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PROCESS SELECTION AND OPTIMIZATION

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by

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SUMMARY

This paper briefly describes characteristics of Canadian coals and some unique problems associated with their cleaning. Degradation of friable coals, shales and release of clay during washing are associated with Western coals, and high levels of finely disseminated sulphur with Eastern coals. Coal preparation technology and equipment related to size reduction, cleaning and dewatering are briefly described in regard to principle of operation, application and limitations. Levels of preparation are summarized in relation to coal preparation economics and factors that influence coal preparation cost.

Criteria for wash plant evaluation and means to predict optimum cleaning are described. Benefits of models in plant optimization, flowsheet design and plant control are reported. Beneficial effects of coal cleaning on power plant operation are shown in relation to improved performance, lower maintenance cost and increased availability of power plant.

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SÉLECTION ET OPTIMISATION DES PROCÉDÉS

par

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SOMMAIRE

Ce document décrit brièvement les caractéristiques des charbons canadiens, ainsi que certains problèmes uniques reliés à leur épuration. On associe aux charbons de l'Ouest les problèmes de dégradation des charbons friables, le schiste et la libération d'argile lors du lavage, alors que les charbons de l'Est présentent une haute teneur en soufre finement réparti. On décrit brièvement la technologie de la préparation du charbon et l'équipement utilisé pour la comminution, l'épuration et l'égouttage, par rapport aux principes opérationnels, aux applications et aux limites du procédé. On résume les niveaux de préparation en fonction de l'économie de la préparation et des facteurs agissant sur son coût.

On décrit les critères pour l'évaluation de l'usine de lavage et les moyens de prédire une épuration maximum. Les avantages qu'offrent les modèles pour l'optimisation de l'usine et de l'épuration du charbon sont présentés par rapport à une amélioration de la performance, une diminution des frais d'entretien et une disponibilité accrue de l'usine de préparation.

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INTRODUCTION

Estimated Canadian coal reserves are 120 billion tonnes, of which 80% are located in Alberta and British Columbia. Canadian coal production in 1980 was estimated at 36 million tonnes, of which just over 16 million tonnes were used at mine mouth generating plants. The remaining 20 million tonnes received extensive preparation prior to transport to distant markets for thermal and metallurgical use. Prepared coal production in Canada has increased ten-fold since 1965. New facilities under construction will bring prepared coal up to 30 million tonnes by 1985. Production is projected to be between three and five times that of 1980 by the end of the century i.e. approximately 100 to 180 million tonnes with a similar proportion of the additional output requiring preparation (90 to 150 million tonnes).

Most of the increase in production will be destined for overseas or central Canada. Presently, transportation cost represents approximately 50% of the total cost per tonne of coal. Limited capacity of Canadian railways and increased cost of transportation from Western Alberta to the west coast terminals ($17.5/tonne in 1981 as compared with $2.50 in 1971) suggest other means of transportation such as slurry pipelining. Preparation of coal for slurry transportation and dewatering and drying coal at the end of the pipeline are applications of coal preparation technology.

Mining costs of Canadian coals are often favourable with the exception of underground operations in Eastern Canada, resulting in an acceptable product cost. Preparation is therefore a major rather than an auxiliary function in the control and costing of Canadian coal production.

COAL CHARACTERISTICS

Canadian coal characteristics related to coal preparation technology can be identified as follows (1):

1. Eastern coals have high sulphur contents, essentially similar to those of eastern United States. Ash removal is easily achieved by preparation resulting in low ash content, however, sulphur removal is

limited.

2. Rocky Mountain metallurgical coals are included in highly sheared seams which have been subjected to rapid coalification. The high friability of these coals means that degradation during mining, handling and processing cannot be avoided. Widely varying geological structure and exposure to the atmosphere and to ground water result in different degrees of oxidation which perform inconsistently in cleaning by froth flotation.

3. Foothills high volatile bituminous coals are frequently interbedded with soft shales and bentonitic clays. The clays disintegrate during washing and produce large volumes of tailings. Clay in the fissures also results in degradation of the otherwise hard coal particles during washing.

