DIVISION OF
ORE DRESSING AND
METALLURGY

DEPARTMENT OF MINES
CANADA

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REPORT

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ORE DRESSING AND METALLURGICAL LABORATORIES

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The Musso Process for the Semi-direct Production of Steel from Iron ore

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Object of Investigation:

The object of this investigation is to assist a group of interested Canadian financiers in arriving at a clear idea of the technical merit and economic possibilities of the Musso Process for the Semi-direct production of steel from iron ore.

The work is a co-operative effort on the part of the financial group on one hand and the Department of Mines on the other. Under the terms of the agreement entered into by the two parties, the Department provided laboratory space and facilities, technical staff and operating labour and also prepared the ores, coals and other raw materials. The financial group provided and installed all special apparatus and machinery, ores, coals and fluxes. It also provided a qualified engineer and all extra labour beyond that supplied by the Department.

The terms of the agreement provided that the tests were to be carried out under the immediate supervision of the inventor. It was also provided that upon the completion of the tests, the special apparatus and equipment installed by the group interested should become the property of the Department.

<u>Nature and Scope of the Musso Process:</u>

The Musso process provides for the manufacture of steel ingots from iron without the use of the blast furnace. As outlined by the inventor, Mr. Alfred Musso, the process consists of four main steps.

1. The production of sponge iron in an externally heated metallic retort from a mixture of finely divided ore and bituminous coal. The maximum temperature within the retort is limited to 950°C so that no fusion takes place. The fuel for heating the retort, consisting chiefly of carbon monoxide, is continuously generated by the action of the carbon on the ore within the retort from which it is continuously evacuated. This gas is burned under surface combustion conditions, in combustion rings that surround the retort.

2. The magnetic separation of the reduced iron from the gangue of the ore.

3. The continuous melting of the concentrated sponge iron in a special melting furnace, in which mechanically adhering particles of gangue, together with other impurities including sulphur and phosphorus are separated from the metal which is then molten and substantially pure iron.

   The fuel for this operation is also the gas generated within and evacuated from the reduction retort.

4. The Alloying and otherwise finishing into steel of this molten iron in a steel making furnace, the molten iron being drawn from the sponge melting furnace at regular intervals for this batch type steel making operation.

Description of the Process:

Iron ore and bituminous coal, finely ground and properly mixed are introduced into a rotary retort. The retort is externally heated and sealed so that it is substantially air-tight, and may or may not be divided into compartments determined according to certain selected temperatures. If partitions are used to separate the compartments, they will be designed so that the solid materials being treated can pass continuously from one compartment to the other, while the gases generated in each compartment will not be allowed to intermingle, but will be rapidly removed from the compartment in which they are generated by means of pumps. The retort may be operated as a single reducing chamber in which case, the gases generated in the various sections may be withdrawn through one or more pipes by means of exhaust pumps.

The rapid removal of the gases and the consequent prevention of the building up of pressure in the retort, are claimed by the inventor as features that greatly accelerate the rate of reduction of the iron ore.

The removed gases constitute the fuel which is used to heat the retort and to supply all the enrgy necessary for the conversion of the sponge iron into steel.

The retort is heated externally by burning the gases evacuated from it, after proper purification in combustion rings which surround the retort. These rings are made of silicon carbide, a porous refractory material and the gas is introduced into them mixed with the theoretical proportion of air necessary for complete combustion. This mixture reaches the combustion rings under pressure and is burned according to the well known method of Catalytic combustion. In this way the combustion is flameless, the refractory material composing the combustion rings is brought up to incandescence, and heat is radiated to the wall of the rotating retort and thence by conduction and radiation to the charge.

The rotation of the retort by mixing the particles comprising the charge in a continuous fashion exposes new charge surfaces to the direct action of the heat and in this way the transfer of heat to the body of the charge is rapid. This is one of the reasons for the adoption of a rotary retort.

As the raw materials pass from the charging to the discharing end of the retort they are brought up to the reduction temperature and maintained at that temperature until reduction has taken place to the desired extent. It is not economically or even technically desirable to carry reduction to completion in the retort as it is more satisfactory to complete the reduction in the melting operation by means of the residual carbon in the sponge since the excess carbon from the coal is never completely removed in the magnetic concentration. For this reason a metallization of 90 per cent is considered quite satisfactory.

From the retort the crude sponge iron passes continuously to a cooler-conveyer through a sealed pipe that excludes the air. From the cooler, the crude sponge iron passes to a storage bin from which it is fed to a magnetic separator.

This magnetic separator is intended to separate the reduced iron from the excess carbon coal ash and such gangue material as may be mechanically free. From the magnetic concentrator the sponge iron passes to a storage bin.

For the conversion of this concentrated sponge iron into steel, the process provides for a two stage melting operation. In the first furnace the sponge is to be melted and the residual gangue and other impurities fluxed off. From this first furnace, the molten metal, assumed to be substantially pure iron, is to be drawn off at intervals and poured into a second furnace in which it is converted into steel by suitable additions.

