INTRODUCTION TO COAL PREPARATION

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INTRODUCTION

Coal is a heterogeneous mixture of organic and inorganic (mineral) material that varies from seam to seam and also horizontally and vertically within the same seam. This heterogeneous aspect of coal influences the physical properties that determine how a coal will be mined, cleaned, and utilized. Coal preparation can eliminate, or at least minimize, this variability.

Coal preparation is a series of unit operations interconnected by a material handling system. At the heart of a coal preparation plant is the actual cleaning equipment. Selecting the optimum cleaning equipment for any particular coal is based on the performance of that equipment and an economic evaluation of the alternatives.

The purpose of this paper is to review the why and what of coal preparation. First, why do you have to clean coal?

What Is Coal?

Coal is a mixture of organic and inorganic material. The inorganic portion is often called mineral matter. This mixture varies from seam to seam; and within a seam both horizontally and vertically over a mines extent. This variation in the relative amounts of organic and inorganic material is reflected in the quality differences from one coal to another. As coal varies in quality, the amount of ash and sulfur change, with a corresponding change in heating value. Other variations are hardness and friability, inherent moisture, and the amount of out of seam material accompanying the coal (dilution). In addition to variation in quality the most notable variation from one coal to another is the rank of the coal.

The standard classification of American coals by rank, developed by the American Society for Testing and Materials, is shown in Figure 1. This classification system is based on the progressive change in coal in response to increased pressure and/or heat (metamorphism) during its formation. This progressive change is shown by a continuous coal series that starts with lignite and runs through the various bituminous coal ranks and ends with anthracite and meta-anthracite. [1,5] Peat is the primary desposit, prior to extensive changes.

Coal In Place

The structure of a coal seam can include the features shown in Figure 2.

Any particular coal seam may have partings or layers of rock within the seam, washouts, channels, or dikes that cut through the seam and non-coal roof and floor material. Depending on how the coal is mined more or less of these materials will be included in the as mined or raw coal. This out of seam material included with the coal is called dilution, because it dilutes the base in-place quality.

These variations cause coal to have various quality and handling characteristics, which effect the economics of how it will be used and how it will be cleaned.

Coal Constituents

Coal cleaning equipment is mostly based on the fact that raw coal can be physically separated into clean coal and refuse because of the specific gravity difference between the two fractions.

As illustrated in Table 1, the two constituents of coal are the organic compounds and the mineral matter. The organic compounds have a lower specific gravity than the mineral matter. The effective specific gravity of the organic portion is dependent on the rank of the coal but generally ranges from 1.2 to 1.7. The mineral matter is heavier, generally greater than 2.0. The proportion of these fractions, as determined by the washability test, determines the coals cleaning characteristics.

Coal Washability

The washability of a coal is determined by sink-float testing as shown in Figure 3. The test is performed by placing a sample of coal in progressively heavier specific gravity baths and scooping off the material that floats. This test shows how the quality and weight of the coal varies as the specific gravity changes. Table 2 gives the results of one of these tests. The table shows how a typical coal would separate at various specific gravities. The cumulative float at any float specific gravity is what a "perfect" separation would produce in the way of clean coal yield and quality, with the cumulative sink being the refuse from the perfect separation.

Coal Preparation Devices

Today most coal preparation devices are based on specific gravity difference inherent between the organic compounds and the mineral matter in the raw coal. Froth flotation of the very finest coal is a notable exception. Flotation is based on the surface chemistry of the coal particles.

Water-Only or Heavy Medium?

Most coal process decisions depend on the choice between all water process and heavy medium processes. Heavy medium involves the use of fluid that is heavier than the coal and lighter than the refuse to assist in the separation. With the most common fluid is a mixture of magnetite and water. Which system to be used is normally decided based on the factors shown in Table 3. Water-only process plants (jigs, tables, and water-only cyclones) are generally cheaper to install and operate than heavy media circuits (heavy media vessels and cyclones). They have the added advantage that, quite commonly, they do not require separation of the feed into various size fractions. On the negative side, however, they all have the following disadvantages compared to the heavy medium circuits.

- They produce lower yields for a given clean coal quality even in the case of coals which are 'easy' to clean.
- They generally do not operate well, if at all, at separation gravities below 1.50.
- In case of 'difficult' to clean coals, they do not operate effectively.

The ease or difficulty of cleaning a coal is defined in terms of near gravity material (Table 4). This is the amount of coal present within ± 0.1 specific gravity units of the selected separating gravity (which in turn depends on the desired clean coal quality).[2,4] The separating gravity is the specific gravity at which the coal cleaning device is operated, the difference of actual separation and the "perfect" separation is a measure of equipment performance.

What Is Coal Preparation

As with any processing system, whether it is coal, minerals, or whatever; coal preparation is a series of unit operations tied together with a material handling system. The main unit operations are: comminution, sizing, concentrating, and dewatering. Comminution, or size reduction (crushing, breaking) is the reduction of coal from run-of-mine size to a plant feed size or sized for use. Sizing (screening or classification) is the separation into various size fractions for processing. Concentrating (cleaning, preparation, or benefication) is the separating of a raw coal into clean coal and refuse. Dewatering or drying is the removal of excess water from the clean coal and/or refuse.

Process Selection

The selection of the appropriate cleaning circuit used for any particular coal is made by considering the desired clean coal specification, how the raw coal separates into clean coal and refuse to give the optimum yield at a quality that can be marketed, and the capital and operating cost that can be borne in a market.

A typical coal preparation plant is made up of several circuits with various cleaning devices in the circuits (Figure 4). Let us now look in more depth at the various devices.

COAL CLEANING EQUIPMENT

Jigs (Figure 5)

Jigging has been the most widely used means of cleaning coarse coal for more than a quarter century. The first coal jigs were direct copies of ore jigs, in which a basket loaded with mixed particles was moved up and down in a tank of water. Thus agitated, the particles became rearranged in layers of increasing density from bottom to top. The same principle is used in modern coal jigs to stratify and separate the coal and refuse products. Highly refined versions exist of the Baum type jig, based on an air impulse concept in which the water is cyclically jogged by air pressure from an adjacent sealed chamber. Jigging can be applied to a wide size-range of particles with top sizes up to eight inches.[6]

Heavy Medium Vessels (Figure 6)

Heavy medium separation provides more accurate separation and higher recovery of salable coal than jigging. Coal is slurried in a medium with a specific gravity close to that of the desired separation. The lighter coal floats and the heavier refuse sinks. The two fractions are then mechanically separated. While other media have been used, most coal cleaned by the heavy medium process is separated in suspensions of magnetite in water. This suspension is achieved using very finely ground magnetite. By varying the amount of magnetite in the suspension, the specific gravity of the medium is changed, which changes the gravity of separation. The process is versatile, offering easy changes of specific gravity to meet varying market requirements, and the ability to handle fluctuations in feed in terms of both quantity and quality. In practice, feed sizes may range from about ¼-inch to about six inches. The feed to any particular vessel will cover a portion of this range.[6]

Heavy Medium Cyclones (Figure 7)

For hard-to-clean coal in a size range of 1-3/4 inch to 28 mesh, the heavy medium cyclone is becoming widely utilized. In its operation, a slurry of coal and medium (magnetite dispersed in water) is admitted at a tangent near the top of a cylindrical section that is affixed to a cone-shaped lower section. The slurry forms a strong vertical flow; and under gravimetric forces, the refuse with its higher specific gravity moves along the wall of the cone and is discharged at the apex. The coal particles of lesser specific gravity move toward the longitudinal axis of the cyclone and finally through the centrally positioned vortex finder to the discharge outlet as clean coal. The heavy medium cyclone functions efficiently even with large amounts of near gravity material in the feed.[7]

Tables (Figure 8)

Tables have been in use for over 60 years in treating 1-1/2 inch x 28 mesh coal. The most generally accepted explanation of the action of a concentrating table is that as the material to be treated is fanned out over the table deck by the differential motion and gravitational flow, the particles become stratified in layers behind the riffles. This stratification is followed by the removal of successive layers from the top downward by cross-flowing water as the stratified bed travels toward the outer end of the table. The cross-flowing water is made up partly of water introduced with the feed and partly of wash water fed separately through troughs along the upper side of the table. The progressive removal of material from the top toward the bottom of the bed is the result of the taper of the table riffles toward their outer end, which allows successively deeper layer of material to be carried away by the cross-flowing water as the outer end of the table is approached. By the time the end of the table is reached, only a thin layer, probably not thicker than one or two particles, remains on the surface of the deck, this being finally discharged over the end of the table. [3]

Water-Only Cyclone (Figure 9 and 10)

Research on cyclones led to the development of the water-only cyclone, which performs a specific gravity separation employing only water and inertia. Its design feature which permits the use of "water-only" is the wide angle or angles in its conical bottom (Figure 10). This promotes the formation of a hindered settling bed, as the dense particles move down the side wall. Less dense particles cannot penetrate this heavy bed and move back into the main hydraulic current to be discharged out the top of the unit through the vortex finder. Applied in easier cleaning situations than heavy medium devices, water-only cyclones have been used to wash coals with a top size range of 1-3/4 inch to 28 mesh, generally as a scalping device to reduce the load on other equipment. Water-only cyclones washing 28 mesh x 0 coal are generally used because of the presence of oxidized coal which has proved difficult to wash by other means. [7]

Froth Flotation (Figure 11)

Flotation, or more specifically froth flotation, is a physicochemical method of concentrating fine coal. Coal, being a hydrocarbon, is not readily wetted by water (hydrophobic); while refuse is readily wetted by water (hydrphilic). By the addition of chemicals, these properties can be enhanced. The process involves chemical treatment of a raw coal pulp to create conditions favorable for the attachment of coal particles to air bubbles. Air bubbles are created by the rapid motion of the agitator mechanism which draws air down the hollow shaft and diperses the air into the pulp. The air bubbles carry the coal to the surface of the pulp and form a stabilized froth which is skimmed off while the ash containing particles remain submerged in the pulp. Although flotation was originally developed in the mineral industry, the process has been gradually extended to the coal field to handle the fines found with fully mechanized mining.

