metallurgical operations in too many cases to be enumerated here."

At some works sulphur dioxide is prepared in liquid form by cooling and pressure. In this state it may be stored in portable iron cylinders; the cylinders used for the purpose have a capacity of one or two hundredweight. Tank cars of 10 tons capacity are employed where larger quantities of liquid are to be transported. The cylinders used on the tank cars are made of wrought iron with welded seams. They are about 23' in length, 2'-3" in diameter, and are tested to stand a pressure of 30 atmospheres. Each car carries three cylinders.

"The principal uses for liquid sulphur dioxide are for refrigerating-machines (Picet's and others), for wood pulp manufacture (to bring the calcium bisulphite liquors up to strength), for the purification of beet root juice, for disinfecting, for bleaching, for the manufacture of glue and gelatine.

Recently liquid sulphur dioxide has been applied by Behrend and Zimmermann as a means for increasing the efficiency of steam engines by utilizing the heat of the exhaust steam for evaporating SO_2 . The high pressure vapours thus produced are utilized in an auxiliary cylinder for generating motive power and are afterwards again condensed to liquid SO_2 . Hitherto this system does not seem to have fulfilled its expectations.

The formerly rather extensive use for bringing calcium bisulphite liquor (for the manufacture of wood pulp) up to strength has very much decreased, since the factories have improved their plants for the direct preparation of strong sulphite liquor.¹

Utilization of Cinder

The cinder residues after roasting consist of ferric oxide and the impurities of the original ore, together with a small portion of unaltered sulphides. The sulphur content will vary from less than one to more than five per cent. Where the cinder contains copper and the precious metals, these can be recovered by a leaching process. In one plant, where a large supply of cinder is available, the cinder is subjected to a chloridizing roast in a large, gas-fired, mechanically operated, single hearth furnace. The copper content is then recovered by leaching with water, the liquors being passed over iron scrap. The residues after leaching form a nearly pure iron ore, which is sintered in a coal-dust fired rotary cement kiln, and is subsequently utilized in a blast furnace. Where the cinders only contain iron oxide as a valuable constituent, they can occasionally be used in iron furnaces, provided there is a large supply and a convenient market. They are also suitable for the manufacture of ferro-silicon. In the majority of cases it will probably be found that the amount of cinder produced in any ordinary plant is too small to be marketed. In this event it can often be utilized locally for filling, or as ballast or road dressing material.

¹ Lunge, *op. cit.*, p. 386-388.

CHAPTER VI.

THE MANUFACTURE OF SULPHURIC ACID.¹

Sulphuric acid is one of the most important of chemicals, not only on account of the large quantities manufactured, but also on account of the many applications which it finds in the arts and in industrial works.

Pure sulphuric acid is a colourless, odourless liquid of an oily consistency having a specific gravity of 1.8384 at 15° C. It boils at 338° C., and at about 400° C. the vapour dissociates into sulphur trioxide and water. At a higher temperature, about a red heat, there is still further dissociation with production of the sulphur dioxide and free oxygen. It freezes to a colourless crystalline solid at 10.5° C. The acid is extremely hygroscopic; when strong acid is mixed with water there is a considerable amount of heat liberated, and there is a decrease in volume.

The acid may be prepared by dissolving sulphur trioxide in water; by gradual oxidation of sulphur dioxide in the presence of water; by burning a mixture of sulphur and saltpetre under a bell jar, absorbing the products of combustion in water and concentrating the resultant solution. All three methods have been used commercially at different times. At present commercial acid is made almost wholly from sulphur dioxide; sulphur dioxide on a commercial scale is made by the combustion of sulphur in air. Formerly sulphur, in the form of brimstone, was exclusively employed for this purpose, but at the present time, the greater portion of commercial sulphuric acid is made from sulphur dioxide obtained by the oxidation of metallic sulphides, especially those of iron and zinc.

The gas produced by the calcining of metallic sulphides usually holds a considerable quantity of dust in mechanical suspension when issuing from the burner. This flue dust must be removed before the gas is subject to further treatment.

Burner gas, if made from pyrites, contains between 7% and 8% of SO₂, if made from sulphur it will usually contain between 10% and 11% SO₂. In addition, it contains the nitrogen and other inert constituents of the air which entered the furnace, and there is also a surplus of unconsumed oxygen. Where burner gas is used for making sulphuric acid, this oxygen usually forms about

¹ The reader who wishes to refer to a technical description of the processes of manufacturing Sulphuric Acid, and of the equipment required, is advised to consult some of the numerous articles in the technical journals and in special texts, such as:—

1. "The Manufacture of Chamber Sulphuric Acid," by F. J. Falding, *Mineral Industry*, Vol. VII, 1898, pp. 651-702.
2. "Sulphuric Acid and Alkali," by George Lunge, 3rd edition, 1903.
3. "The Contact Process for the Manufacture of Sulphuric Acid," Twelfth Census of the United States, 1900, Vol. X, Part IV, pp. 533-537, included in this report as Appendix IV

12% of the mixture, and in the process a portion of it enters into combination with the sulphur dioxide to form the trioxide. On the other hand, when the gas is to be used in the manufacture of sulphite pulp, the oxygen ratio is kept as low as possible to prevent the formation of the trioxide. Burner gas also contains dust particles and other impurities derived from the ore. The coarser dust is removed by passing the gases through dust flues or chambers specially prepared for that purpose; the finer impurities are removed by special forms of apparatus, such as sprays, coke towers, filters and similar appliances.

After purification, burner gas can be used directly for the sulphur dioxide which it contains, principally in the manufacture of sulphite pulp from wood.¹ When the gas is to be used for the manufacture of sulphuric acid, it must first be oxidized to the trioxide. In the absence of what are known as "oxygen carriers," the oxidation of the dioxide to the trioxide and the subsequent formation of the acid would take place only to a slight extent. In the manufacture of the acid, it is necessary to accelerate the oxidation and for this purpose an "oxygen carrier" must be employed. Two general methods are now in use for this purpose. In one, oxidation is promoted by the use of certain oxides of nitrogen; in the other, the catalytic action is promoted by the aid of certain other oxygen carriers, which apparently react by mere contact with the gases. By either method, practically the whole of the sulphur dioxide is ultimately converted into sulphuric acid; where the oxides of nitrogen are employed as oxygen carriers, they are, in practice, always recovered and used over again, with only slight mechanical losses.

These two methods of oxidizing the sulphur dioxide give rise to two general processes for the manufacture of sulphuric acid, known respectively as the "Chamber Process" and the "Contact Process."

Chamber Process for the Manufacture of Sulphuric Acid

In the method of preparing sulphuric acid by the chamber process, nitrous oxides, which act as "oxygen carriers" must be supplied to the gases from the burners. Formerly these oxides were supplied by exposing nitric acid to the action of the hot gases; except in special cases, the nitrous oxides are now mixed with burner gases by passing the latter through a chamber and over a vessel containing nitrate of soda and strong sulphuric acid. The nitrate of soda is decomposed by the sulphuric acid in the presence of the hot gases, and oxides of nitrogen are liberated. These oxides are carried forward by the current of hot gases into the chambers where the further reactions, which result in the formation of the sulphuric acid take place. This reaction between sulphur dioxide and the nitrogen acids only takes place in the presence of water; in practice much more water is needed than that

¹ See Chapter VII, of this report.

theoretically required for the production of H_2SO_4 ; the sulphuric acid formed in the chambers is therefore always dilute and for commercial purposes chamber acid must be concentrated.

While the presence of nitrous oxides is necessary that the chemical reactions involved in the formation of the sulphuric acid may go on rapidly, yet they themselves do not enter into the composition of the final products. In practice, however, a considerable loss takes place, partly mechanically through their being carried forward by the current of waste nitrogen and oxygen from which the sulphur dioxide has been extracted, and partly by reduction to the inactive forms of nitrous oxide or to elementary nitrogen. This mechanical loss is now prevented by bringing the waste gases into contact with strong sulphuric acid in a form of apparatus known as the *Gay-Lussac tower*. The operation of this piece of apparatus depends on the fact, discovered by Gay-Lussac about 1827, that moderately strong sulphuric acid forms with nitrous fumes a compound known as nitroso-sulphuric acid, and this substance remains in solution in the sulphuric acid as "nitrous vitriol." The nitrous oxides from the Gay-Lussac tower are again introduced into the current of gases by exposing the nitrous vitriol, previously diluted with weaker chamber acid, to the action of hot gases fresh from the burners, the apparatus employed being known as the *Glover tower*. As will be explained in a subsequent paragraph, the Glover tower also performs certain other important functions.

The principal reactions in connection with the production of sulphuric acid by the oxidation of sulphur dioxide in the presence of oxides of nitrogen are carried on in large rectangular chambers, known as "acid chambers" or "vitriol chambers."

A plant for the manufacture of sulphuric acid by the Chamber Process, besides the burners, will thus comprise three principal structures, the *Glover tower*, the *Acid Chambers* and the *Gay-Lussac towers*. In addition, there will be the necessary fans, pumps, pipe lines and tanks for handling, storing and distributing the different products; certain pieces of auxiliary apparatus, designed to effect material savings or to accelerate the reactions, may also be introduced into the system. The course of the gases, after leaving the burners will be through the Glover towers—thence to the Acid Chambers. Waste gases from the acid chambers, from which all the sulphur dioxide has been extracted if the operations are conducted under proper working conditions, will then pass through the Gay-Lussac towers and thence into the atmosphere.

Acid Chamber.—The acid chambers are large, rectangular chambers from 15 to 25 feet in height, between 20 and 30 feet in width, and usually about 5 or 6 times as long as they are wide. The bottom of the chamber is formed by an immense pan from 12 to 18 inches in depth, made of heavy sheet lead. The walls and top are also made of sheet lead, somewhat lighter in weight. All seams and joints are made by "burning" or fusing the lead at the lines of junction of the sheets. The walls and roof of the chamber are supported at all points by suitable wooden or steel frame work. Usually

at least three chambers are employed in even the smallest works. In the larger works the total chamber capacity will be several hundred thousand cubic feet.

When the chambers are in operation, burner gas, to which oxides of nitrogen have already been supplied, is introduced at one end of the chamber system. The movement of the gases through the chamber is produced partly by their own chemical action, and partly by the draught produced either by a chimney or by mechanical means, such as a fan. At the same time water in the form of steam, or as a fine spray, is introduced at a number of suitable points, to furnish the moisture necessary to promote the reaction represented by the formula $\text{SO}_2 + \text{O} + \text{H}_2\text{O} = \text{H}_2\text{SO}_4$.

Glover tower.—The Glover tower forms an essential part of every well designed acid plant using the chamber process. A typical tower consists of an outer shell of lead, constructed as in the case of the chambers, and provided with an acid-proof stone or brick lining, no mortar being used in its construction, however. The best lining is "Volvic lava." Where this cannot be obtained economically special "chemical" brick or stone are employed, such as will resist the acids and the heat up to the required extent. The packing of the tower consists of silica, usually in the form of quartz. The quartz should be as pure as possible and massive. Quartz from schists is apt to contain hydro-micas, or other minerals which may be acted on by the acids, and, owing to the development of the schistose structures, it tends to disintegrate under the action of the heat. In some cases, the Glover towers are packed with acid proof bricks.

As indicated in a previous paragraph, acid containing nitrous vitriol is distributed over the top of the packing in the Glover tower. In its course to the base, it is broken into innumerable fine streams or spray, thus being exposed to the action of the ascending hot gases. The hot gases cause the nitrous oxides to be liberated from the acid; a portion of the sulphur dioxide is oxidized to the trioxide and this in turn forms sulphuric acid. In addition, the high temperature of the gases evaporates a considerable portion of the water in the acid as it trickles down over the packing. The moisture driven off by this heat passes into the chambers there to aid in the formation of more acid, and at the same time the acid in the tower is concentrated to the required strength.

The most important and characteristic function of the Glover tower is thus exactly the opposite to that of the Gay-Lussac tower, namely to deprive the nitrous vitriol, running off at the bottom of the Gay-Lussac tower of its nitrous compounds. At the same time, it restores it to a proper state of concentration for applying it again at the top of that tower.

The surplus heat of the burner gases is also thus utilized in the Glover tower to bring the whole of the Chamber acid up to a specific gravity of 1.720 (about 60° B. or 78.92% H_2SO_4), or even as high as 1.760 (about 62° B. or 82.00% H_2SO_4), without any additional expense, other than that necessary to pump the acid to the top of the tower.

HOWARD ZIMM
VIA RAIL

The Glover tower is used in some plants where the potting system of introducing nitrous oxides is not employed for the introduction of the requisite amount of nitrous oxides into the chambers. This is done by running nitric acid down along with the nitrous vitriol. Before it arrives at the bottom of the tower it, as well as the nitrous vitriol itself, is fully denitrated.

Gay-Lussac Tower.—The gaseous mixture escaping from the last chamber of a series contains nitrogen and other inert constituents derived from the air admitted to the pyrites burners. It also contains a certain amount of free oxygen, nitrous oxides, and water vapor. The nitrous oxides are a valuable constituent and their recovery is desirable. This is accomplished by absorbing them from the waste gases by means of the Gay-Lussac tower. The successful operation of this tower is dependent on the fact that strong concentrated sulphuric acid will absorb oxides of nitrogen with the formation of nitrous vitriol.

The Gay-Lussac tower consists essentially of a chamber, whose walls are made of sheet lead, packed loosely with an acid-resisting material. The packing usually consists of dense hard-burned oven-coke. In some of the more modern works, perforated plates or cylinders of acid proof stoneware are employed, either as a substitute for some of the coke or for all of it. This packing is so arranged that a stream of sulphuric acid entering from above is broken into small drops or spray as it descends over the packing. At the same time the current of waste gases rising in the tower is divided into numerous small jets, in its passage through the interstices of the packing, so that the surface of contact between acid and gas is made as large as possible. In this way the nitrous oxides in the waste gases are brought into contact with the strong acid and absorbed by it; the valueless portion of the waste gases is discharged from the top of the tower either into the air, or into a conduit leading to a stack. As already indicated, the nitrous vitriol thus obtained is diluted with chamber acid, and then conducted to the Glover tower where the nitrous oxides are again liberated and passed into the chamber system. At the same time the dilute acid undergoes concentration; a portion of this concentrated acid is sent to the Gay-Lussac tower again, and the balance is discharged into the storage tanks for shipment.

Contact Processes for the Manufacture of Sulphuric Acid¹

The process by which chemical actions are brought about by a substance which is itself recovered unchanged after the reaction is termed *catalysis*. Two groups of such reactions may be recognized; in one, the catalytic agent first combines with one of the components to the reaction to form an unstable chemical compound which immediately reacts with the other components to form the final compound, the catalytic agent being simultaneously liberated and rendered free to again react with the first component; in the other group,

¹ For a history of these methods and a discussion of the processes, consult Lunge, G., "Sulphuric Acid and Alkali," Vol. I, Part II, 3rd Ed., 1903, p. 973 *et seq.*

the catalytic agent appears to react by mere contact without undergoing any change within itself.¹ The oxidation of sulphur dioxide in the presence of nitrous oxides is an example of the first group of catalytic reactions; the combination of sulphur dioxide and oxygen in the presence of finely divided platinum is an example of the second group of catalytic reactions.

Contact processes for the manufacture of sulphur tri-oxide and sulphuric acid, on a commercial scale, depend upon the catalytic action of finely divided platinum or ferric oxide on sulphur dioxide and oxygen, when brought about under suitable conditions. The development of these processes to commercial successes have involved long, tedious, and costly investigations and for the most part the methods employed have been closely guarded secrets.

With regard to the commercial use of these processes, Dr. George Lunge writes as follows:²

“The first successful introduction of the catalytic system for making sulphuric acid took place in the United States in the year 1898, when the Badische Anilin und Soda Fabrik erected, in the State of New Jersey, an experimental plant to follow out the discoveries of Knietsch, and by it demonstrated the extraordinary importance and value of the ideas of this investigator, unhappily so early taken away from science and industry. As a result of this plant as the initial point of the acquisition of the Knietsch patents by the General Chemical Company, the contact method has reached its present extensive development in the United States.

A year later, that is in 1908, the Mineral Point Zinc Co. in their works in the state of Wisconsin, erected an apparatus according to the patents of Schroeder and Grillo, by which the sulphur dioxide gases from the working of arsenic free zinc ores, which until then had been lost, were to be utilized. Since at that time the details of a complete working of the contact method were not at command, it is not to be wondered at that this plant was several times rebuilt and finally discontinued.

The General Chemical Company began the erection of its first plant after the Herreshoff system in the year 1900 and in 1902 carried out the preparation of sulphuric acid according to this method in their chief works in New York. This plant has since then been running uninterruptedly with the same contact material; the catalytic substance has never been touched anew. This was the first factory plant in the United States in which pyrites gases were to be treated, which were arsenic containing and otherwise contaminated.

In the year 1904, one of the Herreshoff patents came into conflict with one of the patents belonging to the Badische Anilin und Soda Fabrik. The final result of the steps resulting from this was that the Badische and the General Chemical Company came to an agreement, in that the General acquired

¹ That this is so has not been definitely established. In fact, some chemists believe that the methods of reaction of both groups of catalytic agents are identical. The conditions under which these reactions take place, however, are so well understood, that the reactions are utilized for industrial processes.

² *Zeitschrift für Angewandte Chemie*, Vol. XXIII, 1910, p. 721 *et seq.*

all the American patents belonging to the Badische; later also those of the Farbwerke vorm Meister Lucius und Bruening, of the Tentelewsche Chemischen Fabrik, and of Rabe.

It is reported that the General Chemical Company has actually since 1903 discontinued all their lead chamber plants in the United States, in that they replaced the old chamber and concentrating plants almost entirely by contact plants. The other factories which operate in the United States by the contact process are, with few exceptions, licensees of the General.

The application of the inventions of Herreshoff to those of Knietsch led to substantial changes which have made the process more suitable to American conditions, but some of which will perhaps have great value in other places under certain circumstances. Among these changes are to be mentioned: the omission of large compressors, the avoidance of passing the gasses through liquids and the altered devices for the heat regulation, by which the heat of reaction is removed in special heat transferrers and not in the contact chamber itself. These systems are so efficient that as it is reported, transformers which have now already been in continual or almost continual operation for nine years, have never been opened and work just as well as ever before. In the field of absorption also, improvements have been introduced by the combined inventive activity of Knietsch and Herreshoff, by which the strength of the acid is kept constant by means of a continuous circulation of large amounts of acid, and by which also the over pressure previously necessary at this place has been brought down almost to zero.

The New Jersey Zinc Company is the owner for the United States of the Schroeder-Grillo method. Besides their own use of it for zinc ores, they have given some licenses to other firms in the United States. Objection was raised by the owners of the Knietsch patents, that the just mentioned, as well as all other usable contact methods, use certain fundamental inventions of Knietsch's method. Suit was commenced, but an agreement was reached which gives the Herreshoff-Knietsch patents the precedence in the future of the chemical field.

Some licenses in the United States use the so-called Mannheim system. According to my authorities, this system stands decidedly behind those mentioned above; furthermore the owners of the Knietsch patents maintain that it infringes their fundamental invention, and they have instituted several suits in the United States for the enforcement of this claim."

In his text on Sulphuric Acid and Alkali, Lunge¹ cites six different processes which are better known partly from the patent specifications and partly from communications received by him from the owners. Three of the methods are in successful operation in American plants and the following

¹ Op. cit., Vol. I, Part II, p. 1012.

mixture of gases over platinized asbestos, or other contact-substance, at a high temperature, has long been known and practised.

I have made certain improvements in this process which are the result of prolonged research and experiment, and their combined effect involves an entire revolution in the manufacture of sulphuric acid and sulphuric anhydride, and is such as to render the conversion of sulphur dioxide into sulphuric anhydride practically complete, the production of sulphuric anhydride being effected so economically that, by the aid of this invention it is possible not merely to produce sulphuric anhydride itself, and all the grades of fuming sulphuric acid advantageously, but even ordinary concentrated sulphuric acid or chamber acid can, according to this invention, be as cheaply produced as by the well known chamber process. Acid weaker than, and up to 50° Be, (that is, containing about 63 per cent. H_2SO_4) can, according to this invention, be prepared at least as cheaply as by means of the chamber process, and all stronger acids are produced in accordance with this invention more cheaply, the advantages being greater, the stronger the acid.

The effects, according to this invention, have not been achieved by a single improvement, but result from a series of investigations into every part of the process, and in order to treat sulphur dioxide, from whatever source obtained, successfully and with the best effect by the contact-process, for the production of sulphuric anhydride, my improvements should be adopted in every part of the process.

The manufacture may be divided into three parts, viz:—

First:—The preliminary treatment of the mixed gases to be operated on.

Second:—The regulation of the conditions, particularly as to temperature, during the combination.

Third:—The disposition, or arrangement, of the contact-substance to avoid undue rise of pressure.

I.—The usual sulphide ores contain various impurities, and many of these, on roasting the ores, are liable to pass, either free, or in combination, and either as dust, mist or gas, into the mixed gases containing the sulphur dioxide. Even if practically pure sulphur be used as the source of SO_2 , some sulphuric anhydride is formed and, since the air used in roasting contains moisture, the result is that the SO_2 produced contains sulphuric acid which passes forward as a suspended mist.

The effect of such impurities on the mixed gases is of various kinds, sulphuric acid, for instance, from any source is liable; in some cases, to injure the lead and iron parts of the apparatus and to cause difficulties in the moving parts of machinery. Further and especially, I have found that the sulphuric acid mist is objectionable as carrying forward other impurities into the contact apparatus. Any admixture of sulphur vapours which have escaped combustion act similarly, and must therefore be excluded. Other impurities may affect the contact substance mechanically, or chemically, either as such, or after chemically combining with the sulphur trioxide, or even, in some cases, they may combine chemically with the contact substance, and in every case its efficiency is impaired.