4. Plains coals include subbituminous coals and lignites. These coals are relatively low in ash, high in inherent moisture and traditionally are used at mine mouth power generation plants without washing.

Many of the characterisics of Canadian coals are similar to those of coals in other countries. However, two characteristics are identified with Canadian coals: friability common in western Canadian coals and finely disseminated pyritic sulphur in eastern Canadian coals.

COAL FRIABILITY

Some western Canadian coals are known for their friability, containing 20 to 60% by mass minus 0.6mm. Tectonic movements are the major cause of extensive fracturing of coal in the mountain districts. Mining method, handling and processing contribute to the generation of fines. However, the amount generated depends significantly on the degree of natural fissuration (2).

The relative friability of different coals is of great importance in preparation because the greater the proportion of fines the greater the total preparation costs. In fact, the cost per tonne of feed is a function of the number of particles per tonne. Thus preparation costs increase rapidly as the mean particle size becomes smaller. For example, preparation of small coal (minus 6 mm) costs four times more in capital investment and five times more in operating expenses than preparation of coarse coal (plus 6 mm). The minus 6 mm size fraction in western Canadian coals represents between 50 and 80% by mass of run-of-mine coal. New preparation plants usually are designed at an early stage of development of a property before the start-up of mining activities. Underestimating the amount of fines influences the preparation plant performance; consequent overloading of fines circuits in the plant causes operating problems and losses of fine coal to discard. A recent performance evaluation study of Canadian washeries showed that yield losses in the fine circuits were approximately 10 times those occurring in the coarse coal circuits.

SULPHUR REDUCTION

Increasingly stringent sulphur emission regulations are forcing the coal industry to search for means to reduce sulphur content. Sulphur reduction in coal can be achieved by partial removal of pyritic sulphur depending on the pyrite's particle size and distribution. Organic sulphur can only be removed by thorough chemical cleaning but at much higher cost than that of the available coal preparation technology. Maritimes coals are known for their high sulphur content (2-6%). Pyritic sulphur represents 30-70% of the total sulphur and in most cases is finely disseminated and crushing and/or grinding is required to liberate it. However, a decrease in particle size of the coal corresponds to an exponential increase in preparation cost.

COAL PREPARATION TECHNOLOGY

Coal preparation involves three basic methods:

a. Size separation
b. Density separation
c. Surface-dependent separation

All preparation equipment involves one or more of the above methods. Equipment selection for different applications is dependent on particle size. Figure 1 shows the ranges of application of different cleaning and dewatering devices. The following is a brief description of equipment used for size reduction, cleaning and dewatering.

SIZE REDUCTION

Crushers are used to reduce the run-of-mine to a particular top size that allows sufficient liberation of coal from reject particles at acceptable cost. Mechanical size reduction methods employ impact, attrition, shearing, compression or any combination. In Canadian washeries run-of-mine coal is reduced to 200, 50 or 38 mm top size depending on coal characterisitics. Also, after cleaning and dewatering, coarse fractions of clean coal product may have to be crushed to a top size of 50 or 38 mm depending on market requirement. Crushers commonly used for coal are described below.

Rotary Breaker

The breaker consists of a cylindrical drum with holes of the required top size. The drum rotates at low speed and size reduction results from the impact of coal falling upon itself and on the fact that the coal is usually softer than shale, stone etc. Any stones, shale or logs that are too large to pass through the holes are discharged as refuse at the far end of the breaker. The rotary breaker therefore partially scalps rock, timber and metal pieces besides crushing the raw coal. Because of the relatively mild breaking action, the production of fines is minimized. However, for harder coals this mild breaking action can result in some coal being lost with rejected materials.

Impactors

This category includes hammer mills which use the impact of rotating steel bars to reduce the coal to the desired size. However, the resulting combination of impact, attrition and shear forces produces a large amount of very fine coal particles and is not recommended when a minimum of fines are required. Hammer mills are usually used before utilization e.g., power plant feed preparation. A special type of impact mill is the vertical-axle cage mill, a grinder that reduces the production of very fine coal to a minimum.