In general, coal particles coarser than 28 mesh cannot be effectively recovered by flotation; consequently, coal that is to be floated must first be sized so that the desired feed is all, or substantially all, smaller than this limiting size. Recent trends have been to process closely sized feeds such as 48 mesh, 60 mesh, or 100 mesh x 0. [8]

PREDICTING PLANT PERFORMANCE

Two pieces of information are required to determine the optimum cleaning circuit and to predict the clean coal yield and quality. The partition curves for the various gravity cleaning device and washability or sink-float tests on the coal.

Partition Curve

Each type of washing equipment has its own characteristic performance curve, commonly referred to as a partition curve. A typical curve is shown in Figure 12. The term "partition" derives from the fact that the equipment separates or "partitions" the coal into two fractions, $\pm$ the specific gravity of separation.) Each curve is substantially independent of the density distribution of the coal being washed. The curve is dependent upon the size distribution of the feed coal.

There are two basic philosophies in dealing with the effect of different size feeds. One philosophy requires a unique partition curve for each size feed and each separating gravity. This procedure becomes very cumbersome and requires a large file of curves. A new or changed feed size requires the development of a new curve. This is the procedure followed by the USBM which has proceeded to sample and test various plants and process equipment, and publish the results. The second philosophy is based upon the work of the Dutch State Mines organization which specifies that each family of curves can be reduced to a single curve that defines the effects at low and high gravities. This curve can then be modified to any feed by adjusting the slope of the center section. This is generally referred to as a normal-ized curve and is based on $\pm$ X specific gravity units from a separating point, referenced as zero.

This second method is the method followed by Kaiser Engineers and several other engineering firms. As such, we have a set of partition curves for different types of processing equipment, and adjustment factors (called Ep's) for the center sections. Ep is an abbreviation for Ecart Probable Error and is a measure of the precision of separation. It is defined as the specific gravity at which 25% of the feed reports to clean coal (d_{25}), minus the specific gravity at which 75% reports to clean coal (d_{75}), all divided by 2, or: $Ep = \frac{d_{25} - d_{75}}{2}$.

A low Ep (.02) indicates a very precise separation, and a high Ep (.20) indicates a very imprecise separation. Other factors such as error area, imperfection, and Tromp area are, and have been, used by various preparation engineers. For a more detailed discussion see reference 1, 2, or 4.

Coal Preparation Prediction at KE

Kaiser Engineers makes use of two computer programs to assist in the prediction of clean coal yield and quality. The first program uses the washability data, adds dilution material as required and composits the data into a form that can be inputed into the second program. This program can be used to develop various raw coal qualities depending on mining conditions and seam mixes. The second program expands the raw coal composite data into 24 gravity fractions based on the statistical relationship of the fractions. This expanded washability data is then multiplied by values from various partition curves, and the clean coal yield and quality is calculated at different separating gravities for the appropriate cleaning devices.

Using a jig partition curve and the typical washability data in Table 2, a jig simulation run was performed to establish the yield versus quality relationship for a coarse coal jig. The results of this simulation are shown graphically in Figure 13, which shows the comparative clean coal yield that can be achieved at different clean coal ash levels, using a jig to clean the coal from Table 2.

CONCLUSION

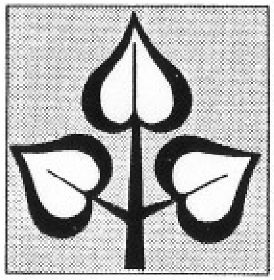
Coal preparation can eliminate or minimize the inherent variability found in run-of-mine coal. The prediction of clean coal yield from any coal at a desired quality level can be performed using partition curves and washability data. The determination of the best cleaning circuit for any coal is based on the desired quality and how the coal separates by gravity. The type of equipment used to clean a coal is more dependent on the gravity at which that coal must be cleaned to produce the desired quality and the economics involved rather than the end use of the clean coal. Many other devices and methods besides those listed here, have been, are, or will be used to produce a clean coal and refuse from a raw coal. This has been a brief review of some of the most currently popular cleaning devices.

References

1. Mitchell, D. R., Coal Preparation, p. 30, AIME, 1950.
2. Leonard, J. W. and D. R. Mitchell, Coal Preparation, p. 4-30, AIME, 1968.
3. Leonard, J. W. and D. R. Mitchell, Coal Preparation, p. 16-34, AIME, 1968.
4. Leonard, J. W. and D. R. Mitchell, Coal Preparation, p. 4-24, AIME, 1979.
5. Cassity, S. M., Elements of Practical Coal Mining, p. 21, AIME, 1973.
6. Coal Preparation Manual, M576, p. 43, McNally-Pittsburg Mfg. Corp.
7. Coal Preparation Manual, M576, p. 59, McNally-Pittsburg Mfg. Corp.
8. Flotation Fundimentals and Mining Chemicals, p. 4, Dow Chemical Co., 1968.

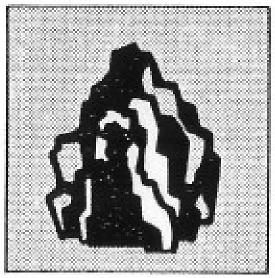
Table 1

Coal



Organic Compounds

- Light (Specific Gravity 1.2 to 1.7)
- Depends on Rank



Mineral Matter

- Heavy (Specific Gravity greater than 2.0)
  - Carbonaceous Shale (approximately 2.0)
  - Shale, Clay, Sandstone (approximately 2.6)
  - Gypsum (2.3)
  - Pyrite (5.0)

Table 2

Float and Sink Tables

Client XYZ Mining Co.
Job Number --
Mine/Plant/Seam A Mine
Type of Sample Raw Coal
Purpose Example
Remarks

Date Today
Percent of Total 100%
Size 4" X 0

Specific Gravity		DIRECT				CUMULATIVE FLOAT				CUMULATIVE SINK			
Sink	Float	Percent Weight	Percent Ash	Percent Sulfur	BTU/LB.	Percent Weight	Percent Ash	Percent Sulfur	BTU/LB.	Percent Weight	Percent Ash	Percent Sulfur	BTU/LB.
	1.30	41.79	5.56	4.10	13332	41.79	5.76	4.10	13332	58.21	32.13	5.38	9179
1.30	1.60	37.23	15.03	4.95	11850	79.02	10.02	4.50	12634	20.98	62.48	6.15	4438
1.60	1.90	2.98	46.44	6.58	7295	82.00	11.35	4.58	12440	18.00	65.13	6.08	3965
1.90		18.00	65.13	6.08	3965	100.00	21.03	4.85	10914				

Table 3

Water Based Processes		Heavy Medium Processes
Lower Cost	❶	Higher Cost
Less Efficient	❷	More Efficient
Less Flexible	❸	Greater Flexibility
1.55 - 2.0 Specific Gravity	❹	Less than 1.7 or greater than 2.0* Specific Gravity