The following bodies come principally into consideration as possible impurities in the sulphurous gases: viz.—iron, manganese, copper, nickel, arsenic, antimony, phosphorus, mercury, lead, zinc, bismuth, thallium and selenium, or compounds thereof.

I have systematically examined the effect of these bodies, in the contact-process, and have found that arsenic, phosphorus and mercury and their compounds are especially injurious and small quantities of any one of these impurities may render comparatively large quantities of the contact substance almost entirely inert and impair the efficiency of the process. I have ascertained that all the said impurities, such as sulphuric acid, sulphur, dust of any kind, and arsenic, phosphorus and mercury, and their compounds, must be removed from the gases in order to allow of the continual use of the contact mass, and a continual, and nearly quantitative, conversion thereby of sulphurous acid into sulphuric anhydride.

The perfect purification of the roaster gases is very difficult, and is one of the principal reasons that the direct production of sulphuric anhydride from the said gases has not hitherto replaced the chamber process.

I have devised a new process which allows of the certain and perfect removal of the said impurities from the roaster gases.

This process discards the idea of immediately passing into the contact mass the relatively dry and hot roaster gases, from the hearths or burners, where the sulphide ore is roasted or burnt, after having freed them from dust as far as could be done by deposit in a flue, and provides a new and particular purification, which, preferably, consists in a special treatment whilst hot with a jet of steam, or air, or other gas, for the purpose of thoroughly mixing the gases (if steam be not used to effect the mixing, a sufficient amount of steam must be introduced to dilute the condensed sulphuric acid) a subsequent gradual cooling, and then repeated washing with water, or sulphuric acid, while using special tests, as hereinafter set forth, and, finally, drying the gases by sulphuric acid, all as hereinafter more fully described. The gases, before entering the contact apparatus, must satisfy two tests, viz:—An optical test to show freedom from dust and mist, and a chemical analytical test to show freedom from arsenic, phosphorus, and mercury, or their compounds.

To achieve this purity a jet of steam is blown into the dust flue which the hot roaster gases enter from the pyrites burners. Amongst other effects the steam mixes the gases thoroughly, and brings about a more perfect combination of any sulphur, or other combustible matter. This mixing and promoted combustion can also be effected by means of a jet of air, or other combustible gas (for example, by means of a portion of the gases to be treated), but then it is recommended that the steam be blown in later. The introduction of steam has several further most important effects.

I have found that it is advantageous, for the purpose of effecting the easy and complete washing of the roaster gases, especially gases from pyrites burners, containing much arsenic, to gradually cool the gases in suitable cooling apparatus. All such gases contain concentrated sulphuric acid

vapours which are condensed when cooling apparatus (usually consisting of iron, or lead) is liable to be strongly attacked and rapidly deteriorated, or destroyed. If, however, sufficient steam be blown into the gases to bring down the concentration of the condensed sulphuric acid to a strength of 10 to 40 degrees Beaume, this difficulty is overcome. Of course where the cooling apparatus comes into contact with condensed dilute sulphuric acid it must be made of lead and not of iron.

A further important effect of blowing in steam is that the coolers do not become incrustated with solid impurities in combination with the sulphuric acid, which form when the gases are cooled and steam is not used, which impurities stop up the pipes and are difficult to remove.

By blowing steam into the hot gases this incrustation is prevented because the said impurities form a mud which is easily removed. The addition of steam also renders it possible to more easily wash the gases subsequently, and enables the desired purity to be attained.

The action of the steam serves also to prevent the formation of volatile hydrogen compounds of the impurities, especially of arsenic, and phosphorus, or their compounds. These would otherwise be formed by the action of the concentrated sulphuric acid on the metal of the coolers and the impurities, and could be removed only with great difficulty, and therefore would pass into the contact mass and eventually render it inactive. The gases pass through a flue, which may be of iron, or brickwork, in which they cool somewhat, and thence into a system of lead pipes arranged to act as a cooler. Here they are cooled down to about 100° centigrade, or lower. They are then passed into washing towers, or other washing apparatus, and washed with water, or dilute, or concentrated sulphuric acid. To the wash water there may be added sodium bisulphite, or similar chemicals, to increase its cleansing action. This washing is best effected in a system of washing bottles, or other washing apparatus, set up in series and pumping machinery is used to move the gases relatively to the washing liquid. If water be the washing liquid employed it soon becomes converted into dilute sulphuric acid; the use of concentrated sulphuric acid is not recommended in ordinary cases because it requires considerable expenditure of power to move it in the washing apparatus and because the said apparatus is liable to become incrustated. The washing apparatus can be constructed on the principle of the ordinary washing bottles, so that the gases have to overcome the pressure of the liquids in them and consequently the liquid which is in constant movement becomes intimately mixed with the gases. Or the gases may be scrubbed by the energetic movement of the washing liquids through the gases. No material should be used in the washing apparatus which, in the presence of the acid liquid, might give rise to the production of noxious gases, for instance, arseniuretted hydrogen. The sulphuric acid, and any sublimates and flue dust, are all precipitated in the cooler, or in the washing apparatus and the liquid running from these is collected in lead boxes and allowed to settle. The sulphuric acid obtained in this way can be poured off from the sediment and be used as diluted sulphuric acid, or it can be converted into concentrated

sulphuric acid by the sulphuric anhydride obtained by the contact-process. If not already washed with concentrated sulphuric acid, the gases are finally thoroughly dried by means of such concentrated acid, or other drying agent. The extent to which the washing must be carried will depend on the nature and amount of the impurities to be eliminated and can be determined by tests as aforesaid.

The tests are effected as follow:

In the first place, the apparatus is so arranged that a layer of the gas, some yards in length, is illuminated by means of a lamp at the one end, whilst, from the other end, the operator can look through the entire layer of gas towards the light. It is necessary that no dusty, or misty, admixture shall be observable. If this optical test be permanently successful, it is only necessary to examine the gases for such impurities as would not be shewn by the optical test. Amongst these impurities there are, in particular, arseniuretted hydrogen and possibly also phosphoretted hydrogen and mercury vapours. In order to detect these, a portion of the stream of the purified gas is passed, for a long period, say 24 hours, through a wash-bottle containing distilled water, and the water so treated is then examined according to any chemical analytical method. In this way any considerable traces of the dangerous impurities can be discovered.

The above description of the process applies most closely to the purification of the gases derived from the furnaces in which pyrites are burnt, or roasted, but gases containing sulphur dioxide from other sources can be purified in a similar way.

II.—It is well known that, when sulphur dioxide is combined with oxygen to form sulphuric anhydride, a considerable amount of heat is evolved. This is stated in literature to be in accordance with the equation $\text{SO}_2 + \text{O} = \text{SO}_3 + 32.2 \text{ Cal.}$ (See Hess Poggendorff's *Annalen*, Vol. 56, p. 471, 1842; Thomsen, *Ann. ch. ph.* (4) Vol. 30, p. 442, 1873; Ostwald, *Allgemeine Chemie*, Vol. II, pp. 123 and 124). The reaction between SO_2 and O only takes place at an elevated temperature, so that it is necessary to submit the gases, either separately, or in admixture, to a preliminary heating. During the reaction the heat of chemical union becomes added to that applied, and thus the temperature may rise to an enormous degree, even to bright red heat, according to the richness of the gas mixture in sulphur dioxide, or the strength of the current of the gases.

I have found that this accumulation of heat and rise of temperature is very injurious when practically manufacturing sulphuric anhydride. The injurious effects are of various kinds. For instance, the iron parts of the apparatus are quickly destroyed by oxidation, the action of the contact-substance employed for promoting, or inducing, the reaction is weakened, the efficiency of the apparatus is diminished, and the course of the reaction, which should be approximately quantitative, becomes essentially less perfect.

The overheating is especially injurious if the arrangement of the apparatus be such that the mixture of gases containing the SO_2 leaves the contact-mass at the point where it has the highest temperature.

I have discovered that this deterioration in the course of the reaction is due to the fact that the reconversion of SO_3 into $\text{SO}_2 + \text{O}$ takes place at temperatures which are but little higher than those at which the formation of SO_3 proceeds most favourably, whilst, at the same time, the union of SO_2 and O takes place very much more rapidly in the first portions of the contact mass than in those following, so that the whole apparatus, from the beginning, attains too high a temperature.

The reversal of the reaction increases in amount the more the contact apparatus becomes overheated by the aforementioned excess of heat, that is, accordingly as more gases, or more concentrated gas mixtures, pass through the contact apparatus. Consequently it is impossible to effect any satisfactory union of sulphur dioxide and oxygen, or some of the sulphuric anhydride formed is decomposed in the reverse direction. The gases leaving the apparatus therefore contain unchanged sulphur dioxide which can only be used in other ways, if at all, such as for the manufacture of sulphuric acid according to the chamber process, or the manufacture of bisulphite or the like.

I have devised a process, and apparatus in which the said process can be carried out, by which the aforesaid disadvantages are avoided. In this process platinised asbestos is the contact substance recommended for use. It can, for instance, be prepared as described in the specification of Winckler's German Patent No. 4566. See also Lunge's Sulphuric Acid and Alkali, 2nd Ed., Vol. I, p. 863, and Dammer, *Chemische Technologie*, Vol. I, p. 189. The process, according to this invention, consists in cooling the contact mass by suitably regulated external cooling, whereby the injurious excess of heat is withdrawn. In this way a condition of temperature in the contact apparatus is attained which is, within wide limits, independent of the quantity and concentration of the gas treated, and which includes the most favourable temperature for the formation of SO_3 . By the process according to this invention it is possible to obtain a practically quantitative yield of sulphuric anhydride, to a degree comparable with the action in the sulphuric acid chambers; further, the contact mass and the apparatus generally, are more durable, owing to the lower temperature to which they are subjected, and their efficiency is largely increased.

The manner of practising this part of the process according to this invention can be varied in many respects, in particular, regard must be had to the concentration of the gases to be treated. The cooling of the contact chamber so as to produce the most favourable range of temperature therein is generally effected by means of a current of gas. Both the rate of flow and the temperature of this current are kept under control. I use, for instance, air in this way, or the actual gases which are to be treated. But the cooling can be effected in other ways, for instance, in liquid baths, especially molten metal baths, whose temperatures are under control.

When the gases to be treated are themselves used for cooling the contact-apparatus, a part, or the whole, of the current of gases so to be treated is caused to pass through the space exterior to the chamber containing the

contact-mass, so as to withdraw from the latter the excess of heat. The gases coming from the cooling chamber are then brought to the temperature best suited for the most favourable course of the reaction. For this purpose, in some cases, a further heating, or a cooling operation is necessary; this depends largely upon the concentration of the gases."

*The Schroeder-Grillo Process*¹

In the development of the contact processes it has been found that when the gases are not perfectly purified, the contact action of the platinum gradually diminishes. The ordinary platinum contact mass cannot be regenerated without dissolving the platinum and transferring it to fresh asbestos. The Schroeder-Grillo process, which was invented by Dr. Schroeder and patented by him together with the Aktien Gesellschaft für Zinc Industrie, is designed to overcome this difficulty in part, by using certain soluble salts, "where, owing to the easy reversal of the surface and the porosity of these substances, the regeneration was bound to be much easier than in the case of platinized asbestos, pumice, and the like." One of the salts used for this purpose is magnesium sulphate; sodium sulphate and certain phosphates can also be used. The contact substances are made by mixing or soaking the salts with a dilute solution of a platinum salt—usually platinum chloride. The platinum is then reduced without the aid of other substances, by passing the hot gases containing SO_2 over the mass.

There are at least six plants in the United States operating these patents. The following is a description of the process as employed at the Mineral Point Zinc Works in New Jersey.²

"The sulphur dioxide is drawn off at the top of the furnace and taken to a brick dust chamber, where the cleaning of the gas begins. This dust chamber is fitted with baffle walls, so that the gas is forced to travel from top to bottom of the chamber several times before it finally escapes. This removes a good part of the flue dust, but there remains various gaseous impurities, such as moisture, sulphur trioxide and silicon tetrafluoride (SiF_4). These are removed by intimate mixture of the gas from the dust chamber with sulphuric acid of varying degrees of concentration, in lead-lined towers filled with coke or quartz according to the strength and temperature of the acid. The sulphuric acid, after having passed through cooling coils when necessary, is pumped back to the top of these towers by means of acid pumps and air lifts. This sulphuric acid is then evenly distributed over the top of the towers by means of a distributor, whence it trickles down over the coke or quartz filling, coming in intimate contact with the sulphur dioxide which enters the towers at the bottom. The cleaning is further continued by passing the gas through lead scrubbers which work on the principle of the laboratory gas washing bottle, and effect a more intimate contact of the acid

¹ Consult Lunge, *Sulphuric Acid and Alkali*, 3rd Ed., Vol. I, Part II, p. 1,057, *et seq.*

² *Engineering and Mining Journal*, New York, Vol. LXXXII, September 1906, pp. 389-390.

and the gas. The mist is removed by passing the gas through filters filled with coke. The last step in the purification is filtration of the gas through layers of asbestos fiber. The gas after passing through this purifying process shows no traces of dust or mist when examined in a flask by means of sunlight and a magnifying glass.

The gas which up to this time has been under a suction action is now forced by Connersville positive pressure blowers through the conversion and absorption apparatus. Before the conversion into sulphur trioxide can be effected the sulphur dioxide must be heated to 400° C. The conversion is effected by the catalytic action of finely divided platinum distributed on particles of magnesium sulphate. This platinum brings about a combination of sulphur dioxide with the excess of oxygen (taken in at the roasting furnace) and sulphur trioxide is formed. After leaving the catalyzers the sulphur trioxide is cooled by passing it through iron pipes before the absorption begins. Finally, the acid is pumped into iron tank cars for shipment.”

*The Mannheim Process*¹

The conversion of dry sulphur dioxide into the trioxide is accomplished by the Mannheim process in two stages. The first conversion is accomplished by passing the gases through a contact space charged with ferric oxide. The second conversion takes place, after further purification, in the presence of a platinum contact.

In roasting pyrites for the preparation of sulphur-dioxide for use in this process, special air-tight furnaces are employed and precautions are taken that all air entering the furnaces shall be first thoroughly dried. This is accomplished by passing it first through towers fed with concentrated sulphuric acid. The dried air is passed underneath the grates of the furnaces to the roasting ore.

The uncooled burner gases pass directly to the first contact mass. This consists of a body of ferric oxide, between 7 and 10 feet in thickness, resting upon a grate, within an iron cased chamber. The chambers are so constructed that fresh oxide of iron (pyrites cinder) can be introduced at the top while the spent oxide is removed below, through the grate. Between 60 and 65% of the sulphur dioxide in the burner gases is converted into the trioxide by the first contact mass.

From this contact chamber the gases are conducted into cooling apparatus and thence to absorbers, where the trioxide is removed. Most of the impurities in the gas have been removed during its passage through the first contact mass. The gas, however, still contains traces of impurities and also some uncondensed anhydride. The last trace of these impurities is removed by some form of filter apparatus. The gases are then subject to the action of a platinum contact mass where the balance of the dioxide is

¹ Lunge, op. cit., p. 1,067.

Clem and Hasenbach, United States patent No. 690,133, Dec. 31, 1901.

converted into the trioxide, the gases being first heated to the temperature requisite for conversion. After passing the platinum contact, they are again cooled and passed through an absorber by which the anhydride is retained.

Applications of Sulphuric Acid

According to Lunge¹ the principal applications of sulphuric acid are the following:—

I.—In a more or less *dilute* state (say from 144° Tw. downwards). For making sulphate of soda (salt-cake) and hydrochloric acid, and therefore ultimately for soda-ash, bleaching-powder, soap, glass, and innumerable other products. Further, for superphosphates and other artificial manures. These two applications probably consume nine-tenths of all the sulphuric acid produced. Further applications are:—for preparing sulphurous, nitric, phosphoric, hydrofluoric, boric, carbonic, chromic, oxalic, tartaric, citric, acetic, and stearic acids; in preparing phosphorus, iodine, bromide, the sulphates of potassium, ammonium, barium (*blanc fixe*), calcium (*pearl-hardening*); especially also for precipitating baryta or lime as sulphates for chemical processes; sulphates of magnesium, aluminum, iron, zinc, copper, mercury (as intermediate stage for calomel and corrosive sublimate); in the metallurgy of copper, cobalt, nickel, platinum, silver; for cleaning (pickling) sheet-iron to be tinned or galvanized; for cleaning copper, silver, etc.; for manufacturing potassium bichromate; for working galvanic cells, such as are used in telegraphy, in electro-plating, etc.; for manufacturing ordinary ether and the composite ethers; for making or purifying many organic colouring-matters, especially in the oxidizing mixture of potassium bichromate and sulphuric acid; for parchment paper; for purifying many mineral oils, and sometimes coal-gas; for manufacturing starch, syrup, and sugar; for the saccharification of corn; for neutralizing the alkaline reaction of fermenting liquors, such as molasses; for effervescent drinks; for preparing tallow previously to melting it; for recovering the fatty acids from soap-suds, for destroying vegetable fibres in mixed fabrics; generally, in dyeing, calico printing, tanning, as a chemical reagent in innumerable cases; in medicine against lead poisoning, and in many other cases.

II. *In a concentrated state.*—For manufacturing the fatty acids by distillation; purifying colza oil; for purifying benzene, petroleum, paraffin oil, and other mineral oils; for drying air, especially for laboratory purposes, but also for drying gases for manufacturing processes (for this, weaker acid also, of 140° Tw., can be used); for the production of ice by the rapid evaporation of water in a vacuum; for refining gold and silver, desilvering copper, etc.; for making organo-sulphonic acids; manufacturing indigo; preparing many nitro-compounds and nitric ethers, especially in manufacturing nitroglycerine, pyroxyline, nitro-benzene, picric acid, and so forth.

¹ Lunge Sulphuric Acid and Alkali, 3rd Ed., Vol. I, Part II, pp. 1169-1170.

III. *As Nordhausen fuming oil of vitriol (anhydride)*. For manufacturing certain organo-sulphonic acids (in the manufacture of alizarine, eosine indigo, etc.); for purifying ozokerite; for making shoe-blackening; for bringing ordinary concentrated acid up to the highest strength as required in the manufacture of pyroxyline and other purposes.

CHAPTER VII.

PYRITES AND THE PAPER MANUFACTURING INDUSTRY.

General.

Canada is possessed of great pulpwood resources, and the production of pulpwood and the manufacture of wood pulp is one of the largest and most rapidly expanding of our industries. At present a very large proportion of our pulpwood is exported in the raw state. As pointed out by Mr. H. R. Macmillan.¹ "If the pulpwood exported in 1910 had been reduced to pulp in Canada, it would have supplied 80 mills of the average size of those now operating in Canada. Thus 131 mills, instead of 51, would have been operating in Canada, would have been employing labour, and advancing Canadian industry."

The ground wood and chemical pulp productive capacity of the mills in the United States (1910), as shown by the records of the American Paper & Pulp Association, was 192 ground wood pulp mills having 1485 grinders, producing 2,008,680 tons of air-dry ground wood pulp; 90 sulphite plants producing 1,204,894 tons of air-dry sulphite fibre; and 31 soda pulp plants, producing 417,387 air-dry tons of that commodity.² In 1910 the production was slightly less than 95% of the capacity of the mills at that time.

In Canada in 1910 there were 51 mills in operation and several others projected; data as to the tonnage capacity are not available. In 1910 the total tonnage of air-dry pulp produced was 474,604 tons. Of this about 78% was manufactured by the mechanical process, about 20% by the sulphite process, and about 2% by a soda process. The greater portion of the sulphite pulp produced was manufactured in Ontario, with Quebec a close second.³

The production of sulphite fibre in Canada, in 1910, was 95,987 tons. In the same year there were 959,971 tons of sulphite fibre produced in sulphite mills in those states of the Union which border Canada on the south, or which lie adjacent to the Great Lakes. The amount of sulphur required for the manufacture of the above quantities of sulphite pulp would be approximately 10,000 tons in Canada,⁴ and 100,000 tons in that portion of the United States which is adjacent to the Canadian border.

¹ Bulletin 26, Forestry Branch, Department of the Interior, Forest Products of Canada, 1910, Pulpwood, p. 14.

² These data, and others used elsewhere in this report relating to the Wood Pulp Industries of the United States, are taken from Senate Document 31, 62nd Congress, 1st session, "Report by the Tariff Board relative to Pulp and New Print Paper Industry."

³ See Bulletin No. 26, Forestry Branch, Department of the Interior, Forest Products of Canada, 1910, Pulpwood.

⁴ The present annual requirements, as shown by returns from the Sulphite Pulp Mills in Canada are slightly over 13,000 tons.

Sulphur is thus an important raw material for use in the manufacture of sulphite pulp, and any expansion of the paper making industry in Canada or in the adjacent States of the Union indicates an increased market for this substance. European paper mills using the sulphite processes, almost without exception, employ pyrites as a source of sulphur for this purpose. In the United States there are two plants in successful operation where this material is used, and one plant is now being constructed in Canada. Several other large corporations have also been investigating this method of preparing sulphite pulp and it is possible that, in the future, if a regular supply of suitable ore can be assured, other mills will be erected equipped with pyrites burners instead of sulphur burners.

As this industry promises to create a new and important market for some of our pyrites mines, the following section of this report, dealing respectively with Sulphite pulp Manufacture, Pyrites as a Substitute for Sulphur in the Sulphite Fibre industry, and some Plants using Pyrites in the Manufacture of Sulphite Pulp have been introduced.

Manufacture of Wood Pulp

The basis of all manufactured paper is cellulose. Cellulose is obtained from vegetable fibre by removing all matter of a resinous or gummy nature which encrusts these fibres or cements them together. Commercially vegetable fibre or cellulose for use in the manufacture of paper is obtained from a great variety of the members of the vegetable kingdom. The most important are Cotton (rags, wool, waste) Hemp (linen, rags, waste) Manilla, Jute, Straw, Esparto grass and Woods of various kinds. In America spruce wood is probably the most important material used for this purpose, especially for newsprint papers. Next in importance to this comes such woods as fir, balsam, hemlock, poplar and willow.