Granulators

The granulator applies a combination of impact, shear and compression and produces a minimum of fines. It is commonly used for size reduction of friable coals fed to preparation plants.

Roll Crusher

This type of crusher may be either the single or double roll type and uses compression and shear for reducing size. In most cases the rolls are equipped with teeth of two sizes: long teeth to split coarse pieces and smaller teeth to make the proper size reduction. The roll crusher can be adjusted to handle changes in the top size of the feed.

CLEANING EQUIPMENT

Heavy-Medium Bath

The heavy-medium bath is a practical extension of the laboratory float and sink test. The raw coal is introduced in the bath which is filled with a medium consisting of water and magnetite. The heavy impurities sink and the lighter coal particles float to the top of the heavy medium vessel. Refuse particles are reclaimed from the bottom of the vessel by a scraper or other means and clean coal is skimmed off the top of the bath. The finest particle size treated in the heavy medium bath is usually about 10 mm.

Heavy-Medium Cyclone

The heavy-medium cyclone has a cone angle of approximately 20°. The medium in which the separation occurs consists of water and magnetite. The raw feed and medium are introduced tangentially into the cylindrical section of the unit where a vortex is created with a central air-core due to the rotational (centrifugal) force induced. Heavy impurities move down the conical section wall and out the cyclone apex. The low-density coal particles move towards the central air core and out the top of the cyclone through the vortex finder. The top size normally treated in the heavy medium cyclone is 50 mm with a bottom limit of 0.5 mm. There are few applications for treating particles smaller than 0.5 mm in the heavy medium cyclone.

Water-Only Cyclone

The water-only cyclone (WOC) differs from the heavy-medium cyclone primarily in the angle of the cone(s) which can range from

75 to 135°. The WOC also has a larger overflow discharge orifice (vortex finder). The most common WOC's in use are the Compound Water Cyclone with a tricone, and the one of Dutch State Mines with a 75° cone. The coal slurry is introduced tangentially and under pressure into the cylindrical section of the cyclone. Centrifugal force separates the particles in proportion to their mass; and accoridng to their relative density in some models (Compound Water Cyclone), where an autogenous hindered-settling bed is formed, as in a jig (3). As the slurry moves downward into the conical section of the cyclone, the centrifugal force acting on the particles increases exponentially as they are dragged closer to the air core by the water current, most of which exits through the vortex finder. Heavy, high-ash particles move outward and downward along the wall whereas the lighter, coaly particles move inward towards the air core in an upward "vortex current" surrounding this central air core and thus report to the clean coal product. The most popular application for water-only cyclones in Canada is encountered in washing the minus 0.6 mm fraction. The size ranges for WOC application is between 50 and 0.1 mm.

Jig

Jigging is the oldest separation method used in coal preparation. Because of its simplicity and good economics (low cost) jigging is still highly regarded in modern technology and today the largest percentage of coal in the world is being cleaned by jigs. Jigging is a process of stratification which results from an alternating expansion and compaction of a bed of particles by a pulsating fluid flow. The particles' rearrangement results in layers of particles which are stratified according to increasing relative density from the top to the bottom of the bed. Jigs are commonly used for washing coarse coal at or above 1.5 relative density of separation. The size range for jig applications in Canada is between 100 and 10 mm.

Concentrating Tables

The table employs the principle of flowing a mixture of coal and water over a series of riffles on a deck which is shaken rapidly to effect a separation of the coal by relative density and particle size. The frequency and amplitude of stroke and the transverse slope are adjusted to suit the material being treated. The shaking motion of the deck combined with the cross current of water stratifies the particles by density similar to the action in the jig. The table is effective in removing pyritic sulphur and fine refuse down to 0.3 mm. Only one plant in Canada employs tables to clean the minus 2.4 mm size fraction.

