THE CHALLENGE OF COAL PREPARATION

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ABSTRACT

About 45-50% of the coal mined in the U.S. passes through coal preparation plants; east of the Mississippi River this number increases to about 75-80%. Although the cost for coal preparation is worthwhile to some, the coal industry faces the challenges of continuing downward pressure on the price of coal and the impact of new environmental regulations. Coal preparation, as commercially practiced today, is an effective process achieving 75-80% ash reduction, 15-80% trace element reduction, and 85-90% Btu recovery; it is less effective for pyrite reduction (35-70%), and on-line operating time (40-60%), and suffers from obsolete control systems.

Methods will be discussed for reducing costs of coal preparation and improving the performance of coal preparation plants. Comments are included on equipment selection, especially for –28 mesh coal, and prep plant operation and control practices. Btu recovery ash and pyrite reduction, fines processing including dewatering and slurry fuel use options are emphasized. Trace element removal and expert control systems for maximization of prep plan operation also will be highlighted.

INTRODUCTION

Coal preparation is the practice whereby raw coal is modified to a more preferred form to enable its utilization. The methods employed to achieve this preferred modification need to be cost-effective, while also being appropriate to the raw coal, the scale of production and the ultimate end user requirements. Since the cost of coal preparation is a measurable part of mine construction and mine operation, any improvement in the process, any efficiency gain or cost reduction obtained, and any improvements in coal product compatibility to end user requirements achieved, are looked on favorably if or when the product is profitably marketed.

HIGH EFFICIENCY COAL PREPARATION: AN INTERNATIONAL SYMPOSIUM

Because of the current imbalance in coal supply and demand and the continuing proliferation of environmental regulations covering all aspects of the coal industry, more efficient and less costly coal preparation methods are needed. Methods to achieve this, and the future direction(s) of coal preparation, are discussed below.

Conventional Coal Preparation Plants

Many developments in coal preparation have occurred since the first dense media cyclone using metal chloride salts dissolved in water, was patented in 1858. The Chance Process using water and sand, was patented in 1917 and was first applied to cleaning bituminous coal in 1925. Although the Conklin Process using magnetite as the medium was tried with anthracite in 1922, it was not until 1938 that the Tromp Process for magnetite medium was used commercially (Leonard, 1991). The purposes of these and other developments was to improve the quality of coal to make it suitable for a specific purpose. Since about 78% of the coal in the U.S. is used to generate electricity (Anonymous, 1993), the properties and quantities of impurities in coal are of major importance in the design and operation of steam generating equipment. Also because of the lover quality of raw coal and the desire to recover more of the coal that is mined, the practice of coal preparation is increasing. According to recent information (Jacobson, 1994) about 75-80% of the coal that is mined east of the Mississippi River is subject to some level of coal cleaning.

Customer requirements center on the needs of the end user – steam generation for electricity and metallurgical coke production for the steel industry. The steam coal users, mostly utilities, require optimum calorific value, consistent customers require a higher degree of product consistency to maximize coke yield, coke strength and ultimate maximum hot metal production and quality. Collectively, these fuel requirements translate into the lowest bus bar power or hot metal cost for the coal purchases.

As we know, most conventional coal cleaning utilizes gravity methods for the coarser size fractions and surface treatment methods for the finest particle sizes. The selection of equipment, especially for the finer sizes, depends on the mining method, coal hardness, and size distribution and amounts thereof. Most commercial circuits utilize dense media vessels of jigs for the coarsest size usually +3/8”, dense media cyclones, concentrating tables or jigs for the 3/8” x 28 mesh size, water-only cyclones or spirals and sometimes flotation for the 28 x 100 mesh size and flotation for the –100 mesh. Screening and centrifugal dryers dewater the coarser products while screen-bowl centrifuges and sometimes thermal dryers are utilized to reduce the moisture content of the finest sizes. Most metallurgical coal cleaning plants utilize thermal dryers hardgrove index. The coal is softer an more friable and thus has a finer size distribution after extraction by the mining machines. Coals for metallurgical use must be thoroughly processed and dried to meet the end user requirements. Additionally, flotation is always utilized in these circuits due to the quantity of coal and quality of the needed end product (low ash, low sulfur). On the other hand some steam coals, especially the harder ones (low hardgrove index), and some coals produced from surface mines have smaller quantities of the –100 mesh size. In many plants there is such a small quantity of the -100 mesh size that this material is sent to disposal and is considered uneconomical to recover.

