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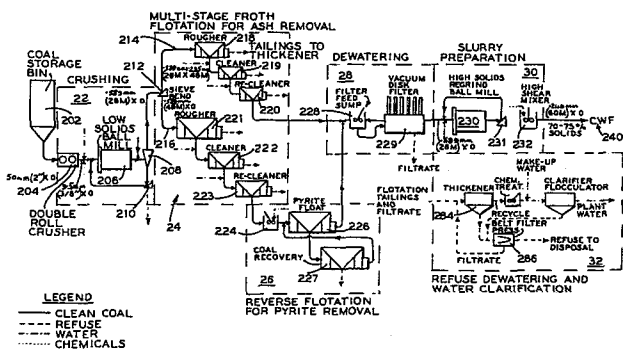
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54 **Coal-water fuel production.**

57 A process and apparatus for producing coal-water fuel comprises crushing and primary grinding of the coal to form a liberated granular material, multiple stage froth flotation of the granulated coal to reduce its ash content and pyritic sulphur content. The resulting product from the froth flotation operations is dewatered to yield a product having a selected solids content. A stable slurry is then produced from the product by establishing a selected particle size distribution. Refuse accumulated from the various previous steps is collected, dewatered and the water is clarified for use in the process steps.



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COAL-WATER FUEL PRODUCTION

The invention relates to a method and apparatus for producing coal-water fuel (CWF) on a commercial scale which uses a unique application of conventional, commercially available equipment.

5 Individual unit operations in the invention include coal crushing, rod milling, sieve bend screening, froth flotation, vacuum filtration, refuse dewatering, and ball milling. These have been practiced in the coal preparation and minerals beneficiation industries for many years. The invention also uses a reverse flotation operation.

10 The size reduction unit operations; crushing, rod milling, and ball milling, are common in mineral processing plants, e.g. copper and molybdenum ore concentration operations. Rod and ball milling are not found in conventional coal beneficiation operations. Current practice is to avoid the production of fine coal, primarily because of the inefficiency of conventional fine coal cleaning operations.

15 In conventional coal froth flotation, chemical reagents are added to the pulverized coal-water mixture to permit air bubbles selectively to attach to coal particles, causing them to rise to the surface. The particles of mineral matter remain on the bottom of the flotation cell. For reverse flotation, a different chemical reagent package provides for depression (sinking) of the coal particles and selective attachment of air bubbles to particles of liberated pyrite. Thus, pyrite, which is the principal sulphur-containing mineral associated with coal, rises to the surface and can be skimmed off, resulting in a reduction of the sulphur content of the feed stream.

25 Froth flotation is a commercially proven technique for reducing the ash content of feed coal. In most conventional coal flotation applications, only ten to twenty percent of the total plant feed is passed through the flotation circuit. In the present invention the entire feed stream may be directed to the flotation circuit depending on coal characteristics.

30 Separation of the flotation feed into coarse and fine streams (split feed) has been demonstrated to improve the performance of the flotation circuit.

Several commercial operations do practice split feed flotation, but this is not common. Separate flotation of coarse coal was first performed about 1960 at the pipeline plant of Hanna Coal Company in Cadiz, Ohio. The Kerr McGee Company has also installed split feed flotation for processing
5 0.589mm (28 mesh) x 0 raw coal in their newest 1200 TPH preparation plant. Multiple stage or "rougher-cleaner" flotation has been practiced in the coal industry for over 20 years. The first rougher-cleaner circuits in the coal industry in the United States were designed and installed in 1963 at three plants of Bethlehem Mines Corporation in Washington County, Pennsylvania.
10 The rougher-cleaner flotation circuits were designed for 60 TPH of 0.589mm (28 mesh) x 0 coal.

The reverse flotation process has been tested at both the laboratory and pilot plant levels (12 TPH coal feed) on a number of Pennsylvania and West Virginia coals. These tests indicate that 70% to 90% of the pyritic
15 sulphur could be removed by reverse flotation. Much of the early work, beginning in the late 1960's, was supported by the U.S. Bureau of Mines. Technical details of the process are available in the literature. Several individual companies continued this work in privately sponsored research programmes.

20 The use of a vacuum disc filter for dewatering of fine particles is common practice in both coal beneficiation and minerals processing plants. The present invention, however, requires more sophisticated control than commonly found in existing coal cleaning plants. However, such sophisticated control is standard practice in iron ore beneficiation systems
25 where filter cake moisture is a crucial parameter in the subsequent pelletizing operation.

The final stage in the CWF production process of the present invention, high density ball milling, has been demonstrated at a pilot scale. A 50 to 100 TPD continuous pilot plant located at Kennedy Van Saun
30 Corporation in Danville, Pennsylvania, has been in operation since February 1982. The coal-water fuel technology is covered in United States Patents Nos. US-A-4 282 006 and US-A-4 441 887 to Funk.

According to one aspect of the invention there is provided a method of producing coal-water fuel from raw coal, characterised by the steps of:-
35 breaking up the raw coal to form liberated granular coal;

adding water and chemicals to the liberated granular coal in a froth flotation process for removing ash and coarse pyritic sulphur from the granular coal to form a reduced-ash and sulphur coal;

5 adding water and chemicals to the reduced-ash coal in a reverse flotation process for removing pyrite from the reduced-ash coal to form reduced-ash and reduced-pyrite coal to form a dewatered coal; and

preparing a slurry from the dewatered coal which has a selected size distribution, the slurry being usable as coal-water fuel.

10 According to another aspect of the invention there is provided apparatus for producing coal-water fuel from raw coal characterised by:-

a crusher for receiving the raw coal and crushing it;

a primary grinder connected to the crusher for receiving the crushed raw coal;

15 froth flotation means connected to the primary grinder for receiving crushed and ground raw coal from the primary grinder to form a reduced-ash coal;

reverse flotation means connected to the froth flotation means for receiving the reduced-ash coal and for forming a reduced-ash and reduced-pyrite coal;

20 dewatering means connected to the reverse flotation means for dewatering the reduced-ash and reduce-pyrite coal; and

slurry forming means connected to the dewatering means for receiving dewatered coal from the dewatering means and forming a slurry thereof which can be used as coal-water fuel.

25 The invention is thus drawn to a method and apparatus for the production of coal-water fuel (CWF) on a commercial scale and using a unique combination of unit operations which, in and of themselves, are conventional. As noted above, the individual unit operations include coal crushing, rod milling, sieve bend screening, froth flotation, vacuum
30 filtration, refuse dewatering, and ball milling, as well as a reverse flotation operation. The operations include the production of fine particles through staged size reduction in the rod and ball mill circuits which is not a common practice in the coal industry. Neither is the complexity in scope of the froth flotation circuit found in this industry. According to the invention the
35 beneficiation circuit is also positioned between the size reduction devices.

Integration of a coal beneficiation circuit in the inventive process provides the capability of reducing the ash and sulphur content of the raw coal. This capability expands the potential supply of acceptable raw coal feedstocks and provides for the possibility of supplying various quality fuels to meet specific customer requirements. The process extends the commonly accepted limitations of conventional coal beneficiation operations. This is possible because the fine grinding required for CWF production also results in liberation of undesirable mineral matter and pyritic sulphur from the raw coal. Production of a coal-water fuel also eliminates the need for thermal drying of the ground coal and the subsequent handling and storage problems associated with fine, dry coal.

