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COAL PROCESSING IN CANADA

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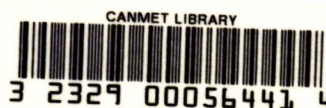
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1. HISTORICAL BACKGROUND OF COAL PROCESSING IN CANADA

Coal processing had its modest beginnings in Canada around the turn of the century. At that time, in most instances, the only treatment given to the mine-run coal was screening. Various "grades" or size fractions of coal were made as a rule.

These grades were produced with a multiple screen on which the raw coal was tipped directly from the mine cars. This installation was called a "tipple", a term that survives to this day and is sometimes used for the modern plants that have been built since the 1960's.

The coarse sizes were named lump or cobble (+4"), stove or egg (6 x 2"), nut (2 x 3/4") and stoker (1 x 1/4"). Fines was the term used for the remaining fraction (1/2" x 0) which had the lowest value because of its tendency to impede combustion or, when used on locomotives, to "carry over" into the stack while still burning and so increase the chances of prairie fires.

To overcome these drawbacks fines would be mixed in with stoker and sold as "slack" (1"X0); or nut coal would be added and its name was "nut slack" (2 x 0). The size designations were subject to variations depending on local usage.

Without wanting to overemphasize, the fines problem of those early days is still with us today, be it for different reasons, to be discussed later on.

The quality of the coal produced with these tipples was controlled to a degree by selective mining, that is by eliminating, from the coal mined at the face, impurities such as bands of shale, slate and clay, and discarding these in the old underground "workings". The coal mining terminology has a number of expressions for these impurities. There is, for instance the word "bone" to identify finely intergrown coal and shale that occurs in flat bands in the coal seam. It is harder and somewhat heavier than coal, as the name infers. It looks very much like coal, but can be identified and eliminated from the mined product when it appears at the top or the bottom of the coal bed, by leaving it in place and mining the coal between these layers.

Another form of impurity are the hard, globular concretions, locally known as "niggerheads". They are often high in pyrite, an iron sulphide (FeS_2) brought in post-genetically by percolating sulphurous waters over long periods of time. It is difficult to eliminate this sort of impurity in the mine without losing time and production.

A third and more common impurity found in the run-of-mine is the very finely divided pyrite that was deposited in the cracks and pores of the coal as small platelets from watery solutions. In this form the mineral poses a different problem in that it raises the sulphur content throughout the coal. Selective mining can not be used in this case, either.

The total content of impurities is commonly measured by the weight of residue that remains after combustion. It is called the ash content. Improvements in cleaning the coal by other means developed gradually as the need for them arose. The raw coal leaving the pithead (called pithead coal, or mine-run, or run-of-mine) would be improved by installing a conveyor from which big pieces of stone were picked by hand and discarded before the coal was screened into the various grades. The smallest size that can be handpicked is 2 in. Thus impurities contained in the nut and stoker sizes remained in the raw state along with the fines. Mechanical devices replacing manual labour were introduced in the form of the mechanical picker (a special kind of shaking screen), the rotary breaker (a revolving trommel screen) designed to break the large coal while rejecting the larger stones, and other devices based on differences between coal and stone as to their respective hardness, size, shape, specific gravity, elasticity, surface friction or resilience. All this equipment was relatively simple; most of it could be made locally. Its efficiency was often more than sufficient for the purpose of improving the coarse coal grades to standards acceptable to the trade. The coarse coal being higher priced than the smaller sizes, this solution remained acceptable for many years, until after World War 1.

The cleaning of the smaller grades - nut, stoker and fines requires methods whereby the particles are separated mechanically while they are able to move freely with respect to one another. All these methods employ the use of a medium to achieve this free movement of individual particles during separation. Only then may a reasonably effective cleaning operation be expected. The old method of separating wheat from chaff by winnowing is a well-known example of this principle, the medium being air.

Dry separators using a pulsating air flow were among the first machines to be added for cleaning the nut and stoker grades, around 1930. The effectiveness was quite satisfactory for removing stone particles from the coal owing to the beneficial ratio between their densities ($2.35/1.3 = 1.8$) as well for the relatively small ratio between the largest and smallest particle size within these "double-screened" grades.

Without going into the theory of dry classification too deeply at this point, it may suffice to say that particles falling in air are separated by the difference in their falling velocities which depends largely on the difference between their densities and on the particle sizes. In order to attain an effective separation according to specific gravity it is necessary that the particles are of approximately the same size, as is the case with nut coal and stoker coal. For the fines fraction, however, the size ratio is very large. As a result the separation with air as a medium is much less effective, more so when the coal is moist.

In the period between the two wars the cleaning of the fine coal was not extensively practised. Where there was a market for slack coal it would be sold by mixing fines with nut or/and stoker coal. Where no market for fines was available briquets were made using asphalt as a binder, as for example with the low-ash anthracite fines produced by Canmore Mines near Banff. On the Prairies, fine coal was sold to the farmers as hog feed for \$1.00/ton, and where all efforts failed, fines were stored to await better times.

2. PRESENT STATE OF THE ART IN CANADA

The coal industry of today presents an image that is very different from the tipples and early wash plants of the thirties and forties. One of the important changes came about when water was introduced as a medium for cleaning the raw coal. It had a profound effect for two reasons, the first one being that wet-mechanical cleaning requires the drying of the coal, especially the fines (1/4" x o). The second reason is that water changes the ratio between stone and coal to advantage, as follows:

$$R = (d_{\text{stone}} - 1) / (d_{\text{coal}} - 1)$$

$$R = (2.35 - 1) / (1.3 - 1)$$

$$R = 4.5$$

Where d = particle density and $(d - 1)$ represents the apparent density of the particles when suspended in water. This shows that R is 2 1/2 times larger when water is used as a medium, compared to when particles are suspended in air. The efficiency of separation is accordingly higher. The successful introduction of wet-mechanical cleaning of coal all over the world proves that increased efficiency has paid for itself in the long run, notwithstanding the higher capital investment and higher operating cost of the new plants. The principle is of special interest for the cleaning of fines requiring ash and sulphur reduction for the purpose of coke making. With the introduction of water as a medium came the need for the dewatering and drying of the products, and the need for treatment of the slimes, the very fine particles of silt and clay that tend to "stay with the water". In Canada, special problems tend to arise from the use of equipment designed for milder climates. The clean coal tends to freeze in the cars during sub-zero weather unless its surface moisture content is less than 4% by weight, except when it is made freeze-proof by the use of oil or certain chemicals. Plants have to be properly insulated and heated to prevent process water from freezing. Outside installations for storage and treatment of plant water and waste sludge cause severe problems in winter. All of which tends to increase the cost of operation and maintenance. For these reasons the more modern washeries have enclosed buildings, covered outside facilities for water treatment and silos for the storage of coal.

The cost of these washeries can only be borne by the return of high-quality coal destined for export to metallurgical markets overseas or to Eastern Canada. The present situation of the coal industry in the energy market is strong. The activity in building new coal-processing plants is greater than it has ever been before. Research on coal processing that has been carried on during the past 25 years is encouraged to support this development in supplying practical answers to the problems that have remained with the industry to this day.

3. PROBLEMS OF COAL PROCESSING

In a recent report¹⁾ to the Minister of Energy, Mines and Resources, a task force for Energy Research and Development has listed the major limitations to the development of coal resources as being, the lack of available manpower, capital and special equipment. This refers to the mining of coal as well as to the processing of it. Starting with manpower, it is evident that the lack of trained personnel is reflected by the fact that there is no formal training for coal preparation engineers available in North America today. No degree in engineering is offered in this field, as it is in several European countries such as Germany, Russia, England and Poland, where coal has been mined over hundreds of years and coal processing started in the early stages of the industrial revolution. In Canada the early development of tipples into wash plants followed the North American trend, which was to transfer technology from the older ore dressing technology in the U.S.A. One example is the concentrating table, a wet separator for finely ground ores which is applied in the North American coal washeries for cleaning fine coal. It is rarely used for this purpose in other countries. The skills required for operating a coal processing plant are basically the same as those required in ore processing. But the two fields differ in that coal has been the Cinderella of the mining world and has only been recognized since the need for energy became evident about a decade ago. Capital has traditionally been hard to obtain for coal mining ventures, because coal used to yield lower returns than most other mining operations.