Conventional coal preparation plants account for about 25% of the cost of the total surface facility. The coal preparation plant cost may comprise 5-15% of the cost of a coal mine. A thermal dryer installation may cost 25-30% of the cost of a coal preparation plant. The cost of coal cleaning itself may be 15-25% of the cost of mining the coal. The obvious question then, is coal preparation worth it? This question is answered by the fact that about 270 preparation plants (Horton and bloom, 1993) are in operation (most in the eastern U.S.) thus indicating, that for at least some coals to be utilized, coal preparation must be practiced. British Coal reported in 1991 (Anonymous, 1991) that where coal is washed for sale, the then current cost for conventional coal preparation as a percentage of the total price is 7-8%. This figure includes the cost of reject disposal. The same report also claims that the cost per ton for cleaning fines is 3 to 4 times higher than the cost of cleaning larger size coal. Additionally if thermal drying is used, an additional cost occurs.

Another way of showing that the cost of cleaning fine coal is at least several times more expensive than cleaning coarse coal is to consider the residence time and throughput for the coarse and fine coal size fractions. The residence time for the coarser size fractions, i.e., +28 mesh, are on the order of several seconds and the units handle up to 100 tons/hr or more. On the other hand, processing fines takes much more time and therefore higher costs result. For example, froth flotation, a surface treatment method, requires 2-5 minutes of processing time even though the throughput is only for 5-20% of the prep plant processing rate. These numbers thus can translate directly to much higher processing costs for fine coal versus coarse coal. Additionally, if one considers the residence time required for vacuum filters, about 1 minute, versus the several seconds needed for centrifugal dryers, and the $12-$16/ton cost of water removed for thermal drying, it is easy to see why processing of fine coal does not come cheaply. Some additional information on this topic is discussed later under the topic of advanced coal cleaning.

The questions under discussion are: what improvements to current coal preparation processing are possible and how could these improvements benefit the coal producer? For benefit to be achieved three questions need to be answered. 1) How much more coal will be recovered? 2) How much does it cost? 3)

What benefit will I receive?

Coal preparaton could benefit by having available equipment that could provide:

Sharper separation – thus less coal lost, better yields and higher quality product.

Simpler circuits - less capital and maintenance costs, less product variability, easier to control circuits, and more product recovery.

Better control – more coal recovery, more coal throughout per unit, better utilization of operating manpower, more consistent product, and product meeting customer specifications (no penalties)

Because coal is nonhomogenous, and the preparation plant must process what the mining sections produce, coal preparation plants must be capable of handling a feed material with widely varying properties. This arises due to variations in the mining conditions and raw coal quality. Also, dilution material and coal quality variations due to difference in inherent seam quality occur. Additionally, particle segregation and storage cause crushing and uneven coal size distribution to the plant circuit. These can cause raw feed to vary by as much as 20% (Hern, 1994). This directly affects the quality by changing the relative ratio of the product for the various unit operations in the cleaning plant. Additionally, process upsets due to wear, lack of unit availability, flow interruptions, etc. are unpredictable. To adequately handle this type of operation – which is the daily prep plant regime – and to achieve maximum coal recovery, maximum ash and sulfur rejection at minimal costs, the unit operations in the plant must provide sharp separation, utilize unit operations that are simple with minimal or no recycle or retreatment and with minimal time to reach equilibrium. The use of automatic on-line control is also a great benefit. This is the essence of what s needed in coal preparation.

Although wear and corrosion was an important topic in the past, the materials of construction now in use in coal prep plants (hardened alloys, ceramics, rubber lining, polyurethane, etc.) have greatly extended equipment life compared to that of ten years ago. Although a reduction in man hours required for repair, resurfacing and replacement would reduce operation costs, little is known about any “harder” or “better” materials that could be cost effectively used in prep plants.

Results of Conventional Coal Cleaning

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Conventional coal cleaning plants are quite efficient for Btu recovery, as well as ash and pyritic sulfur reduction. This can be seen by an examination of Tables 1 and 2. These tables show preparation plant performance for six coals for two different seams, Pittsburgh and Illinois, and two coals from central Appalachia (one from one seam and one from a blend of several seams) (Rosendale et al., 1993). These data are from commercial operations utilizing combinations of dense media baths, dense media cyclones, Baum jigs, Batac jigs, tables, water-only cyclones, and froth flotation. Btu recoveries are generally between 85 and 90%. The ash reductions on a lb. Of ash/MM Btu basis are usually in the mid 70s for Pittsburgh seam coals, and the high 80s for the Illinois and central Appalachian coals. Do note that most comparisons used in this paper will be made on a “per million Btu” basis. We believe this to be the best method (compared to a difference of or use of percentages on weight basis) since the user is buying coal on a Btu basis and it permits a true comparison of differences in coal products.