Thus, the invention can provide a method and arrangement of existing apparatus for producing a coal-water fuel comprising a crushing and primary grinding step and equipment for liberating undesirable components of the coal, a conventional froth flotation step and equipment for pyrite removal, a dewatering step and equipment for concentrating the solids content, a slurry preparation step and equipment for controlling particle size distribution and a refuse dewatering and water clarification step and equipment. While the individual function circuits remain constant in the various embodiments of the invention, individual items of the equipment can be substituted. Thus in an operating plant, parallel equipment would be installed and process piping arranged so that individual units could be by-passed in the event of equipment failure or for alternative product preparation.

The invention is diagrammatically illustrated by way of example with reference to the accompanying drawings, in which:-

Figure 1 is a block diagram showing apparatus according to one embodiment of the invention;

Figure 2 is a schematic illustration of an alternate embodiment of the invention;

Figure 3 is a graph showing the particle size distribution of the flotation feed produced by rod milling Upper Freeport coal;

Figure 4 is a graph showing the particle size distribution of the flotation feed produced by rod milling Pittsburgh seam coal;

Figure 5 is a graph showing the final CWF size distribution for the Upper Freeport seam coal test; and

Figure 6 is a graph showing the final CWF size distribution for the Pittsburgh seam coal test.

Referring to the drawings, the apparatus shown in Figure 1 is producing coal-water fuel and comprises six functional circuits. These are a crushing and primary grinding circuit generally designated 2, a froth flotation circuit for ash and pyritic sulphur reduction designated 4, a product dewatering circuit designated 6 for establishing a selected solids content, a slurry preparation circuit designated 8 for producing a desirable particle size distribution in the fuel, and a refuse dewatering and water clarification circuit designated 10 for treating refuse from one or more of the other functional circuits and for clarifying water from those circuits and for reuse in the CWF production process.

Figure 2 shows another embodiment of the invention with a crushing circuit 22, a froth flotation circuit 24, a reverse flotation circuit 26, a dewatering circuit 28, a slurry preparation circuit 30 and a refuse treatment circuit 32.

The separate functional circuits of the invention will now be described individually with reference to Figures 1 and 2.

Crushing and Primary Grinding

Raw coal arriving at a plant is sampled and stored in separate piles (not shown) if desired. Coal would be moved from the piles to one of several raw coal storage bins one of which is shown at 202 in Figure 2. Separate feeders on each bin would permit blending of coals ahead of the process to meet specific feed requirements.

Initial size reduction of the nominal 76.2 to 127mm (3 to 5 inches) x 0, 10-20% ash raw coal will be accomplished using an impact type crusher 104 in Figure 1 or 204 in Figure 2. Several crushers of this type are commercially available. Hammermill and cage mill designs are potentially attractive alternatives. The crushers 104 or 204 are sized and operated to produce a 19mm (3/4 inch) x 0 product for subsequent processing. An overall reduction ratio of approximately 6:1 is required. Staging of the crushers may be necessary to achieve this reduction ratio. The maximum particle size of the crushed product may be adjusted to meet the specific needs of the particular coal being processed.

In Figure 1 the crushed coal flows by gravity to the primary wet grinding operation at 106. This wet grinding operation serves several important functions: (1) it ensures a consistent coal particle size distribution to downstream processes independent of the raw coal size

distribution, (2) it creates highly active, freshly ground coal surface sites for subsequent froth flotation processing, (3) it inhibits surface oxidation of the newly produced active coal sites, and (4) it acts as an efficient wetting/mixing/conditioning device.

5 Conventional wet ball mills (206 in Figure 2) or rod mills are potential alternatives for this unit operation. Both of these devices are capable of producing a 0.589mm (28 mesh) x 0 product from the 19mm (3/4 inch) x 0 feed, corresponding to a reduction ratio of 33:1. Either mill would be operated at approximately 50% solids. The mill operating
10 conditions and final product size distribution will be determined by the characteristics of the coal being processed.

Two different grinding circuit designs have been considered. The first (Figure 2) is a conventional closed circuit wet ball milling process. In this mode of operation, the mill product is pumped to a hydrocyclone
15 classifier 208. Underflow from the cyclone, containing oversized coal and fine pyrite particles (cyclone separation is based on particle mass), is passed over a sieve bend 210. The sieve bend overproduct is returned to the mill 206 for regrinding, and the pyrite enriched underproduct is directed to a refuse thickener 284 in the circuit 32. Cyclone overflow is directed to the
20 froth flotation circuit 24. This type of circuit may be useful for coals containing a relatively high amount of coarse pyrite contamination.

Open circuit rod milling is a second alternative (not shown). The rod mill alternative would be expected to provide a narrower size distribution, i.e. fewer ultrafine particles, while still producing the minus 0.589mm
25 (28 mesh) product. Reducing the amount of ultrafine particles should improve the performance of the froth flotation circuit.

The minus 0.589mm (28 mesh) product from the grinding circuit 22 may be directed to either the froth flotation circuits 24, 26, forming a beneficiation circuit, or possibly to a vacuum filtration system 229 for
30 dewatering in circuit 28 as feed to the slurry preparation circuit 30. The latter option will be used if the coal is of sufficient quality to meet customer specifications without further ash or sulphur reduction. This option may be used if a pre-cleaned coal is chosen for feed to the process.

Conventional Froth Flotation

35 The performance of the flotation process is dependent to some extent on the distribution of particle sizes present in the feed, as are all

beneficiation techniques. Flotation kinetics and optimal cell operating conditions are particle size dependent. Therefore, close control of particle size may be required to improve selectivity and, hence, ash rejection and coal recovery. The flotation feed may be split into coarse and fine fractions depending on the characteristics of the coal being processed. This choice involves determination of the feed size distribution, to predict the mass flows to each circuit, and analysis of the flotation behaviour of individual size fractions. Note that the grinding mill may be controlled to adjust the product size distribution.

Referring to Figure 2, the grinding circuit product can be classified using a two-stage sieve bend arrangement 212. Provided the grinding mill has been adjusted to produce a consistent 0.589mm (minus 28 mesh) product, the first stage sieve bend is designed to separate the feed stream into 0.589 x 0.295mm (28 x 48 mesh) at 214 or 0.589 x 0.208mm (28 x 65 mesh) and minus 0.295mm (48 mesh) or minus 0.208mm (65 mesh) products at 216. The actual size differentiation will be determined by the characteristics of the coal being processed. Screening inefficiencies will result in some carry-over of fine material with the sieve bend overproduct. This overproduct can be passed over a second sieve bend (not shown, but again designed for a 0.295 or 0.208mm (48 or 65 mesh) cut to improve removal of the fine material. Water sprays are needed on this second sieve bend to improve screening efficiency. The coarse and fine fractions are collected in separate sumps for pumping to the appropriate multistage flotation circuit.

Multistage flotation involves retreating the froth product for further ash and sulphur reduction. Typically, at least one flotation stage 218-223 would be necessary. The actual number of stages required depends on the measured froth product quality and characteristics of the coal being processed. Generally, each successive stage is operated to provide an increasingly higher quality product. Physically, the stages are located at different levels in the plant so that the froth product from one stage may be gravity fed to the next. Note that no recycling of the high ash, high sulphur tailings products is intended. These products are directed to the refuse dewatering and water clarification circuit 32 (dash lines).