*Ferro Silicon

Table 4

Ease of Separation

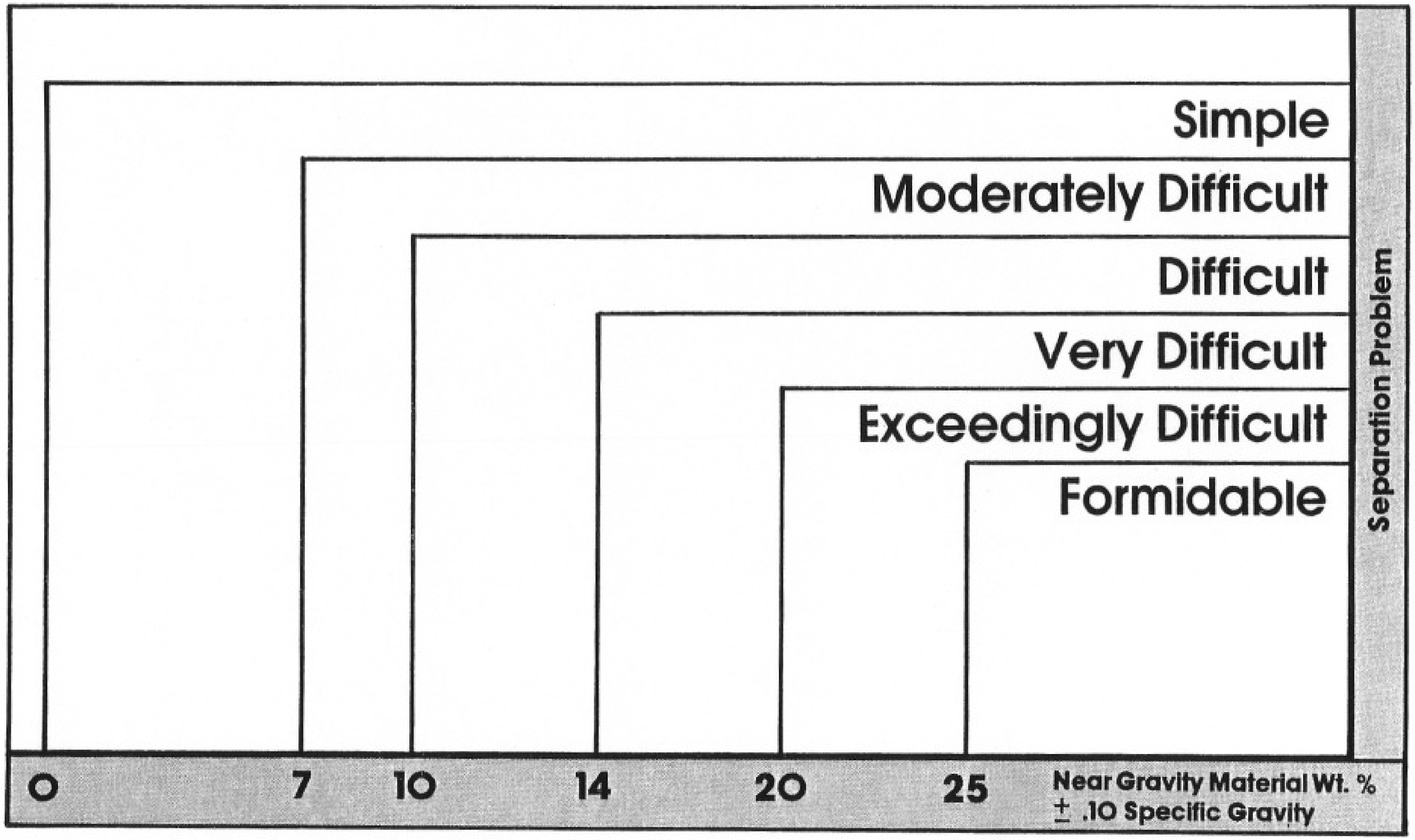


Figure 1

Basis of Rank Classification of Coals in the United States

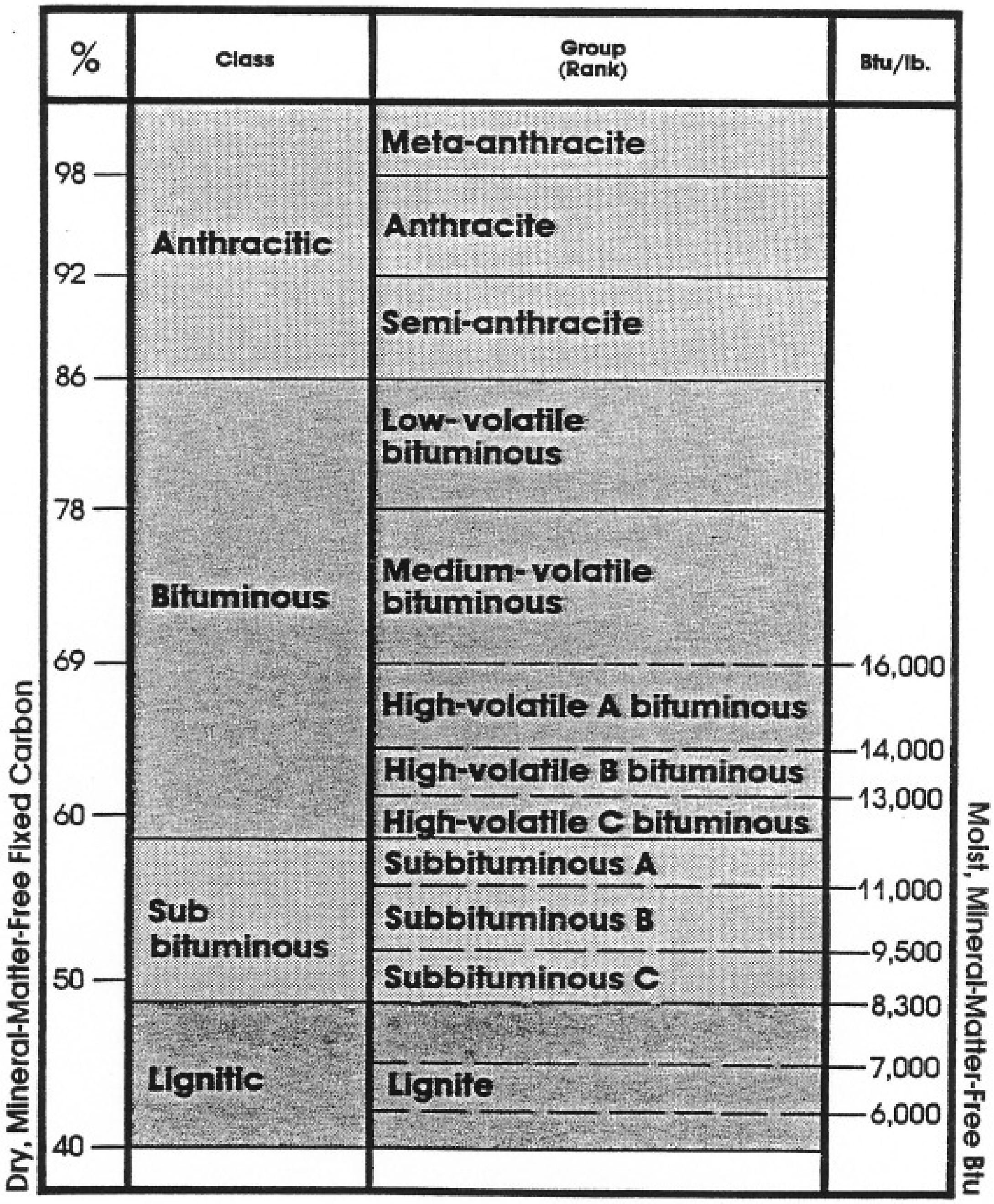


Figure 2