Fig. 1. Generalized Distribution Curves of Major Coal-cleaning Devices

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Physical coal cleaning also causes high reductions of trace elements. The data for the Pittsburgh, Illinois and central Appalachian coals are shown in Table 3 and Figs. 2 and 3 (Rosendale et al., 1993), (Fonseca, et al., 1993. Pittsburgh seam samples show trace element removal, 70-80%. The similarity of trace element removal with ash indicates extensive or predominant association of trace elements with ash although a closer examination of the data in Table 3 and of Figs. 2 and 3 shows some variability in the trace element removal, depending upon the element. Mercury and selenium are noticeable in that their removal is less; about 30% less on a milligram per million Btu basis that the other 11 elements. This is due to the probable association of these elements with either the organic fraction of the coal or its presence as a syngenetic (former contemporaneously with the enclosing deposit) mineral. Thus much of the mercury and selenium could be present during the coalification process. In all cases, conventional coal cleaning does effect a major removal of the trace element material on the same order as that of the ash reduction.

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supply and demand and the continuing proliferation of environmental regulations covering all aspects of the coal industry, more efficient and less costly coal preparation methods are needed. Methods to achieve this, and the future direction(s) of coal preparation, are discussed below.

Conventional Coal Preparation Plants

Many developments in coal preparation have occurred since the first dense media cyclone using metal chloride salts dissolved in water, was patented in 1858. The Chance Process using water and sand, was patented in 1917 and was first applied to cleaning bituminous coal in 1925. Although the Conklin Process using magnetite as the medium was tried with anthracite in 1922, it was not until 1938 that the Tromp Process for magnetite medium was used commercially (Leonard, 1991). The purposes of these and other developments was to improve the quality of coal to make it suitable for a specific purpose. Since about 78% of the coal in the U.S. is used to generate electricity (Anonymous, 1993), the properties and quantities of impurities in coal are of major importance in the design and operation of steam generating equipment. Also because of the lover quality of raw coal and the desire to recover more of the coal that is mined, the practice of coal preparation is increasing. According to recent information (Jacobson, 1994) about 75-80% of the coal that is mined east of the Mississippi River is subject to some level of coal cleaning.

Customer requirements center on the needs of the end user – steam generation for electricity and metallurgical coke production for the steel industry. The steam coal users, mostly utilities, require optimum calorific value, consistent customers require a higher degree of product consistency to maximize coke yield, coke strength and ultimate maximum hot metal production and quality. Collectively, these fuel requirements translate into the lowest bus bar power or hot metal cost for the coal purchases.

As we know, most conventional coal cleaning utilizes gravity methods for the coarser size fractions and surface treatment methods for the finest particle sizes. The selection of equipment, especially for the finer sizes, depends on the mining method, coal hardness, and size distribution and amounts thereof. Most commercial circuits utilize dense media vessels of jigs for the coarsest size usually +3/8”, dense media cyclones, concentrating tables or jigs for the 3/8” x 28 mesh size, water-only cyclones or spirals and sometimes flotation for the 28 x 100 mesh size and flotation for the –100 mesh. Screening and centrifugal dryers dewater the coarser products while screen-bowl centrifuges and sometimes thermal dryers are utilized to reduce the moisture content of the finest sizes. Most metallurgical coal cleaning plants utilize thermal dryers hardgrove index. The coal is softer an more friable and thus has a finer size distribution after extraction by the mining machines. Coals for metallurgical use must be thoroughly processed and dried to meet the end user requirements. Additionally, flotation is always utilized in these circuits due to the quantity of coal and quality of the needed end product (low ash, low sulfur). On the other hand some steam coals, especially the harder ones (low hardgrove index), and some coals produced from surface mines have smaller quantities of the –100 mesh size. In many plants there is such a small quantity of the -100 mesh size that this material is sent to disposal and is considered uneconomical to recover.