Each stage comprises one or more individual flotation cells. The froth from each cell may be collected separately so that product quality can be closely monitored and controlled. If necessary, the froth may be sprayed

with water to remove any loosely held middlings particles. Flotation reagents will be added directly to the flotation cells or to a conditioning tank ahead of the cells. An alcohol or glycol frother, such as methyl amyl alcohol (or methy isobutyl carbinol), will be used to produce a selective, stable froth. If necessary, fuel oil (No. 2 or No. 6) or alternative flotation promoters will be added to improve coal recovery. The actual reagent package required will be coal specific and must be identified by laboratory research for each application of the process.

Separation of the grinding circuit product into coarse and fine streams may or may not be required, depending on the characteristics of the coal being processed.

Following size classification of the grinding circuit product, the solids content of the coarse fraction is too high for effective flotation since most of the water passes through the sieve bend with the fine particles. Plant recirculating water (dot-dash lines), from the water clarification operation 32, is added to the coarse coal sump to dilute the feed to the rougher flotation unit to approximately 10% solids. Low reagent dosages 0.045kg to 0.225kg (0.1 to 0.5 pounds) of reagent per 9071kg (ton) of coal relatively mild aeration 2.8×10^{-3} to $11.2 \times 10^{-3} \text{ m}^3/\text{min}$ (0.05 to 0.20 cfm) per 0.0281 m^3 (cubic foot) of cell volume) are used in the first two rougher cells 218, to increase selectivity. The froth products from these cells may or may not require retreatment in the cleaner stage 219. Additionally, chemical reagents may be added to the remainder of the rougher cells to float as much material as possible. These froth products may be directed to coarse-cleaner flotation 219. The quality of the froth product from the last rougher cell may be substantially lower than that from previous cells. This low grade middlings product may be passed over a sieve bend, (not shown in the Figure) with the overproduct returned to the crushing circuit 22 for regrinding and the underproduct directed to the refuse dewatering circuit 32.

The appropriate froths from the rougher stage 218 may be fed to the cleaner stage 219. Water is added to the rougher cell froth launders 218 to dilute the feed to the cleaner stage 219 to approximately 10% solids by weight. the purpose of this stage is to produce a final clean coal product in terms of ash and sulphur content and carbon yield. Pyrite depressing reagents, such as CaO , KMnO_4 , or $\text{K}_2\text{Cr}_2\text{O}_7$, may be added to the flotation

cells to improve sulphur reduction. The coarse cleaner froth products flow to the vacuum filter feed sump 228. As in the rougher stage, the froth from the last cell may need to be screened and returned to the grinding mill 206. The cleaner tailings are directed to the refuse dewatering circuit 32.

5 The underflow from the classification of the grinding circuit product on line 216 (typically 0.295mm (48 mesh) x 0 or 0.208mm (65 mesh) x 0) flows directly to the fine coal rougher flotation feed sump. The feed solids content of the fine coal rougher circuit 221 is less than that of the coarse rougher 218, probably on the order of 5 to 7% solids. This lower solids
10 content is a result of most of the water from the grinding circuit product (at 50% solids) passing through the sieve bend 212 with the fine coal. It would be impractical to include a dewatering device at this location in the process. Therefore, the fine coal rougher flotation unit 221 must handle all of this water. The dilute feed is beneficial to flotation performance, but
15 may increase the size or number of flotation cells required.

 If necessary, the froth products from all of the fine rougher cells 221 may be cleaned at 222 and then recleaned at 223 at about 10% solids by weight to remove ash and as much sulphur as possible. The actual number of flotation stages will be dependent on the characteristics of the coal being
20 processed. The sulphur reduction at this point will essentially be limited to particle sizes between 48 and 150 mesh. The tailings from all of the stages are directed to the refuse disposal and water treatment circuit 32 for dewatering and water clarification.

 Multiple stage flotation of the fine coal produces an acceptable clean
25 coal product in all sizes in terms of ash content at maximum carbon recovery. Some minus 100 mesh pyritic sulphur may be present in the final froth product leaving the recleaner 223. This product can then be directed to the fine pyrite flotation circuit 26.

Pyrite (or Reverse) Flotation

30 The reverse flotation circuit 26 is operated to reject fine pyritic sulphur and maximize fine coal recovery. Reverse flotation is not applicable for ash reduction, nor is it efficient for separation of plus 0.147mm (100 mesh) pyrite. Consequently, the reverse flotation circuit must be preceded by conventional coal flotation in circuit 24.

35 The inventive process includes a two-stage 226, 227 reverse flotation circuit for reducing the sulphur content of the fine coal froth. This froth

product, at 20% to 25% solids by weight, must be conditioned to prepare the particle surfaces for coal depression and pyrite flotation. Approximately 0.18 to 0.317kg (0.4 to 0.7 pounds) of depressant reagent per 9071kg (ton) of coal and 0.18 to 0.317kg (0.4 to 0.7 pounds) of pyrite flotation reagent per 9071kg (ton) of coal are added to a conditioning tank 224 (dotted line). The actual reagents and reagent quantities used are characteristic of the particular coal being processed. Additionally, the tank contents must be adjusted to a pH of 4. This acidic condition helps to remove certain chemical groups from the pyrite particle surfaces rendering them more hydrophobic. Dilution to 15% to 20% solids may be required prior to feeding this conditioned slurry to the rougher reverse flotation unit 226.

Previous experience has indicated that the rougher reverse flotation stage 226 produces a high sulphur froth and a corresponding low sulphur clean coal tailings product. The reverse flotation rougher tails are directed to the clean coal dewatering circuit 28. However, the froth from the last few cells in the rougher unit 226 may contain excessive amounts of carbon. To recover this carbon, the rougher froth will be retreated in a cleaner stage 227.

The high sulphur froth product from the reverse flotation cleaner stage 227 may be passed over a sieve bend to (not shown) remove coarse coal/pyrite particles containing a significant amount of carbon. The overproduct would then be directed to the crushing circuit 22 for regrinding and liberation of the pyrite particles. The sieve bend underproduct would flow to the refuse disposal and water treatment circuit 32 for dewatering and water clarification.

The reverse flotation cleaner tails may be considered a coal middlings product which can be returned to the reverse flotation rougher feed 226. This product could also be sent back to the crushing circuit 22 for regrinding.

Clean Coal Dewatering

The clean coal dewatering circuit 28 must be designed to provide a closely controlled, high solids content feed to the slurry preparation circuit 30. the approximately 25% solids feed to the disc filter 229 must be dewatered to approximately 75% to 78% solids. This feed is comprised of the conventional coal flotation froth products and the reverse flotation tailings products. Should the beneficiation circuits 24 and 26 be by-passed,

the crushing circuit 22 product will be sent directly to the disc filter feed sump 228.

5 The filter feed sump 228 serves as a storage and mix tank for the filter feed. Laboratory experience indicates that the froth from the flotation circuit 24 products should break up fairly easily under mild agitation. A consistent filter feed at maximum solids concentration aids filter performance.