1) "Science and Technology for Canada's Energy Needs", April, 1975 p. 3

In Canada, as in many other countries, coal has been subsidized for decades with subventions from the federal Government in order to allay the high cost of transportation by rail over long distances. The lack of capital discouraged many young engineers and entrepreneurs from starting a career in what was called by some a "dying business". The after-effects of this long period of hardship are very noticeable in the scarcity of equipment developed especially for coal processing and in the fact that raw materials processing as a profession has not received the same recognition in coal mine management circles as is, for instance, the case in the ore mining and oil industries. This lack of prestige has had an adverse effect on the sponsoring of research in coal processing by individual coal companies. The coal preparation superintendent traditionally had to accept what the mine produced. He had to realise that any pressure from him to improve the mine-run entering the washery might be interpreted as holding up production, even though the advantages of an even feed to the plant were demonstrated to benefit the Company in higher returns per ton run-of-mine; even though the reduction of foreign impurities in the raw coal, like blasting wire, caps, wood chips, scrap metal and highly variable amounts of stone would cut down-time of the washery because fewer clean-ups, less maintenance and repairs would result from simple measures that one might simply classify as "good housekeeping". These are some of the "people problems", and they are still in evidence today.

The purely technical problems of dealing with the fines and meeting environmental requirements of today are in the focus of attention. It is an appropriate time to review, if ever so briefly, the research work that is being done in Canada with regard to the processing of coal, particularly the fines. With respect to the environment, it is of the essence to avoid its pollution at the source where possible. This means that the coal processing plant should ideally have "zero discharge" of all polluting substances. And it should discharge clear water if, as will happen from time to time, more water enters the plant with the run-of-mine than is discharged as residual free moisture with the finished products. To make this review more meaningful, a brief discussion is in order to introduce the main principles of coal preparation, as well as the main categories of equipment that are used in coal processing plants.

4. PRINCIPLES OF COAL PREPARATION

Some definitions first:

When particles of different density, size and shape are allowed to settle in a medium or fluid, a process of separation takes place that is called classification. Because shape infers, in fact, a special size configuration there remain only density and size as the main factors influencing the outcome of any classification event.

In coal preparation, the products of a separator are weighed and routinely analyzed by a screen assay, each screen fraction being subjected to a float-sink analysis using a series of organic liquids of different density, e.g. 1.30 - 1.40 - 1.50 etc. including liquids with a specific gravity as high as 3.30 grams/ml. The resulting data - usually the weight and ash content of each size - density fraction (Fig. 1) - provides information from which it can be determined to what extent a machine produced a separation according to density and to size, respectively. Most separators for coal produce a separation according to size as well as a densimetric separation. The separation according to size is called the sizing effect; the separation according to density will be called the sorting effect. Machines specifically designed for coal screening are called sizers, whereas machines especially designed for densimetric separation will be called sorters. The laboratory analysis mentioned before brings out how effectively each type of machine has performed its basic function.

An example of a separation obtained with a pneumatic table is illustrated diagrammatically as shown on Fig. 2. A nut coal (2 x 1") is cleaned on the slanting, oscillating table deck which is provided with perforations to admit an upward flow of air. The air provides controlled mobility for the coal and shale particles. The oscillating motion of the deck causes the shale particles to climb the deck and discharge at the top, while the coal particles, being lighter, flow downwards and are discharged at the lower end of the table.

The cleaning effect is calculated from the float-sink data and shown in Column T at the far right. Each number in Column T represents the percentage of the gravity fraction in the feed that reported to the reject. It is called the partition number for that density fraction. The partition numbers when plotted on a log-probability graph (See Fig. No. 3) form a curve approaching a straight line, called the densimetric error curve. The cut-point at which the table separated the reject from the clean coal is the density point that corresponds with partition number $PN = 50$ on the error curve. The cutpoint, in other words, is by definition the density of the density fraction that is equally divided between the reject and the clean coal. On the graph this cutpoint, $d_{50} = 1.86$ when using a straight line of best fit. The other curve follows the partition numbers more closely and departs from the straight line. The "break" at the top indicates the influence of a factor that causes relatively more high-density particles of bone and shale to discharge with the clean coal. The relatively flat shape of the shaly particles accounts for this "break" in the error curve at 1.9 density. The example illustrates firstly, that the error curve's slope can be used as an indication of the separator's efficiency, the yardstick being the probable error $r = (d_{75} - d_{25})/2$. Secondly, the shape of the error curve can be used as an indicator of malfunction, or of the need for improvement of the separation device or system.

A flat error curve thus indicates poor separation. An ideal separation (approached by the laboratory float-sink test) produces a straight vertical line. A good sorter is characterized by a steep densimetric error curve (Fig. 4) and by flat size error curves for each densimetric fraction, as calculated from the same float-sink data (Fig. 5).

The most common interference in a densimetric separation is an excessive sizing effect which tends to become more noticeable as particle size decreases. This interference of sizing with the operation of a sorter is reflected in the densimetric error curve in two ways. Firstly, the probable error increases, indicating lower efficiency of the sorting operation.

Secondly, the cutpoint rises for the finer size fractions, indicating a common difficulty in fine coal cleaning, namely that the finer the coal, the harder it is to reduce the ash content. In the above example of the pneumatic table the size range (2 x 1") was very narrow. This eliminates the interference of difference in size and makes for a sharper separation. For this reason it is common practice when cleaning raw coal to screen the washery feed prior to sorting, and to include a de-dusting or desliming step. For the coarse sizes of the raw coal (generally the plus 1/4 in. fraction), dry screening on stationary, oscillating or vibratory screens is practiced. This operation generally requires no medium. For the minus 1/4 in. fines water is generally used to separate the fines at 28 mesh (approximately 1/2 millimeter).

The efficiency of the sizing operations is determined from a sieve analysis in the laboratory, using simultaneous samples collected from the over-product and the under-product of the screen. A size error curve is now plotted on a graph (Fig. No. 6). The cutpoint is shown to be $d_{50} = 70$ microns; the probable error $r = 32$ microns. The curve represents results obtained with a 12-in. classifier cyclone, a sizer frequently used for desliming purposes. To recapitulate briefly, in coal preparation, the two main principles of separation employed are sorting and sizing. Sorting is the dominant principle because the removal of high-density impurities is the prime objective of coal processing. Sizing is of importance for dewatering of products and the recovery of process water. Error curves provide the means for assessing separating efficiency. It is useful as a research tool in comparing separators and for developing special equipment. The five most important types of wet-mechanical sorting equipment used in Canada today are in historical order, the jig, the heavy-medium bath and HM cyclone; the froth flotation cell; and the Compound Water Cyclone. The principle and application of these devices will be briefly discussed in a practical manner. The J i g is a sorter for coal in bulk. It is operated with water as a medium. It consists of an open box in which water is oscillated up and down by means of pistons, vanes or compressed air.

Raw coal entering at one side of this box is fluidized by this oscillating motion as it moves across with the water. The low-ash fraction is kept at or near the surface by the upward thrust of the water and is discharged over a weir and subsequently dewatered on a screen. The reject and middlings (bone coal) settle on a screen located a few feet below the surface and through which the water pulsates up and down. It forms a bed of several layers. All reject is removed by a screw and ejector via a bucket elevator at the feed-end of the jig. The middlings are removed by similar means at the far end of the box. Thus a 3-product separation is achieved. The efficiency of the jig is average and decreases when the cutpoint is increased. It becomes poor when small particles are processed. Cutpoints ranging from 1.45 to 1.72 have been recorded, with probable errors of 0.057 (for 3 x 1 1/4" coal) to 0.13 for (1" x 0). There is little or no cleaning achieved for particles below 28 mesh. The lowest cutpoint that can be achieved is 1.45, which is not sufficient if a low-ash content product has to be made from a raw coal that is difficult to clean.

The H e a v y M e d i u m b a t h is a box-like structure in which coal is floated on, and stone sinks through, a medium with a density near the desired cutpoint. It is a continuous process operating by gravity. In the Heavy M e d i u m c y c l o n e the same process is performed using centrifugal force equivalent to about 25 times the force of gravity. The heavy medium bath and cyclone both operate with a heavy medium consisting of a watery suspension of finely ground magnetite (e. g. 95% minus 325 mesh). Magnetite has a density of ~5.2; the pulp density is kept at any desired level by constant recirculation within a closed circuit. The effective cutpoint range is 1.35 to approximately 1.80, better than that of the jig. The probable error is excellent and ranges from 0.03 to 0.05, for plus 28 mesh particles. The heavy medium bath can process coarse coal down to 1/4 in.

