DRY COAL SORTING: NEXT GENERATION TECHNOLOGY FOR COAL PREPARATION

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ABSTRACT

Electronic ore sorters were first introduced to the minerals processing industry in the late 1940s. Since that time, faster microprocessors, improved sensors, and lower equipment costs have allowed this unique technology to evolve and become commercially attractive for a variety of applications. Recent estimates indicate that nearly 300 industrial-scale sorters are now used worldwide for ore concentration. Electronic sorters utilize specially-designed sensors to evaluate the quality of feed particles that are spread across the surface of a moving conveyor belt. High-speed microprocessors use the sensor data to control pneumatic actuators located at the end of the conveyor. The pneumatic actuators are sequenced so that particles meeting the target quality are diverted into the product stream. This paper describes the DriJet™ sorting technology, which has been designed specifically for coal cleaning applications. This system offers many benefits for coarse coal upgrading including mechanical simplicity, high capacity, low cost and minimal environmental impacts. Recent test data from both run-of-mine coal and waste coal upgrading applications will be presented.

INTRODUCTION

Coal preparation offers may attractive benefits including lower transportation costs, improved utilization properties and reduced emissions of particulate and gaseous pollutants (Akers, 1996; Couch, 1995). However, the industry also faces several challenges associated with increased solid waste disposal requirements and higher demands for process water (Meenan, 2005, Couch, 2000; Ore, 2002; Gardner et al., 2003). To address these issues, several groups have begun to actively develop new technologies that are capable of upgrading run-of-mine coals without any water (Luttrell, 2008). One particularly promising process is electronic sorting. Electronic ore sorters were first introduced to the minerals processing industry in the late 1940s. Since that time, faster microprocessors, improved sensors and lower equipment costs have allowed this unique technology to evolve and become commercially attractive for a variety of applications. Recent estimates indicate that nearly 300 industrial-scale sorters are now used worldwide in the minerals industries for ore concentration. Electronic sorters utilize specially-designed sensors to evaluate the quality of feed particles that are spread across the surface of a moving conveyor belt. High-speed microprocessors use the sensor data to control pneumatic actuators located at the end of the conveyor. The pneumatic actuators are sequenced so that particles meeting the target quality are diverted into the product stream. This system offers many benefits for coarse coal upgrading including mechanical simplicity, high capacity, low cost and minimal environmental impacts. Moreover, the compact size and low unit cost of sorter technology improves the viability of separating rock from run-of-mine coal as close to the working face as possible utilizing a system that is integrated within the production process so that the surface disposal of wastes and water demands could be minimized.

One of the newest and most highly advanced coal sorting technologies is the DriJet™ separator, which is marketed commercially by Mineral Separation Technologies, Inc. The essential working features of this innovative technology are illustrated in Figure 1. During operation, coal is fed onto a conveyor belt as a thin layer. The bed of material passes through a proprietary dual-energy X-ray analyzer that subjects the particles to hundreds of sequential X-ray scans. The X-rays transmit through the bed of solids in proportion to the atomic number of the components present in each particle. As shown in Figure 2, this phenomenon makes it possible to distinguish coal (organic matter composed mostly of carbon with a low atomic number) from rock (inorganic mineral matter composed of various elements such as Si and Al with higher atomic numbers). The resolution and speed of the scanner and associated electronics is of sufficient quality so that a compositional profile of each particle can be reconstructed in fractions of a second. Once identified, controlled microbursts of compressed air from a horizontal array of pneumatically actuated jets divert unwanted particles of rock into the reject stream, while coal particles follow their normal trajectory into the clean coal product stream.