Froth Flotation

Froth flotation relies primarily on coal surface characteristics. The fine raw coal (minus 0.6 mm or less) is mechanically agitated in a liquid containing controlled amounts of water, air and chemical reagents. The reagents cause selective adhesion to air of coal particles that float to the top, and simultaneous adhesion to water of heavier high-ash particles that settle to the bottom. The components thus segregated are diverted to clean coal and refuse circuits respectively. Ordinary flotation is used mainly to reduce the ash content of the fine coal fraction. It is not as effective for reducing sulphur content since it does not discriminate well between coal and pyrite particles. In Canada froth flotation is mostly used to recover clean coal from coal slimes (minus 0.15 mm). Some coal is frequently lost to the reject because of coal oxidation, overloading of the flotation circuits or becuase of the presence of oversize coal particles in the feed that are too heavy to be lifted by the air bubbles.

DEWATERING

Water content of coal and reject must be reduced before these products leave the plant. Removal of water from fine coal and reject is usually more difficult than from coarse particles. Water content is reduced by mechanical and thermal drying processes. Oil can be used as a means for reducing the moisture content of fine coal during the mechanical dewatering process.

Mechanical Dewatering

Vibrating screens: Dewatering coarse material on vibrating screens is simple whereas dewatering fines (minus 2 mm) can be difficult and expensive. Screens can be used to dewater fine coal down to 0.15 mm size.
Centrifugal driers: These driers are mechanical devices which through rotational speed, develop centrifugal forces to cause separation of the solid and liquid components of a slurry. Centrigures are of two general types. Screen-type machines separate the liquid from the particles by forcing it to pass through the screen and the solids retained on the screen surface. The other type, the solid bowl centrifuge, separates the solids from the liquid by centrifugal sedimentation.
Filters: Filters function by applying suction or pressure to a slurry causing free water to be drawn through a fine mesh screen and the suspended solids that are retained on the filter surface. The multiple disc filter is by far the most widely used because it is considered less expensive to purchase and install than the drum type. Filter presses are used to separate liquids from solids through the application of 689 to 1379 kPa pressures to a series of plates separated from each other by a filter medium. Filters in general are used for dewatering minus 0.6 mm or finer materials.
Thickeners: Thickeners are not strictly dewatering devices, however, they are associated with dewatering operations. Two types of thickeners are in general use. Static thickeners employ the effect of hindered settling and compaction of settled solids; sludge blanket clarifiers use bed filtration in combination with hindered settling and compaction of settled solids. Thickeners are usually used in conjunction with centrifuges or filters.

Thermal Drying

Thermal drying reduces moisture content of coal below that achieved by mechanical dewatering in centrifuges and filters. Usually, thermal drying is used to reduce clean coal moisture to 4 to 8% surface moisture. Thermal drying is capital intensive and costs are high to generate the required heat to reduce moisture.

LEVELS OF COAL PREPARATION

Phillips described the levels of coal preparation as the intensity of work done on a raw coal, which in turn is determined by marketing considerations and by coal washing characteristics (4). Six levels of preparation are generally identified (4). At one end, Level 1 employs no preparation at all while at the other end, Levels 4 to 6 call for multistage beneficiation. Higher levels of preparation are expected to improve clean coal quality but they also increase the cost of preparation and reduce thermal recovery. Phillips stated that "It would clearly be of interest to achieve the goals with the least possible effort to ensure that preparation costs are kept below the coal's higher market value" (4).

COAL PREPARATION ECONOMICS

Generally speaking, total cost of preparation is about 14% of mining, handling and beneficiation combined. However, mining costs of western Canadian coals are often favourable. Preparation is therefore a major rather than an auxiliary function in the control and costing of Canadian coal production.

From the economic point of view, cost attributed to preparation and beneficiation must be offset by corresponding benefits. Preparation is required to produce a product with specific qualities that can compete on the market. Environmental and economic facts also influence the decision on preparation and its level. Distance between mine and market is important too. To determine the major costs assignable to preparation, the following methodology is followed:

1. Identify important factors influencing the cost of coal preparation.
2. Quantify and compare relative preparation cost elements as a function of level of preparation.

FACTORS INFLUENCING COAL PREPARATION COST

1. Annual production (TPY) and processing capacity: The larger the capacity of the plant and the higher the utilization rate, the lower

the cost of preparation per tonne.