The H M cyclone processes deslimed (i.e. plus 28 mesh) coal only, the top size being 2 in. The presence of minus 28 mesh tends to interfere with the efficiency of the separation. A separate magnetite recovery circuit is required which includes magnetic separators and separate screen for dense-medium recirculation and dilute-medium recovery. When the coal is soft or

fractured, problems may arise as minus 28 mesh coal slimes created by abrasion build up in the recirculating process water. For one typical H.M. Cyclone section the building space required per tph installed capacity is 715 cu ft starting at the raw coal desliming screen and including the coal/reject dewatering screens.

The Froth Flotation Cell is designed for separating coal minus 28 mesh by utilizing the difference in the surface properties that exist between coal and stone. The coal, being hydrophobic by nature, will attach itself to an air bubble and be lifted out of a watery suspension to form a frothy layer on the surface. The stone particles, being hydrophyllic by nature, will stay with the water and be removed with it. The cell consists of a box aerated at the bottom with compressed air (≈ 2 psi) and fed with a watery suspension of minus 28 mesh fines. A frothing chemical is added to produce conditions favouring froth formation, as soap does. A collector chemical is added to condition the coal particles and improve their hydrophobicity, as oil does. The principle is based on chemical surface properties rather than physical properties such as size and density. The results can, however, be expressed by using the error curves and this permits a direct comparison to be made with true densimetric separators. Cutpoints ranging from 1.57 to 1.69 have been reported for 10 mesh x 0 fines, with probable errors of 0.13 to 0.23. The building space required for housing a froth flotation section is, in one typical application, 494 cu ft/tph installed capacity. Problems encountered with froth flotation are connected with the chemical nature of the coal surface. Firstly, when coal is oxidized at the surface as a result of percolating ground water in the coal deposit or through other exposure to oxygen, it becomes hydrophyllic and tends to report to the reject. Secondly, when coarse particles (say, plus 10 mesh) enter the cell, the flotation forces are insufficient and these particles likewise tend to report to the reject.

The Compound Water Cyclone is a cyclone that, like the jig, is operated with water as medium. It forms a bed of reject like the jig but without the need for a screen. The bed is formed spontaneously in the top section of the triconical bottom (Figures 7 to 10). The bed consists of the coarse, heavy particles of stone contained in the feed. It acts as an autogenous heavy medium where the raw coal is separated in clean coal and reject.

The light, low-ash particles cannot penetrate this bed and leave the cyclone through the central pipe or vortex finder, with most of the water. The heavy particles become part of the bed and in the process displace some of the bed material by thrusting it down the bottom discharge outlet or apex. The operation of this cyclone is demonstrated in a 10-minute colour movie that will be shown at the end of this lecture. The cyclone was developed in Canada and has been in use for ten years for the processing of coal in Canada and other countries, including the USA, Australia and South Africa.

Raw coal is processed in bulk (max. 2" x 0) in compound water cyclones operated in a single-stage or two-stage circuit by mixing it with water and pumping it through, say a 24" CWC at 21 psi, equivalent to a g-ratio of 25. Clean coal and reject are dewatered on 28 mesh screens. The cutpoint range for particles of all sizes above 1 millimeter is 1.20 to 2.20. Probable errors vary with particle size and density for different sizes of CW cyclones (as shown below).

For particles plus 28 mesh $r = 0.03$ to 0.22

" " 28 to 325 " $r = 0.06$ to 0.25

This applies to raw coal with an average solids density of 1.40. For other densities (d') the corrected probable error,

$$r = r (d' - 1) / 0.40$$

With two-stage operation the overall probable error is better than that of the single CWC. The improvement is a function of the cutpoints and probable errors of the primary and secondary CW Cyclones and can be calculated from the

$$\text{fractional partition numbers } p = p_1 p_2 / \{1 - p_1 (1 - p_2)\}$$

The building space required for housing a compound water cyclone installation including the dual mix tank, a two-stage CWC-circuit and three dewatering screens for coal, reject and middlings is 40 cu ft/tph installed capacity. This constitutes about 5% of the space required for the above HM Cyclone circuit.

It is therefore of interest when selecting a process to compare the returns in \$ per ton r.o.m. for each system, to take into account the effect of capital

cost, as well as that of efficiency, on the overall returns per ton r.o.m., that is, to discount the lower cost of capital against lower yield of clean coal of the same quality (ash, sulphur or Btu).

5. RESEARCH AND DEVELOPMENT

The general aims in the R & D program for coal processing in Canada are to develop methods and equipment for the improvement of the existing art, with special emphasis on Canadian requirements and conditions. The requirements are to increase coal production to keep the costs down and to maintain quality at levels acceptable to industry. The conditions are that the environment be protected against pollution, that the plants be convenient and safe for personnel to operate in summer and winter. In Canada, R & D on coal processing has been largely carried out in the Dept. of Energy, Mines and Resources over a period of more than 20 years. The original directive, which still stands today, was to clean fine coal and that any device or process developed should be rugged, simple, cheap and automatic. Work started with a study of the existing art and a survey of the one dozen cleaning plants operating in Canada in the nineteen fifties. Then a cyclonic separator, the compound water cyclone already discussed before, was developed and patented in 1962 - 68 in a number of countries. The introduction of this cyclone in industry triggered other projects dealing with the problem of drying fine coal, the reconditioning of plant water, the automation of the washing process and the integration of its four main functions: feed preparation, cleaning, drying and water recovery, as shown diagrammatically on Fig. 11. Pilot plant facilities initially set up at Edmonton in 1956 were expanded in 1966. A developmental research plant of 10 tph capacity was operated at a new coal mine in Nova Scotia from late 1972 till early 1974 in order to test the process under actual operating conditions. Then a 100 tph plant was installed in an old washery for the reclamation of coal from the washery discard (1974). From the experience gained in the various stages of the program the design for a compact modular plant (Fig.12), resulted, which provides for (2"x 0) raw coal to be processed in bulk using water in closed circuit under zero discharge conditions. The equipment consists essentially of cyclones and screens, including centrifuges for drying the finished products. Another distinguishing feature of the process is that fine particles are separated in stages by recirculation under steady-state conditions. This process is largely self-regulating as the cyclones have a great tolerance for overload, which allows the plant to absorb large variations in feed composition (e.g. free impurity,

fine coal and clay) often encountered in raw coal. Provisions have been anticipated for dealing with spills of water and spills of solids that may be expected as part of normal operation, when some mechanical or electrical failure occurs. Any such failure may cause interruption of the flow of suspended coal and stone particles. Blockage prevention is essential as the suspension of coarse particles in water is highly unstable and tends to settle out very easily. To this end, special mix tanks are provided that allow solids to build up without impeding the flow of plant water. Large-diameter cyclones are used so that stray oversize particles do not interfere with continuous flow anywhere in the circuit. The wet volume of the plant is kept at a minimum of about 10 cu ft/tph installed capacity. This keeps the amount of solids present in the circuit at 1 to 2% of the hourly capacity. When the plant is stopped, this material gravitates back to the mix tanks without plugging the circuit. The plant is designed as a relatively high building (5 floors) to facilitate drainage of spills by gravity. Many spills are caused by inadvertent introduction of foreign material by personnel, such as welding rod remnants, small tools and metallic scrap from repair work and other trash. Routine inspection for maintenance makes it necessary to clean up the equipment at regular intervals. All this material is discharged to the reject bin from each floor by a separate route, using water hoses, the water being separately sent to a dewatering screw on the first floor, which returns it to the water recovery section and to the water tank. Thus the need for a sludge pond is avoided by proper control. A small emergency storage basin (not shown on Fig. 11 and 12) is needed to receive the entire wet volume in case control is lost owing to some unlikely, but not impossible combination of circumstances a freak accident or the like.

Special Research Projects

The processing of very fine particles minus 28 mesh recirculating under zero-discharge conditions was investigated. It was found that these fine coal particles can be agglomerated by wetting with oil in a conditioning tank. The agglomerates formed by the bridging effect of the oil are easily and efficiently dewatered on screens with 28-mesh apertures. When using high-speed centrifugal basket screens, it was found that low moisture contents (6 to 8% by wt. of solids) acceptable to industry could be obtained without the need for additional thermal drying. Thus the need for thermal driers was reduced

and with it the air pollution that often accompanies their application in coal processing plants.

Another advantage of the oil agglomerating method is that the agglomeration is selective. Clay particles are not agglomerated because of their hydrophyllic surface properties. Thus the agglomeration of effluent solids consisting of coal slimes and clay results in an upgrading of the coal, a desirable secondary effect.