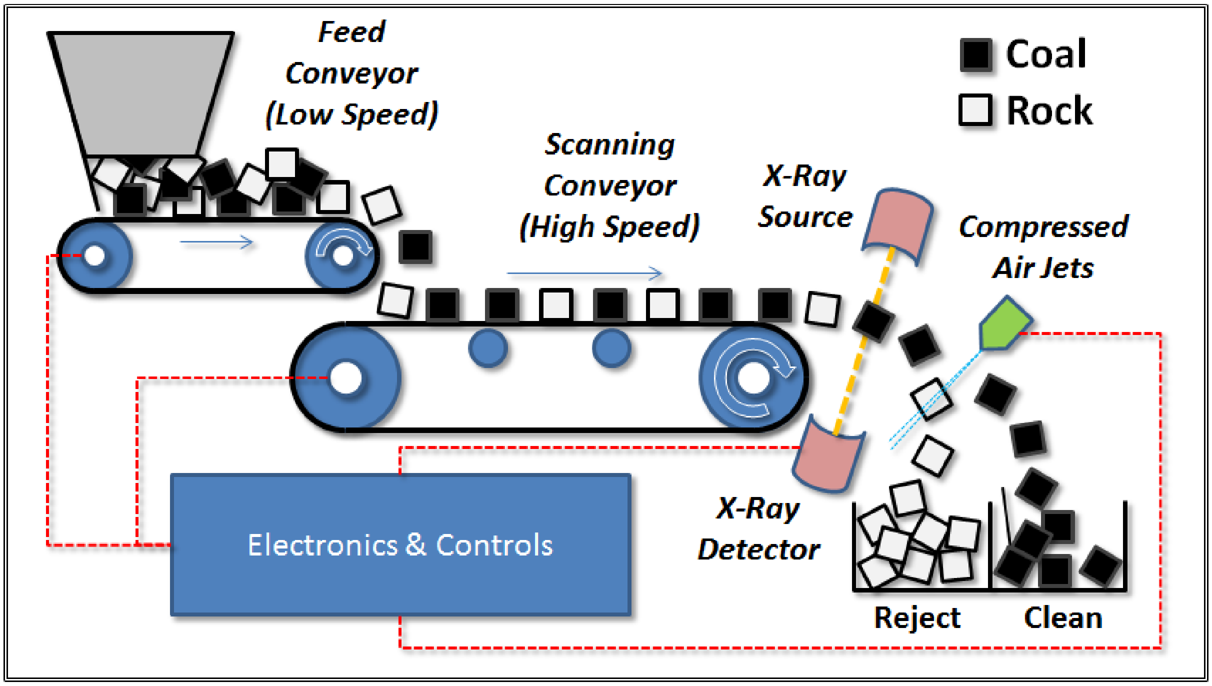


Figure 1. Schematic of the X-ray sorting process.