Structural Variations of Coal Seam Geology

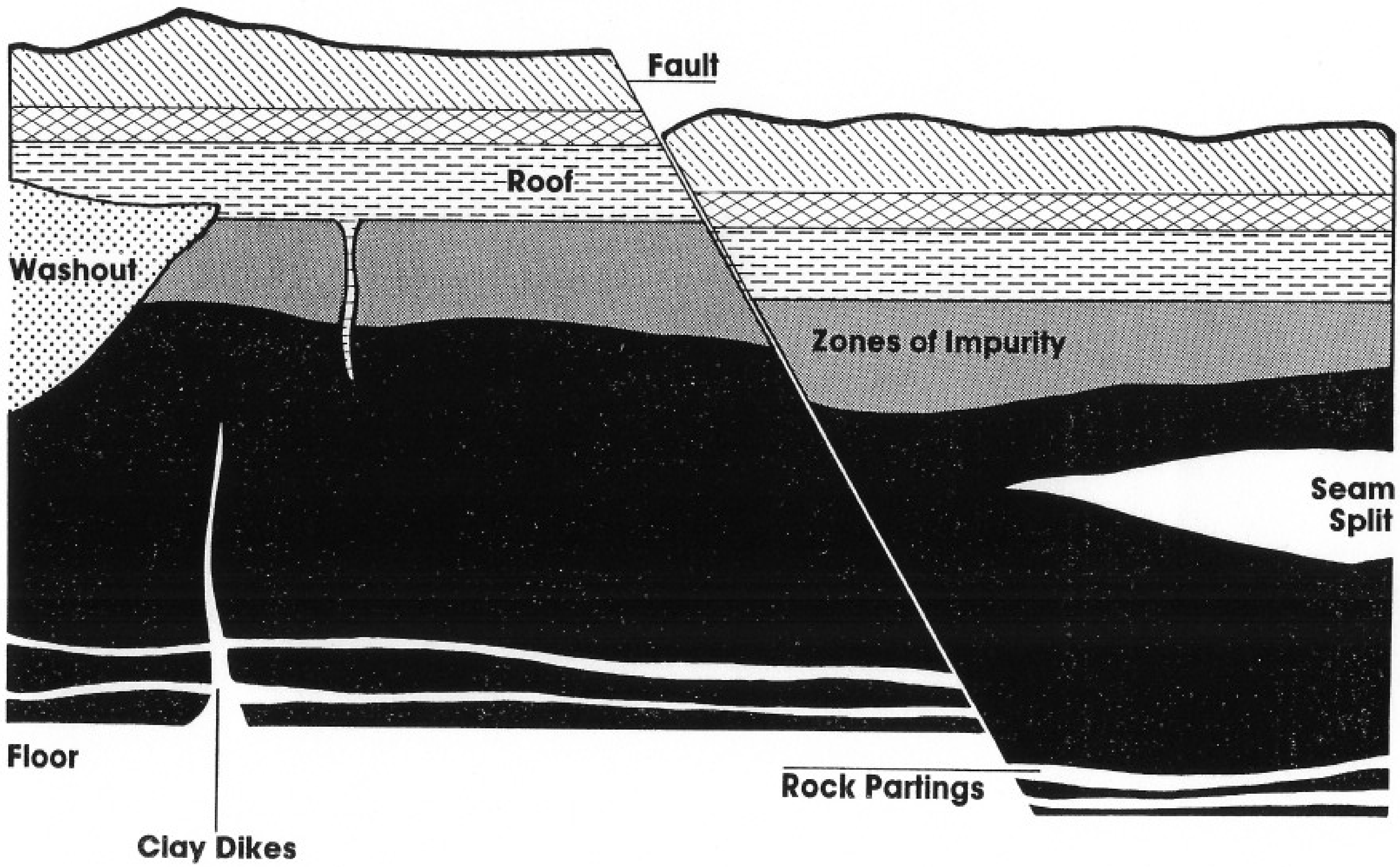


Figure 3

Sink-Float Analysis

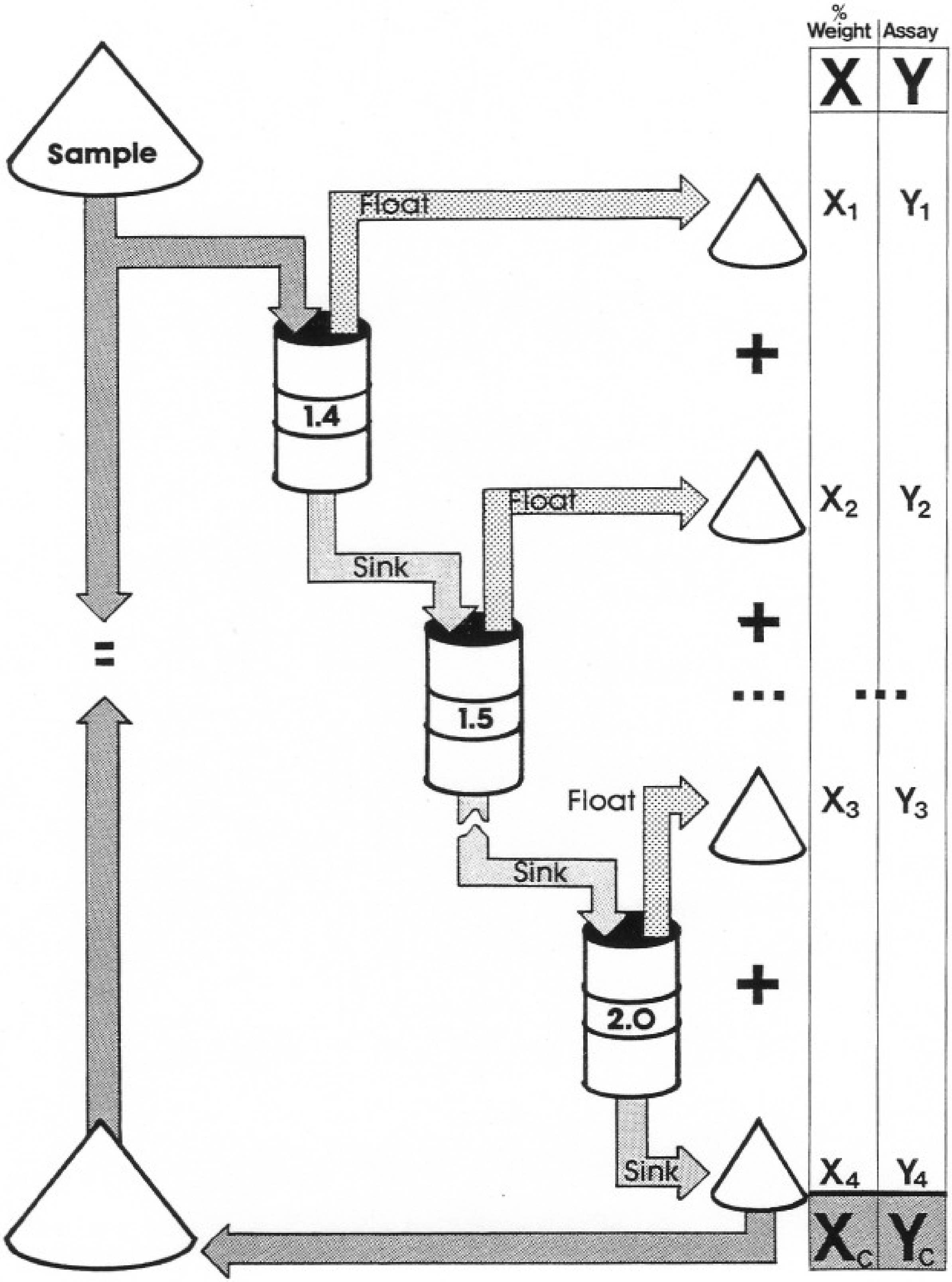
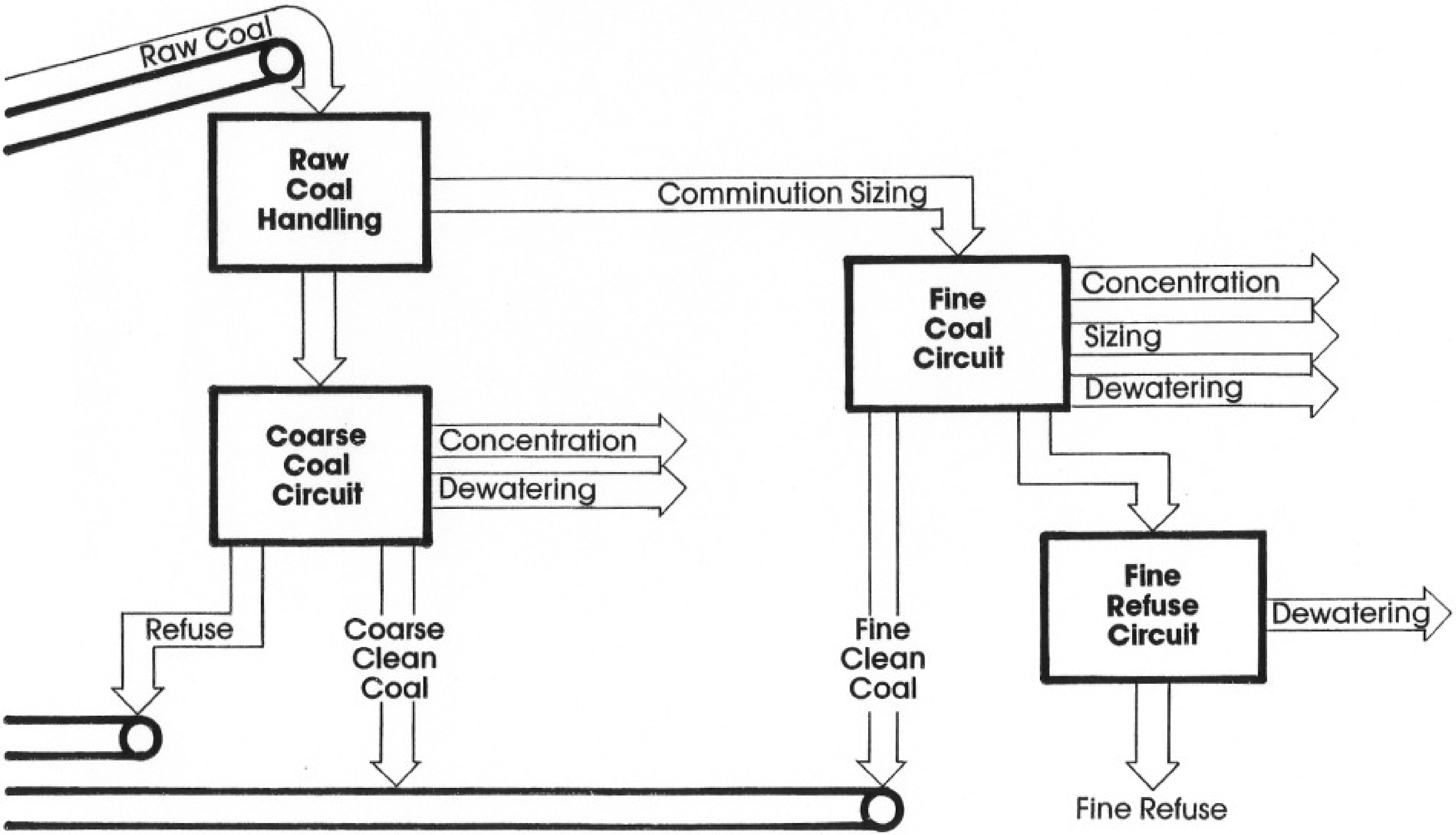