The removal of the clay remaining in the processing water after oil agglomeration was then studied. It was found that the conventional flocculation of clay particles can be improved firstly by interspersing the effluent streams with a flocculant solution in such a manner that the chances of individual contact between clay particle and flocculant molecule are increased to the maximum; secondly, by allowing the small nuclei thus formed to agglomerate by a process of controlled enlargement.

The first step is realized by means of a cyclonic blender in which the contact time is of the order of 1 millisecond. The flocs formed from these nuclei are strong enough to withstand the shear in a classifier cyclone. Most of them will be collected in the apex product. The result of this method is that clarifying of recirculating effluents can be attained largely with cyclones. Thus the need for large static thickeners is reduced, with resultant reduction in plant volume and reduction in the cost of water recovery.

The recleaning of effluent slimes by large-diameter CW cyclones was investigated. It was found that when the cylindrical section of standard 8 in. and 12 in. CW cyclones is extended by 50% and the feed inlet pressure is increased accordingly, the minimum cutpoint of particles minus 1 millimeter (14 mesh) is reduced significantly, to the effect that coal slimes can be reduced to lower ash contents and sulphur contents than has been possible before. In addition, the probable error of separation is noticeably improved. Thus the processing of high-ash slimes has become possible, with attendant economies to the industry and other benefits such as the reduced need for sludge ponds.

6. SUMMARY AND CONCLUSIONS

The development of coal processing in Canada since its beginning is briefly reviewed and commented on, with special reference to the technological aspects, including those of environmental control at the source.

The principles of coal processing are discussed and the "error curve", whereby different separators for "sorting" and "sizing" can be judged as to their efficiency, is described.

The results of research and development done in Canada in the field of coal processing methods and equipment are illustrated by the description of the general model of a modular processing plant in which the main functions of cleaning, drying and water recovery are integrated. Details are provided of the means whereby this integrated plant operates with a closed circuit and "zero discharge" of pollutants to the environment.

FIGURE 1

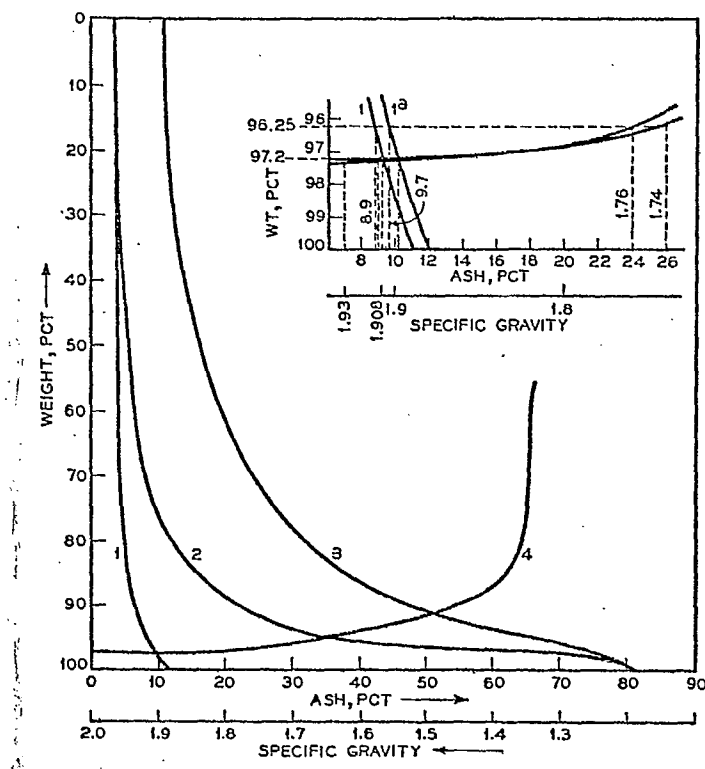


FIGURE 2

Schedule for Calculation of Washery Results

General information												Test data					Test results						
Mine: Washer: Pneumatic Table Test No.: Date: Test performed by: Computed by: Remarks:					Rank (A.S.T.M.): Subbituminous B Grade (A.S.T.M.): A14-F20-S0.7 Size of feed: 1 x 2 in. $\frac{1}{4}$ Feed, tons per hr.: 5 Washing medium: Air Density: $t = 0$ Viscosity: ---							Duration of test 2,40-3,40 p.m. Weight of Samples feed 233, clean 90, refuse 89.1 lb. Number of increments: 80 Feed: Ash content: 11.2 % Floats at 1.60 spec. gravity 94.3 % Yield of clean coal, computed from, (1) the ash contents: 96.1 % (2) the floats at 1.60 sp. gr. 96.4 % Mean: 96.25 %					Theoretical yield: 97.2 % Yield error: 1.0 % Organic efficiency: 99.0 % Ash error: 0.5 % Separating gravity, (1) at the actual yield: 1.74 (2) at the actual ash content: 1.93 (3) from error curve: $d = 1.83$ Probable error of separation: $r = 0.14$ Imperfection $I = \frac{r}{d-t} = 0.08$						
SPECIFIC GRAVITY INTERVAL	CLEAN COAL		REFUSE		COMPUTATION OF FEED							CUMUL. SPECIFIC GRAVITY INTERVAL	COMPUTATION OF WASHABILITY CURVES							Error curve			
	A	B	C	D	E	F	G	H	I	K	L		M	N	O	P	R	S	T				
	Weight %	Ash %	Weight %	Ash %	Weight of clean coal, in % of feed = Yield x A	Weight of refuse, in % of feed = $\frac{C(100 - \text{Yield})}{100}$	Ash in clean coal in % of feed = $\frac{E \times B}{100}$	Ash in refuse, in % of feed = $\frac{F \times D}{100}$	Ash in clean coal + ash in refuse, in % of feed = G + H	Weight of clean coal + refuse in % of feed = E + F	Ash in feed (washabil. curve No. 2) = $\frac{100 I}{K}$		Cumul. weight of feed = K Cumul.	Cumul. ash, in % of feed = I Cumul.	Cumul. ash of floats (washabil. curve No. 1) = $\frac{100 N}{M}$	= 100 - M	= (Sum I) - N	Cumul. ash of sinks (washabil. curve No. 3) = $\frac{100 R}{P}$	Refuse per spec. gr. interval, in % (Tromp numbers) = $\frac{100 F}{K}$				
- 1.32	58.0	5.6	8.7	5.6	55.825	0.326	3.126	0.018	3.144	56.151	5.599	- 1.32	56.151	3.144	5.599	43.849	8.935	20.4	0.6				
1.32 - 1.35	16.4	8.0	3.2	8.0	15.785	0.120	1.262	0.010	1.272	15.905	7.997	- 1.35	72.056	4.416	6.128	27.944	7.663	27.4	0.8				
1.35 - 1.40	15.4	13.2	3.7	13.2	14.534	0.139	1.918	0.018	1.936	14.673	13.194	- 1.40	86.729	6.352	7.324	13.271	5.727	43.1	1.0				
1.40 - 1.45	2.7	18.6	1.8	18.8	2.599	0.068	0.488	0.012	0.500	2.067	18.747	- 1.45	89.396	6.852	7.665	10.604	5.227	49.3	2.5				
1.45 - 1.50	2.0	24.4	1.1	24.4	1.925	0.041	0.470	0.010	0.480	1.966	24.415	- 1.50	91.302	7.332	8.025	8.638	4.747	55.0	2.1				
1.50 - 1.55	1.5	30.4	1.0	30.4	1.444	0.038	0.433	0.012	0.450	1.482	30.364	- 1.55	92.844	7.782	8.332	7.156	4.297	60.0	2.6				
1.55 - 1.60	1.3	36.0	1.5	36.0	1.251	0.056	0.450	0.020	0.470	1.307	35.900	- 1.60	94.151	8.252	8.765	5.849	3.827	65.4	4.3				
1.60 - 1.70	1.5	46.8	5.7	46.8	1.444	0.214	0.676	0.100	0.776	1.658	46.803	- 1.70	96.609	9.023	9.423	4.191	3.051	72.8	12.9				
1.70 - 1.80	0.8	57.2	6.1	57.2	0.770	0.229	0.440	0.131	0.571	0.999	57.157	- 1.80	96.808	9.599	9.916	3.192	2.460	77.7	22.9				
1.80 - 1.90	0.1	66.4	5.9	66.4	0.096	0.221	0.064	0.146	0.210	0.317	66.240	- 1.90	97.125	9.809	10.099	2.875	2.270	79.0	69.7				
1.90 - 2.00	0.1	74.0	6.5	74.0	0.096	0.244	0.071	0.180	0.251	0.340	73.824	- 2.00	97.465	10.060	10.322	2.535	2.019	79.6	71.8				
2.00 - 2.10	0.2	78.8	11.1	78.8	0.192	0.528	0.151	0.416	0.567	0.720	78.750	- 2.10	98.185	10.627	10.823	1.815	1.452	80.0	73.3				
2.10 - 2.20	0.3	80.0	35.9	80.0	0.289	1.346	0.231	1.076	1.307	1.635	79.938	- 2.20	99.820	11.934	11.956	0.180	0.145	80.6	82.3				
2.20 - 2.30	-	-	4.8	80.6	-	0.180	-	0.145	0.145	0.180	80.556	- 2.30	100.000	12.079	12.079	-	-	-	-				