In the preparation of pulp from wood fibre, the object of the treatment is to separate the cellulose from the intercellular materials in which the fibres are enveloped. Ideally, this must be accomplished without injury to the cellulose itself. Numerous inventions and processes have been devised for this purpose, and many of them are in successful operation, though none has attained the ideal separation. The processes in use may be divided into two general groups: Mechanical processes and Chemical processes.

Where pulp is to be prepared by the mechanical process, the wood, previously cut into suitable lengths and freed from bark, is pressed against the surface of revolving buhr stones by hydraulic pistons. The ground fibre thus produced is washed, screened, and sorted to prepare it for shipment or for use in the manufacture of paper.

Where pulp is to be prepared by chemical processes, the wood, previously cut into lengths and barked, is cut into small blocks or chips. In American mills a special chipper is usually used which cuts the wood into thin slices across the grain. After picking and screening, the chips pass to a storage bin and thence to large boilers or digesters. In the digesters they are boiled in

an alkaline or acid solution until the cellulose or vegetable fibre is freed from the hard, gummy and resinous matters of the wood. The solutions used for boiling the wood differ in different processes. Caustic soda, caustic potash, sulphate of soda, carbonate of soda, sulphite of soda, bisulphite of lime and magnesia, or sulphurous acid are some of the substances employed for this purpose.

After treatment in the digester, the pulp is washed and screened, and, where necessary, bleached, before being made ready for shipment or for further treatment in the manufacture of paper.

Mechanically prepared pulps, and a large proportion of that prepared by the sulphite processes are used for the manufacture of newsprint paper. Newsprint paper contains approximately 25% of sulphite fibre and about 75% of mechanical fibre. Finer grades of paper are made largely from chemically prepared fibre, much of the fibre for this purpose being made from materials other than wood.

Sulphite Process

In the manufacture of chemically prepared wood pulp by this process, a solvent liquor containing an acid sulphite of soda, potash, lime, or magnesia is employed. Wood chips are boiled in this solution for a suitable length of time, the temperature being kept high (260°–300°F.) and the liquid being agitated to insure thorough contact between the chips and the solvent. The various processes of manufacturing sulphite pulp differ among themselves in the nature of the solvent used, in the method of preparing the liquor, in the strength of liquor used, in the type of digester used, and in many other minor details. They all however depend for their success upon the fact that the intercellular portions of the vegetable fibres are dissolved, more or less completely by the sulphite solution, and the fibres are left in a condition suitable for the manufacture of paper.

In Canadian and American mills the sulphite process most commonly in use is that in which the sulphite liquor is a weak solution of bisulphite of lime $\text{Ca H}_2 (\text{SO}_3)_2$, or bisulphite of lime and magnesia, containing free sulphurous acid. The following steps in this process can be noted:—

1. Preparation of sulphur dioxide gas.
2. Preparation of the liquor.
3. Subsequent operations—boiling, washing, screening, etc.

1. *Preparation of sulphur dioxide gas.* The sulphite solution used as a boiling liquor in these processes is prepared by bringing sulphur dioxide gas into contact with water in the presence of lime, dolomite or limestone. The gas for this purpose is usually prepared by burning sulphur in air in some form of sulphur burner.¹ As the presence of sulphuric acid is injurious to the fibre (making it brittle and tending to discolour it), and as the acid also corrodes the pipes and otherwise affects them injuriously, precautions must

¹ For description of burners, see Appendix II of this report.

be taken to prevent the formation of sulphur trioxide in the burner gas by admitting only the requisite amount of air. To avoid undue losses of sulphur by volatilization, the temperatures of the burners must be kept as low as possible, at the same time complete combustion being assured.

The quantity of sulphur dioxide gas that will be dissolved by water is mainly dependent upon the temperature at which solution takes place, the quantity of gas absorbed decreasing rapidly as the temperature rises. Therefore, in order to obtain the best results in making the liquors, it is necessary that cold water be used and that the temperature of the gases be as low as possible. In practice this temperature is usually kept around 50°-60° F. (about 10°-15° C.). Burner gases are brought to a suitable temperature for absorption by first conducting them through a system of air-cooled or water-cooled pipes, and thence to the absorbing towers or tanks.

2. *Preparation of the sulphite liquors.* The methods employed for preparing the sulphite liquors may be divided into two groups:—1st. Those in which the gas is brought into contact with the base in solid form as a carbonate or oxide—the tower systems of Kellner, Francke, Mitscherlich, Ritter-Kellner, and others; 2nd. Those in which the gas is brought into contact with the base in solution or in suspension in water—the tank systems of Flodquist, Turner, McDougall, Partington and others. There are also certain systems in which both methods are combined.

Tower System.—In this system raw limestone or dolomite is placed in a tower or towers—circular or square in section, 6'-12' diamter, 50'-150' high, with special internal construction. Cold water is pumped to the top of the tower and distributed over the stone in such a way that it descends through the tower in fine streams or as spray, at the same time coating the rock with a film of water. The cooled burner gases are admitted at the base of the tower, and in their ascent, they meet the descending spray and come into contact with the water films coating the stone. The sulphur dioxide gas is rapidly dissolved by the water to form sulphurous acid, according to the formula $H_2O + SO_2 = H_2SO_3$. The acid thus formed reacts upon the limestone forming sulphite of lime, $CaCO_3 + H_2SO_4 = CaSO_3 + H_2O + CO_2$. Sulphite of lime is almost insoluble in water, but in the presence of an excess of sulphur dioxide and water it is rapidly converted into the soluble bisulphite $CaSO_3 + SO_2 + H_2O = CaH_2(SO_3)_2$. The bisulphite thus formed is carried by the liquor to the bottom of the tower. If the towers are made of a suitable height, and if the supplies of gas, water, and limestone are properly proportioned and regulated, nearly the whole of the sulphur dioxide will be absorbed. The waste gases, which escape into the air at the top of the tower consist chiefly of nitrogen and carbon dioxide. They also usually contain a small amount of sulphur dioxide, which has not been absorbed.

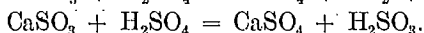
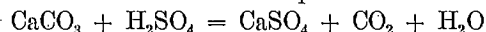
¹ Descriptions of these various processes and the apparatus employed will be found in:—

Hoffmann, *Papier-Fabrikation*, 2nd Ed., Vol. II, p. 1472, *et seq.*

Griffin and Little, *Chemistry of Paper Making*, p. 203 *et seq.*

Watt, *The Art of Paper-Making*, p. 68 *et seq.*

The liquor is collected at the bottom of the tower and pumped to storage tanks. If pure limestone were used the liquor would contain bisulphite of calcium and sulphurous acid in solution. When the stone used is dolomite the liquor will contain bisulphites of calcium and magnesium. The ratio of magnesium to calcium in the finished liquor is always higher than their ratio in the original stone because a portion of the lime is usually rendered insoluble and removed as sulphate of lime. The formation of the sulphate is due to the presence of sulphur trioxide in the burner gases. The trioxide, if present, forms sulphuric acid in the towers, and the acid thus formed reacts on the limestone or on the sulphite of lime to form the sulphate, thus:—



A small portion of insoluble sulphite of lime is also found in the liquor. The insoluble materials can be removed by allowing the liquors to stand until the solids settle to the bottom. The clear liquor is then drawn off. The presence of the insoluble materials is objectionable because such materials involve sulphur losses and they also tend to clog the pipes and screens.

Tank System.—Where this system is employed the cooled burner gas is brought into contact with lime held in suspension in water in a series of tanks. The lime water is prepared by slacking burned lime—preferably made from dolomite—in water. This operation is usually carried out in special machines which insure thorough mixing. The lime water thus formed contains hydrates of calcium and magnesium, partially in solution, partially in suspension.

The prepared lime water is passed through a series of tanks—usually three in a set—so arranged that it can flow by gravity from one to the next lowest. All tanks, except the highest, are made gas tight. Burner gas can be admitted to the bottom of the lowest tank through an appropriate system of pipes and jets. When the gas is admitted it passes upward through the liquor in this tank to the top. Thence it is carried to the base of the next higher in the series, and so on until it reaches the highest tank. Here the undissolved portion of the gas escapes into the air, or through a special vent into a chimney and thence into the air. It is usually necessary to place a pressure fan in the pipe system, below the lowest tank, to force the gas through the liquor in the tanks.

The chemical reactions which take place in the tanks are similar to those in the tower, though they progress more rapidly and the solutions prepared are stronger. The hydroxide in suspension and solution is first converted into the sulphite. Afterward, as excess of sulphur dioxide is supplied, the nearly insoluble sulphite is converted into the soluble bisulphite.

In operating by this system, it is possible to make the operation a continuous one. Any unconverted sulphite which escapes from the lowest tank, and the insoluble sulphate, which also forms if sulphur trioxide be present, can be removed from the liquor by settling. A more satisfactory liquor can be prepared by making the operation intermittent. Then the liquor in the lowest tank can be treated with gas until all the sulphite has

been converted into soluble form. When the action is complete the solution is withdrawn and the tank re-filled from the next above, the stream of gas being temporarily stopped by stopping the blower.

It will be noted that in the preparation of sulphite liquors in this way, the liquor gradually increases in strength as it passes downward through the tanks, while the amount of sulphur dioxide in the gases will be gradually diminishing as they ascend through the system.

The following analysis is given by Griffin and Little as representative of a well made liquor prepared from dolomite.¹

Specific Gravity at 15° C. = 1.0582.

Sulphurous acid (SO ₂)	4.41%
Sulphuric acid (SO ₃)	0.13
Lime (CaO)	0.95
Magnesia (MgO)	0.72
Silica (SiO ₂)	0.04

This may be combined as:—

Sulphate of lime (CaSO ₄)	0.22
Bisulphite of lime (CaS ₂ O ₅)	2.84
Bisulphite of magnesia (MgS ₂ O ₅)	3.04
Free sulphurous acid (SO ₂)	0.11

3. *Subsequent operations.* The subsequent operations in the manufacture of the pulp need only to be briefly described here.

The prepared chips are boiled in the sulphite liquor in a specially constructed steam tight vessel designated a digester. The Mitscherlich digester, a type that is very commonly used in Canada, is cylindrical in form, with conical top and bottom. It is built of boiler plate, lined with lead and acid proof brick, and is constructed to withstand heavy internal pressures. The diameter of these cylinders lies between 12' and 14', the height between 36' and 40', and the capacity between 4,000 and 6,000 cubic feet. Two manholes, for charging, are provided at the top, and two or three, for cleaning and repairs, are provided at the base. Special valves and attached pipes are connected with the bottom of the conical base for the purpose of discharging the contents when the cooks are completed.

Heat is supplied to the digester and its contents by steam, circulated through lead pipes, which cover the lower third of the inside walls of the digester.

To charge the digester it is filled from the top as completely as possible with chips; liquor, containing about 3½% of sulphurous acid (free and combined), is now run in until the digester is full. The manholes are then closed and steam is turned on to heat the contents and the pressure is raised

¹ Chemistry of Paper Making, p. 228.

slowly. The maximum pressure is reached in four or five hours, and the whole cook is completed in 14-16 hours. In some mills the operation is hastened, eight hours being the maximum time consumed. The pressures vary between 65-85 pounds, and the highest temperature between 300-312° F.

After the cook is completed the pressure is lowered to about 30 pounds, the outlet valve at the base is opened, and the pulp is blown out into a drainer, where the liquor is drained off and the pulp is washed. The subsequent operations through which it passes depend upon the purpose for which it is required. Bleaching and screening usually precede the mixing processes preliminary to the manufacture of newsprint paper.

Pyrites as a Substitute for Sulphur in the Sulphite Pulp Industry

The manufacture of sulphite pulp is a comparatively new chemical industry, and the attention of operators has hitherto been chiefly given to the perfecting of the process. In recent years the costs of raw materials and of labour have been advancing and economies in operation are now receiving more attention. Wood costs from 50 to 60 per cent of the total cost of the pulp; the prices have been steadily advancing and there is no probability of their decreasing; labour costs are also increasing with the advance in the cost of living. Any reduction in costs which may be effected will probably come through improved mechanical devices which will still further reduce labour costs per ton, or through economies in the utilization of other raw materials. Sulphur is probably the most important of these materials, and it is essential to the sulphite pulp process. During the early years of the development of the process the sulphur dioxide gas required was prepared in the easiest possible way—by burning raw sulphur in air in the old pan type of sulphur burner. Sulphur costs for the manufacture of pulp in this way only amount to about 10% of the total cost of the pulp, and as a consequence economies at this point have not received the attention that has been devoted to other parts of the operation.

On the other hand, the manufacture of sulphuric acid, the other chemical industry dependent upon a supply of sulphur as one of its essential raw materials, has been carried on for more than a century. The sulphuric acid maker has been continually striving to improve his process and to reduce his costs. To him the production of sulphur dioxide is of prime importance; he has, accordingly, given much attention to the methods of its production and has invented many forms of apparatus designed to this end. Except under very special circumstances, we find that the acid manufacturer prepares his sulphur dioxide by burning pyrites in specially constructed furnaces. He does this, not because it is easier to produce the gas in this way, or because pyrites is more easily obtained than sulphur, or more conveniently utilized but he uses it *because he has found that he can prepare a gas, eminently suited for his purpose, cheaper this way than in any other way*, the relative market prices of sulphur and pyrites being what they are.

The acid manufacturers have thoroughly investigated the matter of using pyrites in place of sulphur, have developed very satisfactory processes and have exhibited sufficient confidence in the results obtained by investing many millions of capital in industrial establishments which are dependent on pyrites as a source of sulphur. In view of the results which they have obtained and of the success both technically and commercially, which has attended their efforts, the possibility of manufacturing a suitable gas economically from pyrites, and of absorbing it satisfactorily, cannot now be questioned.

The sulphide pulp manufacturer in search of methods whereby he may reduce his operating costs should not fail to investigate the processes of the sulphuric acid maker. Under the old conditions when the sulphite process was in its infancy, before the development of the modern "fines" burner, the dilute gas produced in lump burners, with its high percentages of sulphur trioxide and oxygen and load of dust, made it very difficult to produce a satisfactory sulphite pulp when using pyrites. The invention of the multiple hearth, mechanically operated furnaces, and the perfection of the apparatus for removing the dust and other impurities¹ have overcome these difficulties. Many European paper mills are now operating on pyrites in place of sulphur and in many instances they are using American designed and built, mechanically operated furnaces.

The paper manufacturer, proposing to use pyrites burners, will find the plant many times more expensive to install; a somewhat greater degree of technical knowledge may be required of his acid maker, since more care and a greater degree of skill will be demanded in the making of the sulphite liquor. A modern rotary sulphur burner is *said* to need but little attention. It is simple in construction, does not get out of order easily, and is not difficult to operate. The gas produced by such a burner is high in sulphur dioxide. Unless the burner is carefully operated, however, there are quite extensive sulphur losses. The gas losses at the tops of the towers (or tanks) are also often excessive, sometimes being as much as 15% of the gas produced. A strong gas will make a strong liquor quickly, but the losses will be high. A weaker gas will make an equally satisfactory liquor, with much lower losses, provided proper precautions are taken to cool the gases before they enter the absorption towers though more time will be needed to bring it to the required strength.

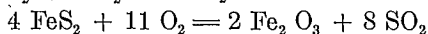
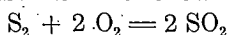
The principal objections to using pyrites as a substitute for sulphur, apart from the question of the weaker gas produced, arise from causes other than the nature of the product. Only a few sulphite mills are favorably located with respect to a supply of suitable ore. As a consequence, freight would increase the cost per ton of sulphur received according to the sulphur content of the ore. An ore containing 45% recoverable sulphur contains 55% of (for the purposes of the sulphite mill) useless material. In other

¹The contact process for manufacturing sulphuric acid requires a far cleaner gas than is demanded in the sulphite pulp industry.

words freight is being paid on 1100 pounds of material not needed. This useless material must also be handled, stored, and finally discarded. Assuming that the sulphur losses in burning pyrites are 2%, a charge of \$1.00 per ton against pyrites, for freight, loading and other similar charges, is equivalent to a charge of \$2.093 per ton, against the recoverable sulphur content of the same ore. For 40% ore this charge would be \$2.631, and for 35% ore it would amount to \$3.03 per ton of recoverable sulphur contained in the ore.

Again, if pyrites burners are not operated properly there is a tendency to form a considerable proportion of the trioxide in place of the dioxide, owing to the catalytic action of the oxide of iron. Also if the combustion is not carefully regulated there may be quite large sulphur losses in the cinder. These, however, are matters which only require care and experience to overcome.

The relative values of the gas as prepared from sulphur or from pyrites may be inferred from the following comparison. In making this comparison it may be assumed that air contains 20.5% of oxygen, by volume. On combustion the following reactions take place:—



Hence when sulphur is burned in air the theoretical maximum volume of sulphur dioxide present in the gas resulting from the combustion will be the same as that of the original oxygen, namely 20.5 per cent. When pyrites is burned, a portion of the oxygen of the air unites with the iron to form ferric oxide; if the combustion is complete eight elevenths of the oxygen will unite with the sulphur of the pyrites to form sulphur dioxide, and the volume of the dioxide produced will be $8/11$ of $20.5 = 14.9$ per cent of the volume of the air consumed.

In practice it will be found that the sulphur burners produce a gas ranging between 12 and 16 per cent sulphur dioxide, while a modern multiple hearth mechanical roaster will readily produce, from pyrites, a gas ranging from 8 to 12 per cent sulphur dioxide.

If a sulphur burner is forced a gas richer than that given above can be made, but, at the same time, the sulphur losses due to sublimation will be increased.

If we consider the relative values of the gases made by each of the two methods, we will find on the one hand that the gas made by burning sulphur contains from two to three times as much free oxygen as that made from pyrites. The presence of free oxygen is objectionable because it may lead to the oxidation of the sulphurous acid in the towers and to the formation of insoluble sulphates in the liquors. On the other hand an objection arises from the supposed difficulty of making a satisfactory liquor from the weaker gas produced by pyrite burning. In answer to this it may be stated that sulphuric acid makers experience no difficulty in making a much stronger liquor (of a different composition, it is true) for the manufacture of sulphuric acid. To offset the use of a weaker gas for a paper mill plant it will be necessary

to increase the dimensions of the absorption system and to take precautions to insure a more thorough cooling of the gases to secure better absorption.

In this connexion it may be noted that in experiments at Sault Ste. Marie, Ontario, it was found that with a tower system, and with cold water from Lake Superior, a 12-14 per cent gas was more economical for the production of the liquor than a richer gas. A gas of this strength, made in the roasting and gas cleaning plants gave better and more economical results than that made from sulphur in the sulphur burners.¹

The question of the utilization of pyrites as a substitute for sulphur in a sulphite mill is no longer dependent on technical difficulties of manufacture. A gas free from dust and of suitable strength can be produced and this gas can be used to prepare a suitable liquor. The crux of the matter is the *relative cost*. Where mills are so situated that sulphur can be obtained easily and cheaply, while pyrites is not so cheaply available, they should use the cheaper material. On the other hand there are many mills so located that they could substitute pyrites for sulphur, and (at the present relative market prices) make a notable saving in their annual costs.

In the article to which reference was made above, Mr. Sjöstedt discusses the question of costs as follows:

"Pure pyrite contains 46.67 per cent iron, and 53.33 per cent sulphur; and brimstone, about 100 per cent sulphur. Consequently one ton of pyrite corresponds in sulphur content to 0.533 ton brimstone. However, pure pyrite deposits are not found in nature, the commercial product generally containing from 45 to 50 per cent sulphur; whereas commercial brimstone, usually, is 98 or 99 per cent pure. A ton of brimstone, therefore, equals in sulphur value from 2 to 2.2 tons pyrite. At present quotations, pyrite fines with 45 per cent sulphur at 10c. per unit, would cost \$4.50 per long ton; consequently the sulphur contents in such material would cost at the rate of \$10.00 per long ton; while the Louisiana brimstone is quoted at \$22.25. This is a difference of \$12.25 per ton in favor of the pyrite. True, against this we must place a number of sundry expenses, such as the difference in losses, in cost of labor, in power, in water, in cost of plants, in freight charges, etc; but notwithstanding, this under-rated article can generally bear it all. These items, however, will differ in each particular place, and will thus produce a different balance sheet in each case; and as no general argument, therefore, would here be sufficient or of any real value, a definite instance has to be presented. Our own case may, therefore, be accepted as an illustration:

The brimstone used at Sault Ste. Marie came from a Louisiana mine, from which point the freight rate amounted to \$7.87 per gross ton; and at the time referred to brimstone cost \$27.25 per ton f.o.b. here. The pyrite came from the Helen Mine property, Michipicoten (where large pockets of granular ore are found, containing about 47 per cent sulphur); and the low freight

¹ Sjöstedt, E. A., *Brimstone versus Pyrite for Wood Pulp Manufacture*, Eng. and Min. Journ., Vol. LXXXI, 1906, p. 803.

rate from this place, together with the cheap mining, would make it a profitable proposition to deliver it to the roasting plant at \$5. per ton (or about 11c. per unit).

During the trials referred to, about 3000 tons of pyrite and 375 tons of brimstone were used, thus affording us an opportunity for obtaining accurate data for comparison. The roasters used for treating the pyrite are of our own modification of the MacDougall type.¹ For burning brimstone we used ordinary cast iron sulphur furnaces.