10 To maintain optimum filter performance, a filter vacuum must be maintained at a constant, high level. Dual-stage vacuum pumps are required to maintain vacuum with ground coals of varying filter cake porosity. A second means of maintaining a high vacuum is to ensure that the filter tub remains full. Filter rotation speed and, hence, production of filter cake, is controlled to match the tonnage of clean coal product from the froth flotation circuits. However, coal flotation products would be pumped to the filter at a rate higher than the operating filter capacity so that a steady overflow back to the filter feed sump 228 is provided. This overflow results in a constant flotation product level in the filter tub of the vacuum disc filter 229. A snap blow feature should be included for a good cake discharge.

20 The importance of the dewatering circuit 28 to coal-water fuel production cannot be overemphasized. The solids content of the dewatered product must be kept as high as possible to provide some degree of flexibility in the subsequent slurry production circuit 30.

Coal-Water Slurry Preparation

25 The slurry preparation circuit 30 consists of a second grinding step at 230 to produce the optimal particle size distribution. Slurry rheology is controlled in two sets of high sheer mixer tanks 232 in series; the first for viscosity control, the second for controlling slurry stability. Note that the slurry preparation system 30, like the flotation systems 24 and 26, includes the necessary chemical handling, storage and metering equipment (not shown).

30 The dewatered, clean coal filter cake from the vacuum disc filter 229 falls directly onto a belt conveyor through plastic lined chutes. Conveyor belt scales are used to provide an accurate measurement of the feed rate to the grinding mill 230. The cake drops into a ball mill screw feeder where a portion of the chemical dispersant reagent, pH adjustment chemicals, and

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any required dilution water will also be added (dotted line). The regrind ball mill 230 is operated in a high solids mode (70% to 78% solids by weight). Consistent control of the product particle size distribution is achieved by controlling the viscosity of the mill coal-water slurry via the addition of
5 chemical based dispersants. The regrind ball mill operating variables, including ball size distribution, ball charge loading, and mill speed, are chosen to maximize product throughput and minimize power consumption. since the ball mill is a very efficient mixer, the need for sophisticated solids takedown mechanical mixers is eliminated.

10 For some coals, high solids ball milling may not efficiently produce a sufficient amount of very fine particles to maintain the correct rheological and stability properties of the slurry. To correct this situation, a portion of the vacuum filter cake may be directed instead to a stirred ball mill (not shown). Enough water would have to be added to dilute the stirred ball
15 mill feed to 50% to 60% solids. The product from this ultrafine grinding device would then be added to the ball mill feed to provide the needed amount of fine particles. It is important to note that the solids content in the ball mill 230 must be maintained at a high level, above 70% solids. If the amount of stirred ball mill product is sufficient to significantly reduce
20 the overall slurry solids content in the ball mill, it may be necessary to return this product back to the disc filter 229 rather than feed it directly to the ball mill 230.

The semi-finished coal-water slurry from the mill will have a viscosity ranging from 1.5 to 4 Pa.S (1500 to 4000 centipoise) and a solids
25 content of 70% to 75%. This slurry is pumped to a viscosity process blend tank (not shown) equipped with low speed, high efficiency impeller mixers where the remaining chemical based dispersants are added to lower the slurry viscosity to approximately 0.5 to 2 Pa.S (500 to 2000 centipoise).

30 The product from the viscosity process blend tank (not shown) is pumped to a high frequency vibrating screen 231 for removal of oversize material 0.295mm (+48 mesh particles). The amount of oversize material is projected to be less than 3% by weight and will be recycled to the ball mill 230 feed for additional grinding. This vibrating screen is an external classifier which forms a closed grinding circuit to provide control of the
35 maximum particle size.

The vibrating screen 231 underflow will flow by gravity to a stabilizer process blend tank 232 for final slurry preparation. A chemical stabilizer to inhibit particle settling and caustic chemical for pH adjustment may be added to the blend tank to obtain final product quality. All of the chemicals used in slurry preparation are commercially available, environmentally acceptable, and can be readily obtained from existing chemical suppliers.

The final coal-water fuel (CWF) product at 240, is pumped from the stabilizer process blend tank to storage tanks. These storage tanks are insulated and equipped with mixers to ensure product homogeneity. The product can be transferred from the storage tanks for shipment by tanker truck, rail or barge.

Refuse Dewatering and Water Clarification

The refuse dewatering and water clarification circuit 32 is designed to prepare the plant refuse for environmentally acceptable disposal and to provide clean process water for reuse in the plant. Any contamination of recirculating water can adversely affect product quality. Therefore, proper performance of this system must be ensured to maintain overall process performance and product quality.

All of the process rejects, including tailings from the conventional froth flotation circuits 24, froth from the rougher reverse flotation operation 26, and filtrate from the vacuum disc filter 229, flow by gravity to a static thickener 284. The thickener provides a fairly quiescent environment in which solid particles may settle out, leaving a clarified water layer. This thickener overflow is returned to the plant water supply system for recycling to the process. Fresh makeup water must also be added to the water supply system.

Thickener underflow, at approximately 25% to 30% solids by weight, is pumped to a belt filter press 286 for further dewatering. The belt filter press was selected because of its ability to handle ultra fines and clay slimes. The belt press filtrate is returned to the static thickener 284. The dewatered refuse filter cake, 60% to 80% solids by weight, is transferred to an external storage pile by a belt conveyor for subsequent landfill disposal.

To protect the CWF production process against shutdown in the event of an upset in any portion of the refuse dewatering and water clarification circuit, several ponds will be constructed at the plant site. The ponds also

provide storage for excess plant water, supply process makeup water on a continuing or intermittent basis, and provide a receiving basin for thickener drainage during scheduled and unscheduled plant shutdowns.

5 The inventive process offers several advantages for both slurry production and coal beneficiation. These advantages may be broadly categorized as resulting from the modular design or attributed to operating flexibility.

10 The invention evolved through consideration of distinct unit operations to address specific functional needs such as ash and pyritic sulphur liberation, ash reduction, pyritic sulphur removal, dewatering, and slurry preparation. This approach resulted in a modular structure which should permit:

- Optimal management of individual unit operations.
- Sampling between modules to pinpoint sources of specific performance problems.
- 15 - Addition of parallel units to increase plant capacity.
- Substitution of advanced unit operations as they are developed (coal beneficiation in particular).

20 The invention has been designed to permit a high degree of operating flexibility to respond to variations in feed coal quality and customer product specifications. a few examples of flexibility include:

- Control of the feed size distribution to the initial milling operation to respond to variation in the coal breakage parameters.
- 25 - Control of the size distribution to the beneficiation process dependent on the degree of grinding required for ash and pyrite liberation.
- Ability to by-pass the beneficiation circuit completely if the raw coal quality satisfies the customer's specifications. This would also allow the refuse filtration system to be shut down.
- 30 - Ability to consolidate the split feed froth flotation operation.
- Ability to by-pass the sulphur reduction portion of the beneficiation circuit for low sulphur, high ash feed coals.

35 The inventive CWF production process is unique in that it specifically addresses the problem of fine particle pyritic sulphur removal.