FOOTNOTES—¹ The feed figures are used for the computation of the yield, together with those of the clean coal and refuse.² The separating gravities at actual yield and at actual ash are found from washability curves Nos. 1 and 4.³ The probable error of separation is one-half of the specific gravity interval lying between Tromp numbers 25 and 75 on the error curve.⁴ The calculation of the error curve (data given in column T) requires the data in columns A, C, E, F, and K only.

FIGURE 3

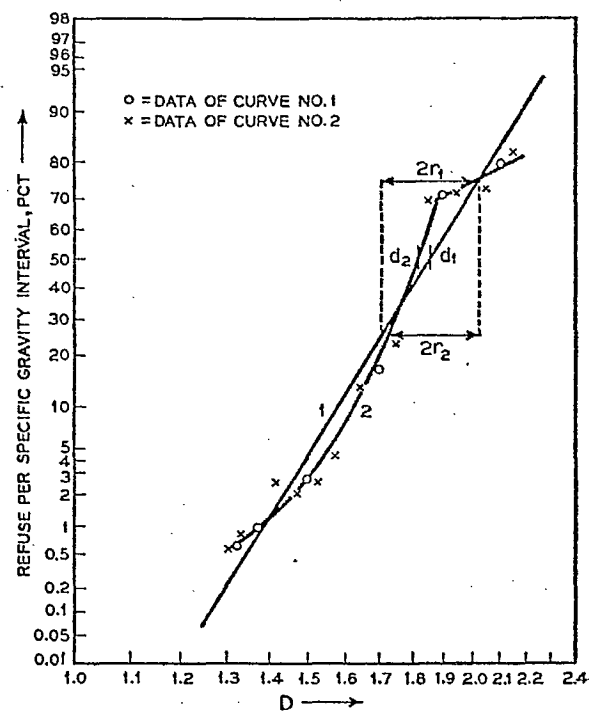


FIGURE 4
Density Error Curves For
2-Stage C.W.C. Plant

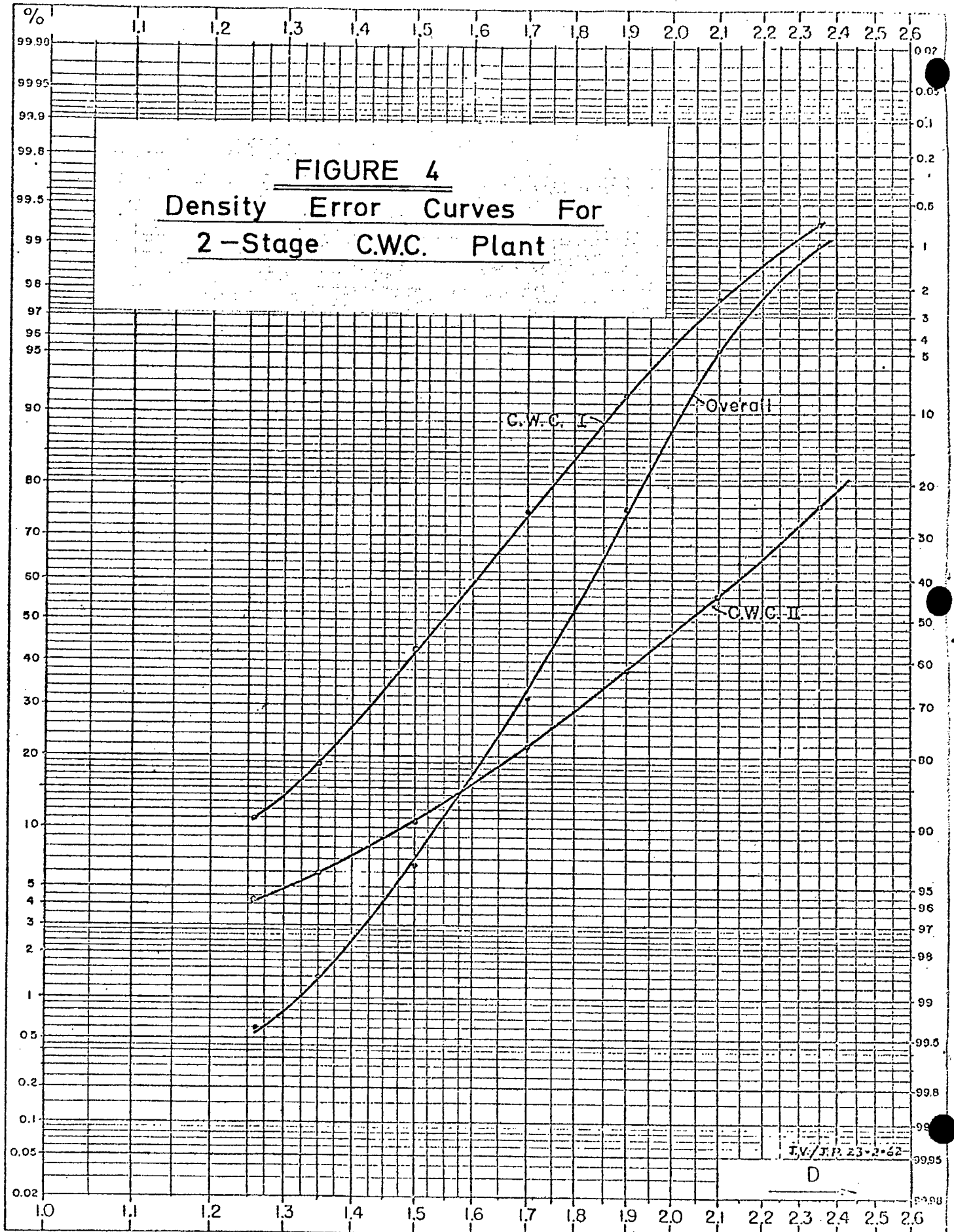


FIGURE 5
Size Error Curves

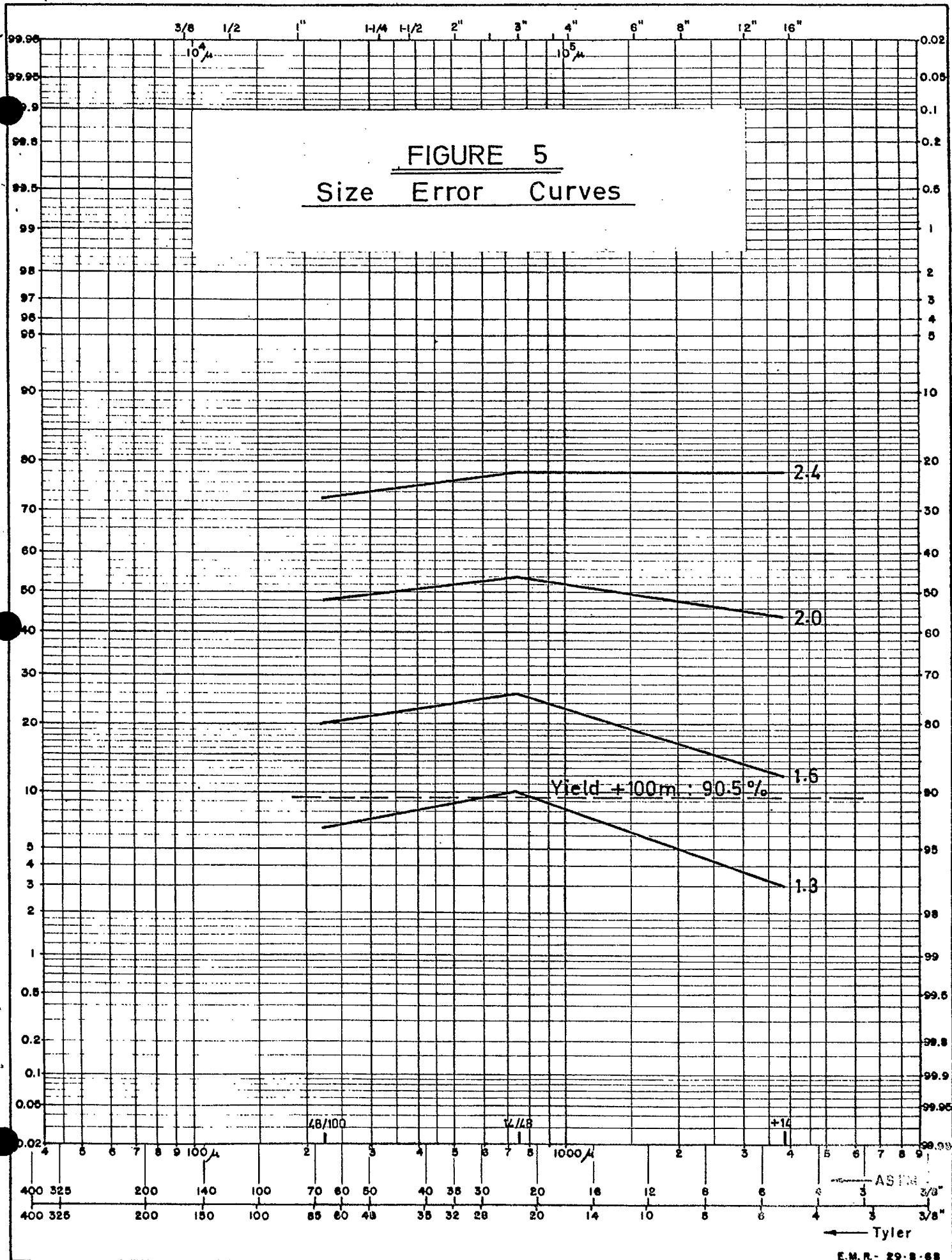
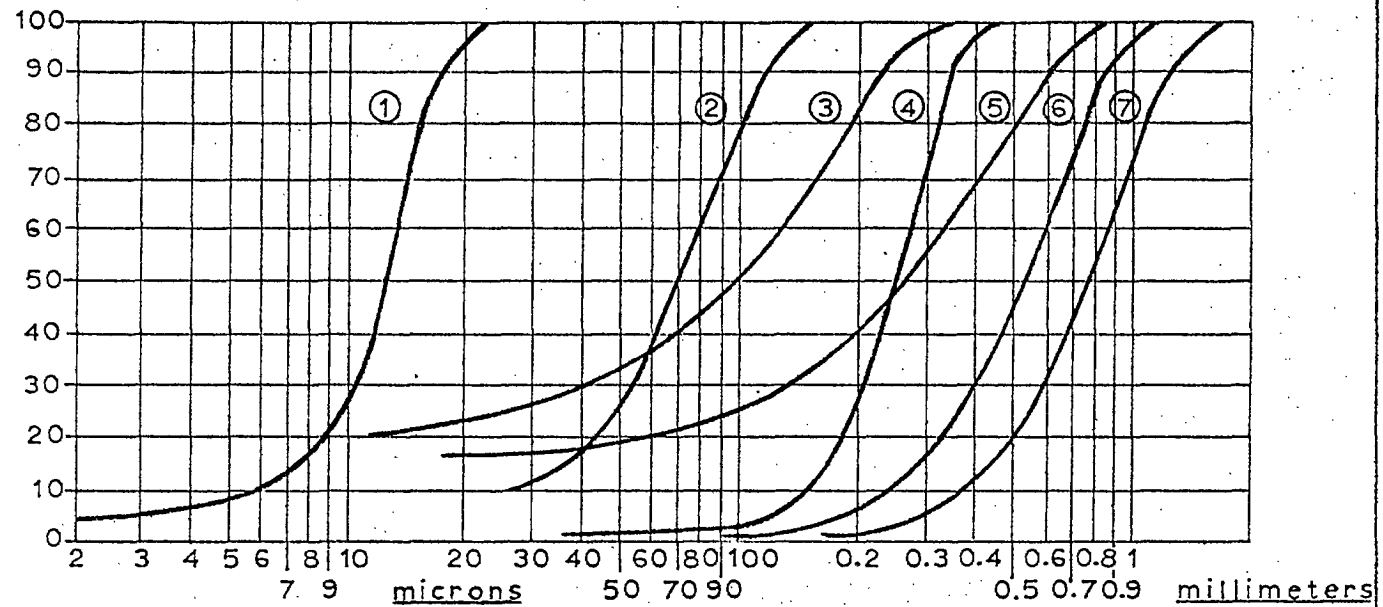


FIGURE 6



SIZER ERROR CURVES

- (1) Thickener Cyclone
- (2) Classifier "
- (3) Screw Classifier
- (4) Hydroscillator

- (5) Rake Classifier
- (6) Upward Current Separator (Rheax)
- (7) Fahrenwald Sizer