Omitting all details, it suffices to state that, in our practice, we found that on an average 2.25 tons of our 47 per cent pyrite equal, in efficiency and in amount of liquor and pulp produced, to 1 ton of brimstone. In roasting 22.5 tons of pyrite and burning its equivalent of 10 tons of brimstone per day, our daily expenses were as given herewith:

When Burning.	Pyrite.	Brimstone.
Labor, about.....	\$20.00	\$8.00
Steam for drying pyrite.....	10.00	.....
Power, water and light.....	5.00	2.00
Repairs and sundries.....	9.00	1.00
Depreciation of plant, 10%.....	15.00	1.50
	<hr/>	<hr/>
	\$ 59.00	\$ 12.50
Material, 22.5 tons pyrite at \$5.....	\$112.50	
Material, 10 tons brimstone at \$27.25.....	.....	272.50
Balance in favor of pyrite.....	113.50	
	<hr/>	<hr/>
	\$285.00	\$285.00

This means a saving of pyrite at the rate of \$11.35 per gross ton sulphur used, which in a 50 ton sulphite mill would alone amount to about \$30,000 per annum."

The same matter has been discussed by F. J. Falding before the New England Section of the Society of Chemical Industry.² While Mr. Falding's data are intended to apply to New England localities, they are also equally applicable to many places in Quebec, and in the vicinity of the Great Lakes. In the case of some Ontario points favourably situated with reference to a supply of pyrites, the difference in cost between the two methods would be even more striking. Falding writes as follows: "Whilst it is difficult to submit cost figures which will apply to every case, I think that the following figures are reasonably conservative when applied to many New England localities, and, at any rate, may form a basis upon which more accurate calculations may be made for any given locality. It is assumed that the best of each class is used, and in the case of brimstone, that such a quality is supplied, that 99 per cent of its weight will be recoverable as sulphur dioxide,

¹ Canadian Patent, No. 81,495, June, 1903; described in Journal of the Canadian Mining Institute, Vol. VII. See Chapter V, p. 122, this report.

² Journal of the Society of Chemical Industry, May 1906, Vol. XXV.

and that pyrites will be used which will yield 49 per cent by weight of sulphur as sulphur dioxide. Fines or granular pyrites are assumed, as it is only by the combustion of "fines" pyrites in MacDougall type furnaces, that strong gas can be secured.

The cost of such a quality of brimstone and of the very best quality of "fines" pyrites, delivered *ex ship* at Atlantic port, would to-day be respectively about \$22.00 and \$6.00 per long ton. To this price must be added 0.25 dols. per ton for the cost of unloading at factory, sampling and assaying. The cost of handling and roasting will vary with the quantities handled, and the character of the equipment at any factory. When the quantities handled are about equivalent to 7.5 tons of actual sulphur in 24 hours, it may be said that brimstone should not cost over 40 cents per ton and pyrites not over 50 cents per ton, including repairs and incidentals. Should the factory be located away from tide water, railway freight would have to be added. The equivalent of a freight of \$2.00 per ton on pyrites, would be \$2.75 per ton of brimstone. We have, therefore, the following costs of delivering and handling our raw materials: Brimstone: Atlantic port, \$22.65 per long ton; inland, \$25.40; pyrites, Atlantic port \$6.75; inland, \$8.75 per long ton.

Therefore 1 ton (2,000 lbs.) of sulphur will be equivalent to 1.01 ton of 99 per cent brimstone, and 2.143 tons of 49 per cent pyrites; hence the cost of one short ton of sulphur at Atlantic port as brimstone will be \$20.43, and as pyrites, \$12.92. At inland factory as brimstone, \$22.91; and as pyrites, \$16.74.

Take the case of a factory at the seaboard and inland respectively as above, using 7.5 tons of sulphur daily, or 2,700 tons yearly. If this sulphur is supplied as brimstone it would cost \$55.161 seaboard, and \$61.857 inland. If it were supplied as pyrites it would cost \$34.884 seaboard, and \$45.198 inland, leaving a difference of cost in favour of pyrites of \$20.277 seaboard, and \$16.659 inland.

As the plant for roasting pyrites and purifying the gas would cost at a liberal estimate about \$30,000 for a plant of this capacity; 12 per cent may be written off for interest and amortisation, which would leave the net difference some \$3,600 less, or \$16,677 seaboard, and \$13,056 inland, which would represent the net saving or cheapening of the manufacturing cost of the pulp. This should amount to from 75 cents to \$1 per ton of pulp; and with care and the purchase of a cheaper pyrites may be considerably more.

I believe these figures are conservative. They will undoubtedly vary according to the locality, conditions at any given plant, and the skill used in making the change; in operating, in purchasing supplies, and, in short, with the excellence of the individual management.

In the sulphuric acid industry, it is a very common statement, that, before a change from pyrites to brimstone could be considered, brimstone would have to be sold at from \$12.00 to \$14.00 per ton, according to the location of the factory."

In using pyrites, acid makers naturally purchase the best available ore. At present the supply of high grade pyrites available is not equal to the demand. As a consequence low grade ores are mined, some acid works purchasing ore which contains less than 35 per cent sulphur. Pyrites containing only 30 per cent of sulphur is being successfully burned without any external firing, and produces a gas containing about 7 per cent sulphur dioxide.¹

For the operation of a sulphite mill equipped with mechanical roasters it would, of course, be desirable to obtain as high grade pyrites as possible. On the other hand, there are many prospects, especially in Ontario, where an immense tonnage of lower grade ore could be obtained. Much of this ore will contain not far from 35 per cent sulphur. The following comparative estimates for the operating of a pyrites burning plant have been prepared with this fact in mind.

Estimated Cost of Producing Sulphur Dioxide Gas for a 100 ton Sulphite Pulp Plant

A. Using Sulphur:

Sulphur required 250 lbs. per ton of pulp produced.

25,000 lbs. = 12.5 tons.

Assuming 99.5 per cent pure, 12.63 tons of commercial sulphur will be required.

12.63 tons at \$22.50 per ton. \$284.18

Equipment:

Rotary burners.	\$ 5,000
Piping, etc.	500
Building.	5,000
	\$10,500

Allowing 10 per cent depreciation = \$1,050 per annum.

(Assuming 300 working days to year).

Daily cost.	3.50
Repairs and maintenance.	2.00
Labour	5.00

Total daily cost. \$294.68

Sulphur costs per day per ton of sulphite pulp = . . . \$ 2.95

B. Using 45% Pyrites:

Assuming a sulphur loss of 2 per cent in roasting, each ton of ore will contain 860 pounds of recoverable sulphur. The pyrites equivalent to 25,000 pounds of sulphur will be 29.07 tons of this ore.

¹The makers of some mechanical roasters claim that they can burn ore containing only 20% of sulphur, without the use of external heat.

45% ore at 11 cts. per unit cost.....	\$4.95 per ton
Freight, etc., say.....	1.05

Cost per ton.....	\$6.00
29.07 tons at \$6 per ton = daily cost of.....	\$174.42

Equipment:

Mechanical roasters.....	\$36,000
Dust chamber, flues, etc.....	7,800
Elevator, conveyors, etc.....	2,700
Scrubbers.....	3,000
Pumps, fans, valves, etc.....	800
Piping and shafting.....	1,200

\$51,500

Building.....	15,000
---------------	--------

\$66,500

Allow an annual depreciation charge of 10%:

Depreciation will be \$6,650 per annum.

“ “ for a 300 day year, per day.....	\$ 22.17
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Annual repair charges \$1,000, or per day.....	3.33
--	------

Labour and superintendence:

$\frac{1}{2}$ machinist at \$4.00.....	\$2.00
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3 men at \$2.25.....	6.75
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3 men at \$1.75.....	5.25
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Labour charge per day.....	14.00
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Sundry supplies, oil, waste, etc.....	.25
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Power, 10 horse power at \$20.00 per H.P. year..	\$200.00
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Daily power charge.....	.66
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Total daily costs for 10 tons of sulphite.....	\$214.83
--	----------

Cost per ton of sulphite pulp per day =.....	2.15
--	------

C. Using 35% Pyrites:

Assuming a sulphur loss of 3 per cent in roasting, each ton of ore will contain 640 pounds or recoverable sulphur.

The pyrites equivalent to 25,000 pounds of sulphur will be 39.07 tons of this ore.

35% pyrites at 11 cents per unit, costs	\$3.85 per ton.
---	-----------------

Freight, etc., say.....	1.05
-------------------------	------

Cost per ton.....	4.90
-------------------	------

39.07 tons at \$4.90 per ton = daily cost of.....	\$191.44
---	----------

Equipment:

Mechanical roasters.....	\$36,000
Dust chamber, flues, etc.....	9,000
Elevator, conveyors, etc.....	2,700
Scrubbers.....	4,000
Pumps, fans, valves, etc.....	800
Piping and shafting.....	1,200
	<hr/>
	53,700
Building.....	15,000
	<hr/>
	68,700

Allow an annual depreciation charge of 10%.

Depreciation will be \$6,870 per annum.

" " " for a 300 day year, per day.....	\$ 22.90
Annual repair charges \$1,400, or per day.....	4.67

Labour and superintendence:

$\frac{1}{2}$ machinist at.....	\$4.00	\$ 2.00
3 men at.....	2.25	6.75
5 men at.....	1.75	8.75
		<hr/>
		\$17.50
Labour charge per day.....		\$ 17.50
<i>Sundry supplies, oil, waste, etc.</i>.....		.30
Power, 14 horse power at \$20.00 per H.P. year.....	\$280.00	
Daily power charge.....		.94
		<hr/>
Total daily costs for 100 tons of sulphite.....		\$237.75
Cost per ton of sulphite pulp per day.....		= \$ 2.38

1. In allowing only 250 pounds of sulphur per ton of sulphite pulp produced, the estimate given here may be considered conservative. In American practice the sulphur consumption per ton of pulp produced ranges from 520 to about 450 pounds. The following tables show respectively the sulphur costs per ton of sulphite in one Canadian mill over a period of three years, and the average sulphur cost at 25 sulphite mills in the United States over a period of nine years.¹

¹ Report by the Tariff Board Relative to Pulp and Newsprint Paper Industry, Senate Document 31, Washington 1911, p. 84, and p. 82.

TABLE XIX.

Cost of Sulphite Pulp in a Canadian Mill

Year.	Sulphur cost. \$	Cost of Wood. \$	Total Cost.	Sulphur % of total.	Wood % total.
1908.....	2.73	14.57	29.49	9.25	49.41
1909.....	2.82	13.13	26.47	10.65	49.60
1910.....	2.72	11.99	24.02	11.32	49.92

TABLE XX.

Average Cost of Sulphite Pulp in United States Mills

Year.	Sulphur cost.	Cost of wood.	Total cost.	Sulphur % of total.	Wood % of total.
1901.....	3.24	12.74	25.72	12.59	49.53
1902.....	3.24	13.50	26.08	12.45	51.76
1903.....	3.32	14.02	27.08	12.36	51.77
1904.....	3.15	15.51	28.69	10.98	54.04
1905.....	2.97	16.18	29.14	10.19	55.52
1906.....	2.87	17.03	29.97	9.58	56.83
1907.....	2.81	17.75	31.32	8.97	56.67
1908.....	2.74	21.42	32.52	8.42	65.86
1909.....	3.01	22.27	35.02	8.59	63.59

The average cost of sulphur for all mills in the United States reporting was \$3.21 per ton of sulphite pulp produced.

2. Again, sulphur is assumed to cost \$22.50 per ton. At Western Ontario points, the present cost is about \$27.00 per ton. The following table shows the effect of the increased cost of sulphur, the other data used in making the estimate being constant.

TABLE XXI.

Change in Estimated Cost of Sulphur per Ton of Sulphite Pulp for each Dollar increase in the price of Sulphur.

Sulphur per ton.	Cost per ton of sulphite.
\$18.00	\$2.38
19.00	2.51
20.00	2.63
21.00	2.76
22.00	2.88
23.00	3.01
24.00	3.14
25.00	3.26
26.00	3.39
27.00	3.52
28.00	3.64
29.00	3.77
30.00	3.89

From this table it may be inferred that mills located at points so far from the seaboard that freight rates materially increase the sulphur cost would find it particularly advantageous to install a pyrites burning plant, provided an adequate supply of suitable ore could be obtained near at hand.

Pyrites Burning Equipment for a Sulphite Pulp Mill

The equipment required for making sulphur dioxide gas from pyrites for use in a sulphite mill consists of the following principal pieces of apparatus:—

1. Roasting furnaces.
2. Dust chambers.
3. Scrubbers or washers.
4. Fans, pumps, etc.

1. *Roasting Furnaces.* In a few European mills lump burners are still employed; some other few mills are still using the old form of shelf roaster. Modern mills are usually equipped with some form of mechanically operated shelf roaster. In the preceding section of this report several of these furnaces of European origin are described. While primarily designed for acid works some of these furnaces have already been introduced into pulp mills. Among the furnaces of American invention and manufacture, which are said to have found most favour with European mills are the Herreshoff and the Wedge.

A well equipped plant should be designed with due regard to both the quality and the quantity of ore which is to be handled. In all but the smallest plants a certain amount of capacity should be held in reserve, in case

it is necessary to shut down any one furnace for repairs. Modern mechanical roasters are so constructed, however, that lengthy shut downs are rare; minor repairs such as replacing rabblers or arms can usually be made in, at most, a few hours.

An efficient plant will be designed to reduce labour charges to a minimum by the introduction of mechanical handling of ore and cinder. In determining the location of the plant and in making the design, as full advantage of the location as possible should be taken to provide for convenient and cheap methods of moving the ore and cinder. Nearly all furnaces are provided with hoppers that hold about a ton of ore. In a few modern plants cylindrical hoppers with conical bottoms are employed, being made large enough to hold ore for a single shift. Where the conditions will allow it, ore should be delivered to storage bins above the level of the tops of the feed hoppers of the furnaces. Where a number of furnaces are operated as a battery, the ore can be distributed to the feed hoppers of the several furnaces by belt or bucket conveyors. In smaller plants it is still customary to use barrows and hand labour to fill the hoppers. Unless labour is very cheap this cannot be considered an economical method of moving either ore or cinder.

Many plants provided with elevators, conveyors, and mechanical feeders, still employ iron barrows and hand labour for removing the cinder. In small plants using high grade pyrites, this may be economical under local labour conditions. A plant operating on low grade ores, where the cinder forms from 50 to 65 per cent or more of the original ore, should be provided with belt or bucket conveyors to remove the cinders to a special bin. The contents of the cinder bin can then be removed intermittently through chutes to carts or to cars for final disposal.

2. *Dust Chamber.* Ordinary dust chambers are formed simply by enlargement of the flues. Their operation depends upon the fact that an increase in cross section of the flue reduces the velocity of the current of gas and a decrease in the velocity of the gas current reduces the quantity of solid matter which can be swept along with it, and therefore facilitates the separation. Where the quantity of dust is apt to be large this is usually not sufficient, unless the flue is very large, and special forms of flue have to be employed.

Flue dust can be made to deposit by cooling, by retarding the velocity of the current of gas, and by the introduction of surfaces against which the gas will impinge and to which the dust particles will cling.

One of the simplest modifications of the ordinary flue is the introduction of baffle walls whereby the gas current is made to take a zigzag course. The baffles may be in the form of partitions reaching nearly across the flue, from each side alternately, so that the gas flows in a zigzag course in a horizontal plane. Again, the baffles may take the form of partitions which reach completely across the flue, openings being left at top and bottom alternately; the path of the gas will be a zigzag course in a vertical plane.

The introduction of baffle walls lying across the path of the current tends to interfere seriously with the draft. This interference is partially obviated in another type of dust chamber where the baffle walls are placed parallel to the direction in which the current travels. One of the most recently patented of this type of dust chamber is the Howard, in which the partition plates are placed in a horizontal plane and only about two inches apart. The operation of this dust chamber is said to be very effective.

An efficient dust chamber must be provided with a suitable means of removing the accumulated dust, from time to time, without disturbing the current of gas, and without even temporarily increasing the amount of dust carried forward into the scrubbers.

3. *Scrubbers or Washers.* The gas which has passed the flues will still contain a very considerable amount of suspended impurities including all the sulphur trioxide. In purifying the gas for use in the contact process these deleterious constituents are removed by the use of sprays and specially constructed coke or quartz filters of which several types are in use.¹

For sulphite mill practice so complete a purification does not appear to be necessary, and the apparatus employed need not be so elaborate. In a number of plants where this process is employed spray washers are installed. The writer has been informed that many European mills are using the Pedersen rotary washer for this purpose.² The stream of gases is passed through a horizontal cylinder. A rotary arm lying in the axis of the cylinder distributes spray against the current of gases.

Another type of washer that has been used with success consists of a vertical cylindrical tower with rose sprays at the top. The stream of gas is admitted at the base and passes upward against the descending spray.

In installing the scrubbers for a sulphite plant it will probably be found advantageous not to throw the whole burden of cleaning the gases on a single scrubber. Where scrubbers of the spray type are used, any unusual disturbance of the dust chambers may suddenly precipitate a large amount of dust into the scrubber, choke it, send unclean gas into the coolers, and necessitate a shut down. Danger of this kind can be guarded against by introducing scrubbers in series. For example a set consisting of a heavy water spray scrubber followed by a brick (quartz or coke) scrubber would be found both effective and easy to operate.

The water used for the spray tower can be circulated by a centrifugal pump and used over again. It will practically become a mixture of sulphurous and sulphuric acids. Where acid is required around the works it can from time to time be drawn off and fresh water added. Otherwise when it becomes too strong and overloaded with dust it may be discharged and fresh water added.

¹ See Lunge, Sulphuric Acid, Vol. I, Part II, page 1012, *et seq.*

² The inventor is Nils Pedersen, Sarpsborg, Norway. Details of this invention are not available when going to press.

Details of construction of the several types of scrubbers will be found in the technical works on the manufacture of sulphuric acid. Some very efficient forms of scrubbers are protected by patents but these can usually be supplied complete by the manufacturers of the mechanical rotary furnaces. It is therefore not necessary to discuss details of design here.

4. *Fans and Pumps.* In a sulphite pulp mill equipment it is necessary to introduce fans somewhere in the circulatory gas system to regulate the flow. The natural draft of the towers is not sufficient to produce the best results, and it will vary from day to day according to the weather conditions. The gas current suffers retardation in the dust chambers, in the scrubbers and in the coolers, and it is necessary to have some means of controlling the circulation. Some form of centrifugal fan is generally used for this purpose. The location of the fans differ in different acid plants. A most convenient place, however, is between the dust chambers and the scrubbers. It then acts as suction fan on the furnaces and on the dust chambers, and sends the current of gases through the scrubbers, coolers, and into the towers under forced draft. The scrubbers will also require an auxiliary pumping equipment to keep the spray water in circulation.

The West Virginia Pulp and Paper Company

The West Virginia Pulp and Paper Company installed a pyrites burning plant in their sulphite mill in Covington, Va. in 1909.

The following brief description of the plant is published through the courtesy of the principal officers of the company.

The original plant consisted of two Wedge furnaces, each 21'-6" in diameter. The furnaces were connected directly to a small sheet steel flue, square in cross section. The gas from the furnaces was carried through a fan to the scrubbing tower, and from there it passed through a 16" lead flue to the cooler and then to the strong acid mixing tower. The excess of gas was carried through coke towers (6' diameter, 50' high) in which the sulphur dioxide was absorbed by water. This sulphur dioxide was subsequently recovered and returned to the general circulation by a system of pre-heaters and a hot pan, the waste water being then discharged into the drain. The hot pan was located above the flue and derived its heat from the furnace gases.

In the operation of this equipment, though satisfactory results were obtained, much difficulty was experienced with flue dust, especially when cleaning the flues. The excess of dust would clog the scrubbers at times.

The plant was reconstructed in 1910-11 and the accompanying sketch, Figure 23, will serve to give a general idea of the layout at the time of my last visit in January 1911. The plant was not then in operation.

An additional Wedge furnace has been installed to increase the capacity. A large flue was built behind the furnaces, rectangular in cross section, 7' x 12'-4", and running the whole length of the battery of furnaces. The upper hearth of each of the furnaces was connected with this flue by a pipe,

rectangular in cross section, 7'-6" wide, and the full height (2'-2") of the gas chamber of the furnace. The main flue is provided with dust hoppers in its bottom, the bottoms being at the proper height above the floor to discharge into barrows, but there are no baffle plates in the flue.

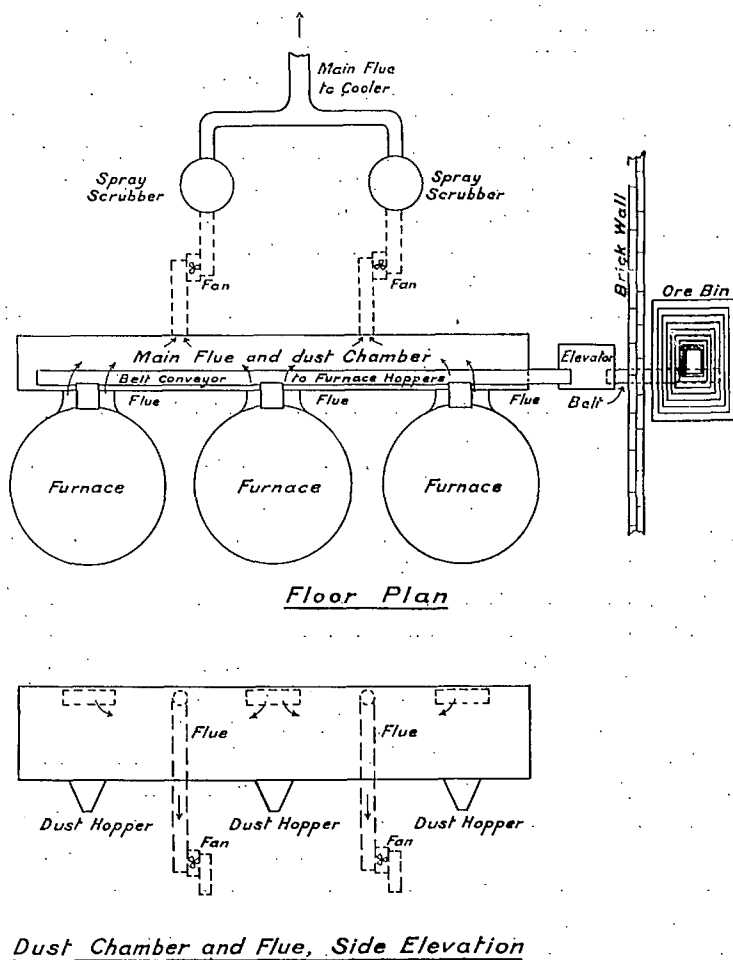


FIG. 23. Plan of the pyrites roasting plant of the West Virginia Pulp and Paper Company.