As to the type of furnace to be used for these melting operations, the inventor is not very definite. He provides that they may be electric furnaces, more or less of the standard type or they may be furnaces heated by the surface combustion of the gas produced as a by-product from the reduction retort.

He favours the use of furnaces heated by the catalytic combustion of gas, since the cost of the plant would be lower than if electric furnaces were used and since it is his belief that there is an ample supply of a suitable gas produced in the reduction retort.

Principal Features of Construction of Pilot Plant:

The pilot plant was designed on the basis of a productive capacity of four tons of metallic iron per day. The retort, which is 24 inches in inside diameter by 12 feet long, is made of Resistal No. 4 plate, welded. The interior fittings of the retort, the head of the discharge end and the supporting rolls are also built of heat resisting metal of the nickel-chromium-iron type. The retort is enclosed in a stationary brick furnace structure and the ends of the retort register with two end plates which seal the space between the retort and the brick structure, so that no air from the outside can penetrate and convert the more or less neutral atmosphere therein into an oxidizing one which would lower the life of the retort.

The stationary heads carry sliding rings which have wearing surfaces in contact with flanges on the ends of the rotating retort. The sliding rings are held against the flanges of the retort by coiled springs located outside the stationary head in a cool atmosphere. Graphite lubricant is forced against the wearing surface of the sliding ring through hollow rods which support the springs. The wearing surface of the sliding ring is water cooled.

Due to the continuous generation of gases in the retort, the pressure of the atmosphere tends to build up, but exhaust pumps serve the double purpose of keeping this pressure down to about atmosphuric and making the gases available for combustion around the outside of the retort and elsewhere.

The combustion rings are distributed along the retort body and concentric with it so as to ensure a certain temperature gradient of from 200° C at the charging end to a maximum of 950° C at the other. In the pilot plant, the temperature and the pressure used the retort were regulated manually, but there should be no difficulty in making these controls automatic.

For the purpose of cooling and purifying the gases exhausted from the retort, certain apparatus was installed between the retort and the gas holder in three parallel circuits. The gas exhausted from the intermediate and final zones of the retort passed in separate circuits successively through (1) a heat exchanger (2) a 24" X 8' - 0" water tube condenser and (3) an exhaust pump. The circuit through which the gas from the first zone of the retort were drawn, was similar to the others except that the heat exchanger was omitted. From the pumps, the gases from the three zones were mixed and passed through a tar washer and thence to a gas holder.

For use as a fuel in the combustion rings, the gas is drawn from the gas holder by a gas compressor which boosts the pressure up to ten pounds per square inch. At the burners, the gas is mixed with the proper amount of air also at ten pounds pressure. These burners are provided for each combustion ring, one being situated at the bottom and the others at the sides of the retort.

For melting and steel making, the inventor provided two special crucibles for this pilot plant. These were shaped like converted cones and were 20" in diameter at the top and 25" deep. These crucibles were of silicon carbide lined with chromit. It was originally intended that these should be of serconia, or at least lined with zirconia, but some trouble was encountered in the fabrication of this material and the idea was temporarily abandoned. The crucibles were housed in a brick furnace, and, like the rotary retort, were designed to be fired by surface combustion of the retort gas.

Trial Runs and Difficulties Encountered:

Actual experimental work with the pilot plant was begun on June 26th, 1930, and during the period ending August, 29th, 1930, a total of six attempts were made to operate the plant long enough to get some data on the metallurgical characteristics of the process, without success.

The tests to-date have demonstrated that the plant, as originally designed, is inoperative and that the mechanical facilities provided by the inventor are inadequate to permit even a technical demonstration of the soundness of his theories.

The mechanical difficulties encountered may be classified under three heads.

1. Difficulties in cleaning and purifying the gas.

2. Difficulties in getting the material to move positively and smoothly through the retort.

3. Difficulty in getting the material to discharge freely from the retort into the cooler.

It should be stated that the difficulties grouped under (2) and (3), namely, those concerned with the movement of the material through and out of the retort were anticipated by many who had had experience in handling hot materials. That the metallurgical advantages to be gained, if any, by the dividing the retort longitudually into three zones, mechanically partitioned from one another would be insignificant compared with the mechanical difficulties in the way of obtaining a free flow of material from one compartment to the other, was predicted, and our tests have demonstrated the soudness of the principle that such a retort should be of simple construction, free from internal fittings and complications.

It should also be pointed out, however, that these mechanical compexities that were incorporated into the design of the retort for the pilot plant are not vital to the process and could readily be eliminated with advantage. There appears to be no reason why a retort could not be designed that would permit a free passage of the material through and out of the retort.

While the difficulties encountered in the handling and cleaning of the gas might have been anticipated, they apparently were not. Two hours after the start of the first trial, trouble was encountered in the form of clogging of the suction pumps with dust and tar, and after beginning the second trial, three tanks containing water through which the gas was made to bubble were installed between the pumps and the condensors. These were effective in protecting the pumps.

That the gas handling and cleaning apparatus provided was totally unsuited for the purpose at hand, was abundantly clear by the time the third attempt to operate had been made. At this time it was found that the pipes leading from the retort were almost filled with dust and the heat exchangers were closed tight with dust and tar making it impossible to pull any gas out of the retort and this in turn making it impossible to operate the system.