Test Results

The feasibility of the basic concept has been demonstrated in the laboratory using several coals. The coal samples were first ground in a laboratory batch rod mill, cleaned by multiple stage froth flotation with a laboratory flotation machine, dewatered by vacuum filtration, and ground in a laboratory batch ball mill. Representative test results for two coal seams, the Upper Freeport seam coal and the Pittsburgh seam coal, are presented here. The individual operations will be discussed sequentially.

Rod Milling

The degree of primary grinding required for liberation of the mineral matter and pyritic sulphur contaminants from the coal matrix is dependent on the nature and distribution of these contaminants. The contaminants in the Pittsburgh seam coal are more finely disseminated than those characteristic of the Upper Freeport seam coal. Therefore, the Pittsburgh seam coal must be ground finer to attain the desired liberation. The size distribution of the final coal-water fuel product represents a limit to the amount of grinding permitted at this stage. Flotation feed particle size distributions produced by rod milling in the laboratory are presented in Figure 3 and Figure 4.

Froth Flotation

The froth flotation circuits examined included multiple stage coal flotation and reverse flotation. Significant reductions in the ash and sulphur contents of the feed were achieved with high recoveries of the combustible material as shown in the following table.

TABLE

FROTH FLOTATION CIRCUIT PERFORMANCE

	<u>PITTSBURGH SEAM COAL</u>	<u>UPPER FREEPORT SEAM COAL</u>
<u>PERCENT</u>		
ASH IN FEED	6.08	9.17
SULPHUR IN FEED	1.32	1.74
ASH IN PRODUCT	3.45	5.16
SULPHUR IN PRODUCT	1.07	0.76
JOULE (BTU) RECOVERY	8968 (85)	9706 (92)

Vacuum Filtration

5 The froth products from the flotation testing were dewatered using a filter leaf test kit. A range of filtration cycle characteristics and vacuum pressures were investigated. The tests indicated that dewatered cake solids contents ranging from 68% to 77% solids could be obtained from the fine particle flotation products.

CWF Preparation

10 The dewatered froth products were mixed with chemical reagents and ground in a laboratory batch ball mill to produce stable coal water slurries. The slurry characteristics are indicated in the following table:

	<u>PITTSBURGH SEAM COAL</u>	<u>UPPER FREEPORT SEAM COAL</u>
15 Solids Content - %	70.6	73.4
Slurry Viscosity - Pa.S (Cp at 100 reciprocal sec.)	0.87 (870)	0.85 (850)

The particle size distributions of the slurries are presented in Figures 5 and 6.

CLAIMS

1. A method of producing coal-water fuel from raw coal, characterised by the steps of:-
breaking up the raw coal to form liberated granular coal;
adding water and chemicals to the liberated granular coal in a froth
5 flotation process for removing ash and coarse pyritic sulphur from the granular coal to form a reduced-ash and sulphur coal;
adding water and chemicals to the reduced-ash coal in a reverse flotation process for removing pyrite from the reduced-ash coal to form reduced-ash and reduced-pyrite coal to form a dewatered coal; and
10 preparing a slurry from the dewatered coal which has a selected size distribution, the slurry being usable as coal-water fuel.
2. A method according to claim 1, including breaking up the raw coal using a first crushing step and a following primary grinding step.
15
3. A method according to claim 2, including crushing the coal to produce a 19mm (3/4 inch) x 0 granulated coal and grinding the 19mm (3/4 inch) x 0 coal in the primary grinding step to form 0.589mm (28 mesh) x 0 granular coal.
20
4. A method according to claim 3, including primary grinding of the coal using a closed circuit wet ball milling process to form the granular product, hydrocyclone classification of the granular coal to form an overflow and an underflow, directing the overflow to the froth flotation process, directing
25 the underflow to an optional sieve bend depending on coal characteristics to produce an overproduct and an underproduct, the overproduct being returned to the wet ball milling step and the underproduct being supplied to a refuse thickener.
- 30 5. A method according to claim 3, including primary grinding of the coal using an open circuit rod milling process to produce the 0.589mm (28 mesh) x 0 granular coal.

6. A method according to claim 3, wherein a low ash and low pyrite raw coal is used, including passing the 0.589mm (28 mesh) x 0 granular product directly from the primary grinding to the dewatering step.
- 5 7. A method according to claim 1, including executing the froth flotation process in at least one stage and possibly multiple stages including an initial rougher flotation stage, a second cleaner flotation stage and a final re-cleaner flotation stage depending on coal type.
- 10 8. A method according to claim 7, including providing two parallel froth flotation circuits, each having at least one stage and possibly multiple stages including a rougher, a cleaner and a re-cleaner flotation stage, and including passing the granular product through a sieve bend before it reaches the froth flotation stages, the overproduct of the sieve bend being supplied to one of the flotation circuits and the underproduct of the sieve bend being
15 supplied to the other flotation circuit.
9. A method according to claim 1, including dewatering the reduced-ash and reduced pyrite coal using an initial clean-coal tank and a following
20 vacuum disc filter.
10. A method according to claim 9, including preparing the slurry using a high solid regrind ball mill for breaking up the dewatered coal, a vibrating screen for maximum particle size control, and at least one mixing step for
25 receiving an output from the high solids regrind ball mill to form the slurry.
11. A method according to claim 1, wherein refuse is produced by the flotation processes and the dewatering process, including accumulating the refuse in a thickener to produce recycled water and a thickened refuse
30 product, pressing the thickened refuse product to form a disposable refuse product and treating the recycle water to produce usable plant water.
12. Apparatus for producing coal-water fuel from raw coal characterised
by:-
35 a crusher (104, 204) for receiving the raw coal and crushing it;

- a primary grinder (106, 206) connected to the crusher (104, 204) for receiving the crushed raw coal;
- froth flotation means (4, 24) connected to the primary grinder (106, 206) for receiving crushed and ground raw coal from the primary grinder to form a
5 reduced-ash coal;
- reverse flotation means (4, 26) connected to the froth flotation means (4, 24) for receiving the reduced-ash coal and for forming a reduced-ash and reduced-pyrite coal;
- dewatering means (6, 28) connected to the reverse flotation means (4, 26)
10 for dewatering the reduced-ash and reduce-pyrite coal; and
- slurry forming means (8, 30) connected to the dewatering means for receiving dewatered coal from the dewatering means (6, 28) and forming a slurry thereof which can be used as coal-water fuel.
- 15 13. Apparatus according to claim 12, including refuse disposal and water treatment means (10, 32) connected to the dewatering means (6, 28) and to the reverse flotation means (4, 26) for receiving refuse from the dewatering means and the flotation means and for treating the refuse.
- 20 14. Apparatus according to claim 13, wherein the primary grinder comprises a closed circuit wet ball mill (206, 208, 210, 206).
15. Apparatus according to claim 13, wherein the primary grinder comprises an open circuit rod mill.
- 25 16. Apparatus according to claim 13, wherein the froth flotation means (4, 24) comprises one or more successive froth flotation stages (218 to 223) depending on coal type.
- 30 17. Apparatus according to claim 16, wherein the froth flotation means includes a sieve bend (212), said at least one stage series connected froth flotation stages (221-223) connected to the sieve bend (212) for receiving an underproduct thereof and a second set of at least one flotation stages (218-220) connected in series and connected to the sieve bend (212) for
35 receiving an overproduct thereof.

18. Apparatus according to claim 16, wherein the dewatering means (28) is connected to an output of the froth flotation stages (24, 26).