Figure 4

Typical Coal Preparation Plant Flow Scheme



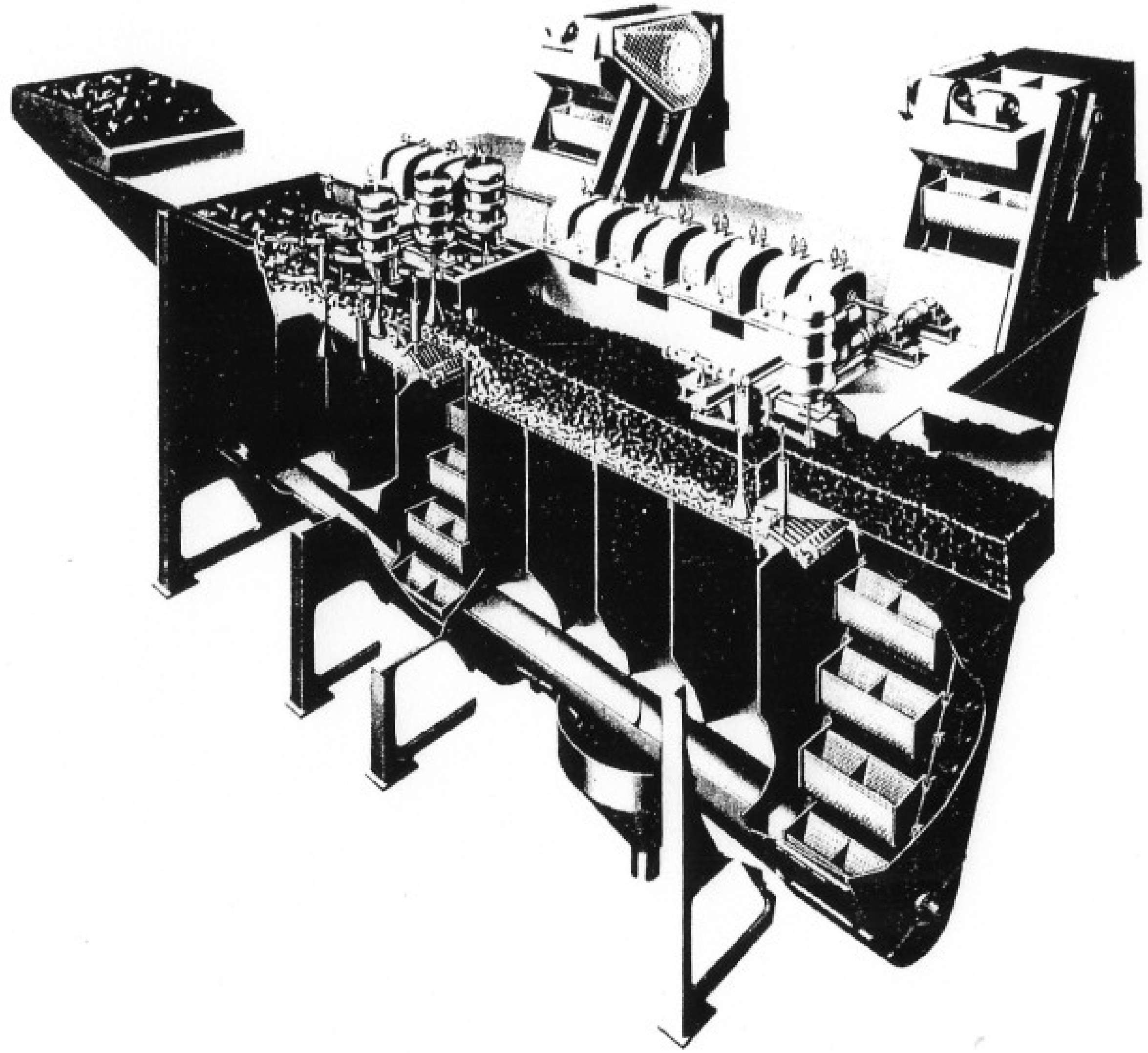


Figure 5

Baum Jig

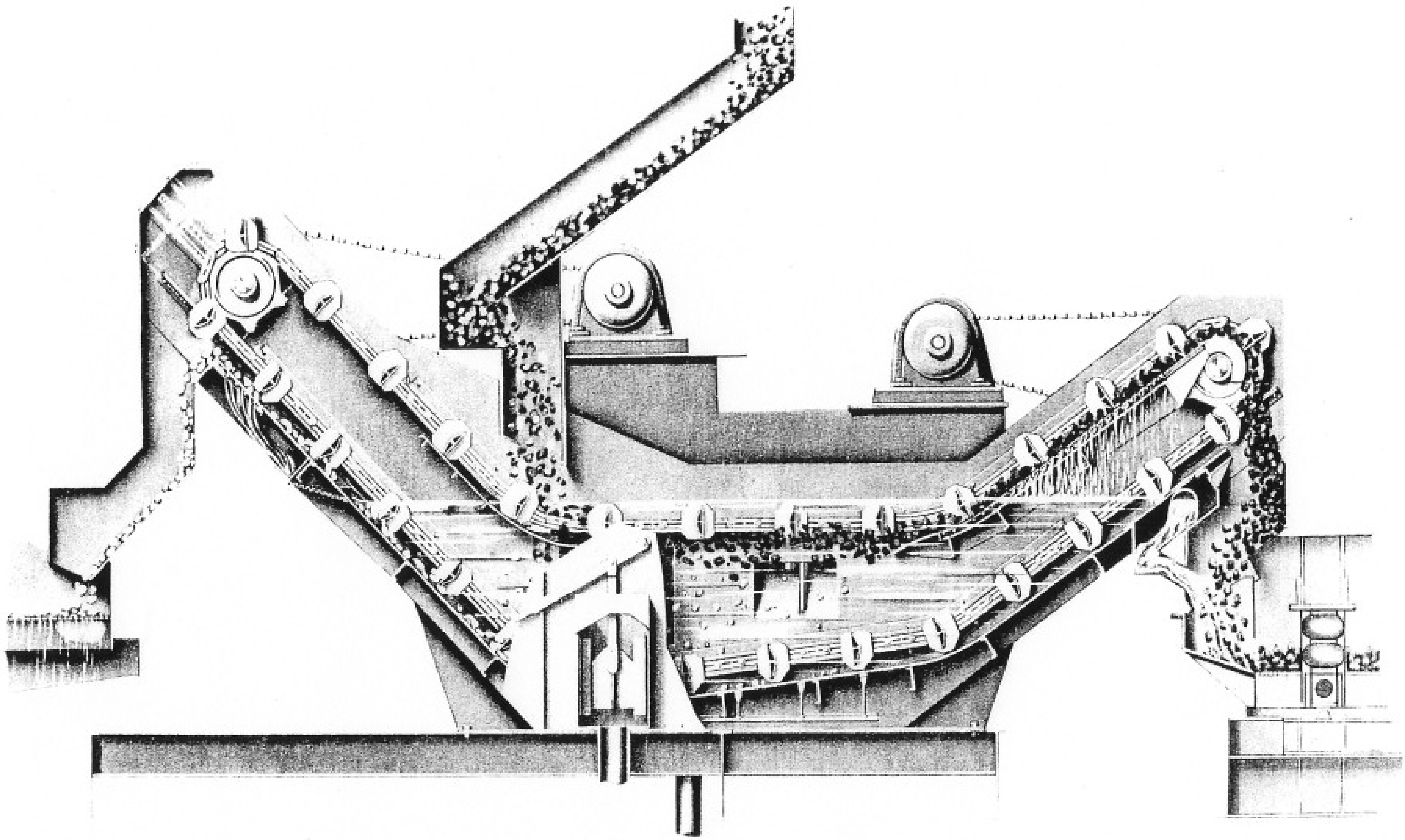