It was then decided to discard the heat exchangers and condensers and to instal a simple spray washer close to the retort for the purpose of washing the tar and dust from the gas as soon as possible so as to prevent their deposition in the pipes and pumps. By this time the partitions had been removed from the retort which was now being operated as a single reducing chamber. Before beginning the fourth trial, changes were also made in the piping for removing the gas from the retort, the three small diameter pipes originally installed being replaced by one six inch pipe. This six inch pipe served to convey the gases from the retort to the spray washer. In order to prevent the separation of dust in this pipe it was kept as short as possible and means were provided for cleaning it continuously.

These changes were decidedly helpful and throughout the three trials that followed, no serious trouble was experienced in handling the gas that was generated. In each of these three latter tests, however, serious trouble was encountered due to the failure of the discharging mechanism to function. This failure to discharge naturally caused the material to build up in the retort and ultimately led to stalling. Such minor changes in the discharging mechanism as could be made were carried out without materially improving the situation and as it had become obvious that substantial changes in the design of the retort would have to be made before it would function, the tests were discontinued, pending a decision from those interested as to their intentions.

Following the cessation of the reduction tests, experiments were commenced with the crucible furnaces. As had been expected, it was found impossible to attain steel melting temperatures in these crucibles, even when empty.

General Considerations:

Since it purports to be a steel process and not merely a sponge iron process, the Musso process must be regarded in that light. It is, therefore, convenient in discussing the advantages and disadvantages of the process to consider first the sponge making phase and then the steel making phase.

While the trial runs with the pilot plant have demonstrated that the plant, as originally designed is a mechanical failure, they, together with the work we have independently carried out in these laboratories on the production of sponge iron from ore-coal mixtures (see report), have indicated that sponge iron can be produced by the Musso method, provided the proper mechanical facilities can be worked out.

That the grade of sponge iron so produced may not be at all suitable for conversion into steel does not appear to have been appreciated by the inventor, who apparently assumed that the bulk of the impurities present in the crude sponge iron would be rejected in magnetic concentration and that any not so rejected would be readily fluxed off in the sponge melting furnaces.

The two most serious difficulties in the way of making sponge iron by the Musso process suitable for conversion into steel are (1) the fact that the separation of gangue and other impurities in magnetic concentration to an extent sufficient to permit of the production of a concentrate containing 90% iron, is possible only with certain ores, (2) the fact that a large proportion of the sulphur (and often phosphorous) contained in an ore-coal mixture is found in the magnetically concentrated sponge iron, and that the removal of this high sulphur content from the sponge iron in melting is technically difficult and economically out of the question. The Musso process, as outlined by the inventor assumes that the sulphuric contained in the concentrated sponge iron, together with any phosphorus and gangue present, can be fluxed off in the first or sponge melting operation. The feasibility of this is extremely doubtful, and, in any case no data has been presented to show that it has been or can be done.

Quite apart from the Musso demonstration, the possibility that it might be feasible to combine the sulphur content of the ore-coal mixture with lime, in the retort during the reducing operation, has engaged our attention, and the results obtained to date have been most encouraging. The indications are that by charging lime with the ore-coal mixture into the retort and carrying out the reduction under suitable conditions, the sulphur present is largely if not entirely fixed as calcium sulphide, which, being non-magnetic should be rejected in the magnetic separation.

The extent to which this calcium sulphide and other finely divided non-magnetic materials are rejected in magnetic concentration depends upon the efficiency of the separator and it is clear that there is a demand for a more efficient separator for the dry concentration of sponge iron. Recent work done in these laboratories indicates that by charging lime with the ore and coal, practically all the sulphur may be converted into calcium sulphide, since by wet magnetic concentration, a concentrate containing but .04 to .10 per cent of sulphur is obtained. Dry separation of this same material however, yields a concentrate containing 0.15 to 0.20 per cent sulphur, the difference between the results obtained by the two methods being of course attributable to the relative inefficiency of the dry separator. While the wet concentration of sponge iron may be feasible under certain conditions, the liability to oxidation and the necessity of drying before the sponge iron can be melted render such an operation less desirable than dry separation.

Conclusions:

The tests carried out in these laboratories have failed to demonstrate that the Musso process, in its present state of development has any technical or commercial value. This failure is attributable to the inadequency of the mechanical means provided by the inventor to carry out his ideas and does not necessarily mean that the ideas themselves are unsound.

As a result of our experience with this pilot plant and after a careful study of the data available, we are of the opinion that the steel making features of the Musso process are weak and impracticable, and that the process must, therefore, be regarded simply as a sponge iron process.

As an undeveloped sponge iron process it appears to possess possibilities. There is reason for believing that it is feasible to design and construct a metallic retort that would function satisfactorily in the production of sponge iron from an ore-coal mixture, using Musso's principle of heating the retort extremely with the gases evacuated from it. The suitability of this sponge iron for the manufacture of steel depends upon the characteristics of the ore from which it was produced and also upon the perfection of a method for eliminating the sulphur and gangue contents of the sponge iron before melting.