5 19. Apparatus according to claim 12, wherein the dewatering means comprises a clean-coal tank (228) and a vacuum disc filter (229).

10 20. Apparatus according to claim 12, wherein said slurry preparation means comprises a ball mill (230), a screen classifier (231), and at least one subsequent mixing step (232).

15 21. Apparatus according to claim 12, wherein the dewatering means comprises a clean-coal tank (228) and a vacuum disc filter (229), the vacuum disc filter (229) produces refuse, the flotation means (24, 26) produces refuse, and the refuse disposal means (32) is connected to the vacuum disc filter (229) and the flotation means (24, 26) for receiving refuse therefrom and treating the refuse.

FIG. 1

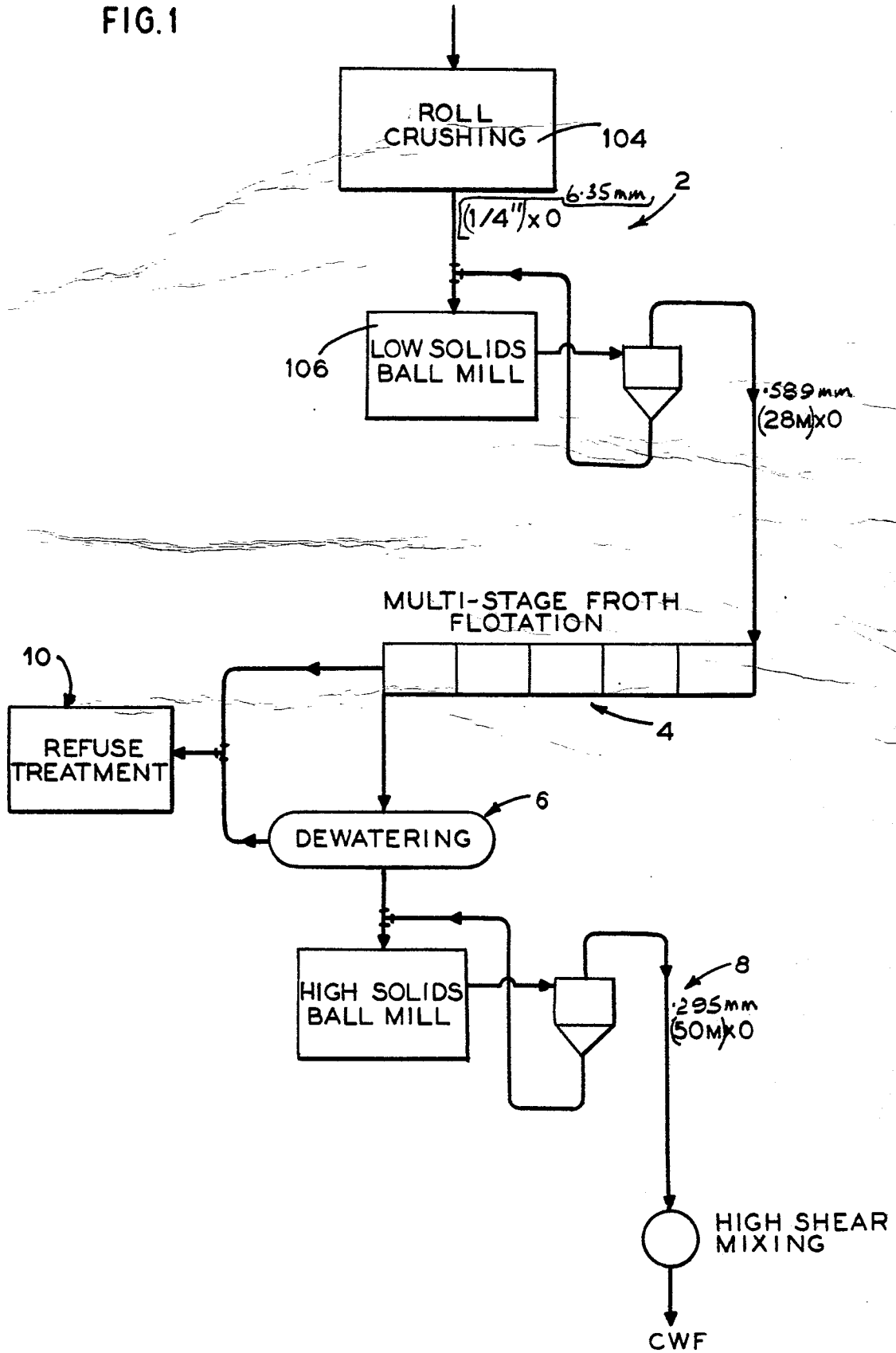


FIG. 2

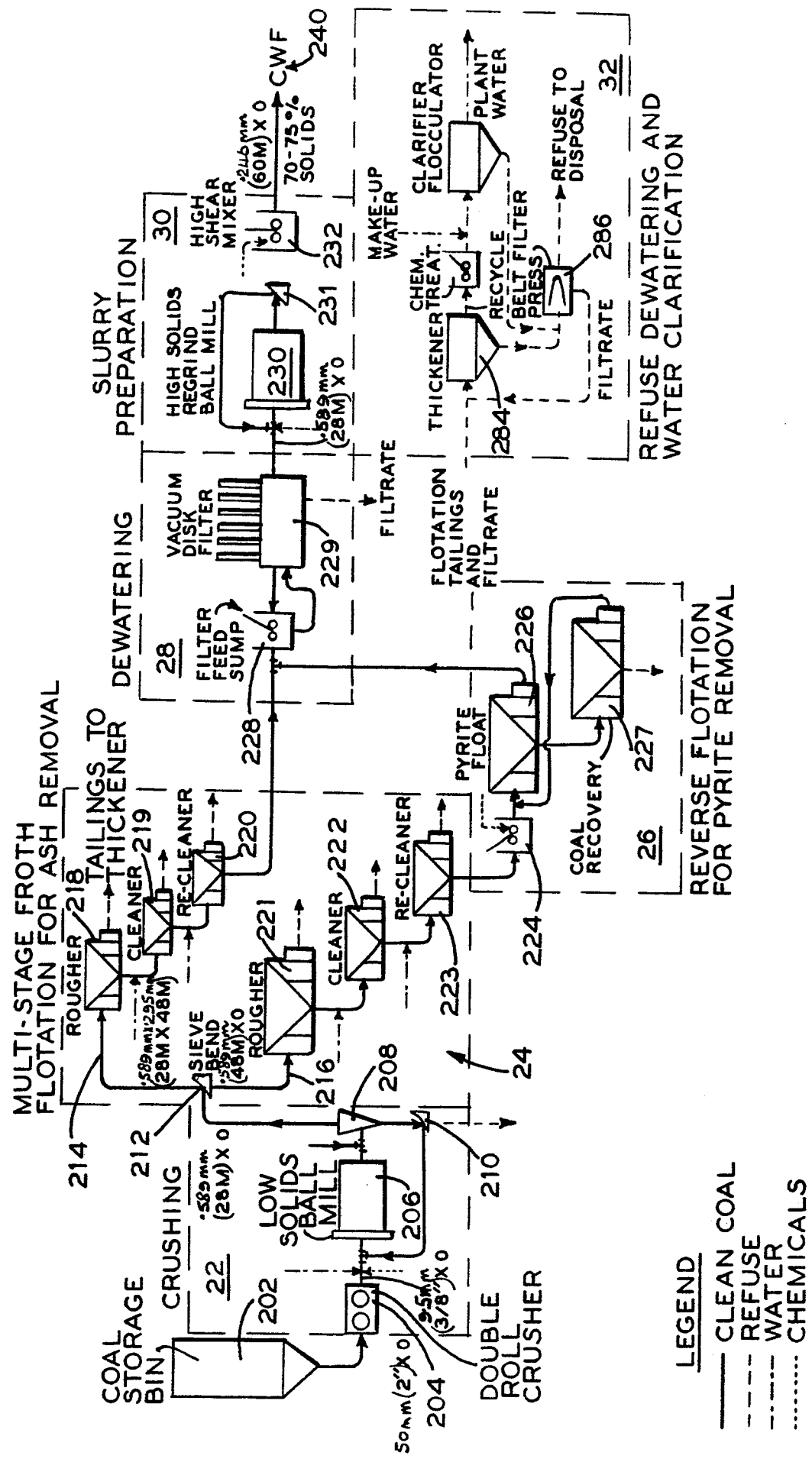


FIG. 3

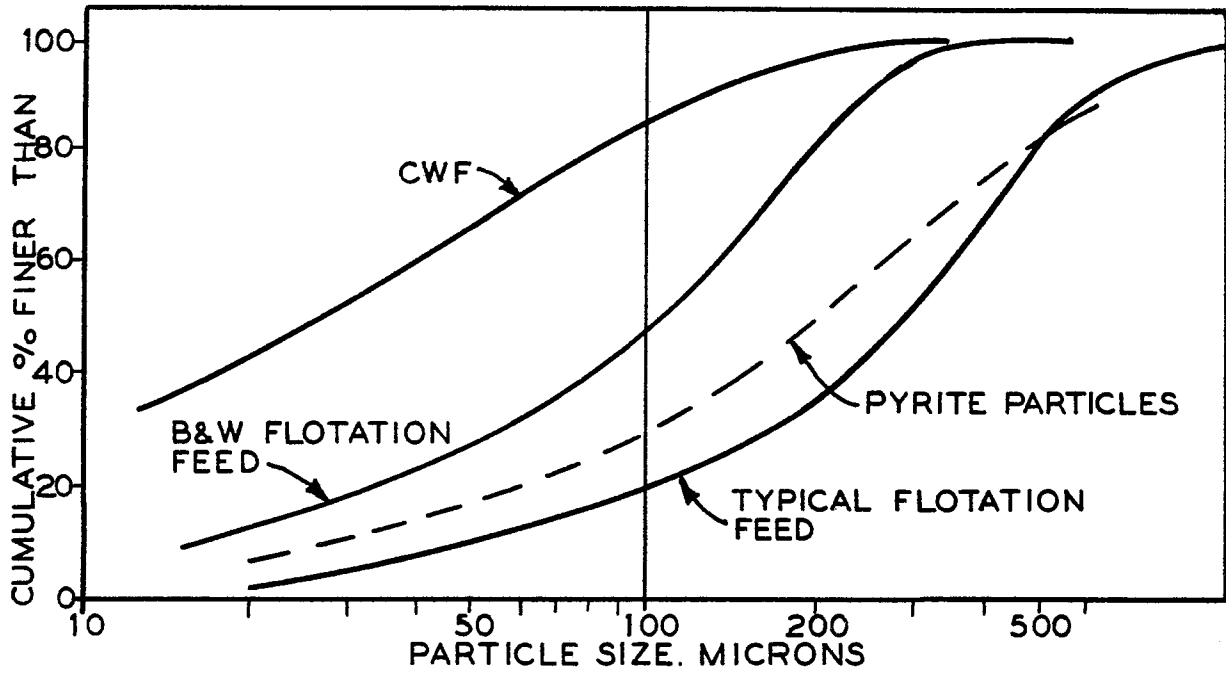


FIG. 4

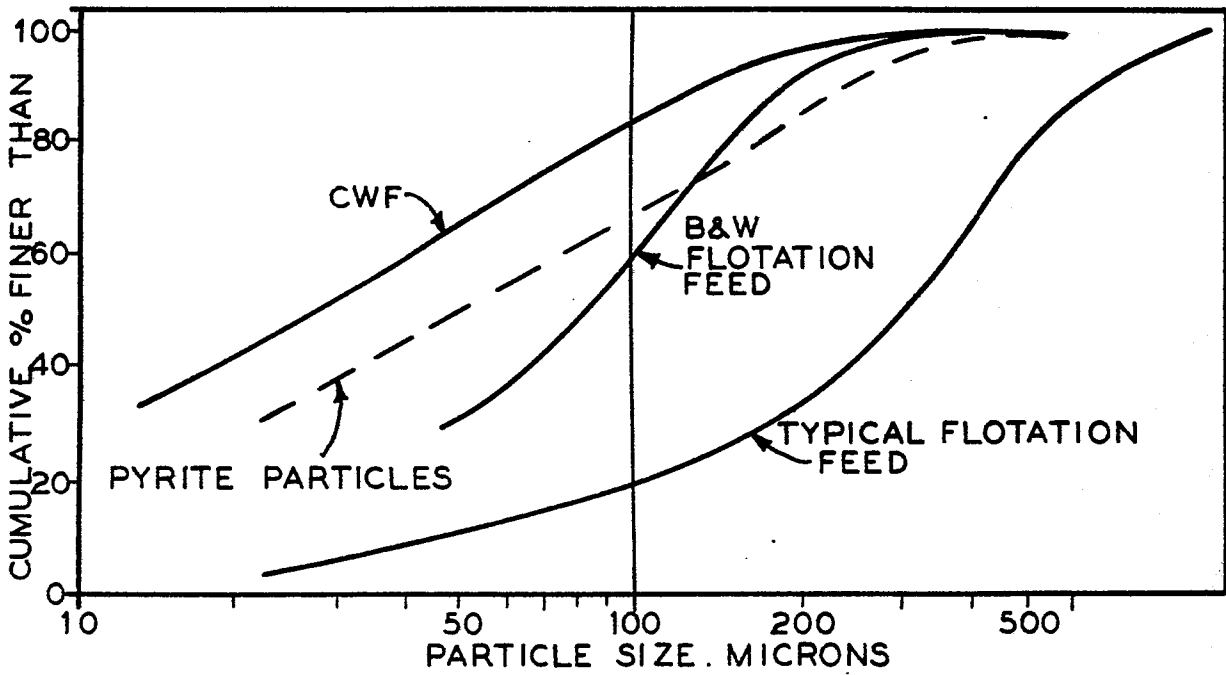
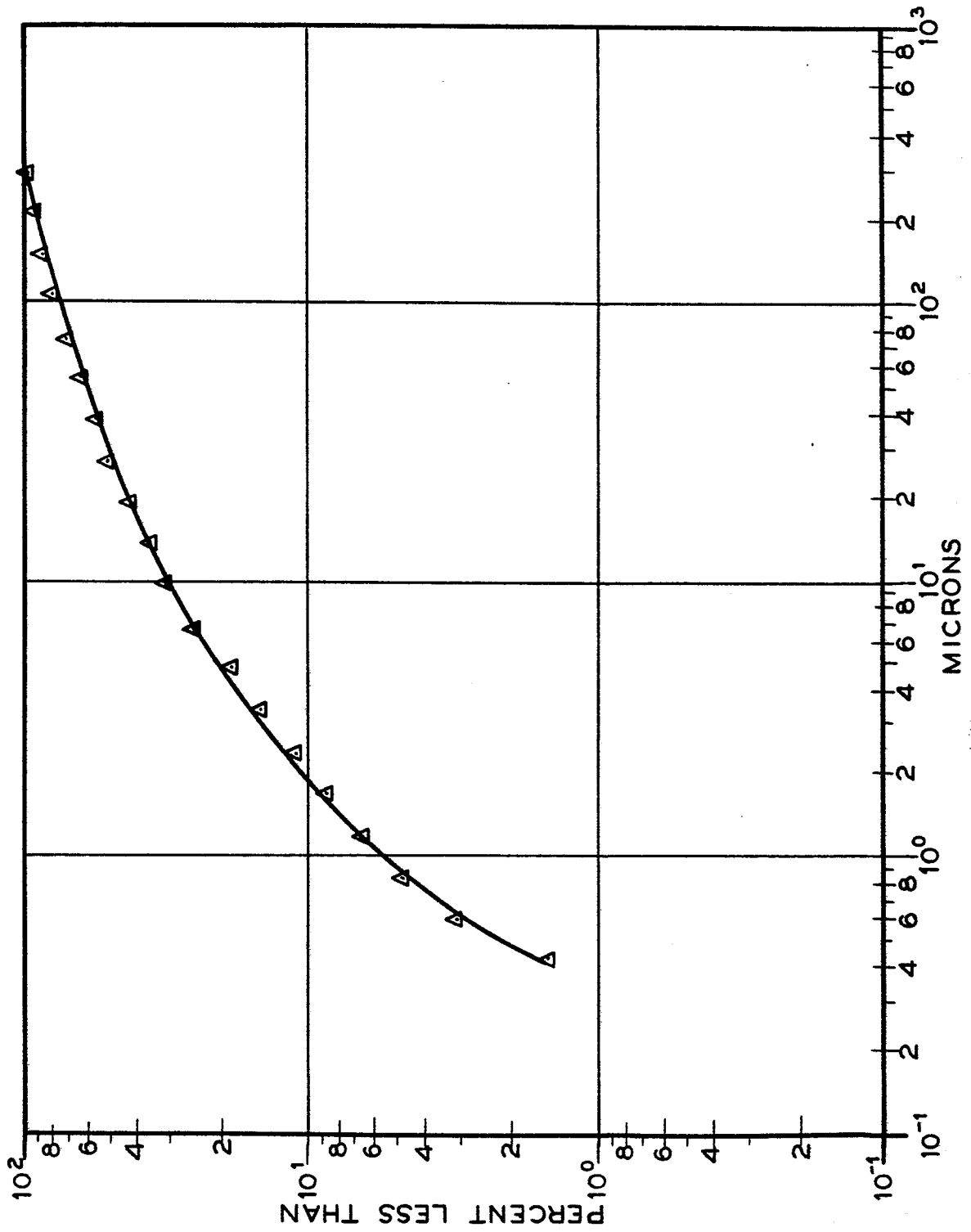


FIG. 5



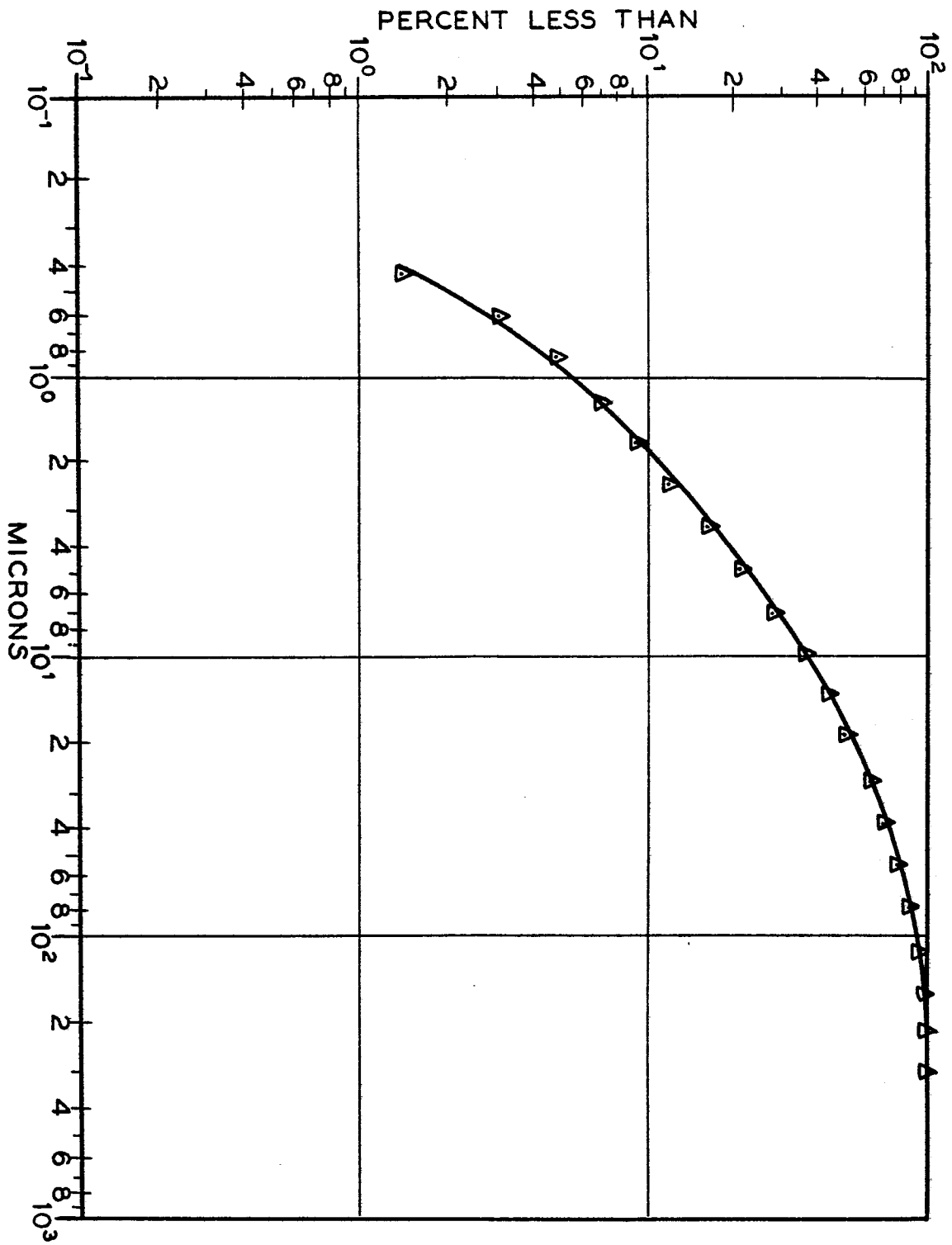


FIG. 6