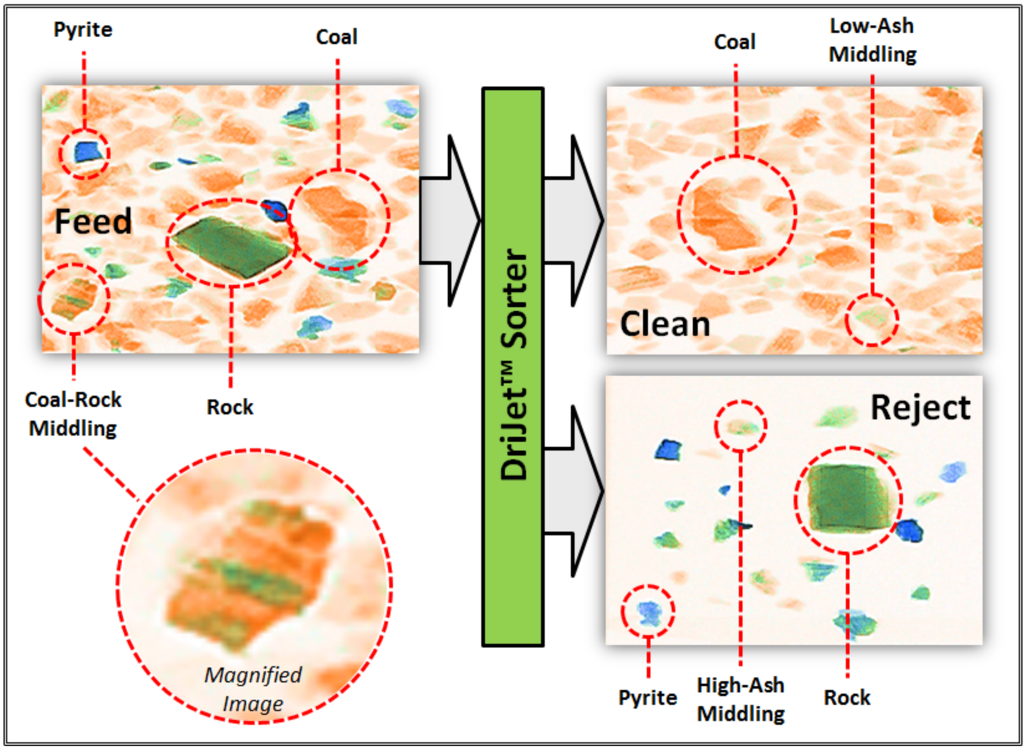
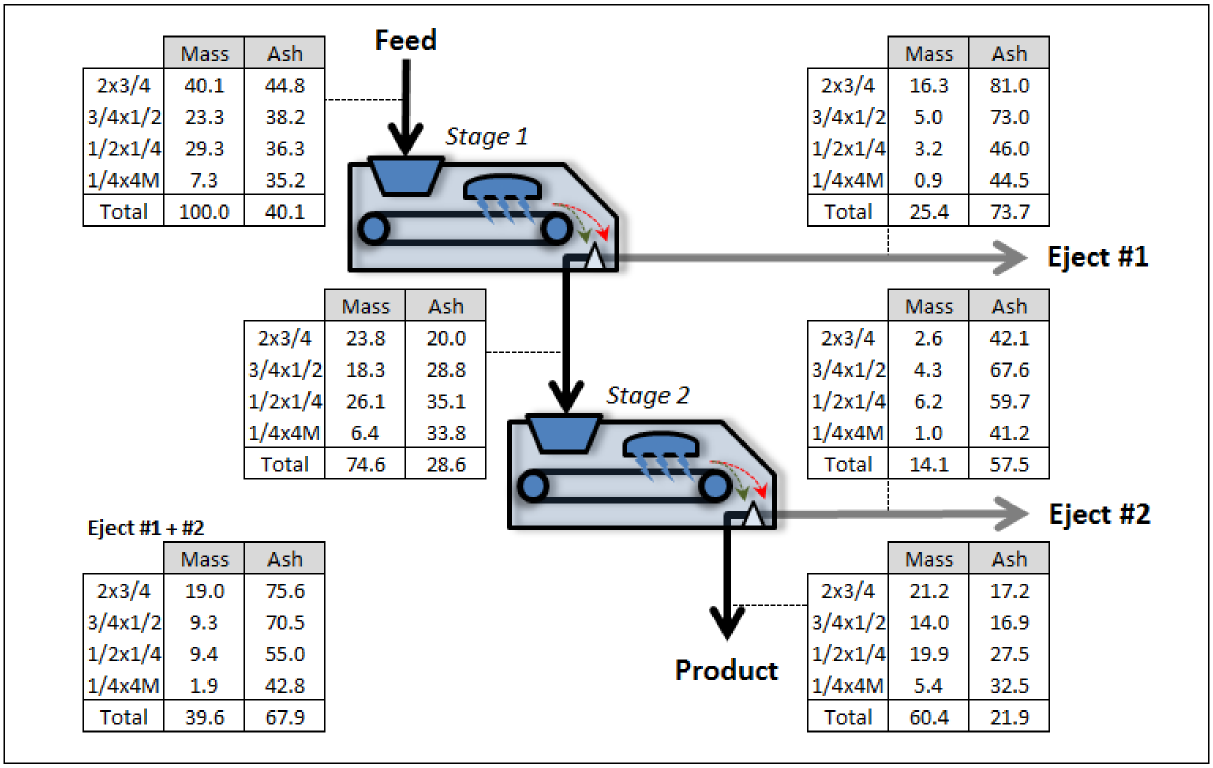


Figure 2. X-ray images of run-of-mine feed, rejected material, and clean coal.