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FIGURE 7

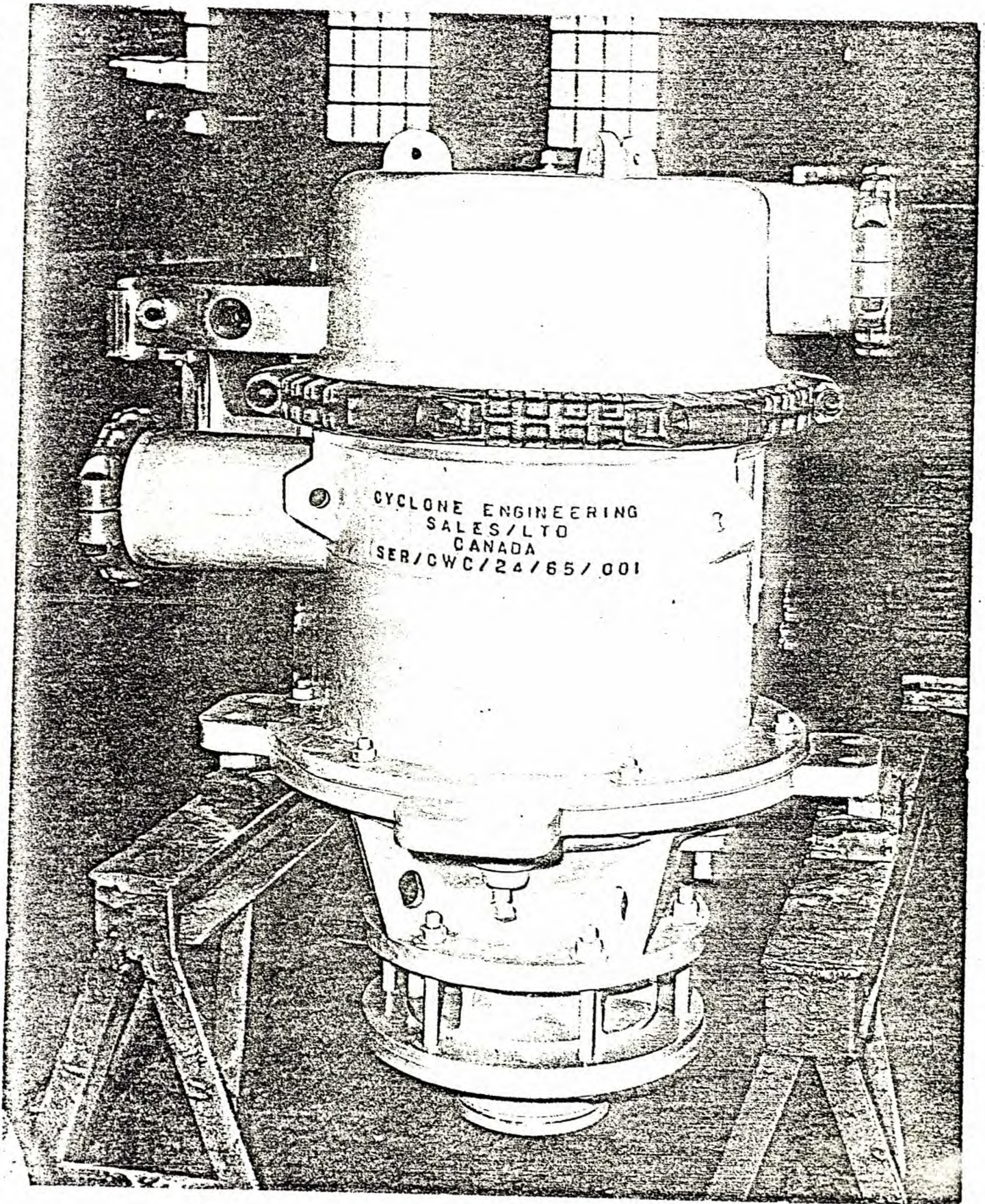


FIGURE 8
COMPOUND WATER CYCLONE

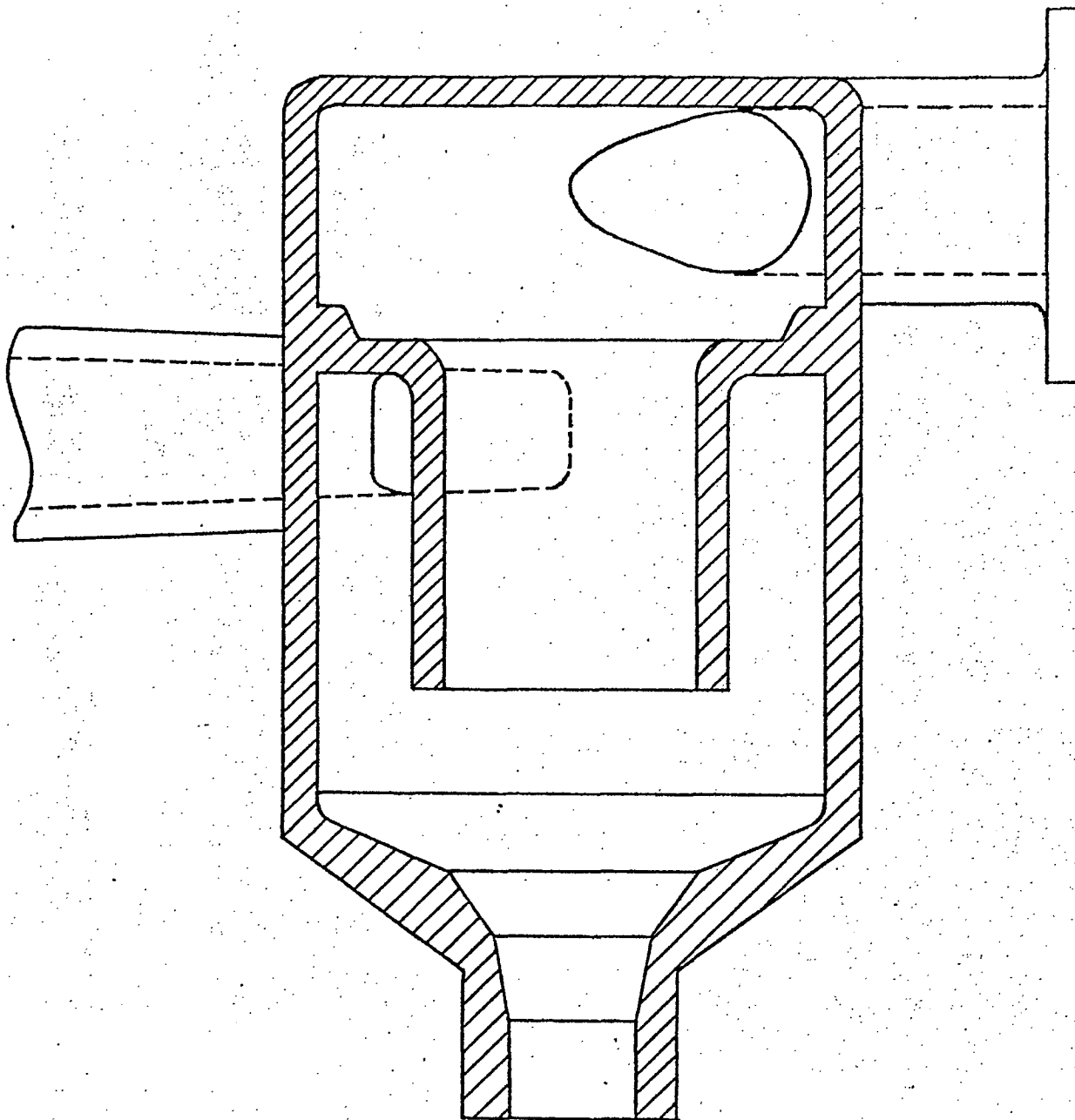


FIGURE 9 - COMPOUND WATER CYCLONE

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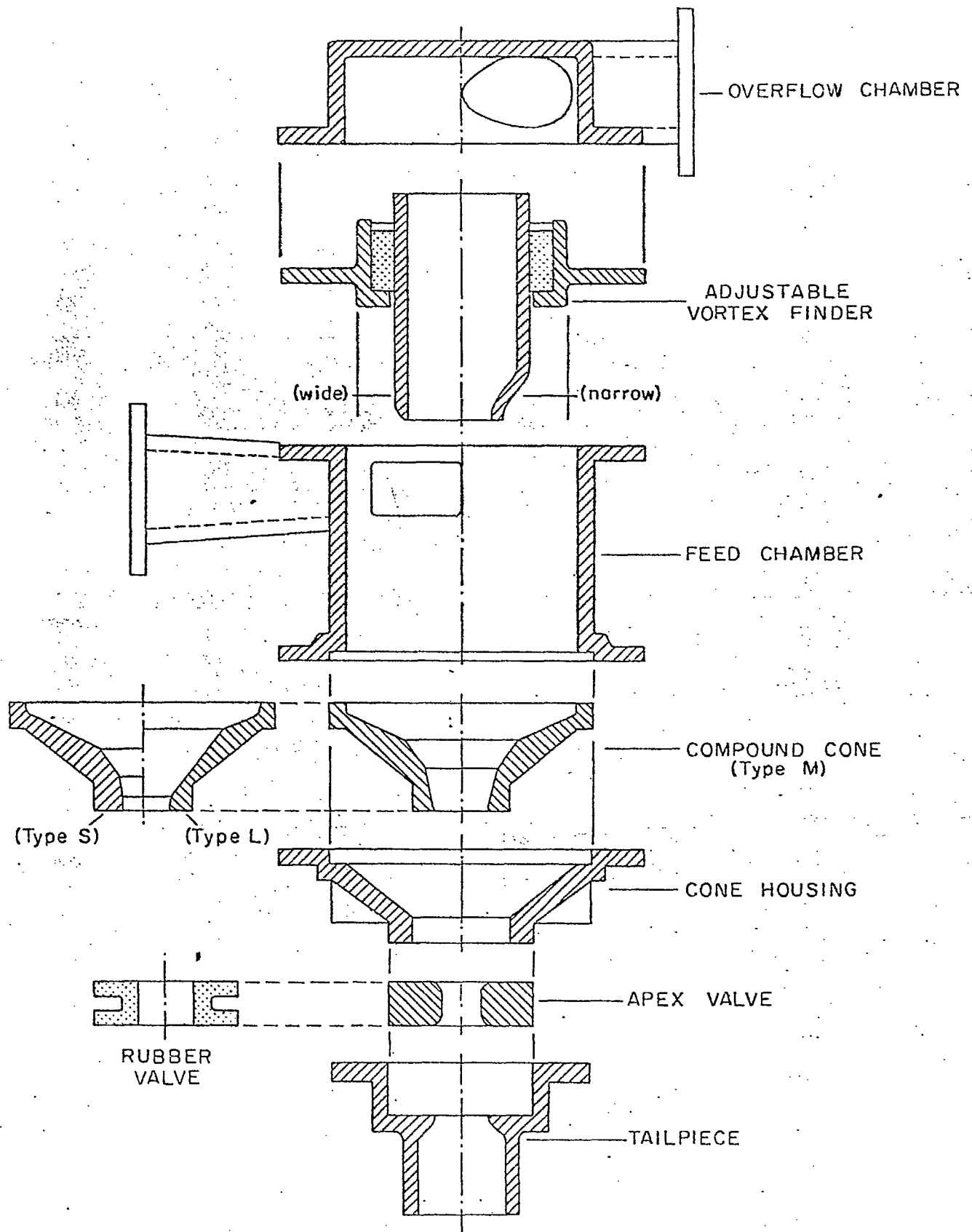