Conventional coal preparation plants account for about 25% of the cost of the total surface facility. The coal preparation plant cost may comprise 5-15% of the cost of a coal mine. A thermal dryer installation may cost 25-30% of the cost of a coal preparation plant. The cost of coal cleaning itself may be 15-25% of the cost of mining the coal. The obvious question then, is coal preparation worth it? This question is answered by the fact that about 270 preparation plants (Horton and bloom, 1993) are in operation (most in the eastern U.S.) thus indicating, that for at least some coals to be utilized, coal preparation must be practiced. British Coal reported in 1991 (Anonymous, 1991) that where coal is washed for sale, the then current cost for conventional coal preparation as a percentage of the total price is 7-8%. This figure includes the cost of reject disposal. The same report also claims that the cost per ton for cleaning fines is 3 to 4 times higher than the cost of cleaning larger size coal. Additionally if thermal drying is used, an additional cost occurs.

Another way of showing that the cost of cleaning fine coal is at least several times more expensive than cleaning coarse coal is to consider the residence time and throughput for the coarse and fine coal size fractions. The residence time for the coarser size fractions, i.e., +28 mesh, are on the order of several seconds and the units handle up to 100 tons/hr or more. On the other hand, processing fines takes much more time and therefore higher costs result. For example, froth flotation, a surface treatment method, requires 2-5 minutes of processing time even though the throughput is only for 5-20% of the prep plant processing rate. These numbers thus can translate directly to much higher processing costs for fine coal versus coarse coal. Additionally, if one considers the residence time required for vacuum filters, about 1 minute, versus the several seconds needed for centrifugal dryers, and the $12-$16/ton cost of water removed for thermal drying, it is easy to see why processing of fine coal does not come cheaply. Some additional information on this topic is discussed later under the topic of advanced coal cleaning.

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thods for the coarser size fractions and surface treatment methods for the finest particle sizes. The selection of equipment, especially for the finer sizes, depends on the mining method, coal hardness, and size distribution and amounts thereof. Most commercial circuits utilize dense media vessels of jigs for the coarsest size usually +3/8", dense media cyclones, concentrating tables or jigs for the 3/8" x 28 mesh size, water-only cyclones or spirals and sometimes flotation for the 28 x 100 mesh size and flotation for the –100 mesh. Screening and centrifugal dryers dewater the coarser products while screen-bowl centrifuges and sometimes thermal dryers are utilized to reduce the moisture content of the finest sizes. Most metallurgical coal cleaning plants utilize thermal dryers hardgrove index. The coal is softer an more friable and thus has a finer size distribution after extraction by the mining machines. Coals for metallurgical use must be thoroughly processed and dried to meet the end user requirements. Additionally, flotation is always utilized in these circuits due to the quantity of coal and quality of the needed end product (low ash, low sulfur). On the other hand some steam coals, especially the harder ones (low hardgrove index), and some coals produced from surface mines have smaller quantities of the –100 mesh size. In many plants there is such a small quantity of the -100 mesh size that this material is sent to disposal and is considered uneconomical to recover.

Conventional coal preparation plants account for about 25% of the cost of the total surface facility. The coal preparation plant cost may comprise 5-15% of the cost of a coal mine. A thermal dryer installation may cost 25-30% of the cost of a coal preparation plant. The cost of coal cleaning itself may be 15-25% of the cost of mining the coal. The obvious question then, is coal preparation worth it? This question is answered by the fact that about 270 preparation plants (Horton and bloom, 1993) are in operation (most in the eastern U.S.) thus indicating, that for at least some coals to be utilized, coal preparation must be practiced. British Coal reported in 1991 (Anonymous, 1991) that where coal is washed for sale, the then current cost for conventional coal preparation as a percentage of the total price is 7-8%. This figure includes the cost of reject disposal. The same report also claims that the cost per ton for cleaning fines is 3 to 4 times higher than the cost of cleaning larger size coal. Additionally if thermal drying is used, an additional cost occurs.

Another way of showing that the cost of cleaning fine coal is at least several times more expensive than cleaning coarse coal is to consider the residence time and throughput for the coarse and fine coal size fractions. The residence time for the coarser size fractions, i.e., +28 mesh, are on the order of several seconds and the units handle up to 100 tons/hr or more. On the other hand, processing fines takes much more time and therefore higher costs result. For example, froth flotation, a surface treatment method, requires 2-5 minutes of processing time even though the throughput is only for 5-20% of the prep plant processing rate. These numbers thus can translate directly to much higher processing costs for fine coal versus coarse coal. Additionally, if one considers the residence time required for vacuum filters, about 1 minute, versus the several seconds needed for centrifugal dryers, and the $12-$16/ton cost of water removed for thermal drying, it is easy to see why processing of fine coal does not come cheaply. Some additional information on this topic is discussed later under the topic of advanced coal cleaning.