Two gas flues lead from the main flue and dust chamber through centrifugal fans to a pair of scrubbing towers. These towers are about 7' in diameter and 18' in height. In each tower the gas enters at the base and passes upward against a descending spray of water, from six rose sprays, located at

the top of the tower. From the scrubbers the gas passes directly into the main flue and thence to the coolers located in another building. The water for the scrubbers is circulated by a centrifugal pump, and after use is discharged.

To facilitate the handling of the ore, a storage bin is provided just outside the building into which the ore can be dumped from the cars. A belt conveyor located beneath the bin carries the ore into the burner building and dumps it into the boot of an elevator. The ore is then raised, and another belt conveyor, located on top of the main flue, carries the ore to the feed hoppers immediately above the furnaces. The cinders are removed in cars on an industrial railroad by hand labour.

The ore used, from the Arminius mine in Virginia, contains about 41% sulphur; the cinder contains about 4.5 to 5%. The gas produced contains 11% sulphur dioxide.

Hinckley Fibre Co., Hinckley, New York

This firm have been experimenting for some time on the use of the Jones Rotary Sulphur Burner and auxiliary appliances for the preparation of sulphur dioxide for sulphite pulpliquors.¹ The kiln installed at Hinckley is 8' in diameter, and 70' in length (Plate XXIV, and Figures 24 and 25). This has been found sufficient to roast enough pyrites, running as low as 22% sulphur, for the manufacture of 55-60 tons of sulphite fibre per 24 hour day, with, it is stated, "most excellent success." United States, Canadian, and Spanish fine have been tried in this plant with equal success.

In operating this plant the ore is crushed to pass a one inch ring, but it is not screened, fines and coarse being charged together. Working on ore carrying 35-40% sulphur it is stated that the furnace will roast to 2% sulphur in the cinder; cinder as low as 0.7% has been obtained. The plant at Hinckley has been able to obtain a gas containing 6.5%-7.5% sulphur dioxide when using ore carrying 22%. The strength of the gas increases as the sulphur content of the ore increases; it is claimed that a 12% gas, or near this point can be maintained with a 40% ore. No data are available as to the quantity of sulphur which it is necessary to vaporize in the auxiliary oven in order to keep the gas obtained from the low grade pyrites ores up to 7% of sulphur dioxide, nor is the amount of sulphur in the cinder definitely stated in this case.

When burning rich ores it is claimed, according to the Canadian Patent specifications, that it is not necessary to use the auxiliary oven to vaporize sulphur to supplement that obtained from the ore. In the statements already received it has not been shown whether it was possible to cease vaporizing sulphur in the auxiliary oven when maintaining a steady output of gas containing 12% sulphur dioxide.

¹ For a description and drawing of this apparatus, see this report, page 125. This description and the accompanying Plate XXIV are published through the courtesy of the Hinckley Fibre Company, and the Pyrite Engineering Company of Carthage, N.Y.

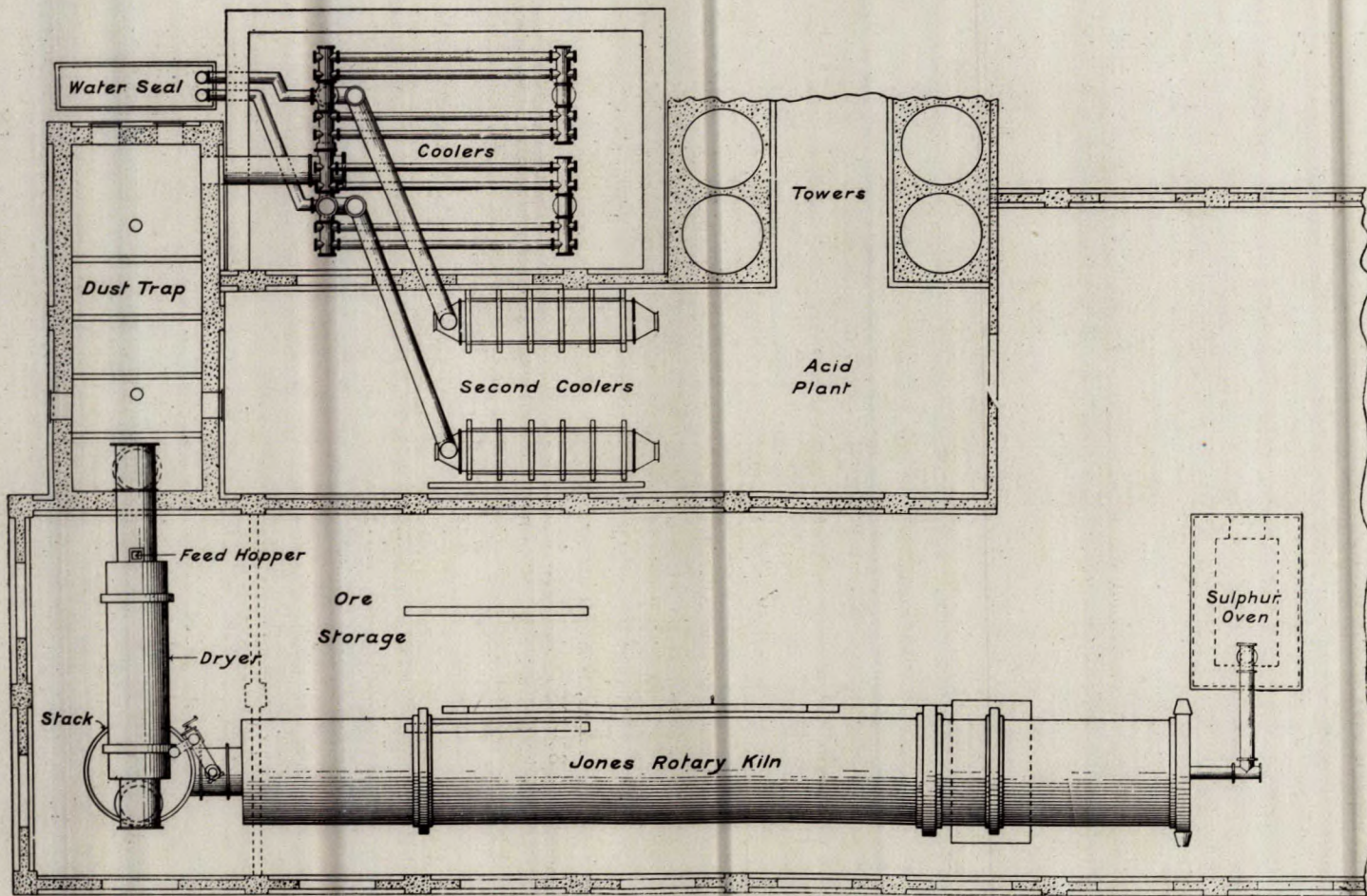
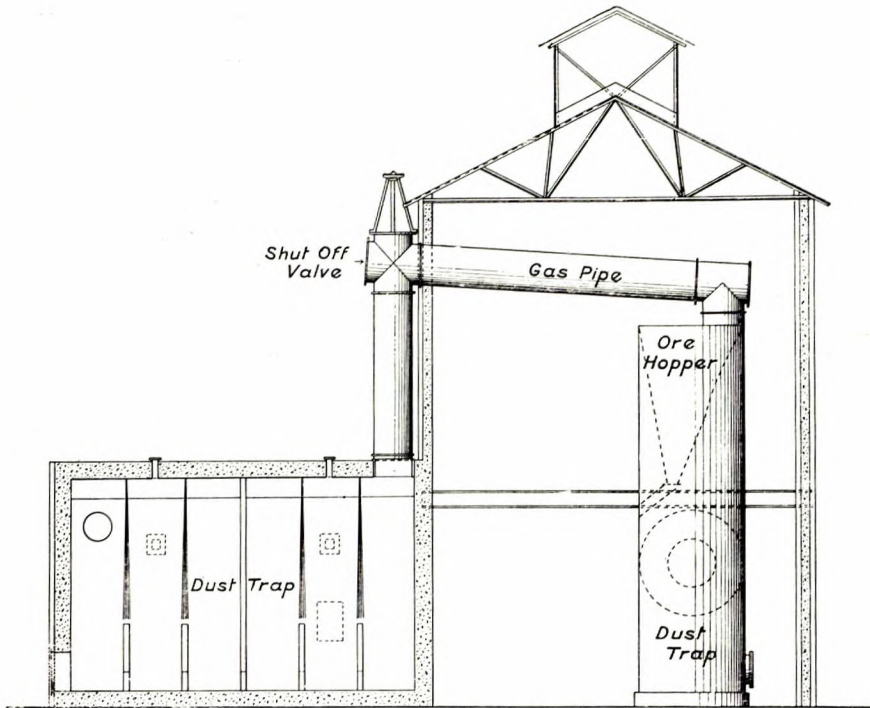


FIG. 24. Pyrites roasting plant, Hinckley Fibre Company, Hinckley, New York. Plan.

No data as to the relative quantities of sulphur and pyrites needed to produce a standard gas, using ores of different grades, are available, and no cost data have been supplied.

The power required to operate a burner of this size, capable of roasting about 30 tons of ore per 24 hours, is approximately 12 H.P. not inclusive of that needed to crush the ore.



END SECTIONAL VIEW

FIG. 25. Pyrites roasting plant, Hinckley Fibre Company, Hinckley, New York. Transverse section.

The accompanying plan and section (Figures 24 and 25) supplied through the courtesy of the Pyrite Engineering Company, Carthage, New York, shows the Jones Plant installed at Hinckley. A complete description of the kiln, driers, dust chamber, and method of cooling the gases is given in the section describing the Jones Burner (p. 125) and it is not necessary to repeat that description here.

Lake Superior Paper Company, Sault Ste. Marie, Ontario

On a previous page of this report the Sjöstedt modification of the MacDougall type of furnace is described in some detail. Four batteries of the Sjöstedt

furnaces—16 units in all—were installed at Sault Ste. Marie, Ontario, some years ago.¹ Sulphur dioxide was prepared in these furnaces for various purposes, and, among other uses, it was applied to the preparation of the sulphite liquors in the sulphite pulp mill. Mr. Sjöstedt found it quite practicable to prepare liquors of suitable strength. He writes: "Our experience here has taught us that for economically obtaining such a liquor a minimum of 5% SO₂ in the roasting gas is required. . . . We succeeded in producing an 8 per cent SO₂ gas from pyrrhotite with less than 25 per cent sulphur (as previously shown), and found subsequently no difficulty in making a gas of 8-10 per cent SO₂ contents from a rich (30 per cent S) pyrrhotite, and in obtaining a recovery efficiency of 70-80 per cent."

The writer was informed by the late Mr. Sjöstedt that it was intended to use this installation of pyrites burners in the sulphite mill of the newly organized Lake Superior Paper Company. It is also proposed to use one of the large towers, formerly used for preparing the sulphite liquors, as a special spray tower for purifying and cooling the gases before passing into them the absorbing towers. Further details with respect to the new installation are not available.

¹For full description see "Acid Making from Pyrrhotite," by Ernst A. Sjöstedt, Jour. Can. Min. Inst., Vol. VII.

APPENDIX I.

FIRMS INTERESTED IN CANADIAN PYRITES

TABLE XXII.

Firms in Canada Mining and Shipping Pyrites in 1912.*Quebec*

1. Eustis Mining Co., Mine at Eustis, Quebec. Head Office, Box 1422, Boston, Mass.
2. East Canada Mining and Smelting Co., Mines at Weedon, Quebec. President, Charles E. Force, 49 Wall St., New York.

Ontario

3. Nichols Chemical Co., Mines at Sulphide, Ontario, Canadian Office, 222 St. James St., Montreal, Que.
4. Ontario Sulphur Mines, Limited, Mines near Sulphide, Ontario. Manager B. A. C. Craig, National Club, Toronto.¹
5. Canadian Sulphur Co., Limited, Mine near Queensboro, Ontario, Manager, A. B. Willmott, 404 Lumsden Building, Toronto, Ontario.
6. Northern Pyrites Co., Mines near Graham, Ontario. Head Office, 25 Broad St., New York.
7. Lake Superior Corporation, Helen Mine, 15 miles from Michipicoten Harbour, Lake Superior, Mines Manager, R. W. Seelye, Sault Ste. Marie, Ontario.

TABLE XXIII.

Firms in Canada Manufacturing Sulphuric Acid.

1. Dominion Iron and Steel Company, Limited, Sydney, Cape Breton.
2. Nichols Chemical Co., Office 222 St. James St., Montreal, Works at: Capelton, Quebec. Sulphide, Ontario. Barnet Bay, British Columbia.
3. Grasselli Chemical Co., Head Office, Cleveland, Ohio. Works at: Hamilton, Ontario, under construction.
4. Lake Superior Corporation, Sault Ste Marie, Ontario.²
5. Victoria Chemical Co., Limited, Victoria, British Columbia.

¹ Mine closed near end of year, 1911.

² Plant under construction.

TABLE XXIV.

Firms in the United States Adjacent to Canada, who Operate Pyrites Burners.

Firm name.	Address.			Products.	Location of Works.	Port of Entry.
	Street.	City.	State.	A. Acid only. C. Chemicals. F. Fertilizers.		
Armour Fertilizer Works.	Union Stock Yards,	Chicago,	Illinois.	A. F.	Chicago. New York. (several in southern states.)	Chicago. New York.
American Agricultural Chemical Co.,	2 Rector St.,	New York,	New York.	A. C. F.	Buffalo, Cleveland, Detroit, Atlantic Coast points.	Buffalo, Cleveland, Detroit.
American Alkali and Acid Co.,		Bradford,	Pennsylvania.	A. C.	Bradford, Penn.	Buffalo.
Buffalo Fertilizer Company,		Buffalo,	New York.	F.	Buffalo.	Buffalo.
Contact Process Company,		Buffalo,	New York.	A. C.	Buffalo.	Buffalo.
Cochrane Chemical Co.,	40 Central St.,	Boston,	Mass.	A. C.	Everett, Mass.	Charlestown, Mass.
Detroit Chemical Works,		Detroit,	Mich.	A. C. F.	Detroit.	Detroit.
E. I. du Pont de Nemours Powder Co.,	815 Du Pont Bldg.,	Wilmington,	Delaware.	A. Powders.	Barksdale, Wis.	Washburn, Wis.

General Chemical Co.,	25 Broad St.,	New York,	New York.	A. C. F.	Chicago, Ill.; Cleveland, Ohio; Buffalo, N.Y., Pittsburgh, Pa.; Camden, N.J.	Chicago, Cleveland, Erie, Buffalo, Camden, N.J.
Grasselli Chemical Co.,	784 The Arcade,	Cleveland,	Ohio.	A. C. F.	Chicago, Ill.; Cleveland, Ohio.	Chicago, Cleveland.
Jarecki Chemical Co.,		Cincinnati,	Ohio.	A. C. F.	Cincinnati, Ohio; Sandusky, Ohio.	Cleveland, Sandusky Buffalo.
Kalbfleisch, Franklin, H. & Co.,	Broadway and 16th St., Metropolis Building,	New York,	New York.	A. C.	Erie, Pa.	Erie.
Lister's Agricultural Chemical Works,	P.O. Box 286,	Newark,	New Jersey.	A. C.	Newark, N.J.	Newark, N.J.
Merrimac Chemical Co.,	33 Broad,	Boston,	Mass.	A. C.	South Wilmington, Mass.	Charlestown, Mass.
Nangatuch Chemical Co.,		Nangatuck,	Conn.	A.	Nangatuck, Conn.	
New Jersey Zinc Co.,	55 Wall St.,	New York,	N. Y.	A.		
Pyrite Engineering Co.,		Carthage,	New York.	Sulphite.	Hinckley, N. Y.	Oswego, N. Y.
Riverside Acid Works,		Warren,	Penn.	A.	Warren, Penn.	Erie, Penn; Buffalo, N. Y.
Smith Agricultural Chemical Company,		Columbus,	Ohio.	A.	Columbus.	Erie, Buffalo.
Standard Oil Company,	26 Broadway,	New York,	N. Y.	A.	Chicago, Bergenport, N. J.	Chicago, Bergenport, N. J.
Swift and Company,	Fertilizer Department,	Chicago,	Ill.	A. F.	Chicago, Cleveland.	Chicago, Cleveland, Buffalo.

APPENDIX II.

TYPES OF FURNACES USED FOR BURNING SULPHUR

One of the earliest methods in vogue to produce sulphur dioxide for the manufacture of sulphuric acid was to place sulphur in an iron vessel and ignite it. The pot of burning sulphur was then placed in an air tight lead chamber filled with moist air. The combustion of the sulphur would continue until the oxygen of this air was exhausted. After waiting for a suitable period of time until the vapors produced had been absorbed by the water in the chamber, the doors were opened, fresh air was admitted, a new supply of burning sulphur was introduced, and the process was repeated. Naturally such an intermittent method of promoting the oxidation of the sulphur was both slow and expensive, and the quantity of acid that could be made in this way was small and costly.

Then followed the invention of the process of burning the sulphur in air in a vessel outside the acid chamber, and the possibility of manufacturing the acid by a continuous process.

The kinds of burners that have been employed for this purpose are very numerous. Until recent years the flat or pan type of burner in its various forms has been most widely used. Many of these burners are still used in acid works and in some sulphite pulp mills, and in other industrial plants. The necessity of obtaining a very rich gas for the manufacture of sulphite pulp, and the desire to overcome the many defects of the flat burners has led to the development of several types of mechanical burners of much higher efficiency than the old style of burner. These mechanical burners are widely used in sulphite pulp mills and other industrial plants, and appear to be displacing the older kinds even in chemical works where sulphur is used.

There are a large number of different kinds of flat burners in use. The reader who is interested in the details of their construction and operation had best consult some of the technical works on this subject.¹

It has not been considered desirable to republish detailed descriptions of the various kinds of flat burners and the description offered in this report applies rather to the type than to any individual burner.

The descriptions of the mechanically operated burners used in American mills have been made more complete because this type of burner is coming into more general use and because descriptions of these burners are not so readily available as those of the older type.

¹ Lunge—Sulphuric Acid and Alkali, 3rd Ed., Vol. I, Part I, pp. 268-286.
Hoffmann—Papier Fabrikation, 2nd Ed., Band II, pp. 1454-1462.
Papier—Zeitung, 1894, 1895, and other issues.

Flat or (Pan) Burners.—The simplest form of pan burner consists of a flat bottomed cast iron pan covered with a cast iron or brick arch to form a chamber. The pans vary in size, depth 3"-7", width 3'-4', length 6'-8'. The bottom of the pan rests on cast iron standards or upon brick columns or walls. The bottom of the pan is usually slightly dished or inclined so that the molten sulphur will collect in a pool nearer the forward end. To facilitate the removal of ash and to simplify the charging of the furnace, the front side of the pan is often reduced to a mere rim, 2" in height, or less. A door is usually provided at one end of the chamber, and the other end connects with

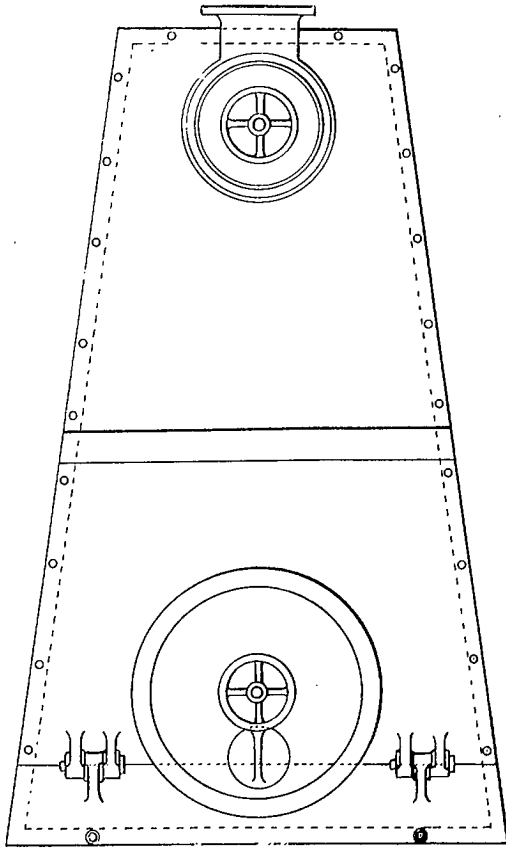


FIG. 26. Plan of Kellner pan sulphur burner (Hofmann).

the flue leading to the place where the products of combustion are to be utilized. The door, which reaches across the whole end of the furnace, is hinged at the top. In charging, it is raised, sulphur is spread evenly over the forward end of the pan, and the door is lowered. Air is admitted to the furnace through the forward end by keeping the edge of the door slightly raised by means of hand screws provided for this purpose.

The operation of oxidizing sulphur in a burner of this type is started by building a small fire of wood chips in the front of the furnace to warm the pan and brick work. When the furnace becomes hot enough to fuse sulphur, the fire is withdrawn and sulphur is shovelled in and ignited. The heat generated by the combustion causes it to melt and the molten sulphur spreads over the forward two-thirds of the pan. As the sulphur burns away, fresh supplies are introduced from time to time as required.