FIGURE 10
SEPARATION MECHANISM IN
COMPOUND WATER CYCLONE

- Legend
- COAL
 - ⊗ LIGHT MIDDLEINGS
 - ⊖ HEAVY MIDDLEINGS
 - REFUSE

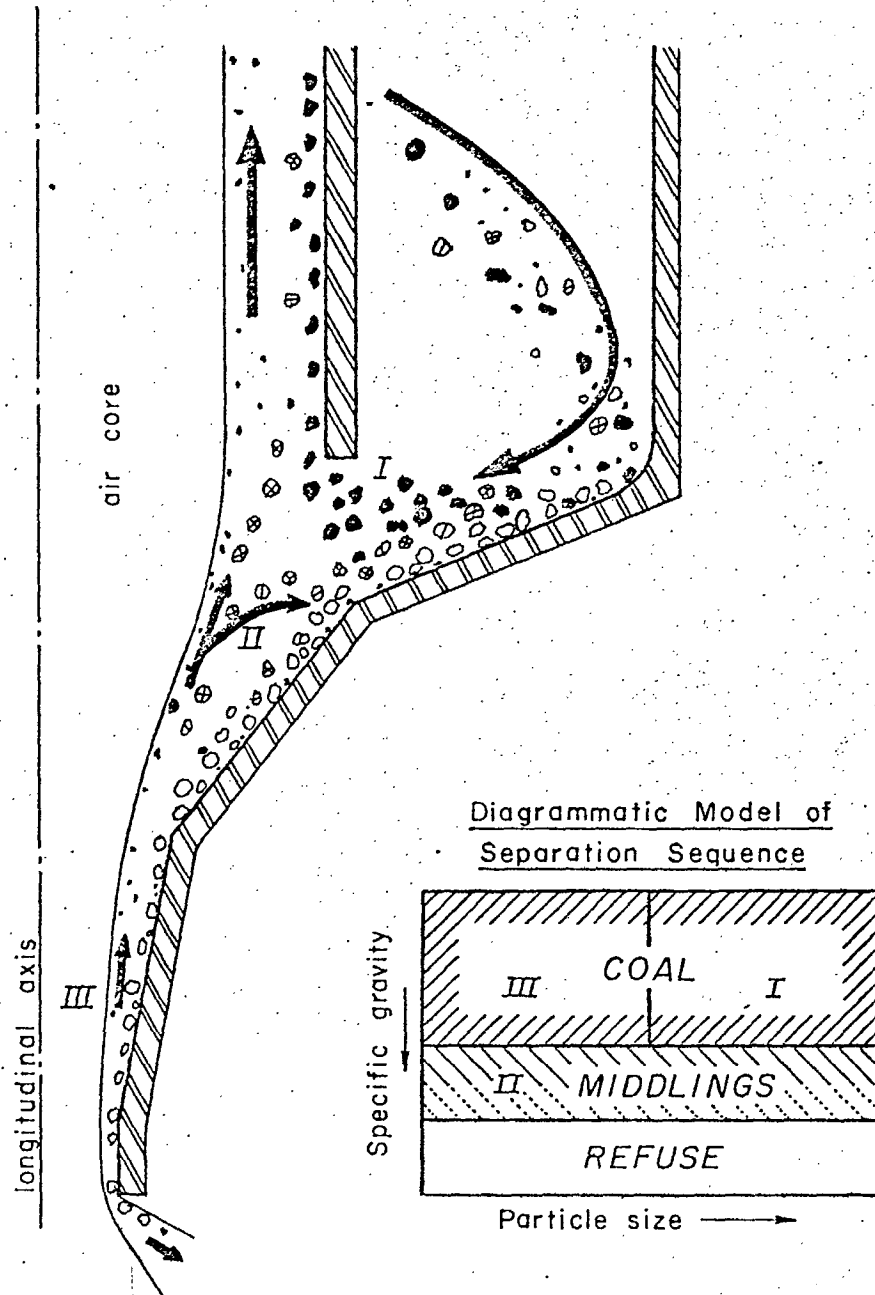
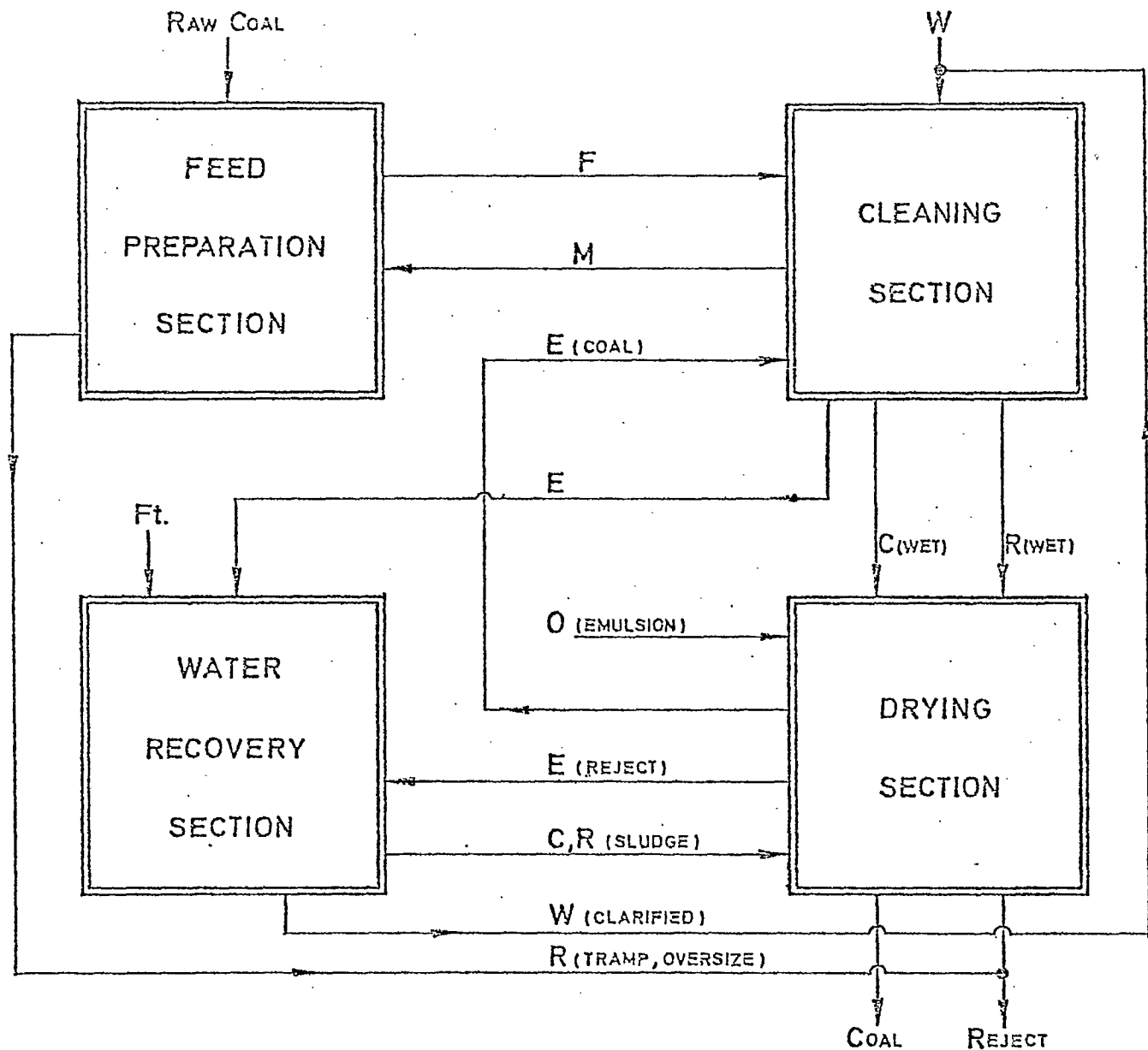


FIGURE 11

MODULAR E.M.R. COAL PROCESSING PLANT
GENERAL FLOWSHEET



LEGEND

F = WASHERY FEED
C = CLEAN COAL
M = MIDLINGS
R = REJECT
E = EFFLUENT
W = WATER
Ft. = FLOCCULANT
O = FUEL OIL

DEPARTMENT OF ENERGY, MINES
& RESOURCES — CANADA

WESTERN RESEARCH LABORATORY
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FIGURE 12 - General Flowsheet

MODULAR EMR PLANT (250 tph cap.) for processing mine-run coal (2"x0)