2. Level of preparation: The higher the level, the higher the cost of preparation.
3. Raw coal properties: Amounts of high ash material, coal washing characteristics such as near-density material, ash distribution and amounts of fines influence the cost of preparation.
4. Clean coal properties: Clean coal ash, sulphur and surface moisture would influence the choice of level of preparation and recovery achieved and in turn the cost of preparation.
5. Refuse characteristics: The lower the yield and the higher the refuse amounts, the higher the disposal cost. The means of disposing fine refuse would also influence the preparation cost.
6. Coal handling facilities: Coal handling, crushing and blending directly related to preparation can influence the preparation cost.
7. Plant location: whether close to the mine, to consumer or both. For example, disposal cost may be cheaper in one location than another.

EVALUATION AND PREDICTION OF OPTIMUM CLEANING

The purposes of evaluating the performance of washing units are to establish how effectively a unit is operating and to obtain data that can be used to predict results which can be expected when treating different coals. Therefore, performance criteria are of value as they act as a yardstick in helping to determine whether better plant performance could be expected (5). Performance criteria can be classified according to the degree to which they are dependent upon the densimetric composition of the raw coal.

DEPENDENT CRITERIA

The yield and quality of a washed coal are the factors of direct and practical interest in any washing operation. However, they depend directly on the washability characteristics of the raw coal and are thus inadequate for routine day-to-day control. For example, if a wash plant's yield is at any time lower than average, this does not necessarily mean that control action should be taken. It is possible that the plant is still operating at its optimum and that the cause of low yield is a high-ash raw coal feed resulting in more reject material than usual.

To optimize plant performance, it would be useful to have a standard for comparison that does not depend directly on washability data. Three criteria: organic efficiency, ash error and yield error are less dependent on feed washability than are yield figures, and therefore would be more suitable for routine control purposes.

Organic Efficiency

The organic efficiency expresses the yield of washed coal relative to the theoretical yield at the same ash content as determined by float-sink analysis. Mathematically, it is written as:

$$\text{Organic efficiency} = \frac{\text{actual yield of washed coal}}{\text{theoretical yield}} \times 100$$

High organic efficiency by itself, does not necessarily indicate satisfactory performance. Ash reduction must be considered as well.

Ash Error

Ash error is a direct measurement of the degree to which the ash content of the washed coal is increased by the separation errors inherent to any process. It is the numerical difference between the actual and theoretical ash content (as determined by float-sink analysis) of the washed coal at the yield obtained.

Ash error = (% of clean coal ash) - (% of float coal ash at the recovery of clean coal obtained)

Yield Error

Yield error is the difference between the yield of the coal actually obtained and the theoretical yield (as determined by float-sink analysis) at the ash content of the washed coal.

Yield error = (% of clean coal recovered) - (% of float coal recovered at the ash content of clean coal obtained)

Organic efficiency as well as ash and yield errors are directly related to impairment in yield and ash content caused by imperfect washing. Caution: since these dependent criteria are influenced by the separation cutpoint, direct comparisons between equipment treating coals with different washability characteristics or washing them as substantially different cutpoints cannot be made on the basis of these criteria.

INDEPENDENT CRITERIA

By definition, independent performance criteria are characteristic only of the washing unit and are substantially independent of coal washability. Ideal performance would be achieved if all coal lighter than the cutpoint density reported to the washed coal and all the material heavier than the cutpoint reported to the refuse. No cleaning process achieves this goal, but some of them approach it more closely than others. The independent criteria include probable error, error area and the imperfection; and they all refer to the sharpness of separation.

Two criteria, error area and probable error (Fig. 2) are derived from the distribution curve. The distribution curve shows the percentage of each density fraction of the feed to the washing unit that reports to the refuse product. The distribution curve is essentially a characteristic of the washing unit itself and is substantially unaffected by the density composition of the coal being treated. However, it is noted that densimetric composition may vary with particle size; with resultant shift in cut-point (6). The probable error for a distribution curve is half of the relative density interval for the curve to pass through the ordinates of 25 and 75 per cent and thus, is simply a measure of the average slope of the middle portion of the distribution curve. The lower the probable error, the steeper the curve and the sharper the separation.