It can easily be seen that the method of feeding sulphur intermittently by opening the door across the whole end of the furnace causes a large quantity of cool air to be suddenly admitted to the furnace. This air will not only cool the furnace and gases temporarily but will also dilute the products of combustion, and thus renders the operation of the furnace irregular.

Where a number of furnaces are employed, opening into a common flue, the disturbance produced by opening the doors for charging can be greatly reduced by feeding the furnaces in regular order at stated intervals.

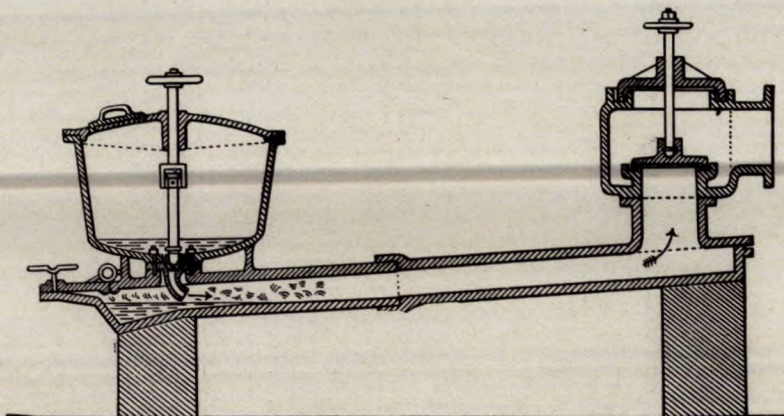


FIG. 27. Section of Kellner pan sulphur burner (Hofmann).

According to Lunge the capacity of furnaces of this type is about one pound of sulphur per square foot per hour.

The modifications of this type of furnace are very numerous. Many of the pan burners are made wider in front than at the rear. On some, special devices are employed to retain or utilize the heat, especially in those flat burners which are designed for use in chemical works. On others a method of water cooling is introduced in an attempt to reduce the volatilization of the sulphur to a minimum, and incidentally to assist in the cooling of the gases for use in the manufacture of the liquors for the sulphite pulp industry.

One of the most important modifications of this type of burner is the utilization of a portion of the heat of combustion for the purpose of fusing the feed sulphur—which then can be introduced in liquid form without opening the doors and without disturbing the drafts.

The accompanying drawings (figures 26 and 27) show in plan and section one form of pan sulphur burner. In this type the pan is inclined forward and a well is provided to hold the molten sulphur. The rear end of the furnace acts as a combustion chamber. This burner is fitted with a special cast iron feed hopper placed near the forward end of the furnace. Sulphur is shovelled into the hopper through an opening in the top. Heat radiated or conducted from the cast iron top of the burner is sufficient to fuse the sulphur in the bottom of the feed hopper. The melted sulphur can then be discharged into the burner below through the spout provided for that purpose. The flow of molten sulphur is regulated by means of a valve seated in the base of the spout. The door of the furnace can be raised for removing ash. It is also provided with hand screws whose stems engage with the lip of the lower edge of the pan. By adjusting these screws the door can be made to serve as a damper for admitting the requisite amount of air to promote combustion. The rear end of this furnace is provided with a special cast iron valve chamber for regulating the flow of the burner gases.

*Tromblee and Paull Rotary Sulphur Burner.*¹—The Tromblee and Paull Rotary Sulphur Burner consists, essentially, of a cylindrical steel shell which can be rotated around a horizontal axis. This cylinder is provided with cast iron heads, in the form of truncated cones. One of these heads is fitted with a feed door, draft slots, and a damper; the other leads to a combustion chamber (Plate XXV).

The shell of the burner is made of flange steel, (rivetted and corked seam), and is 36" in diameter and 8' in length. The cone-shaped heads are made of cast iron. The flanges of the heads serve as annular rails upon which the burner moves when rotated. The flanges rest on two pairs of cast iron rolls mounted on cast iron foundation plates. The rolls are rotated by chain-driven gears.

The door on the free end of the burner is slotted and is provided with a rotary damper by which the air supply admitted to the furnace can be regulated.

The combustion chamber supplied by the makers consists of a cast iron box 30" wide, 44" high, and 48" long. The neck of the rear head of the burner passes into the side of this chamber. An auxiliary damper for admitting air to the combustion chamber is placed on one side. A door is provided on the rear of the chamber for cleaning.

The pipe connection for the escape of the gases is placed on the top of the chamber at the rear. When in operation, sulphur is fed to the burner through the door at the front end of the machine. As the burner revolves the sulphur is carried over, making a complete coating of sulphur on the inside of the burner. The whole inside surface of the burner thus becomes coated with burning sulphur. By a proper adjustment of dampers a nearly perfect combustion can be obtained. According to the makers, the actual time consumed

¹ Manufactured by the Glen Falls Machine Works, Glen Falls, New York. Canadian Patent 75,826, United States Patents 685779 and 749,311.

in feeding a single burner per 24 hours is about 45 minutes. The speed of rotation should be about 12 turns per minute; the power required is about $\frac{1}{4}$ horse power. The floor space required is $7' \times 16'$.

The capacity of the burner is 6,000-7,000 pounds of sulphur per 24 hours.

The approximate cost of the burner is \$700 each¹ at Glen Falls, New York.

The more recent form of burner is now supplied with a self feed so arranged that it is not necessary to open the door of the furnace when charging. This attachment consists of a hopper which is placed directly in front of the furnace. A spout leads from the bottom of the hopper through the centre of the furnace door. The raw sulphur fed into the hopper by a shovel is forced into the spout and thence into the furnace by a worm gear.

At one plant visited by the writer he found the Tromblee-Paull furnaces fitted with an automatic feed of local design. A sheet steel feed hopper had been constructed just above the furnace in such a position that the heat of the furnace melted the sulphur in the bottom of the hopper. The fused sulphur was then conducted through a 2" pipe to the centre of the feeding door, and thence into the furnace. A valve on the pipe, close to the hopper enabled the operators to control the rate of flow.

The advantage arising from an automatic feed lies not alone in the saving of labour, but also in the fact that the furnace is kept in operation continuously under uniform conditions. The intermittent opening of the furnace doors, to charge the furnace, temporarily admits an excess of air to the furnace and alters the composition of the gases produced.

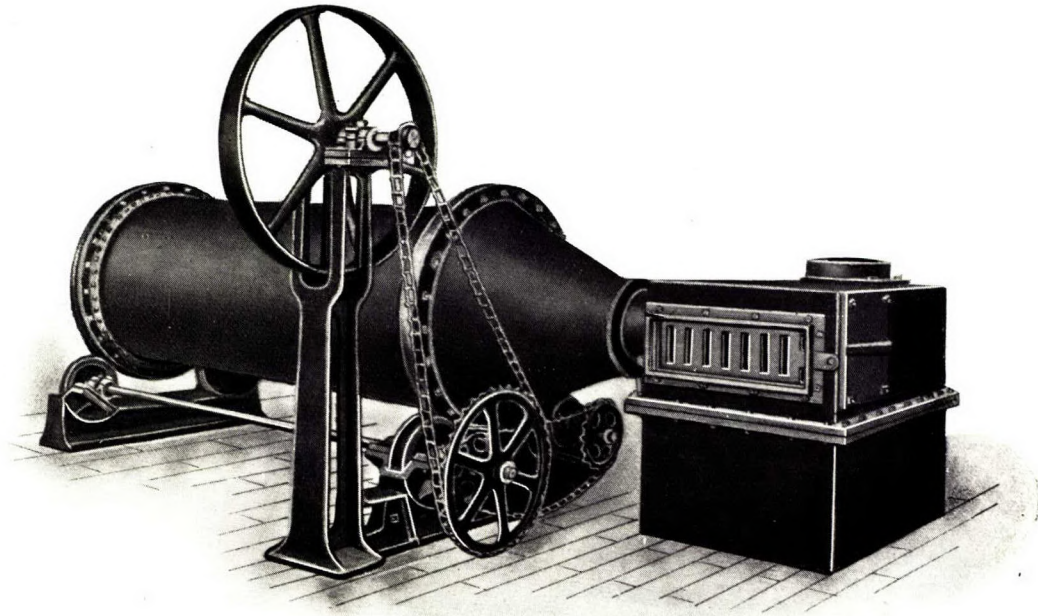
At another plant, in which two of these burners are installed, special combustion chambers, having a much greater capacity than the standard chamber had been installed. The chambers were set end to end back of the burners. Each chamber consists of a cylindrical shell built of boiler plate and lined with fire brick. The cylinder is 48" in diameter and the total length is 24', each chamber being 12' in length. The fire brick lining is 6" thick, so that the central free space is 36" in diameter. Two sets of fire brick checker work are introduced in each chamber to insure perfect mixing of the gases. Air is admitted to the chamber with the gases from the furnace, by means of a large opening, controlled by a damper, in the pipe connecting the furnace and the combustion chamber. The temperature within the combustion chamber is said to be between 1,200° and 1,600° F. The gas comes off at about 900° F.

*Stebbins Rotary Sulphur Burner.*²—The Stebbins Rotary Sulphur Burner consists of a cylindrical steel shell, the ends of which are closed by outwardly dished steel heads, the whole mounted on rollers in such a way that the burner can be rotated about a horizontal axis. At the free end of the cylinder

¹ Subject to ordinary market fluctuations.

² Manufactured by the Stebbins Engineering and Manufacturing Company, Rooms 74-76, Smith Building, Watertown, N.Y.

Canadian Patent number 123,629; United States Patents numbers 906,574 and 934,700.



Tromblee and Paull rotary sulphur burner.

provision is made for feeding liquid sulphur to the furnace and for admitting a controlled supply of air. The distal end of the furnace is provided with orifices and dampers to admit auxiliary air supplies and with baffle plates to insure a thorough mixing of the air, gases and vapors, thus promoting combustion.

The general construction and operation of the furnace will be understood by a reference to Plate XXVI and Figures 28 and 29. On Plate XXVI, "A" shows a stationary casting to which is attached a swinging door (1). This door is provided with draught slots arranged in a circle and controlled by an annular rotary damper. The feed hopper (2) is placed above the casting A. This hopper is constructed with two sulphur receiving compartments, the sides of which are curved inwards at the lower ends. The mouth of the hopper is closed by sliding doors that run in guides. The bottom of the hopper is provided with a trough or chute that projects into the head of the furnace (Figure 28).

The rear head of the furnace includes an annular section of the same diameter as the body cylinder. This section is provided with an opening at its centre, the walls of which curve inward as shown in the drawing (Figure 28). A removable baffle plate is secured to the rear side of this partition. The walls of this baffle plate are flared outward to form a mouth concentric with but of less diameter than the mouth of the section.

Beyond this partition is arranged an annular plate, (Plate XXVI, 3) provided near its periphery with a number of openings (six or more, not shown). The section of the shell between these two partitions is provided with a number of inwardly projecting nozzles, the inlet ends of which are controlled by dampers. A regulated quantity of air can be admitted through these openings to the chamber formed by the partition and the plate. The next chamber, formed between the plate and the head section, is also provided in its end with an annular plate communicating with the outside. The passage of air through these orifices into this chamber is controlled by dampers (Figure 28). Gas from this chamber is discharged into the fixed tee fitting (C, Plate XXVI), the vertical extension of which connects with the flue leading to the place where the gases are to be utilized. The rear end of this casting is also provided with a plate having ventilating orifices that are controlled by a damper.

The body of the burner, Plate XXVI, B, consists of a cylindrical steel shell. This body is provided with two annular tracks formed by the flanges on the heads, and these tracks rest on rollers. The body is provided internally with longitudinal flights or buckets (shown in section, Figure 29) which serve to carry the fluid sulphur from the bottom of the burner and discharge it in the tract of air as this passes through the burner to the outlet.

The heads of the cylinder engage with the fixed castings A and C, Plate XXVI, by a suitable arrangement of flanges and rings so adjusted that the cylinder is free to rotate about its horizontal axis, while the joints are sufficiently close to prevent the escape of gases.

The rotation of the burner is accomplished through the rotation of the rollers on which the flanges of the cylinder rest. Power is applied to the rollers from any convenient source through a suitable arrangement of gears and shafting.

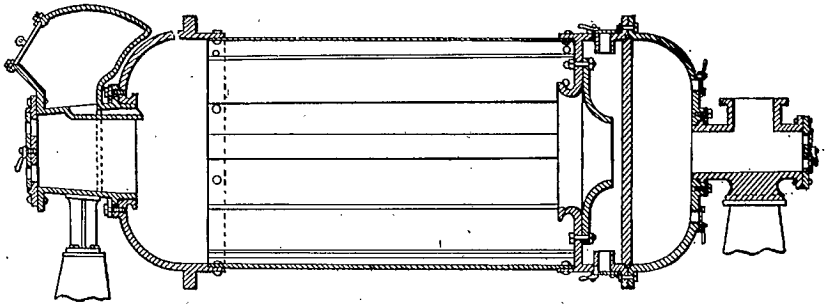


FIG. 28. Section through a Stebbins burner, longitudinal.

The furnace is put in operation by placing sulphur in the hopper and igniting it. As soon as it begins to melt, the molten sulphur runs down the trough and discharges into the cylinder. When the furnace becomes heated by the combustion of the sulphur, the heat radiated to the hopper is sufficient to keep the supply in a liquid condition so that a continuous feed is obtained. As soon as the sulphur is ignited, power is applied and the burner begins to

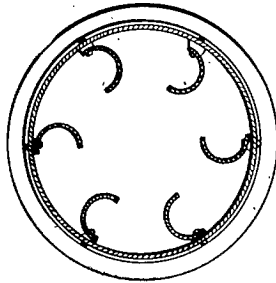
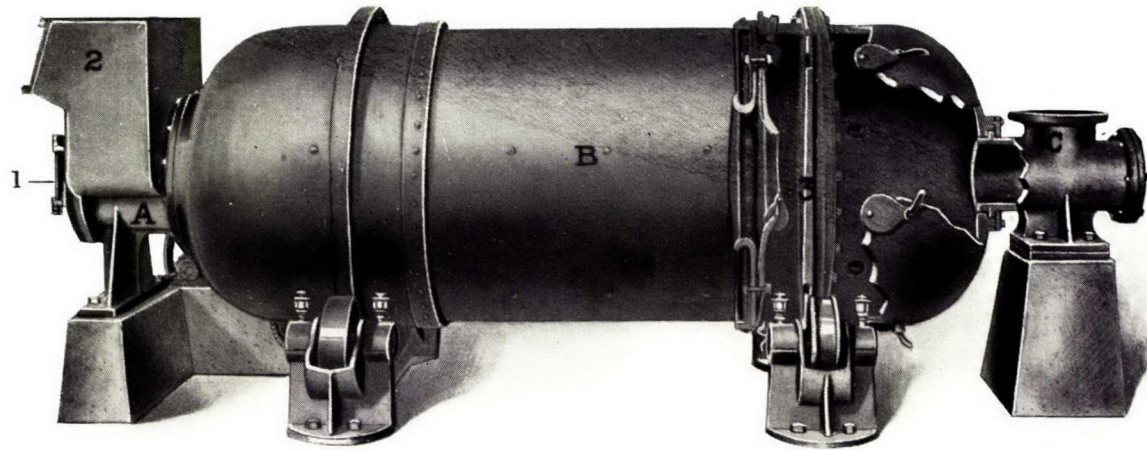


FIG. 29. Transverse section through a Stebbins burner.

rotate. As the cylinder revolves the longitudinal buckets pick up the molten mass and drop it through the current of air supplied through the draft openings in the door. The gases produced pass through the circular opening in the baffle plate into the first chamber. Here, if further oxidation is required, additional air may be secured by operating the dampers on the nozzles discharging into this chamber. The gases then pass through the openings in the periphery of the partition plate into the rear head chamber, where if necessary a further supply of air can be introduced by means of the annular



Stebbins rotary sulphur burner.

damper in the rear. Thence the gases pass into the fixed tee chamber, where again air can be admitted if needed. Finally the gases pass out through the flue to the place of use.

In this furnace it will be noted that the chambers formed at the rear end of the cylinder serve as combustion chambers, auxiliary combustion chambers not being required. It is claimed by the makers that perfect combustion can be obtained without the use of the air inlets and dampers on the tee chamber at the rear of the furnace. These openings are, however, provided as a precaution in case they may happen to be required.

*Wise Agitating Sulphur Burner.*¹—The essential features of the Wise Agitating Burner are as follows:—

1. A cylindrical cast iron pot to hold the liquid sulphur during combustion.

2. A rotating arm with rakes which agitate the liquid sulphur, increases the oxidizing surface, and otherwise promotes the rapidity of combustion or volatilization.

3. A combustion chamber placed above the pot and so constructed that thorough combustion of the sulphur can be obtained.

The general construction of the furnace can be seen by reference to the accompanying Plate XXVII.

In starting the furnace, a sufficient quantity of sulphur is thrown in the front door and ignited in the ordinary way. As soon as this sulphur is melted the agitator is started and all subsequent charges of sulphur are fed through the feed hoppers. Once the burner is started the front door remains closed continuously, thus preventing the inrush of cold air.

The feed hoppers are attached to the sides of the burner pot. The heat radiated from the combustion of the sulphur in the pot melts the sulphur in the hoppers. The liquid sulphur is then permitted to flow into the pot through valve controlled openings provided for that purpose. The rate of feed is so adjusted that the quantity of liquid sulphur in the pot remains constant.

The liquid sulphur in the pot is kept in motion by stirrer blades attached to a rotating arm. Power is applied to the arm through a shaft and bevelled gears located below the pot. The agitator arm makes only four or five revolutions per minute, and the power required is about $\frac{1}{3}$ horse power.

Draught slots controlled by dampers are arranged to admit air around the periphery of the pot. This method of admitting the air, whereby equal volumes of air advance towards the centre of the pot simultaneously from all sides, tends to promote uniformity of the conditions throughout the pot and at the same time promotes uniform combustion of the sulphur.

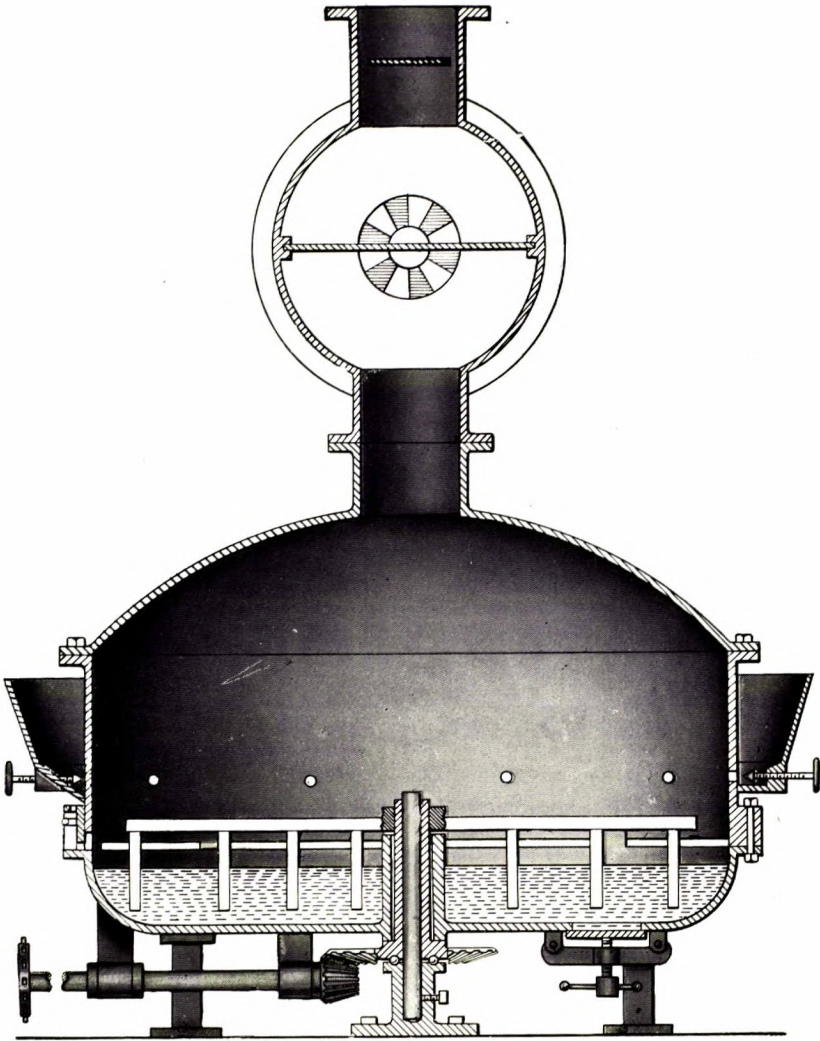
¹ Manufactured by the Raquette Foundry and Supply Co., Massena, N.Y.
Canadian Patent No. 103780.
United States Patent No. 835,926, Re-issue No. 12,921.

The pot is covered with a cast iron dome through the top of which a short conduit leads to the combustion chamber. The stream of gas entering this chamber from the pot below is divided into ten equal streams by a horizontal baffle plate or slotted partition placed in the bottom of the chamber. Draught slots or dampers are also located, one at the end of each slot in the baffle plate.

The amount of air admitted is under control by means of adjustable shutters. This auxiliary admission of air makes it possible to insure the complete combustion of the sulphur which may have been driven off as vapor from the pot below.

A single burner of this type requires $38\frac{1}{2}$ square feet of floor space, is 10'-6" high, and weighs approximately 10,000 pounds. The standard burner has a capacity of 12,000 pounds of sulphur per 24 hours. A smaller burner with a capacity of about 6,000 pounds is also constructed by the makers. The market price[†] for the larger size is approximately \$1,100 at the works.

[†] Subject to ordinary market fluctuations.



Wise rotary sulphur burner.

APPENDIX III.