Figure 6

Heavy Medium Vessel

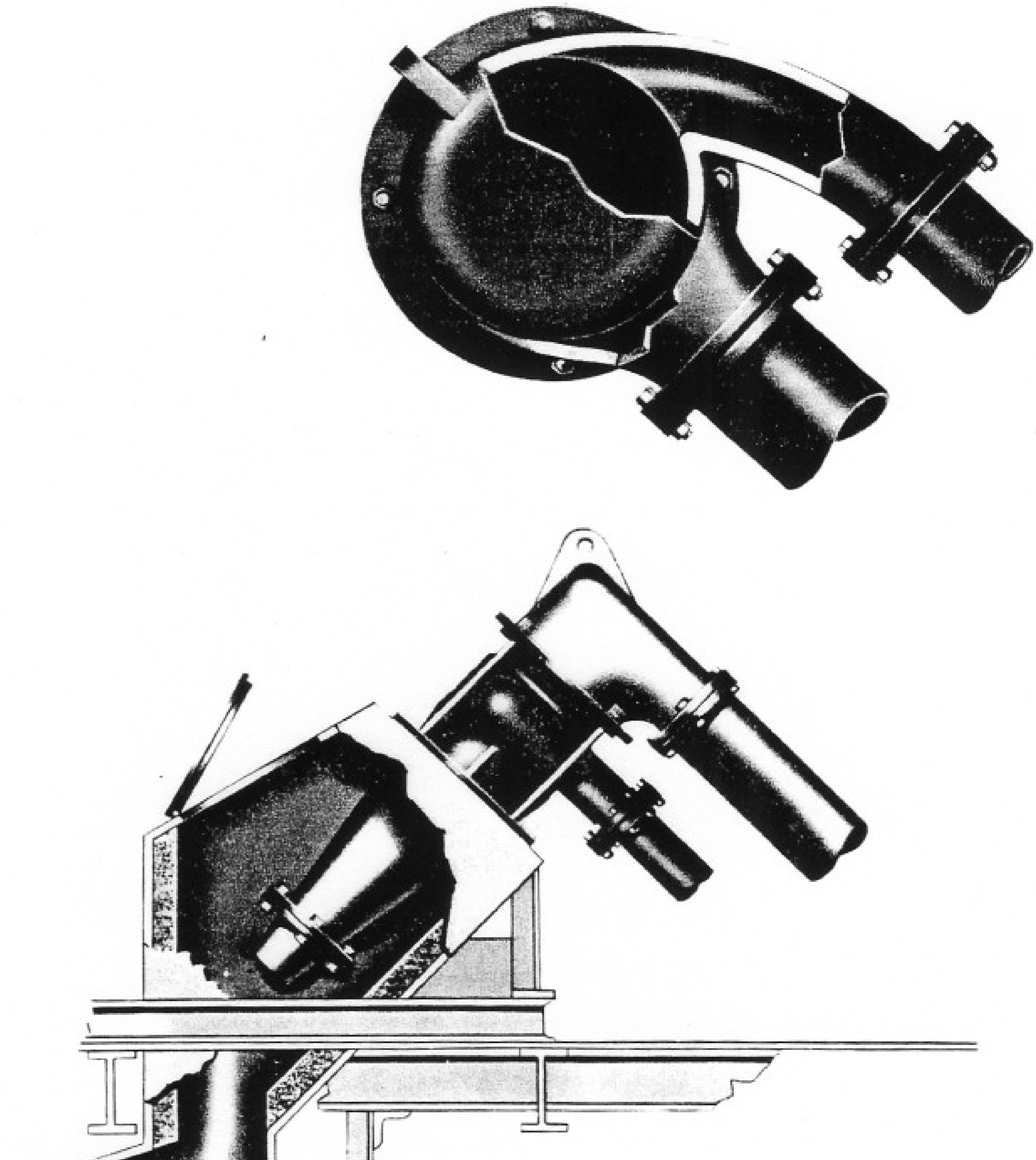


Figure 7
Heavy Medium Cyclone

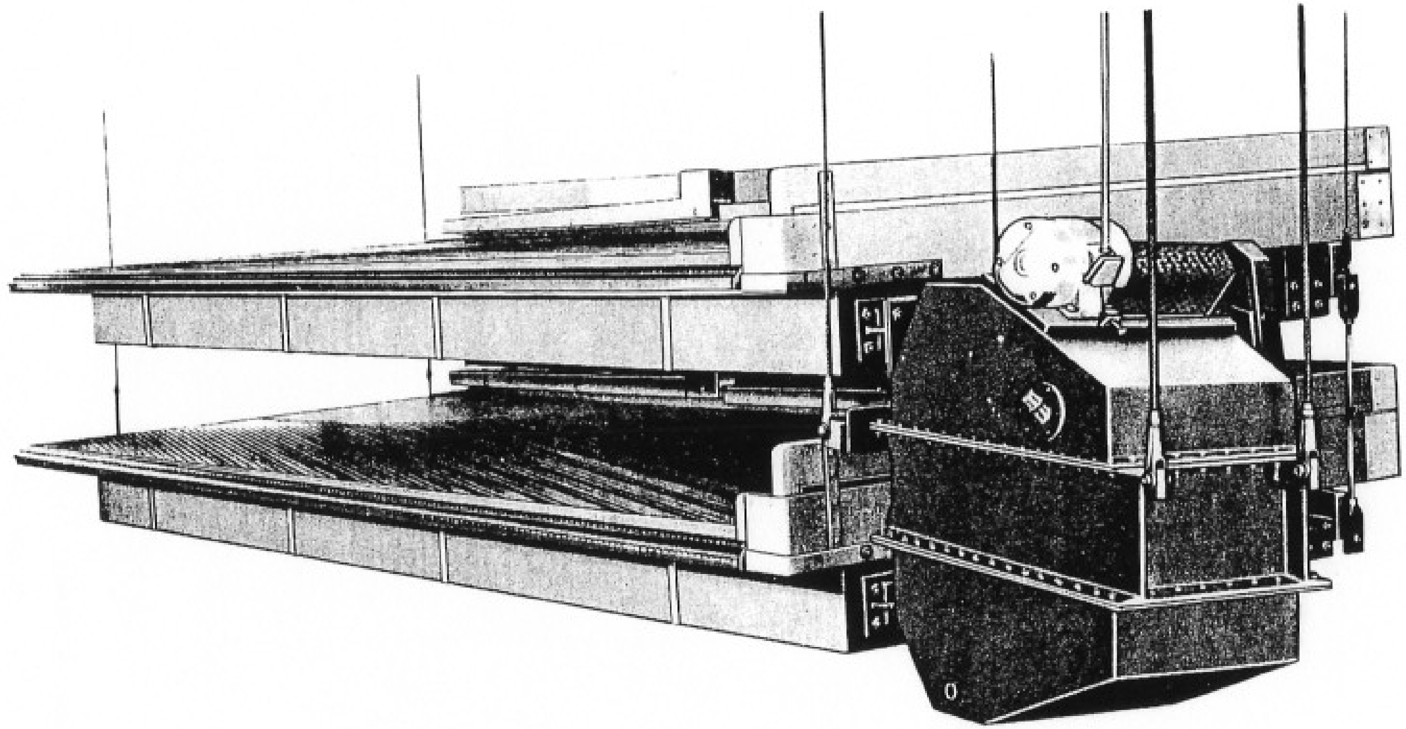


Figure 8

Concentrating Table