SORTER TESTING

Several series of dry coal cleaning tests were conducted using a prototype pilot-scale version of the DriJet™ technology. These exploratory experiments were performed using a sample of high-ash (approximately 40% ash) sample of run-of-mine coal from an operating mine site located in the eastern U.S. coalfields. Due to production constraints, the feed sample was approximately sized into a nominal 2 x ¼ inch fraction using a pilot-scale screening system. The sized feed was then manually fed to the separator through a feed hopper onto a feed belt. The feed belt discharged onto a faster moving scanning belt so as to evenly spread the feed particles into a thin layer for the x-ray scanning system. In order to establish the performance limits for the machine, the test runs were conducted using multiple stages of sorting (i.e., the clean coal product from one stage was reprocessed by a second stage of sorting). After each series of tests, the resultant clean coal and reject products were each collected and placed into separate containers for transport to a coal analysis laboratory. In the laboratory, each product was sized into 2 x ¾, ¾ x ½, ½ x ¼, ¼ inch x 4 mesh and minus 4 mesh fractions. Each of these size fractions was then crushed, split into smaller representative lots, and then subjected to ash analysis.

Figure 3 provides a graphical overview of the size-by-size results obtained from testing of the two-stage DriJet™ circuitry. For ease of comparison, size-by-size recovery values obtained from the test are plotted as functions of clean coal ash and ash rejection in Figures 4 and 5, respectively. The recovery (R) values represent the percentage of combustible matter present in



	Mass	Ash
2x3/4	40.1	44.8
3/4x1/2	23.3	38.2
1/2x1/4	29.3	36.3
1/4x4M	7.3	35.2
Total	100.0	40.1

	Mass	Ash
2x3/4	16.3	81.0
3/4x1/2	5.0	73.0
1/2x1/4	3.2	46.0
1/4x4M	0.9	44.5
Total	25.4	73.7

	Mass	Ash
2x3/4	23.8	20.0
3/4x1/2	18.3	28.8
1/2x1/4	26.1	35.1
1/4x4M	6.4	33.8
Total	74.6	28.6

	Mass	Ash
2x3/4	2.6	42.1
3/4x1/2	4.3	67.6
1/2x1/4	6.2	59.7
1/4x4M	1.0	41.2
Total	14.1	57.5

Eject #1 + #2

	Mass	Ash
2x3/4	19.0	75.6
3/4x1/2	9.3	70.5
1/2x1/4	9.4	55.0
1/4x4M	1.9	42.8
Total	39.6	67.9

	Mass	Ash
2x3/4	21.2	17.2
3/4x1/2	14.0	16.9
1/2x1/4	19.9	27.5
1/4x4M	5.4	32.5
Total	60.4	21.9

Figure 3. Circuitry used in the initial round of testing of the DriJet™ sorter.

the feed that reports to clean coal. Mathematically, this performance indicator was calculated using:

$$\mathrm{R} = \mathrm{Y} \times \left(\frac{100 - \mathrm{Ac}}{100 - \mathrm{Af}} \right) \qquad [1]$$

where Y is the clean coal yield (%), Ac is the clean coal ash content (%) and Af is the feed ash content (%). The rejection (J), which represents the percentage of ash present in the feed that reports to the reject stream, was calculated using:

$$\mathrm{J} = (100 - \mathrm{Y}) \times \left(\frac{\mathrm{Ar}}{\mathrm{Af}} \right) \qquad [2]$$

where Ar is the ash content (%) of the solids reporting to the reject stream. The diagonal dashed line in the recovery-rejection plot represents a completely nonselective process, such as a material splitter, for which the recovery and rejection add to 100% at any point.