The probable error and error area are both adequate in making broad comparisons between various types of cleaning equipment. Caution: densimetric distribution curves should be made of narrow size fractions in order to avoid bias, especially where slimes separation is tested. However, when applied to evaluate the performance of a particular washing unit for purposes other than sharpness of separation, they may be less satisfactory. Probable error is determined entirely by the sharpness with which the near-density material is separated and ignores the recovery of the light coal and how the entire feed is treated. The two criteria can give different relative evaluations (5). As well, the question of which evaluation is correct can be answered best by examining the significance of each in terms of yield and ash.

Finally, it should be always remembered that no performance characteristic can be better than the set of samples from which it was determined. In plant experiments as in pilot tests, these sets should be collected isokinetically i.e., simultaneously from the products, especially where the ratio of separator volume to throughput capacity, that is the retention time is small as for example in a cyclone. It is one of the most common oversights in testing, because of the confusion that exists about what constitutes a sample for quality assessment of a product and a sample set for testing the performance of a separator.

PLANT OPTIMIZATION

Simulation models are used in flowsheet design and optimization, in monitoring operating plant performance and in aiding to correct its operation. The most common application of models is to estimate recoveries, quality of products and material balances for designing new preparation plants. However, the use of models is also important for off-line and for possible future on-line optimization. There are two cases where a coal preparation plant operator should consider adjusting plant operating conditions to produce the required product or products:

1. when feed washability characteristics change
2. when there is a departure from optimum performance.

In the first case the operator can use simulation models to predict the required cutpoint of separation and yield at the desired ash content. The calculated data, then, can be used to change operating parameters to achieve optimum performance.

In the second case, partition curves, organic efficiency and ash and yield errors would quantify deviation from optimum performance. This deviation could be caused by several conditions including over-loading certain sections of the plant, slimes build-up, cyclone plugging, variation from set cutpoints and various mechanical and maintenance problems. Computer calculations and simulation model data can be used as a yardstick to evaluate actual performance, thus indicating when corrective action is necessary.

A recent study showed that advance control systems for on-line control could improve cleaning plant thermal recovery by at least 5% while also significantly improving plant availability (7).

BENEFICIAL EFFECT OF COAL BENEFICIATION ON POWER PLANT OPERATION

An Electrical Power Research Institute (EPRI) investigation of the impact of coal cleaning on the cost of new coal-fired power generation plants showed net electricity generation cost savings for most new, large plants when coal cleaning was used (7). Additional savings realized through the improvement in plant availability resulted in an estimated additional saving of $1.5 million per year.

The principal objectives of coal preparation, other than controlling size consist are to lower the ash content and to decrease the sulphur level. The effects of coal beneficiation on power plants are summarized as follows:

1. Lower non-combustible content will increase thermal content of clean coal and result in the following benefits:
   a. Grinding Cost: reduction of mineral matter with abrasive characteristics would lower maintenance cost of the grinding system.
   b. Reduction in ash and sulphur content would result in lower fly ash and sulphur (SO_2) released to the environment and in turn reduce the size and cost of the flue gas treatment system and lower the maintenance cost of the boiler.
2. Burning coal that does not fluctuate in heat value as in the case of cleaned coal improves combustion efficiency.
3. Blending requirements and costs before burning are reduced due to lower variability in clean coal quality.

These benefits have to be compared with loss of heat value in the reject produced by the cleaning process.

REFERENCES

1. Butcher, S.G. and Wright, P.L. "The purpose and practice of coal preparation in Canada"; Coal: Phoenix of The '80's - Proceedings 64th CIC Coal Symposium; Halifax, N.S.; May 1981.

2. Mikhail, M.W., Patching, T.H. and Parsons, I.S. "Evalution of a procedure for predicting coal size degradation"; Proceedings of the XIV International Mineral Processing Congress; Toronto, Ontario; October 1982.

3. Williams, D. G. "Coal cleaning"; Coal Handbook; pp. 272-276; Ed. Robert A. Meyers, New York (1981).

4. Phillips, P.J. "Coal preparation for combustion and conversion"; Electrical Power Research Institute - EPRI AF-791; p. 2-46; May 1978.