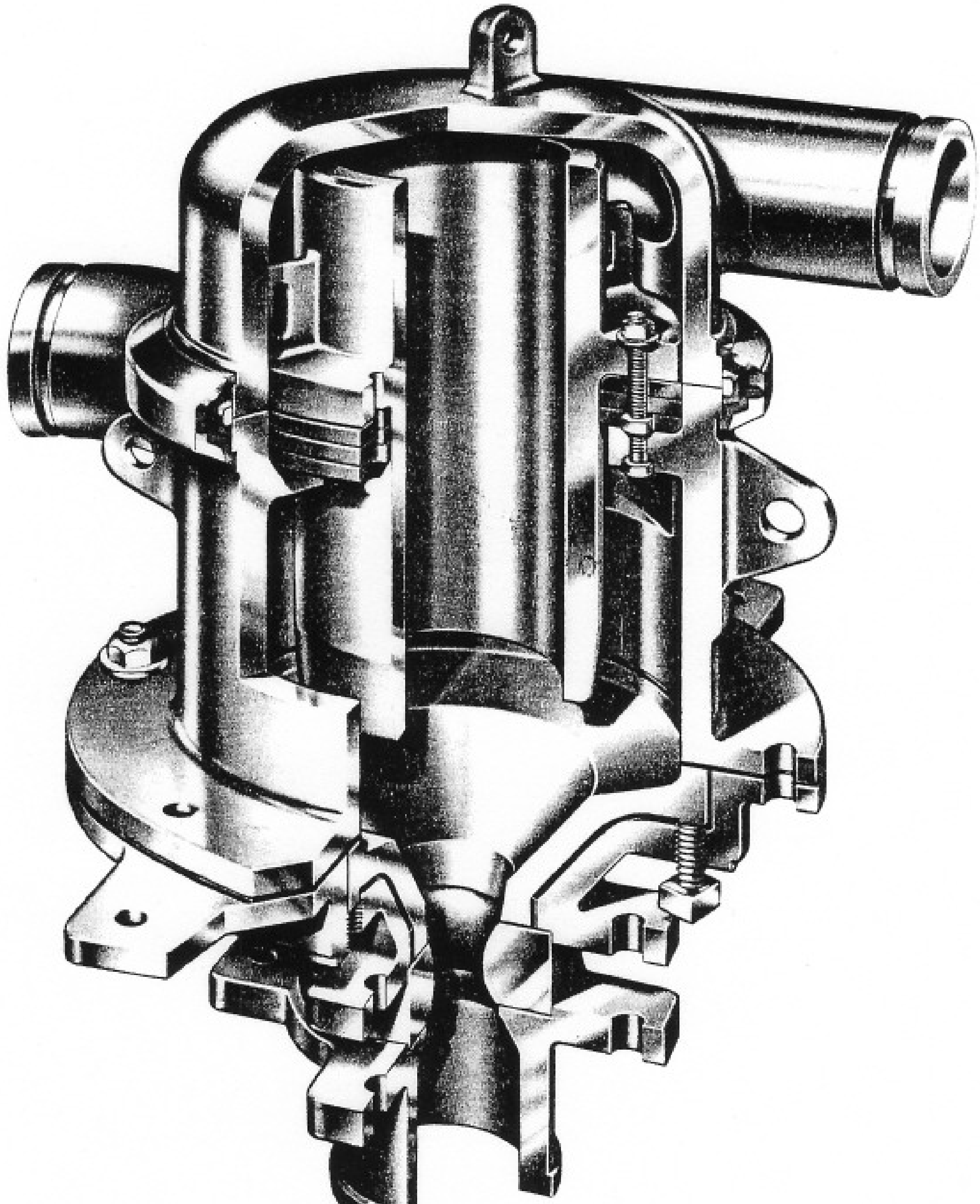


Figure 9

Water Only Cyclone

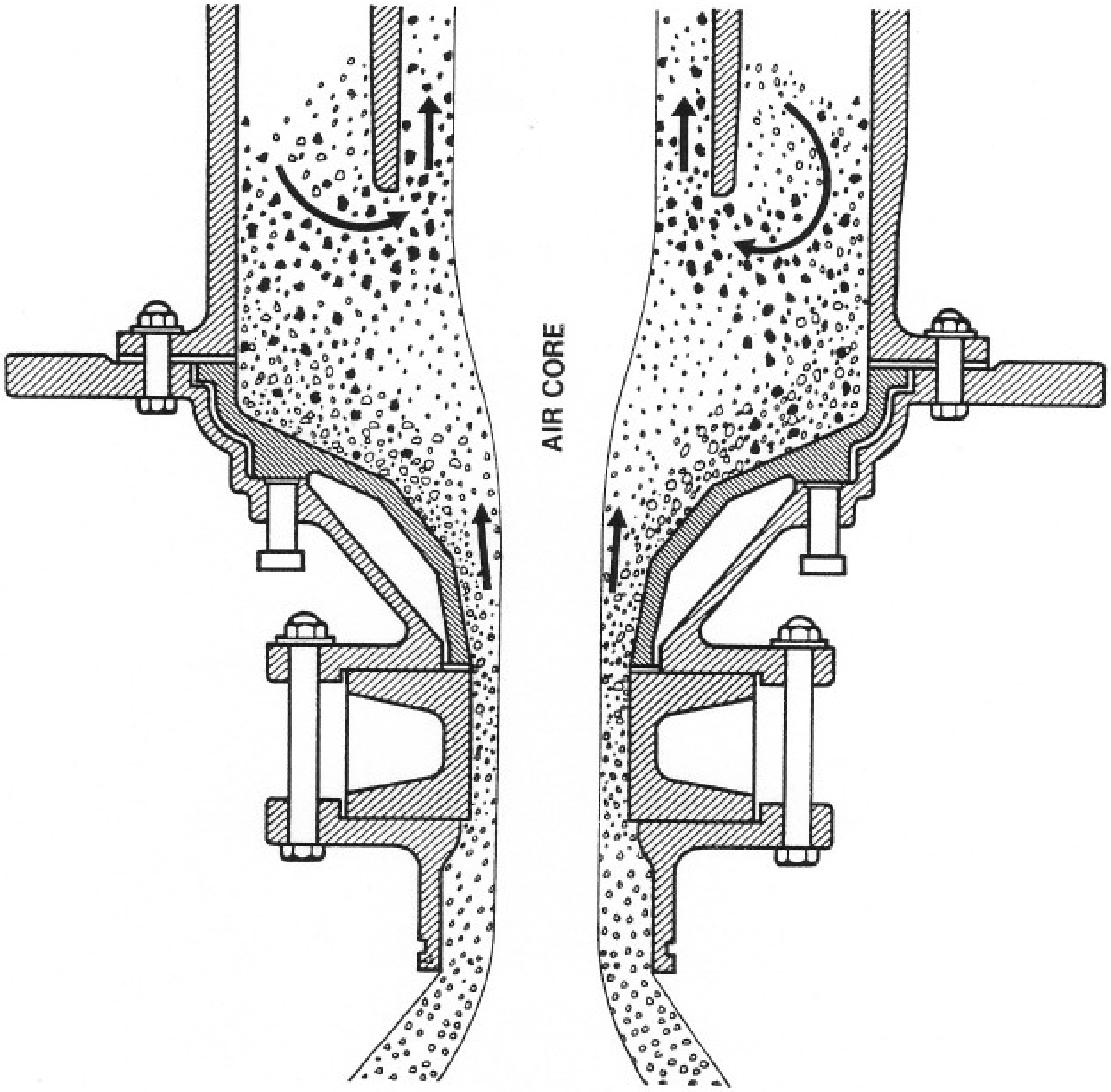


Figure 10

Water Only Cyclone
(Internal)