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Fig. 3.   Association Between Ash & Elemental Reductions

Additional trace element removal is accomplished by the utility boiler particulate removal system (ESP, baghouse, etc.). These devices are very effective in removing trace elements to the same extent as particulate matter is removed. Modern ESPs show particulate removal efficiencies on the order of 99+% (Tumati and DeVito, 1992). Two notable exceptions occur, mercury and selenium. These are present as volatile species in the flue gas and they are only slightly removed by the utility boiler particulate removal devices. Other methods are available for their removal from flue gas but this is not the subject of this report.

Cost of Conventional Coal Cleaning

The cost of coal cleaning varies greatly depending upon plant size, circuit design, manpower requirements, etc. Reportedly, British Coal (Anonymous, 1991) found that cleaning the fine fraction was 3-4 times more costly that cleaning the coarse; if thermal drying is included an additional cost is involved. Preparation costs are generally between \$2-\$5/ton. The sulfur removal costs (\$/ton of SO_2 reduced) via conventional coal cleaning of the coals discussed above are shown in Table 4. It can be seen that there is a wide range- from \$22-\$680/ton SO_2 at a \$2/ton coal cleaning cost to \$56-\$1700/ton SO_2 for a \$5/ton cleaning cost. The five Pittsburgh seam mines show an average of 51-129 \$/ton SO_2 for the 2 and 5 \$/ton coal cleaning costs. The cost for Illinois coal is higher, \$117-\$2193 while the costs for central Appalachia are \$670-\$1700. The central Appalachia coal has little pyritic sulfur and cleaning only reduced the sulfur (51.6%) is removed. It seems clear that, for conventionally operated prep plants whose processing costs are between \$2 and \$5/ton that conventional coal cleaning is cheaper than FGD. As a point of comparison SO_2 credits can currently be purchased for about \$150/ton.

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The subject of advanced coal cleaning and the removal of additional sulfur (pyrite) to help meet the Clean Air Act Amendments of 1990 is discussed at most coal preparation conferences. However, the important question "what does it cost to achieve addition sulfur reduction over and above that achieved by conventional coal cleaning?" The cost of this improved cleaning (per ton equivalent SO_2 reduced) cannot be more than that for FGD, the purchase of sulfur dioxide credits, or that of fuel switching. CONSOL found that for most situations additional extensive cleaning is not cost effective. Thus extensive size data in this table show raw coal cleaned to three levels; 1) conventional, 2) size reduction to top size of 9.5mm (3/8"), 3) and size reduction to top size of 1.4mm (14 mesh). The incremental SO_2 reductions are conventional cleaning 32% (lb. SO_2/MM Btu basis), top size of 9.5mm (3/8"), 41%; and top size 1.4mm (14 mesh) 51% sulfur reduction. To determine comparative costs for this example, use the conventional cleaning cost of 4\$/ton of coal. Thus the 9.5mm and 1.4mm top size were found to cost \$8.77 and \$17.40/ton of coal, respectively. On a \$/ton of SO_2 reduced costs of \$128, \$202 and \$350 result for the three levels of coal cleaning. But on an incremental \$/ton of SO_2 removed over and above conventional cleaning, it can be seen that crushing and cleaning all coal at 9.5mm (3/8") top size and 1.4mm (14 mesh), costs \$454 and \$718/ton of SO_2 reduced, respectively. Thus the purchase of SO_2 credits, fuel switching or the installation of FGD would be more cost effective than utilizing "advanced coal cleaning" techniques.

The Needs of Coal Preparation

IF a coal producer were asked about his needs for coal preparation, a probable response would be, "reduce coal preparation costs and improve quality." For the producer of mid or high sulfur coal, the added desire of the ability to produce a low sulfur coal product may also be stated. The following is noted for the coal seams discussed above: 1) conventional coal cleaning methods are very good for ash removal and Btu recovery (although improvements are always possible), and 2) surprisingly good pyritic sulfur reduction occurs, at least for two of the three seams examined.