5. Geer, M.R. and Yancey, H.F. "Evaluation of washery performance"; Bureau of Mines, Report of Investigations 8093; 1962.

6. Williams, D.G. "Coal cleaning"; Coal Handbook; Fig. 20, p. 277; Ed. Robert A. Meyers, New York (1981).

7. Karlson, F.V. "Development of Coal Cleaning Technology"; Mining Engineering; p. 1367; Vol. 34 No. 9; September 1982.

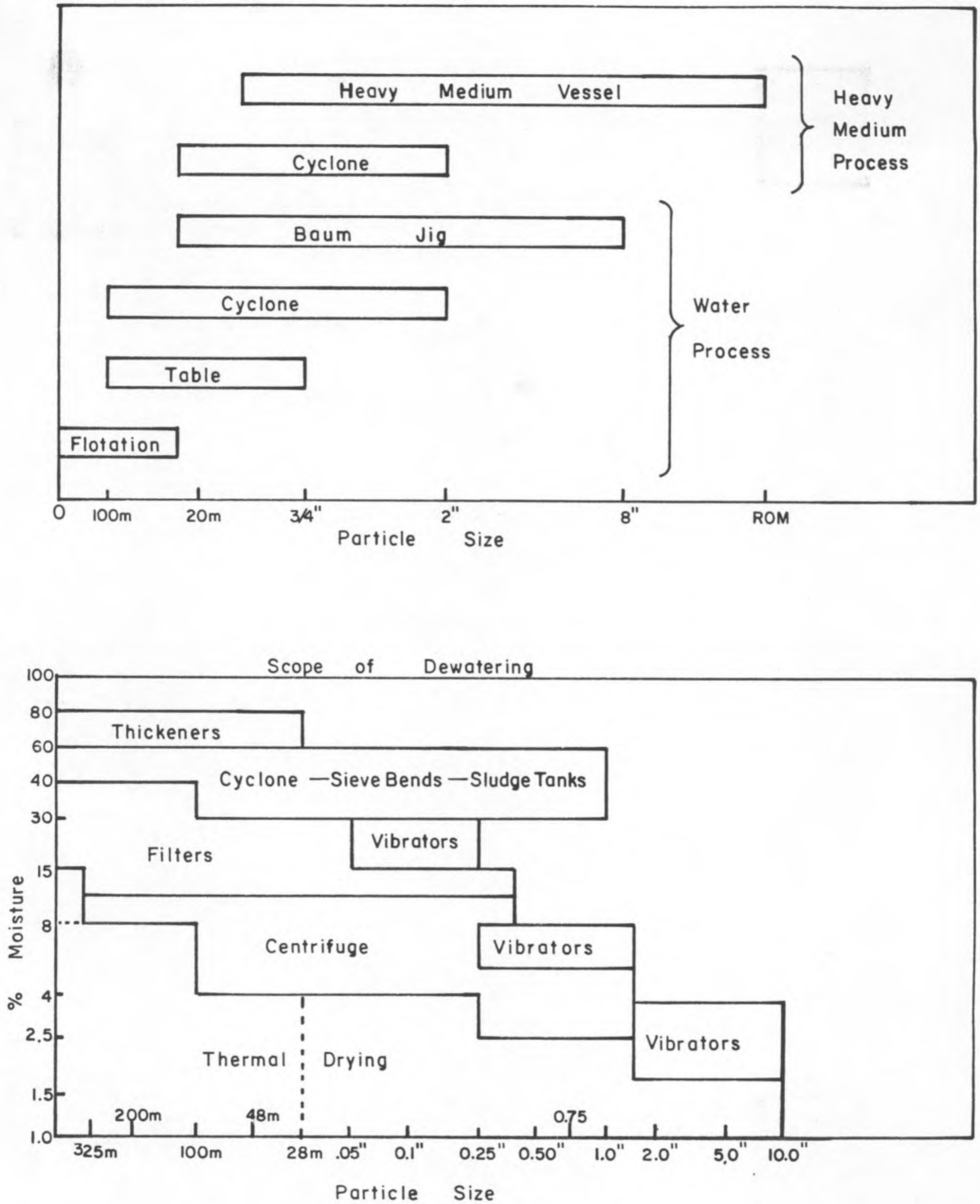

Fig. 1 - Cleaning and dewatering equipment application in relation to particle size.