PYRRHOTITE AS A SOURCE OF SULPHUR.

Magnetic pyrites or pyrrhotite, when pure, contains 39.6% of sulphur.¹ Pyrrhotite ores, as mined, would contain less than this; the sulphur content of the nickeliferous Sudbury ores varies to as low as 15%. Ores of this character are not usually regarded as sources of sulphur. The prevailing opinion held by many professional men until the last few years is summed up in the following quotation:—

“One of the most serious errors ever perpetrated in the manufacture of acid from pyrites is the attempted employment of pyrrhotite, or the monosulphide of iron, for pyrite—bisulphide of iron. Aside from the greatly lessened proportion of sulphur, 36%, as against 53%, the monosulphide will not even yield freely what sulphur it contains, but crusts with oxide of iron, turns black, and is soon extinguished when treated in an ordinary pyrites kiln. It seems scarcely possible that extensive works for the manufacture of sulphuric acid (and copper) should have been erected, their ore supply being entirely derived from a deposit of the valueless monosulphide; but such has been the case in more than one instance, and will continue to be so in enterprises conducted without the aid of skilled direction.”²

The further perfection of the modifications of the McDougall fines roasters, have, however, reached such a stage that it is beginning to be recognized that in the absence of other suitable ores, it may be commercially practicable to utilize pyrrhotite ores as a source of sulphur. Gas containing about 4% sulphur dioxide has been obtained by roasting pyrrhotite in a Wedge burner without any external source of heat. The best results attained, so far as these have been made public, appear to be those obtained by Mr. Ernest A. Sjöstedt, at Sault Ste. Marie, Ontario. The following extract, taken almost verbatim from Mr. Sjöstedt's published account of his experiments, is of more than passing interest.³

The problem presented to Mr. Sjöstedt was to recover sulphur and iron values from low grade Sudbury pyrrhotites-ores which averaged 15-20% sulphur, 1-3% nickel, 0.5-2% copper, the balance being made up of iron and gangue. Because of the ease with which pyrrhotite (pale yellow in colour) can be distinguished from chalcopyrite (deep yellow), it was possible to obtain a partial separation in the rock-house, at the crusher, and on the sorting table at the mine. Two workable grades of ore were obtained, one

¹ Assuming the Formula Fe_7S_8 . See page 13.

² Peters, *Modern Copper Smelting*, 1901, pp. 168-9.

³ Sjöstedt, Ernst A., “Acid Making from Pyrrhotite,” *Jour. Can. Min. Inst.* Vol. VII, 1904, pp. 480; *Can. Min. Jour.*, Vol. XXIII, pp. 64-69, 1904.

high in copper and gangue and low in sulphur, designed for the ordinary matte smelting process, and the other, low in copper and gangue, but high in sulphur and nickel, intended for the acid plant. This latter grade usually averages about 28% sulphur, 3% nickel, 0.5% copper and 50% iron.

The sulphur in this ore was to be recovered in the form of sulphur dioxide by roasting the pyrrhotite in a closed furnace. After cleaning and cooling, the gas was to be utilized for the following purposes:—

1. The manufacture of a "bisulphite liquor" to be used in the sulphite pulp mill.

2. The manufacture of liquid sulphurous anhydride, intended as a reserve supply for the sulphite mill, in case of any stoppage or interruption at the roasting plant, or when the pulp mill would call for more or a stronger gas than that furnished by the roasters in operation; it was also intended as a separate commercial product to be sold for the purpose of refrigeration, ice-making, sugar refining, bleaching, disinfecting, etc.

3. The manufacture of sulphuric acid—50° B, 66° B, and 98% strong—for the general market.

A number of different experiments were tried in shaft and reverberatory furnaces, and later in cylindrical mechanical roasters. Eventually the type of furnace, styled the Sjöstedt furnace in this bulletin¹ was evolved. After a series of successful experiments, a plant consisting of four batteries of kilns—16 units—was built having a total capacity of treating 40 tons of ore per day. Several auxiliary plants were also installed. One of these was a dressing plant consisting of one 24" x 15" jaw crusher, two 36" rolls and two revolving screens of No. 16 mesh, with a capacity of pulverizing about 80 tons of ore per 10 hour shift. Two Dellwik-Fleischer No. 4 water gas generators were also installed, each having a capacity of producing 20,000 cubic feet of water gas per hour, or with a total capacity of about 800,000 cubic feet per day. The electric installation for supplying the required power consisted of three 95 H.P. General Electric motors.

At first water-gas was used as an auxiliary fuel, but by gradually improving the details of the roasters and gaining in experience, they finally succeeded in doing without it. Since then the pyrrhotite has been roasted without any extraneous fuel (even at times when the sulphur in the ore averaged but 20-25%), producing a gas of sufficient strength (6-10% SO₂) for making bisulphite liquor and liquid sulphur dioxide; also a fairly well roasted ore, running as low as 0.20-0.75% sulphur when admitting a liberal amount of air and obtaining a weak gas, but generally from 1% to 3% sulphur when producing a good gas. The significance of 6-10% sulphur dioxide gas from pyrrhotite will be appreciated when it is noted that the theoretical maximum is 12.78%, assuming air to contain 21% of oxygen, by volume.

The annexed tables are from the records of a two weeks' run in February, 1904.

¹ See Chapter V, p. 122.

TABLE XXV.

Composition of Ore used (Average Samples taken from each 40 ton lot.)

	a	b	c	d	e	Average.
Insoluble.....	24.74	29.20	24.95	21.03	16.10	22.50
Sulphur.....	26.30	23.81	24.67	27.60	29.90	24.46

TABLE XXVI.

Roasting Results (Average of Tests made each Hour.)

February.....	11-12	13-14	15-16	17-18	19-20	21-22	23-24
Strength of Gas, % SO ₂	8.60	8.30	7.90	7.90	7.40	7.60	7.70
Roasted fines, % S....	1.66	1.86	2.04	2.54	1.78	0.95	1.86

In making a further comparison of the relative costs of raw sulphur and sulphur recovered from pyrrhotite, Mr. Sjöstedt gives the following additional data:—

“If to this amount we add depreciation of plant (say 14 cents per ton), the cost of the raw ore (say \$5.00 per ton), and the cost of briquetting the fines (say 75 cents per ton), and then subtract the value of the briquetted ferro-nickel ore, (which we will assume to be equal to that of the unroasted ore, or \$5.00 per ton), we obtain a total of \$2.75 as the cost of 914 pounds of sulphur dioxide, equal to \$6.00 per ton of sulphur dioxide gas recovered, corresponding to \$12 per net ton, or \$13.44 per gross ton of sulphur.”

At first no other raw material than pyrrhotite was used for acid making; subsequently, pyrites being available, some of it was used at times when treating a low grade pyrrhotite, or when an extra supply of gas was required. Altogether, at the time of writing, 10,000 tons of pyrrhotite and 3,000 tons of pyrite had been roasted in Mr. Sjöstedt's kilns at Sault Ste. Marie.¹

¹ Mr. Sjöstedt's discussion of the preparation of Bisulphide Liquors from gas prepared by burning pyrrhotite is given on page 159.

APPENDIX IV.

THE CONTACT PROCESS FOR THE MANUFACTURE OF SULPHURIC ACID.¹

Extract from the "Twelfth Census of the United States," 1900, Volume X, Part IV, pp. 533-537.

1. Historical.—The production of sulphuric acid is a matter of the greatest importance, as it is not only the foundation of the inorganic heavy-chemical industry and is used for many other purposes, but also has lately become a most important material in the organic dye-stuff industry, especially in the production of alizarine colours and of synthetic indigo. The contact process is causing a complete revolution in the methods of manufacture of sulphuric acid; hence an account of its historical development and present status should be of great interest. The historical development of this process may be divided into four periods.

First period: Phillips, in 1831, discovered the catalytic action of platinum in hastening the union of SO_2 and O to form SO_3 .

Second period: Wohler and Mahla in 1852, showed that many other substances besides platinum possess catalytic properties, and explained the character and course of the reaction.

Third period: Winkler used definite gas mixtures for the production of sulphuric anhydride, as it was then considered that only in this way could good quantitative yields be obtained.

Fourth period, the present one, is noted by the successful use of the furnace gases directly.

The investigations of the third period were directed toward the production of fuming sulphuric acid, which was then very expensive, while the investigations of the first and second periods had the same end as the work of the present time, that is, the replacement of the chamber process by improved methods.

The catalytic action of platinum was discovered by Humphry Davy in January, 1818, who showed that platinum wire, when warmed and then introduced into a mixture of oxygen (or air) with H , CO , ethylene, or cyanogen became incandescent, and that the gas mixture oxidized, usually gradually, but often rapidly.

Edmund Davy, in 1820, discovered that finely divided precipitated platinum, when moistened with alcohol and exposed to the air, becomes incandescent and the alcohol burns.

Doevereiner, in 1822, found that finely divided platinum, obtained by heating ammonio-platinic chloride, acted in the same manner, and, in 1824,

¹ R. Knietsch, Ber. d. d. Gesel., 1901, p. 4069.

that such platinum could ignite a stream of hydrogen, when this impinged upon it in contact with air, and utilized this discovery in his celebrated "lighting machine."

The honour of having first utilized this catalytic action, for the production of sulphur trioxide, is due to Peregrine Phillips of Bristol, England, who, in 1831, took out an English patent for his discovery, and, in 1832, Doevereiner and Magnus each confirmed the observations of Phillips. Although this discovery attracted much attention, nothing practical followed until 1848, when Schneider exhibited a working model of an apparatus, which produced sulphuric acid through the contact action of a specially prepared pumice. This alleged discovery was presented with great claims, but never was able to show a success, although wonderful results were confidently predicted. The same may be said of the method of Richard Laming, who also used a contact mass of pumice, prepared by boiling it in concentrated sulphuric acid, washing it in ammoniacal water, drying, and then impregnating it with about 1 per cent of manganese dioxide, finishing by heating the mass in a retort to 600° and allowing it to cool out of contact with the air. Here we note for the first time, the use of another contact substance, which, like platinum, can exist in various grades of oxidation, namely, manganese.

Especially noteworthy in this connection is the English patent of Jullion, 1846, because here, for the first time, the use of platinized asbestos as a contact mass is claimed. In 1849, Blondeau passed a current of a mixture of sulphur dioxide, steam, and air through a highly heated tube containing ferruginous, argillaceous sand and obtained sulphuric acid, while, in 1852, Wohler and Mahla found that oxides of iron, copper, and chrome also work catalytically upon a mixture of SO_2 and O, a mixture of cupric and chromic oxides being especially efficacious. These investigators gave, moreover, a correct explanation of this catalytic action; they found, namely, that cupric and ferric oxide, when heated in a current of sulphur dioxide free from oxygen, became reduced to cuprous and ferrous-ferric oxides with simultaneous formation of sulphuric acid which, however, ceased as soon as the reduction of the oxides was completed. On the other hand, chromic oxide, under similar conditions, remained entirely unaltered and no sulphuric acid was produced, while metallic copper, in spongy form, exerts no action upon a mixture of 2 vol. SO_2 + 1 vol. O at ordinary temperatures, but, when heated, cupric oxide is first formed, and then sulphuric acid.

They also call attention to the fact that this union of SO_2 and O can take place in the complete absence of H_2O .

Upon these important discoveries are based the later researches of Lunge and others upon the catalytic action of pyrites cinder in causing the formation of SO_3 . Quartz has also been recommended for this purpose, as have also platinized asbestos, platinized pumice, and even platinized clay.

Hundt, 1854, passed the hot roaster gas through a flue, filled with quartz fragments and heated by the gas, expecting to convert the greater part of the SO_2 into sulphuric acid with further treatment of the residue. The work of

Schmersahl and Bouk, 1885, followed the same lines, as did also the method of Henry Deacon, which was patented in 1871, and may be considered as closing the second period.

So far, not only had all attempts to supersede the chamber process failed, but also no practical method for the production of fuming sulphuric acid had been devised. In 1875, Clemens Winkler published his celebrated researches upon the formation of sulphuric anhydride, for which industrial chemistry must always be greatly indebted to him, as originating successful methods for the economical production of the fuming sulphuric acid for which, as it has become cheaper, many new uses have been discovered.

Winkler concluded, as a result of his experiments, that the SO_2 and O should always be present in the molecular proportion of 2:1, any excess of either gas having a deleterious influence upon the completeness of the reaction, and he obtained this desired proportion by simply breaking up ordinary hydrated sulphuric acid into H_2O , SO_2 , and O, removing the H_2O , and then recombining the SO_2 and O by means of appropriate contact substances, the preparation of which he greatly improved by utilizing the reducing action of formic acid. All subsequent work in this branch continued to follow the lines laid down by Winkler; hence, while little progress was made towards superseding the lead chamber, the manufacture of fuming sulphuric acid became highly developed.

II. *Knightsch's Work—Purification of the Gas*—This work was undertaken by the Badische Anilin-und-Soda-Fabrik to determine if a complete conversion of the SO_2 in roaster gas was as practically feasible as it is theoretically possible.

It is well known that the outgoing gases of the chamber process still contain 6 volume per cent of oxygen, and that the roaster gas employed in the contact work contained a similar excess. Hence, it was difficult to understand why, in the latter process, the yields were not nearer that of the former.

Experiments showed that when pure SO_2 was used the yield was close to the theoretical, even when a very large excess of O was present, which was contrary to the accepted views of Winkler.

When roaster gas was used in laboratory experiments, it was found that when this was carefully cooled, washed with sulphuric acid, and completely purified before it was allowed to enter the catalytic tube, the results were very satisfactory, nor could any diminution of the efficiency of the contact mass be noted even after several days' use. It was therefore supposed that the problem had been solved, and arrangements were made to carry on the process on full working scale.

It was, however, soon found that in practice the contact mass gradually lost all of its efficiency, no matter how carefully the gases were cooled and purified. Extended laboratory investigations were undertaken to determine the cause of this inefficiency, and it was ultimately discovered that there are substances which, when present in the gas, even in excessively small quantities, injure the catalytic properties of platinum to an extraordinary degree. Of all of the substances which may be found in roaster gas, arsenic is by far

the most deleterious, next mercury, while Sb, Bi, Pb, Fe, Zu, etc., are injurious only so far as they may coat the contact mass.

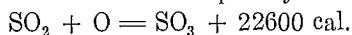
It was also found that as the white cloud of sulphuric acid which was present in the gas contained arsenic, the complete removal of this was necessary, although such removal had always been considered an impossibility. This was, however, finally accomplished after an enormous expenditure of time, labour and money, so that in the end, by extended washing and filtration, the gases were obtained in a condition absolutely free from all impurities. (D.R.P. 113933, July 22, 1898).

Slow cooling of the gas was found to be absolutely necessary as a preliminary to its purification. It is a fact, the cause of which is not yet clearly known, that the removal of the white cloud is rendered far more difficult if the gas is rapidly cooled.

To insure slow cooling, a system of iron tubes was used because it was supposed that, as the sulphuric acid in the gas was in a so highly concentrated condition any action upon the metal would yield SO₂ only. It was now found that although the contact mass remained active for a much longer period, it still gradually lost its power, no matter how carefully the gas was purified. The cause of this was ultimately found to be a gas containing arsenic, probably hydrogen arsenide, produced by the action of the acid upon the iron by which hydrogen was evolved, although the formation of this gas under such conditions had always been considered impossible. As soon as the cooling apparatus was so arranged that no condensed acid could attack the iron, the trouble from this source entirely ceased.

A final difficulty occurred in the occasional formation of a faint cloud of unburnt sulphur which contained arsenic. The cure for this was found to be a proper mixing of the hot gases, thus insuring complete combustion, and this mixing was effected by means of steam, which is also beneficial, by diluting the strong sulphuric acid present in the gas, so that it did not condense in the iron pipes of the first portion of the cooling apparatus, and attack them; when condensing in the lead pipes of the remainder of the apparatus, the acid was too weak to injure the lead. The use of steam also prevented the formation of hard dust crusts, which tend to stop up the pipes.

III. *Cooling of the Gases.*—The next important element in the successful carrying out of the contact process is the effective and economical utilization of the heat developed by the reaction which is exothermic.



The utilization of this heat had been suggested by Lunge, but only in the case of the use of a mixture of pure SO₂ and air, containing about 25 per cent of the former. On the other hand, it was universally considered that it was necessary to employ extra heat when the much weaker roaster gases are to be treated. Hence the apparatus used in this work was furnished with special heating arrangements so that the tubes could be kept at red heat, the tubes being arranged vertically like those of an upright boiler. Small, vertical tubes are much superior to the larger, horizontal ones, originally employed, as economizing the expensive platinized asbestos and insuring a more certain

contact of the gases with the mass. The proper filling of the tubes with the asbestos is a matter of importance; it must be so done that no portion of the gas can pass through a tube without coming in contact with the mass, while the mass must not offer much resistance to the passage of the gas. Owing to the nature of asbestos, this latter difficulty is likely to occur, but can be avoided by the simple device of packing the asbestos in successive layers, separated by perforated diaphragms sliding upon a central rod, but kept apart at regular intervals. In this way all of the tubes can be similarly and evenly packed.

As soon as this apparatus was started in the ordinary way at low red heat, the surprising discovery was made that not only was the output of acid increased, but that the strength of the gas current could be made greater when the tubes, instead of being heated artificially, were, on the contrary, cooled by the admission of cold air. This discovery, a contradiction of what had been considered correct practice, gave a rational method of work; i.e., the apparatus must be systematically cooled to obtain the maximum effect and production. As now operated, the tubes are cooled by the cold, purified gases, which thus become heated to the proper temperature for the reaction. In this the following advantages are gained:—

First. Overheating of the apparatus is avoided, and thus a yield of 96 per cent—98 per cent of the theoretical—is obtained.

Second. The iron parts of the apparatus are protected by this cooler working, and are therefore more durable.

Third. The contact mass does not become overheated, and its efficiency remains unimpaired.

Fourth. The absolute efficiency of the contact mass, and of the entire apparatus, is greatly increased because the rapidity of the gas stream can be increased, and the contact mass be maintained at the most efficient temperature.

Another important discovery is that the reaction proceeds at atmospheric pressure, since it was formerly supposed that compression of the gases was necessary to overcome the hindrance of the indifferent gases present. In fact, if the other conditions are right the reaction proceeds almost quantitatively at atmospheric pressure. This is very important since, if this method is to compete with the chamber process, every unnecessary expense must be avoided.

IV. Absorption of the Produced Anhydride.—The affinity of sulphuric anhydride for water is greater than for concentrated sulphuric acid, as shown by the relative amount of heat developed during the absorption; hence it might be expected that the easiest and most complete absorption of anhydride from the contact process would be effected by the use of water. It is found, however, that oil of vitriol containing 97-99 per cent of H_2SO_4 is much more effective than either water or sulphuric acid of any other strength. The absorbing power of the acid at this degree of concentration is so great that a single absorption vessel is sufficient for the removal of the SO_3 from a very rapid current of gas, provided that the strength of the acid be kept uniformly

between the above limits by a steady inflow of water or weak acid, and a proportional outflow of the excess of strong acid thus produced.

Sulphuric acid, at this particular degree of concentration, possesses certain marked qualities. Its boiling point is a maximum, so that if a weaker acid is evaporated, it loses water or weak acid until the residue attains a strength of 98.33 per cent H_2SO_4 , at which point it distills without further change at a constant temperature of about 330° . Similarly, a stronger acid gives off anhydride until this constant strength is reached. Again, at this particular degree, the vapour pressure is at its minimum, the specific gravity is at the maximum, the electrical resistance suddenly rises, while the action on iron decreases considerably.

When fuming sulphuric acid is to be made, one or more absorption cells must precede the regular apparatus. For these, cast iron, which is quite suitable as the material for the other vessels, becomes unavailable, because, although it is only slowly attacked, it, what is worse, becomes fragile and even explodes. This appears to be due to the fuming acid diffusing into the iron and then breaking up into SO_2 and H_2S , thus causing a condition of internal stress. Wrought iron is attacked by fuming acid containing less than 27 per cent of SO_3 , but when the contents of anhydride exceeds this, the acid has practically no action upon wrought iron, and vessels of this material can be used for years without sensible corrosion.

V. *Theory of the Contact Process.*—The results of many experiments showing the influence upon the reaction of variations in the temperature, the composition of the gases, the rate of flow (or the proportion of contact substance over which the gas passes) are given in the form of curves, and discussed, yielding the following results:—

1. Complete conversion of the SO_2 into SO_3 occurs only when there is at least twice as much oxygen present as the reaction formula indicates. When using the gas obtained from the roasting of pyrites, and which contains about 7 vol. per cent of SO_2 , 10 vol. per cent of O, and 83 vol. per cent of nitrogen, the nitrogen is absolutely without influence upon the reaction, except as diluting the gas and reducing the output.

2. The completeness of the reaction depends upon the temperature and not upon the nature of the contact substance. The reaction begins at about 200° . As the temperature rises, so does the degree of conversion, until, at about 400° , a nearly complete (98 to 99 per cent) conversion of the SO_2 is feasible. Any further rise in temperature is injurious, the degree of conversion falling so that at about 700° only about 60 per cent can be converted, while at about 900° the reaction ceases entirely.

3. The nature of the contact substance has no influence upon the completeness of the reaction, but, for practical results, a substance must be employed which shows a high degree of efficiency at the proper temperature of 400° . Substances which require a higher temperature to develop their greatest efficiency, are evidently unsuited, since, as shown above, the degree of conversion falls with the rise in temperature. Up to the present time only

one substance fulfilling the necessary conditions is known and that is platinum. None of the other metals of the platinum group approaches it in efficiency.