A noted above, the dense media processes- bath, vessel and cyclones- for coarse coal (0.5mm, +28 mesh) are very efficient and provide sharp separation. This is possible as long as the processing system is kept in the designed range of solids content, size content, media, and control, etc., and clean water and proper maintenance of equipment is maintained. Improved operation is possible by use of an automatic on-line process control system (Hern, 1994), and will be discussed later. The low cost, high efficiency obtained in the coarse circuit has not yet been demonstrated on a routine basis on the –0.500 mm (-28 mesh) processing circuit. Although some coal producers are reasonably satisfied with the 0.5-0.15mm (28 x 100 mesh) processing (water-only cyclones, spirals), pyrite reduction is less successful compared to coarser circuit pyrite reductions (see fig. 1 for the effectiveness of various pieces of coal cleaning equipment). For particles in the –0.15 mm (-100 mesh) size range, pyrite reduction is very poor and few processes are operating in commercial plants whose aim is for pyrite rejection. The primary purpose of flotation is ash removal, any pyrite that is rejected is considered a side benefit. It is the –0.5 or 0.5-0.15 and –0.15 mm (28 x 0 or 28 x 100 and 100 x 0) circuits that could benefit by 1) sharper separations, 2) better methods for pyrite and ash rejection, 3) more efficient and less costly methods for dewatering, and 4) improved process control for more consistent product and maximization of processing capacity. In the author's opinion, these are the challenges that the coal preparation industry must address to accomplish the foal of "reducing coal preparation costs and improving quality of the product coal."

Development of Gravity Methods for Fine Coal Cleaning

The use of increased gravity devices (such as dense media cyclone) for cleaning the –0.5 mm (-28 mesh) coal fines to maximize ash and pyrite separation has been the subject of numerous studies (Klima, et al., 1990), (Leonard, 1991), but the lower limit of the coal particle size that can be separated is governed by the size of the magnetite particle and the difficulty or success in recovering the magnetite. Workers in South Africa (Fourie, 1980) reportedly demonstrated the feasibilty of cleaning to 75µm, but to get sharp separations at that level at least 50% of the magnetite had to be smaller than 10µm. Consumption of magnetite was also on the order of a kg/ton of coal. Workers at the University of British Columbia report that for dense media separation performance the separating efficiency at a cut point for coarse particles (greater that 2.0mm) was mainly determined by the medium stability while the separation performance medium rheology (Hee and Laskowski, 1994).

The Custom Coals method for cleaning fine coal recognizes the above problems and attempts to optimize performance. Custom Coals reports (Godfrey, 1994) that cleaning 105 x 25 µm coal is possible with dense media cyclones with –5 micron magnetite. Multistage classification precedes the heavy media cyclone and multistage magnetite separation is used on the clean coal and the refuse streams. Custom Coals claims magnetite losses of 2 kg/ton will result. A plant is now being built is Somerset County, Pennsylvania to incorporate this technology (Godfrey, 1994).

Several new gravity devices – nondense media methods – are now in various stages of development and testing for coal use. These devices attempt to enhance particle inertia relative to surface drag forces by application of a centrifugal field. Several of these devices are: the Kelsey Centrifugal jig. The Falcon Concentrator, and the Knelson Concentrator. Another device called the Mozley Multigravity Separator uses the flowing film technique for coal – ash separation. Professor Roe Hoan Yoon and his team at Virginia Tech (Luttrell, et al., 1994) report that by using the Mozley Multigravity Separator, rejection on fine pyrite is possible and that performance is improved if the high level of ash material are removed (by froth flotation) prior to gravity cleaning. The raw coal used in his tests was 80% -0.075 mm (-200 mesh). The work showed very good pyrite rejections to and below the 0.045 mm (325 mesh), but scale-up of the device above 2.1 M (7 ft) in length processing up to 25 ton/hr has not been made. Units of this size are used to process heavy mineral sands; coal throughput would be somewhat less. Recently, this multigravity separator has been used at processing sites for tin and graphite (Luttrell, 1994). Because of the inherent limitations of flowing film devices, this author believes that large multi-ton units necessary for today's modern coal cleaning sites will not be forthcoming. Thus the cost for cleaning coal would be too high for commercial use (too many units required).