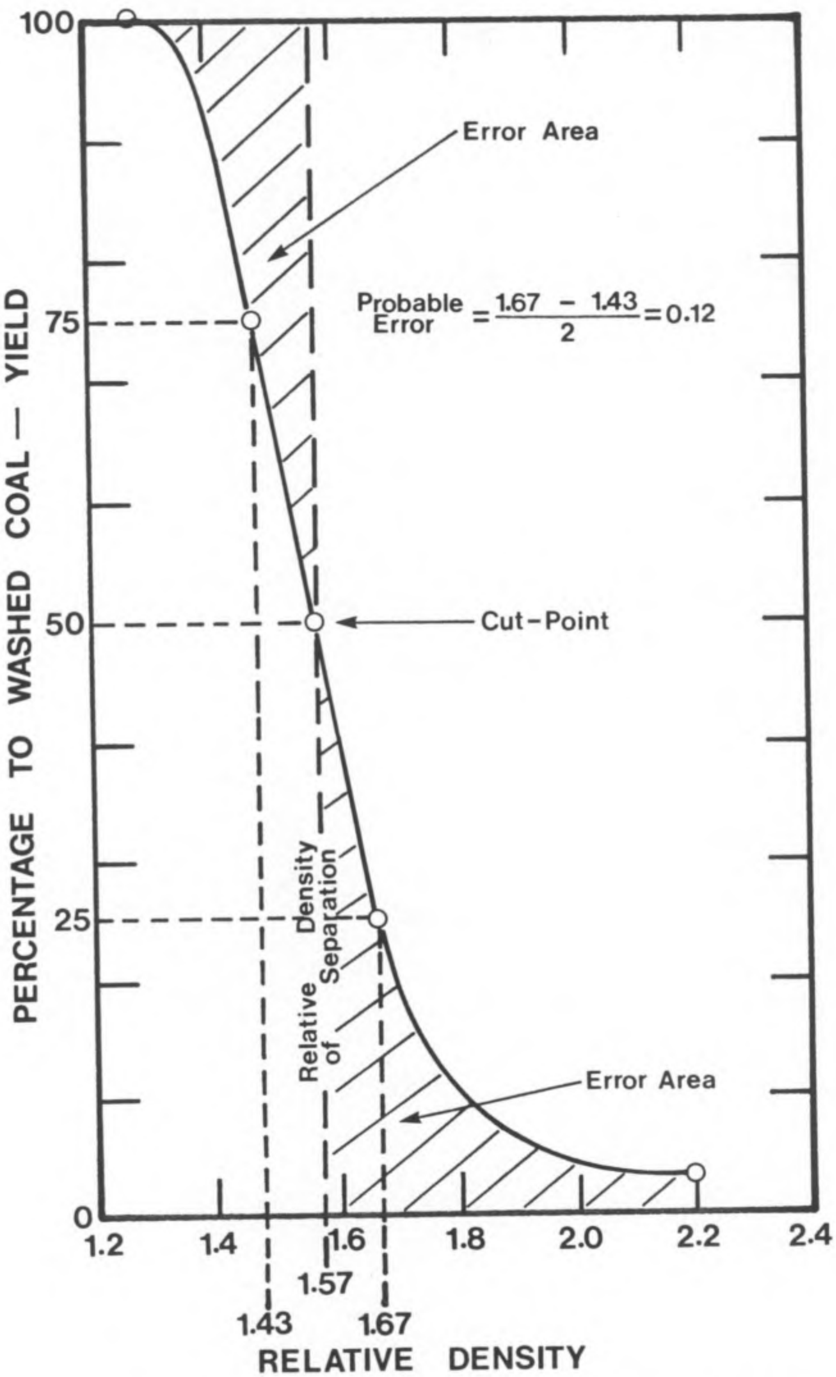

Fig. 2 - Distribution curve showing probable error and error area.