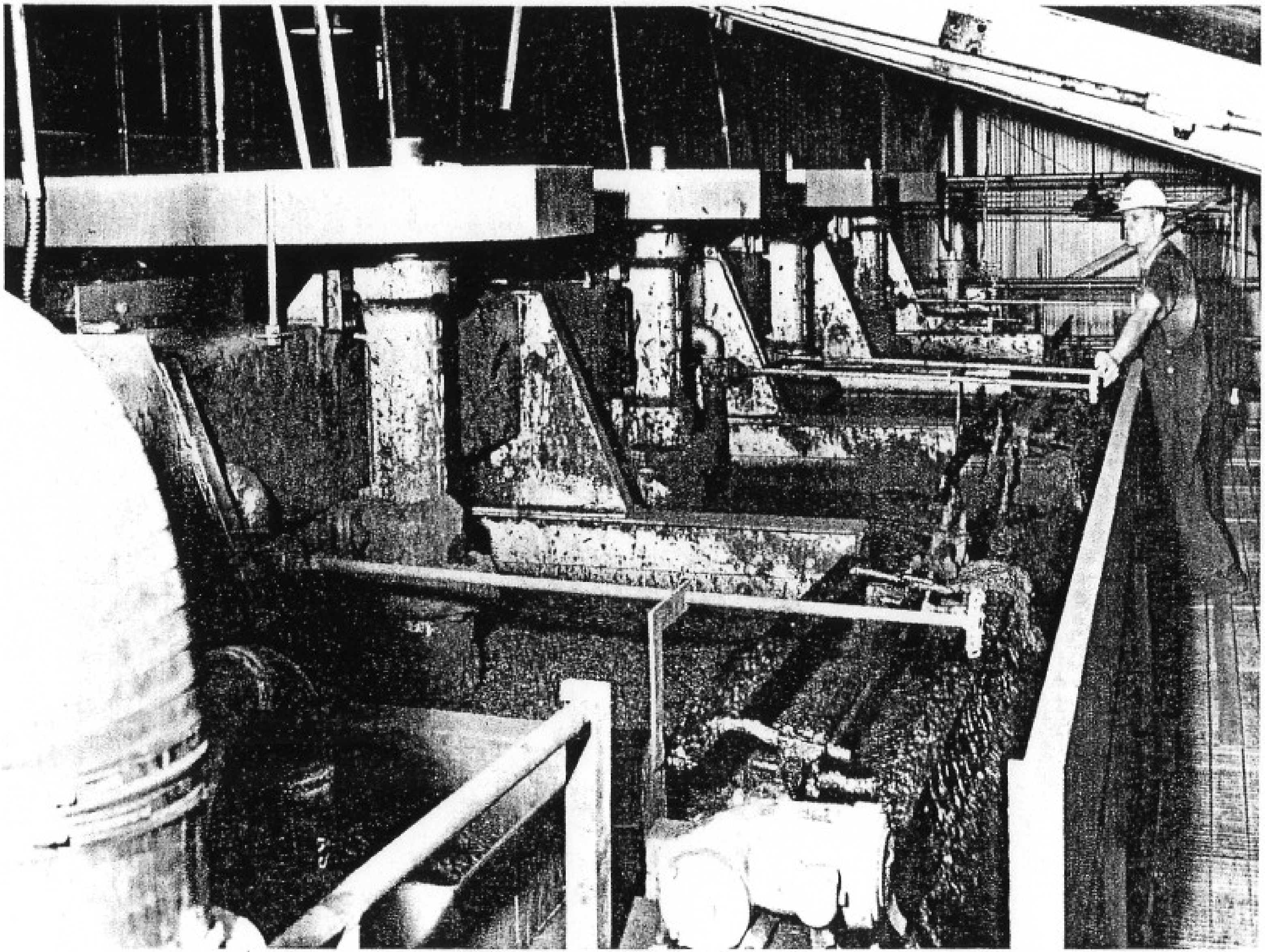


Figure 11

Flotation Cells

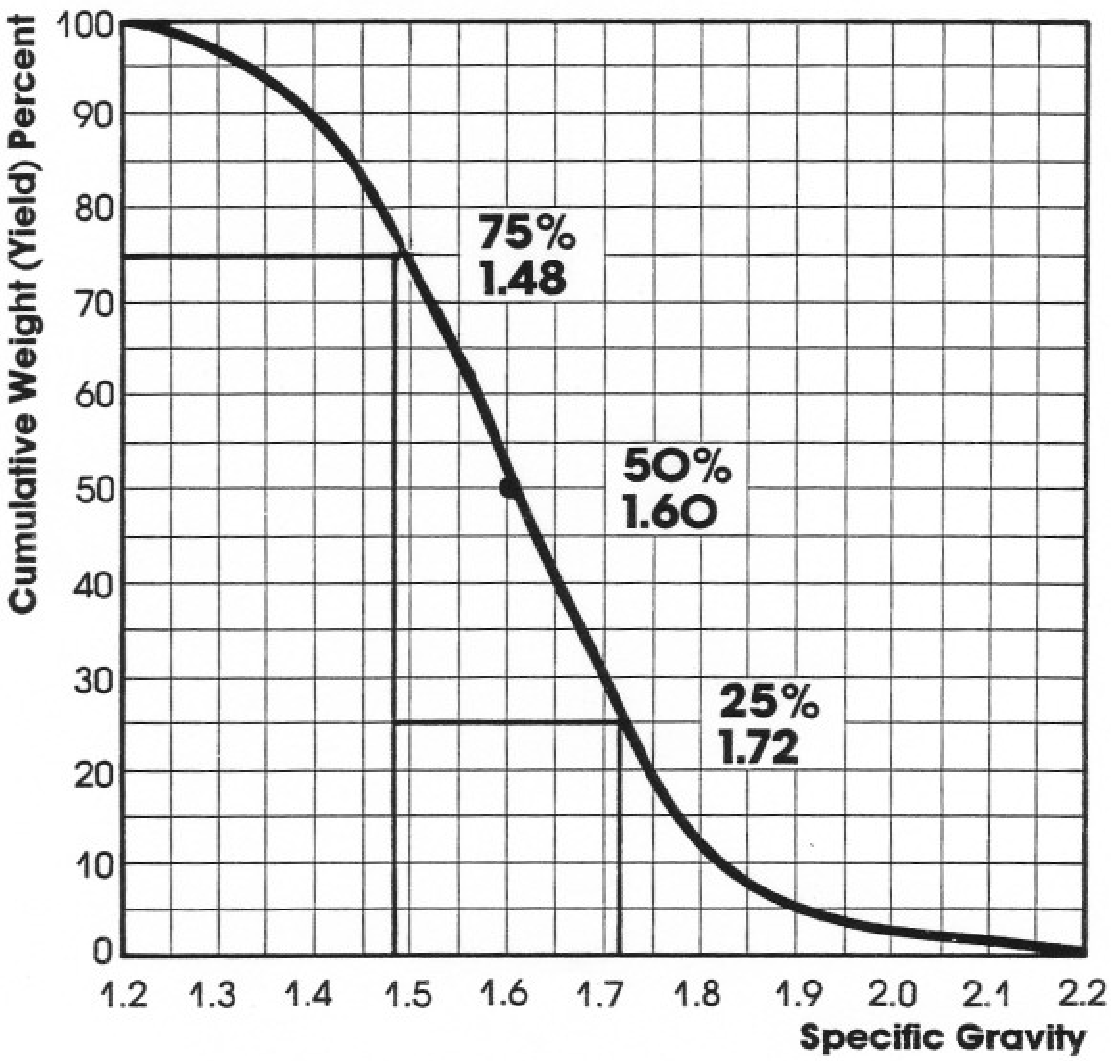
Figure 12

Baum Jig Partition Curve

Specific Gravity of Separation = d = **1.60** (50% Yield)

$$Ep = \frac{\text{Specific Gravity}_{25} - \text{Specific Gravity}_{75}}{2} = \frac{1.72 - 1.48}{2} = \mathbf{0.12}$$

$$I = \frac{Ep}{d-1} = \frac{0.12}{1.6-1} = \mathbf{0.20}$$



FORM 9

Figure 13

Washability Curves

Client XYZ Mining Co.

Date Today

Job Number --

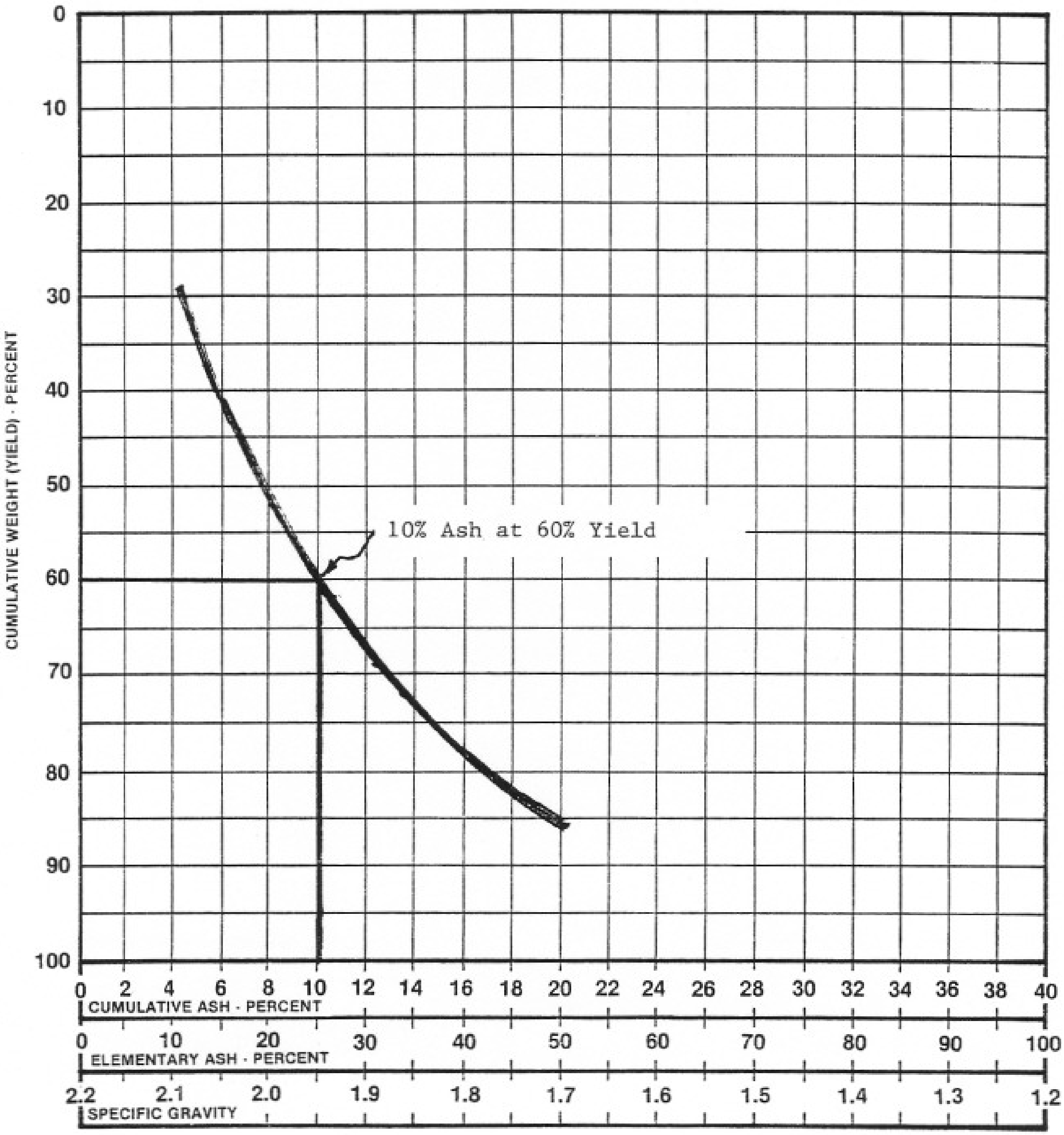
Mine/Plant/Seam A Mine

Type of Sample Clean Coal

Purpose Example

Remarks Jig Performance

Yield vs Ash



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