The Falcon Concentrator is manufactured by the Falcon Concentrator Company of Vancouver, British Columbia. It currently is used in commercial operations (noncoal) for fold and iron ore recovery. A commercial scale Falcon centrifugal concentrator capable of treating mass flow rates of between 1 and 2 ton/hr was tested at Southern Illinois University. The test aim was to evaluate the feasibility for treating –0.5 mm (28 mesh x 0) coal as an alternative to froth flotation and as a method to increase the rejection of pyrite sulfur in the very fine coal sizes (Paul, et al., 1994) Tests with –0.5 mm (-28 mesh) froth flotation feed showed the unit to be very effective for cleaning the 0.5-0.045 mm (28 x 325 mesh) size fraction. For No. 5 Illinois seam coal, the ash content was reduced to 8% from 18% for the 0.106-0.045 mm (100 x 325 mesh) size fraction while achieving +95% Btu recovery. The total sulfur content was reduced from 2.6% to 1.7%. High mass throughputs should be obtainable with commercial units. The company reports units of 150 ton/hr capacity have been designed. The bowl of the Falcon Concentrator used in this study measured 254 mm (10 inches) in diameter and could apply up to 300 g's of centrifugal force. The centrifugal force causes deposition and stratification of the fine particles against the inside of the smooth bowl (Paul, et al., 1994). Eps of 0.10 to 0.14 were obtained for the –0.5 mm (28 mesh x 0) coal. Although the pyrite rejection for the 0.5 x 0.15 mm (28 x 100) mesh coal was found to be very good, the best performance was obtained for the 0.15 x 0.045 mm (100 x 325) mesh size coal in the 1 to 2 ton/hr unit. Pyrite rejection to 10μm was observed. The sulfur content of the high sulfur Illinois No.5 coal was reduced from 7 1b of SO_2/MM Btu (Paul, et al., 1994). This device seems to hold much promise for pyrite rejection in the coal size fractions to 325 mesh or below. Long-term operation under plant conditions is needed.

The Knelson concentrator is another commercial unit in use in other mineral processing areas. It is also a centrifugal bowl device. It uses a series of rings placed at an equal distance apart along the vertical axis of the bowl wall to entrap the heavy particles. The device used to test coal had a 305 mm (12 inch) bowl diameter and could develop up to 60 g's of force on the fluidized bed. The fluidized bed is maintained by injecting water around the circumference of the bowl along the bottom edge of each ring. The heavy particles are discharged using nozzles, a pinch controls the rate of discharge. The tests with coal were not as successful as those with the Falcon Concentrator (Paul, et al., 1994) probably due to the lower level of G-force used. The unit has high throughput and very good pyrite and ash rejection in the +0.21 mm (+65 mesh) size, but less pyrite is rejected in the 0.150-0.38 mm (100 x 400 mesh) size fraction than the Falcon concentrator tested with similar coals.

The Kelsey centrifugal jig was developed for concentrating mineral sands using centrifugal force in the range of 30-200 g's. This is achieved by rapidly spinning a cylindrical screen and injecting the feed at its bottom edge. Water is pulsed through the screen as the material is force up the screen by the incoming feed. A ragging bed of the coarser higher density particles forms on the screen, at least one commercial use of the jig for processing tin is reported (Merwin, 1993). Commercial tests with coal were reported for two sites in Australia with a 5 ton/hr unit (Riley and Firth, 1993). The unit was found to be efficient for ash rejection in the 0.5 x 0.106 mm (28 x 150 mesh) and better than spirals and column flotation for the 0.106 x 0.038 mm (150 x 400 mesh) size coal. The type and choice of ragging material directly impacts separation achieved and capacity limitations may exist as large amounts of reject have to be drawn through the bed (Riley and Firth, 1993).

Column Flotation

Column flotation has been reported to be an efficient method for ash rejection for fine coal, especially for those sizes finer than 150 μm (100 mesh) (Davis, 1993), (Luttrell and Yoon, 1994). The ability of froth washing permits maximum rejection of entrained clays from the coal. Since column flotation operation is based on surface chemistry differences of ash, coal and pyrite it is not as selective for pyrite rejection, especially since much of the pyrite in this size range is a coal-pyrite mixed particles. As reported earlier (Luttrell and Yoon, 1994) and therefore will not be further discussed. Column flotation, in the opinion of this author, will find use for cleanup of high ash fine coal tailing streams and ponds to permit maximum Btu recovery. It is very amenable to automatic control.

Dewatering

A troublesome aspect of fine coal processing is the need to dewater the clean coal. Vacuum filtration or centrifuges are generally used to dewater the –0.5 mm (28 mesh x 0) clean coal. Thermal dryers are also used by some coal producers to permit the maximum specification in the coal product required by the end user.