This valuable paper concludes with a series of tables, giving the results of exhaustive sets of determinations of the following properties of sulphuric acid, and of fuming sulphuric acid of various strengths from 1 to 100 per cent of SO_3 :

1. Melting point. 2. Specific gravity. 3. Specific heat. 4. Heat of solution. 5. Electrical resistance. 6. Action upon iron. 7. Boiling point. 8. Vapour pressure. 9. Viscosity. 10. Capillarity. 11. Table giving the percentage of free SO_3 in a fuming sulphuric acid when the total contents of SO_3 is known.

Production of Sulphur Trioxide.—The growth and present magnitude of the operations of this process in the works of the Badische Anilin-und-Soda Fabrik are shown by the following figures:—

Sulphur trioxide produced in—

1888.....	18,500 Tons
1894.....	39,000 “
1899.....	89,000 “
1900.....	116,000 “

It will be seen from the foregoing, that this process has long passed the experimental stage, and now that the general conditions of successful operation are known, its speedy adoption in this country is to be expected. The advantages are many: First, no expense of construction and maintenance of the entire chamber system, including the Gay-Lussac and Glover towers and the steam and niter plant. Second, no expense for niter and for the sulphuric acid used therewith; although the resulting niter cake can be utilized, it is rarely a desirable product. Third, the acid produced is pure, strong oil of vitriol, requiring no concentration for sale or use. Concentration of chamber acid to high strengths requires the use of platinum stills, which thereby lose in weight, the dissolved platinum being irrevocably lost. The rate of loss is much reduced by previous purification of the acid, but is always a considerable item of cost. Fourth, the contact acid is also free from arsenic, lead, or iron salts. The fundamental difference in the character of the reactions in the chamber process and of those in the contact method indicates the possibility of substantial improvements in the methods of roasting. Fifth, although the 50° acid, as it comes from the chambers, is desirable for many purposes—for example, in making superphosphates—it is held by some authorities that it can be made more cheaply by diluting the strong acid with the needed proportion of cold water, than by introducing this water into the chambers in the form of steam. This, however, is denied by others, and it is probable that the chamber process will continue to exist, though in a more restricted field.

On the other hand, this new process appears to require a well planned and carefully managed system of purification for the roaster gases, and will need, for its successful operation, a higher order of chemical engineering skill

than has usually been deemed necessary for the operation of an acid plant. This, however, should hardly be considered an obstacle in this country, where all other branches of engineering manufacture have reached such a height, mainly because the works have demanded and made liberal use of the highest order of trained ability, and have not hesitated to "scrap" expensive plant where it failed to give satisfactory results. In this connection the Badische Anilin-und-Soda-Fabrik is an instructive example. Its chemical force numbers over 100 men, many of whom are engaged solely upon researches, the results of which, when promising, are at once put into operation on a sufficiently large scale to determine their practical value. That such a course pays in a strict business sense is shown by the enormous dividends paid by this company, and by the practical monopoly which it has long maintained in certain lines, simply because it has been a little ahead of its competitors in knowing just how a given thing should be done, and then at once protecting the discovery by patents.

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CANADA
DEPARTMENT OF MINES

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HON. ROBERT ROGERS, MINISTER; A. P. LOW, LL.D., DEPUTY MINISTER;
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REPORTS AND MAPS OF ECONOMIC INTEREST

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REPORTS.

1. Mining Conditions of the Klondike, Yukon. Report on—by Eugene Haanel, Ph.D., 1902.
2. Great Landslide at Frank, Alta. Report on—by R. G. McConnell and R. W. Brock, M.A. 1903. (Out of print).
3. Investigation of the different electro-thermic processes for the smelting of iron ores, and the making of steel, in operation in Europe. Report of Special Commission—by Dr. Haanel, 1904. (Out of print).
4. Rapport de la Commission nommée pour étudier les divers procédés électro-thermiques pour la réduction des minerais de fer et la fabrication de l'acier employés en Europe—by Dr. Haanel. (French Edition), 1905. (Out of print).
5. On the location and examination of magnetic ore deposits by magnetometric measurements—by Dr. Haanel, 1904.
7. Limestones, and the Lime Industry of Manitoba. Preliminary Report on—by J. W. Wells, 1905. (Out of print).
8. Clays and Shales of Manitoba: Their Industrial Value. Preliminary Report on—by J. W. Wells, 1905. (Out of print).
9. Hydraulic Cements (Raw Materials) in Manitoba: Manufacture and Uses of. Preliminary Report on—by J. W. Wells, 1905. (Out of print).
10. Mica: Its Occurrence, Exploitation, and Uses—by Fritz Cirkel, M.E., 1905. (Out of print: see No. 118).
11. Asbestos: Its Occurrence, Exploitation, and Uses—by Fritz Cirkel, 1905. (Out of print: see No. 69).
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16. *Experiments made at Sault Ste. Marie, under Government auspices, in the smelting of Canadian iron ores by the electro-thermic process. Final Report on—by Dr. Haanel, 1907. (Out of print).
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22. Iron Ore Deposits of Thunder Bay and Rainy River districts. Report on—by F. Hille, M.E.
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26. The Mineral Production of Canada, 1906. Annual Report on—by John McLeish, B.A.
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29. Chrome Iron Ore Deposits of the Eastern Townships. Monograph on—by Fritz Cirkel. (Supplementary Section: Experiments with Chromite at McGill University—by Dr. J. B. Porter).
30. Investigation of the Peat Bogs and Peat Fuel Industry of Canada, 1908. Bulletin No. 1—by Erik Nyström, and A. Anrep, Peat Expert.
31. Production of Cement in Canada, 1908. Bulletin on—by John McLeish. (Out of print).
32. Investigation of Electric Shaft Furnace, Sweden. Report on—by Dr. Haanel.
42. Production of Iron and Steel in Canada during the calendar years 1907 and 1908. Bulletin on—by John McLeish.
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59. Chemical Analyses of Special Economic Importance made in the Laboratories of the Department of Mines, 1906-7-8. Report on—by F. G. Wait, M.A., F.C.S. (With Appendix on the Commercial Methods and Apparatus for the Analysis of Oil-shales—by H. A. Leverin, Ch.E.)
Schedule of Charges for Chemical Analyses and Assays.
62. Mineral Production of Canada, 1909. Preliminary Report on—by John McLeish.
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69. Chrysotile-Asbestos: Its Occurrence, Exploitation, Milling, and Uses. Report on—by Fritz Cirkel. (Second Edition, enlarged).
71. Investigation of the Peat Bogs, and Peat Industry of Canada, 1909-10; to which is appended Mr. Alf. Larson's Paper on Dr. M. Ekenberg's Wet-Carbonizing Process; from *Teknisk Tidskrift*, No. 12, December 26, 1908—translation by Mr. A. Anrep; also a translation of Lieut. Ekelund's Pamphlet entitled 'A Solution of the Peat Problem,' 1909, describing the Ekelund Process for the Manufacture of Peat Powder, by Harold A. Leverin, Ch. E. Bulletin No. 4—by A. Anrep. (Second Edition, enlarged). (Out of print).
79. Production of Iron and Steel in Canada during the calendar year 1909. Bulletin on—by John McLeish. (Out of print).
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81. French translation: Chrysotile-asbestos: Its Occurrence, Exploitation, Milling, and Uses. Report on—by Fritz Cirkel.
82. Magnetic Concentration Experiments. Bulletin No. 5—by Geo. C. Mackenzie.
83. An investigation of the Coals of Canada with reference to their Economic Qualities: as conducted at McGill University under the authority of the Dominion Government. Report on—by J. B. Porter, E.M., D.Sc., R. J. Durley, Ma.E., and others—
Vol. I—Coal Washing and Coking Tests.
Vol. II—Boiler and Gas Producer Tests.
Vol. III—
Appendix I
Coal Washing Tests and Diagrams.
84. Gypsum Deposits of the Maritime Provinces of Canada—including the Magdalen islands. Report on—by W. F. Jennison, M.E. (Out of print).
85. Production of Cement, Lime, Clay Products, Stone, and other Structural Materials during the calendar year 1909. Bulletin on—by John McLeish.
88. The Mineral Production of Canada 1909. Annual Report on—by John McLeish.
89. Reprint of Presidential address delivered before the American Peat Society at Ottawa, July 25, 1910. By Dr. Haanel.
90. Proceedings of Conference on Explosives.
92. Investigation of the Explosives Industry in the Dominion of Canada, 1910. Report on—by Capt. Arthur Desborough. (Second Edition).
93. Molybdenum Ores of Canada. Report on—by Dr. T. L. Walker.
100. The Building and Ornamental Stones of Canada. Report on—by Professor W. A. Parks.
102. Mineral Production of Canada, 1910. Preliminary Report on—by John McLeish.
103. Mines Branch Summary Report 1910. (Out of print).
104. Catalogue of Publications of Mines Branch, from 1902 to 1911; containing Tables of Contents and Lists of Maps, etc.
110. Western Portion of Torbrook Iron Ore Deposits, Annapolis county, N.S. Bulletin No. 7—by Howells Fréchette, M.Sc.
111. Diamond Drilling at Point Mamainse, Ont. Bulletin No. 6—by A. C. Lane, Ph.D. with Introductory by A. W. G. Wilson, Ph.D.
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150. The Mineral Production of Canada, 1911. Preliminary Report on—by John McLeish. (Out of print).
151. Investigation of the Peat Bogs and Peat Industry of Canada, 1910-11. Bulletin No. 8—by A. Anrep.
154. The Utilization of Peat Fuel for the Production of Power; being a record of experiments conducted at the Fuel Testing Station, Ottawa, 1910-11. Report on—by B. F. Haanel, B.Sc.
167. Pyrites in Canada: Its Occurrence, Exploitation, Dressing, and Uses. Report on—by Dr. A. W. G. Wilson.
170. The Nickel Industry: with special reference to the Sudbury region, Ont. Report on—by Prof. A. P. Coleman, Ph.D.
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199. Production of Copper, Gold, Lead, Nickel, Silver, Zinc, and Other Metals in Canada, during the calendar year 1911. Bulletin on—by John McLeish.
200. The Production of Coal and Coke in Canada during the calendar year 1911. Bulletin on—by John McLeish.

Note.—Lists of manufacturers of clay products, stone quarry operators, and operators of limekilns, are prepared annually by the Division of Mineral Resources and Statistics, and copies may be had on application.

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83. An investigation of the Coals of Canada with reference to their Economic Qualities; as conducted at McGill University under the authority of the Dominion Government. Report on—by J. B. Porter, R. J. Durley, and others—
- Vol. IV—
Appendix II
Boiler Tests and Diagrams, by R. J. Durley.
- Vol. V—
Appendix III
Producer Tests and Diagrams, by R. J. Durley.
- Vol. VI—
Appendix IV
Coking Tests, by Edgar Stansfield and J. B. Porter.
Appendix V
Chemical Tests, by Edgar Stansfield.
156. French Translation: The Tungsten Ores of Canada. Report on—by Dr. T. L. Walker.
196. French translation: Investigation of the Peat Bogs and Peat Industry of Canada, 1909-10; to which is appended Mr. Alf. Larson's paper on Dr. Ekenberg's Wet-Carbonizing Process: from *Teknisk Tidskrift*, No. 12, December 26, 1908—translation by Mr. A. Anrep, also a translation of Lieut. Ekelund's Pamphlet entitled "A Solution of the Peat Problem," 1909, describing the Ekelund Process for the Manufacture of Peat Powder, by Harold A. Leverin, Ch. E. Bulletin No. 4—by A. Anrep. (Second edition, enlarged).
197. French translation: Molybdenum Ores of Canada. Report on—by Dr. T. L. Walker.
198. French translation: Peat and Lignite: Their Manufacture and Uses in Europe—by Erik Nyström, 1908.
201. The Mineral Production of Canada during the calendar year 1911. Annual report on—by John McLeish.
202. French translation: Graphite: Its Properties, Occurrence, Refining, and Uses—by Fritz Cirkel, 1907.
203. Building Stones of Canada—Vol. II: Building and Ornamental Stones of the Maritime Provinces. Report on—by W. A. Parks.

MAPS.

- †6. Magnetometric Survey, Vertical Intensity: Calabogie mine, Bagot township, Renfrew county, Ontario—by E. Nyström, M.E., 1904.
- †14. Magnetometric Survey of the Wilbur mine, Lavant township, Lanark county, Ontario—by B. F. Haanel, 1905.
- †33. Magnetometric Survey, Vertical Intensity: Lot 1, Concession VI, Mayo township, Hastings county, Ontario—by Howells Fréchette, M.Sc., 1909.
- †34. Magnetometric Survey, Vertical Intensity: Lots 2 and 3, Concession VI, Mayo township, Hastings county, Ontario—by Howells Fréchette, 1909.
- †35. Magnetometric Survey, Vertical Intensity: Lots 10, 11, and 12, Concession IX, and Lots 11 and 12, Concession VIII, Mayo township, Hastings county, Ontario—by Howells Fréchette, 1909.
- *36. Survey of Mer Bleue Peat Bog, Gloucester township, Carleton county, and Cumberland township, Russell county, Ontario—by Erik Nyström, and A. Anrep.
- *37. Survey of Alfred Peat Bog, Alfred and Caledonia townships, Prescott county, Ontario—by Erik Nyström, and A. Anrep.
- *38. Survey of Welland Peat Bog, Wainfleet and Humberstone townships, Welland county, Ontario—by Erik Nyström, and A. Anrep.

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2. Maps marked thus † have been printed independently of reports, hence can be procured separately by applicants.

- *39. Survey of Newington Peat Bog, Osnabrook, Roxborough, and Cornwall townships, Stormont county, Ontario—by Erik Nyström, and A. Anrep.
- *40. Survey of Perth Peat Bog, Drummond township, Lanark county, Ontario—by Erik Nyström, and A. Anrep.
- *41. Survey of Victoria Road Peat Bog, Bexley and Carden townships, Victoria county, Ontario—by Erik Nyström, and A. Anrep.
48. Magnetometric Map of Iron Crown claim at Klaanch river, Vancouver island, B.C.—by Einar Lindeman.
49. Magnetometric Map of Western Steel Iron claim, at Sechart, Vancouver island, B.C.—by Einar Lindeman.
50. Vancouver island, B.C.—by Einar Lindeman.
51. Iron Mines, Texada island, B.C.—by E. H. Shepherd, C.E.
52. Sketch Map of Bog Iron Ore Deposits, West Arm, Quatsino sound, Vancouver island, B.C.
- *53. Iron Ore Occurrences, Ottawa and Pontiac counties, Quebec, 1908—by J. White, and Fritz Cirkel, M.E.
- †54. Iron Ore Occurrences, Argenteuil county, Quebec, 1908—by Fritz Cirkel.
- †57. The Productive Chrome Iron Ore District of Quebec—by Fritz Cirkel.
- †60. Magnetometric Survey of the Bristol mine, Pontiac county, Quebec—by Einar Lindeman.
61. Topographical Map of Bristol mine, Pontiac county, Quebec—by Einar Lindeman.
- †64. Index Map of Nova Scotia: Gypsum—by W. F. Jennison, M.E.
- †65. Index Map of New Brunswick: Gypsum—by W. F. Jennison.
- †66. Map of Magdalen islands: Gypsum—by W. F. Jennison.
70. Magnetometric Survey of Northwest Arm Iron Range, Lake Timagami, Nipissing district, Ontario—by Einar Lindeman.
- †72. Brunner Peat Bog, Ontario—by A. Anrep.
- †73. Komoka Peat Bog, Ontario—by A. Anrep.
- †74. Brockville Peat Bog, Ontario—by A. Anrep.
- †75. Rondeau Peat Bog, Ontario—by A. Anrep.
- †76. Alfred Peat Bog, Ontario—by A. Anrep.
- †77. Alfred Peat Bog, Ontario: Main Ditch profile—by A. Anrep.
- †78. Map of Asbestos Region, Province of Quebec, 1910—by Fritz Cirkel.
94. Map showing Cobalt, Gowganda, Shiningtree, and Porcupine districts—by L. H. Cole, B.Sc.
95. General Map of Canada showing Coal Fields. (Accompanying report No. 83—by Dr. J. B. Porter).
96. General Map of Coal Fields of Nova Scotia and New Brunswick. (Accompanying Report No. 83—by Dr. J. B. Porter).
97. General Map showing Coal Fields in Alberta, Saskatchewan, and Manitoba. (Accompanying Report No. 83.—by Dr. J. B. Porter).
98. General Map of Coal Fields in British Columbia. (Accompanying Report No. 83—by Dr. J. B. Porter).
99. General Map of Coal Field in Yukon Territory. (Accompanying Report No. 83—by Dr. J. B. Porter).
- †106. Geological Map of Austin Brook Iron Bearing district, Bathurst township, Gloucester county, N.B.—by E. Lindeman.
- †107. Magnetometric Survey, Vertical Intensity: Austin Brook Iron Bearing district—by E. Lindeman.
- †108. Index Map showing Iron Bearing Area at Austin Brook—by E. Lindeman.
112. Sketch plan showing Geology of Point Mamainse, Ont.—by Professor A. C. Lane,
- †113. Holland Peat Bog, Ontario—by A. Anrep.
- 119-137. Mica: Townships maps, Ontario and Quebec—by Hugh S. de Schmid.
- †138. Mica: Showing location of Principal Mines and Occurrences in the Quebec Mica Area—by Hugh S. de Schmid.
- †139. Mica: Showing Location of Principal Mines and Occurrences in the Ontario Mica Area—by Hugh S. de Schmid.
- †140. Mica: Showing Distribution of the Principal Mica Occurrences in the Dominion of Canada—by Hugh S. de Schmid.

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- †141. Torbrook Iron Bearing District, Annapolis county, N.S.—by Howells Fréchette.
- †146. Distribution of Iron Ore Sands of the Iron Ore Deposits on the North Shore of the River and Gulf of St. Lawrence, Canada—by Geo. C. Mackenzie.
- †147. Magnetic Iron Sand Deposits in Relation to Natashkwan harbour and Great Natashkwan river, Que. (Index Map)—by Geo. C. Mackenzie.
- †148. Natashkwan Magnetic Iron Sand Deposits, Saguenay county, Que.—by Geo. C. Mackenzie.
- †152. Map showing the location of peat bogs investigated in Ontario—by A. Anrep.
- †153. Map showing the location of peat bogs investigated in Manitoba—by A. Anrep.
- †157. Lac du Bonnet Peat Bog, Ontario—by A. Anrep.
- †158. Transmission Peat Bog, Manitoba—by A. Anrep.
- †159. Corduroy Peat Bog, Manitoba—by A. Anrep.
- †160. Boggy Creek Peat Bog, Manitoba—by A. Anrep.
- †161. Rice Lake Peat Bog, Manitoba—by A. Anrep.
- †162. Mud Lake Peat Bog, Manitoba—by A. Anrep.
- †163. Litter Peat Bog, Manitoba—by A. Anrep.
- †164. Julius Peat Litter Bog, Manitoba—by A. Anrep.
- †165. Fort Francis Peat Bog, Ontario—by A. Anrep.
166. Magnetometric Map: part of McKim township, Sudbury Nickel district, Ont.—by E. Lindeman. (Accompanying Summary Report, 1911).
168. Map showing Pyrites mines and prospects in Eastern Canada, and their relation to the United States market—by Dr. A. W. G. Wilson.
- †171. Geological Map of Sudbury Nickel Region, Ont.—by Prof. A. P. Coleman, Ph.D.
- †172. Geological Map: Victoria Mine—by Prof. A. P. Coleman.
- †173. Geological Map: Crean Hill Mine—by Prof. A. P. Coleman.
- †174. Geological Map: Creighton Mine—by Prof. A. P. Coleman.
- †175. Geological Map: Showing contact of norite and Laurentian in vicinity of Creighton mine—by Prof. A. P. Coleman.
- †176. Geological Map: Copper Cliff Offset—by Prof. A. P. Coleman.
- †177. Geological Map: No. 3 Mine—by Prof. A. P. Coleman.
- †178. Geological Map: showing vicinity of Stobie and No. 3 Mines—by Prof. A. P. Coleman.

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- †185. Magnetometric Survey, Vertical Intensity: Blairton iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911.
- †185A. Geological Map, Blairton iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911.
- †186. Magnetometric Survey, Belmont iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911.
- †186A. Geological Map, Belmont iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911.
- †187. Magnetometric Survey, Vertical Intensity: St. Charles mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911.
- †187A. Geological Map, St. Charles mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911.
- †188. Magnetometric Survey, Vertical Intensity: Baker mine, Tudor township, Hastings county, Ontario—by E. Lindeman.
- †188A. Geological Map, Baker mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911.
- †189. Magnetometric Survey, Vertical Intensity: Ridge iron ore deposits, Wollaston township, Hastings county, Ontario—by E. Lindeman, 1911.
- †190. Magnetometric Survey, Vertical Intensity: Coehill and Jenkins mines, Wollaston township, Hastings county, Ontario—by E. Lindeman, 1911.
- †190A. Geological Map, Coehill and Jenkins mines, Wollaston township, Hastings county, Ontario—by E. Lindeman, 1911.

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- †191. Magnetometric Survey, Vertical Intensity: Bessemer iron ore deposits, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911.
- †191A. Geological Map, Bessemer iron ore deposits, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911.
- †192. Magnetometric Survey, Vertical Intensity: Rankin, Childs, and Stevens mines, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911.
- †192A. Geological Map, Rankin, Childs, and Stevens mines, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911.
- †193. Magnetometric Survey, Vertical Intensity: Kennedy property, Carlow township, Hastings county, Ontario—by E. Lindeman, 1911.
- †193A. Geological Map, Kennedy property, Carlow township, Hastings county, Ontario—by E. Lindeman, 1911.
- †194. Magnetometric Survey, Vertical Intensity: Bow Lake iron ore occurrences, Faraday township, Hastings county, Ontario—by E. Lindeman, 1911.
- †204. Index Map, Magnetite occurrences along the Central Ontario railway—by E. Lindeman, 1911.
- †205. Magnetometric Map of Moose Mountain iron-bearing district—by E. Lindeman.

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