A recent development in fine coal filtration is the hyperbar filter. This filter utilizes pressure above one atmosphere to drive the moisture through the filter cake. This permits a much greater driving force than the less-than-one-atmosphere of driving force available by vacuum filtration. More than a dozen of these filters are now in commercial use in Europe, dewatering fine coal (Dodson, 1994), (Nowak, 1994). The device is reported to be able to reduce the moisture content by about five absolute percent below that obtained with vacuum filtration. A joint CONSOL – DOE sponsored pilot plant test program is ongoing effecting the use of this equipment for dewatering fine coal. Although the test program is not complete, five absolute percent moisture reductions for –0.5 mm (28 mesh x 0) coal were obtained. The operating costs are still to be determined and the capital costs are reported to be high. The device is essentially a vacuum disc filter in pressure vessel. The key to the unit operation is the design and operational life of the product discharge gate. Hyperbar filters may be a good alternative to thermal drying, especially if the moisture product specifications of the prep plant can be met. The long-term operability and operating costs need to be determined.

Coal-water Slurry Fuels

The use of coal water slurries –0.150 mm (100 mesh x 0) co-fired with PC coal or fired as a reburning fuel for No_x reductions may be an attractive alternative to dewatering and drying fine coal. Pennsylvania Electric (GPM Service Corporation) is testing the co-firing of CWS at 10% to 20% of the fuel load at the 32 megawatt Seward Power Station in Pennsylvania. Good results are reported (Battista, 1994 A). Successful tests were demonstrated for a 12 to 16-hour time duration. Long-term tests during cold weather are planned (Battista, 1994 B). A cold weather test will be performed with 2.5 million gallons of slurry fuel at 50% solids content. The logistics of boiler location and CWS source are obviously very crucial in the use of this technology. There are also several pluses for the use of CWS co-firing in boilers, and include: 1) The use of CWS as a reburning fuel for NO_x reduction for cyclones and PC units; up to 50% NO_x reduction is possible. 2) The fuel can be used to extend or recover lost plant capacity due to insufficient pulverizer capacity as the fuel bypasses the pulverizers. 3) A 10% to 20% reduction of NO_x was observed with co-firing CWS and PC coal. 4) Better control of boiler is possible because the slurry can be used as a tempering fuel to permit better operation of the boiler and more efficient and even operation of the pulverizers.

Automatic Control

There are substantial benefits of automatic on-line control. Along with revenue optimization, rapid product analyses prior to shipment allows the producers to avoid off-specification material. Operational error, manual control response and "comfort level" of operation are circumvented to produce the optimum economic product (highest ton per hour rate while keeping coal product with customer specifications). There are various levels of commercial practice for "on-line control", these range from the use of rapid nuclear product analyses to complete monitor and expert or supervisory control system. The latter system provides feedforward and feedback control based on plant feed analyses and control of each unit operation will occur so that the product specification is met at load-out.

The key to automatic control is the availability of the necessary process monitoring methods and software. On-line sulfur, moisture and ash monitors are available from several commercial vendors. On-line slurry monitors are also available from several process vendors. These are currently in use in flotation and thickener control (Burchfiel, 1993), (Fonseca, et al., 1993), (Nygren, 1992).

Process information such as belt scale weights; pump operation; sump and tub levels; solids ash; moisture and sulfur levels; filter rpm; thickener overflow clarity, thickener settling rate, flotation tailings ash and coal content; reagent additions rates; coal product moisture; ash and sulfur; etc., can be used to optimize, via automatic control the operation of each unit operation and the entire prep plant operation. With the plant under supervisory control, operators are mow more available to maintain equipment permitting maximum operation. With the plant under supervisory control, operators are now more available to maintain equipment permitting maximum operation. Beside keeping product coal within specifications and preventing penalty payments, reduced operating costs, greater equipment utilization, higher throughput, and less downtime will result.

CONCLUSION

Preparation plants currently in use today are very efficient for ash reduction, pyrite and trace element removal. The alloy and ceramic materials of construction have permitted extended equipment operating life. Future improvements in the area of coal preparation lie in better equipment for processing the fine coal -.500 mm (-28 mesh). This includes efficient and low cost methods for coal noncoal separation, fine coal dewatering, and automatic control systems for the entire coal preparation plant. These would permit reduced operating costs, maximum pyrite, ash rejection and fine coal recovery, and maintenance of coal product with user required specification.

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