The test data provided in Figures 4 and 5 indicate that the sorter performed very well in upgrading material in the larger two size classes above ½ inch. This finding was not surprising since the sorter electronics were initially configured for processing coarser solids. For the 2 x ¾ inch material, the sorter reduced the feed ash from 44.8% down to below 20.0% after the first stage of cleaning and down to 17.2% after two stages of cleaning. Most importantly, the ash

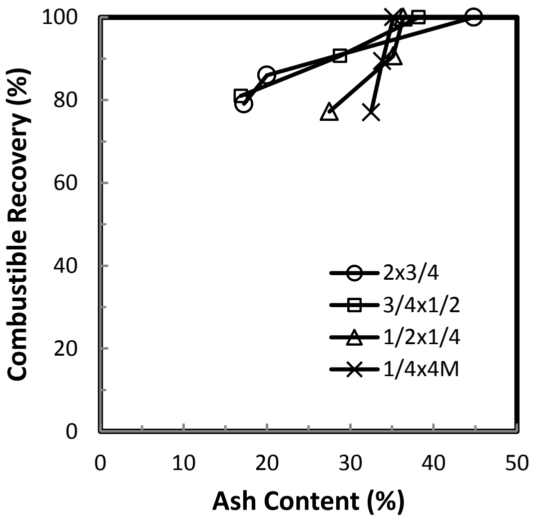


Figure 4. Size-by-size combustible recovery and clean coal ash obtained while the sorter was configured for coarse coal cleaning.

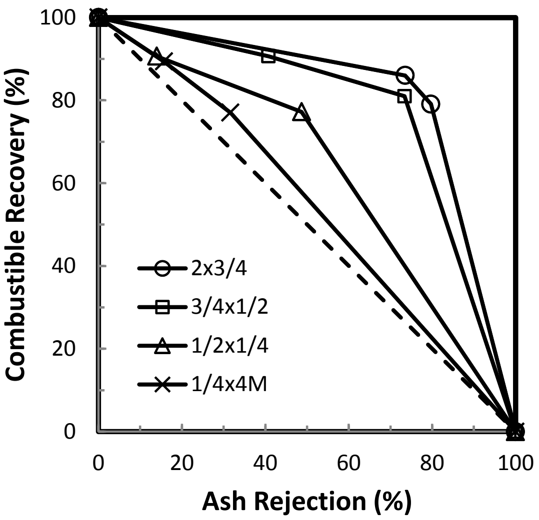
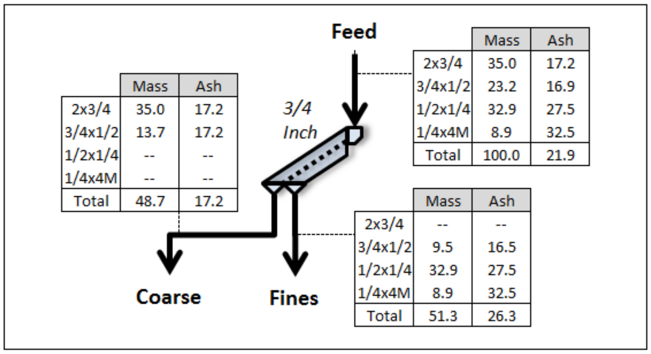


Figure 5. Size-by-size combustible recovery and ash rejection obtained while the sorter was configured for coarse coal cleaning.

content of the reject material was exceptionally high (81.0% ash) after the first stage of processing, which demonstrates that very little carbonaceous material was being lost after the first stage. In fact, very little reject material remained in this 2 x ¾ inch size class after the first stage of processing, as indicated by the significantly lower reject ash (42% ash) obtained after a second stage of processing. In contrast, the slightly finer material contained in the ¾ x ½ inch size class continued to benefit from the additional stage of cleaning. After one stage, the sorter reduced the ash content in this size fraction from 38.2% ash down to 28.8% after one stage of processing and down to 16.9% ash after two stages. The corresponding reject ash values after the first and second stages were 73.0% and 67.6%, respectively. The rather small difference between the two reject ash values suggests that the single-stage sorter was not ideally configured for upgrading ¾ x ½ inch solids and that two stages of cleaning was able to minimize this problem.

The data plotted in Figures 4 and 5 also indicate that finer particles in the two smaller size classes (½ x ¼ inch and ¼ inch x 4 mesh) were not well upgraded in the initial two-stage test program. As indicated previously, this finding was not unexpected since the sorter electronics were originally configured for upgrading coarser particles. Therefore, to alleviate this shortcoming, a second round to pilot-scale tests was conducted in which the machine was reset to conditions more appropriate for the upgrading of finer particles. The feed for these experiments were prepared by screening the clean

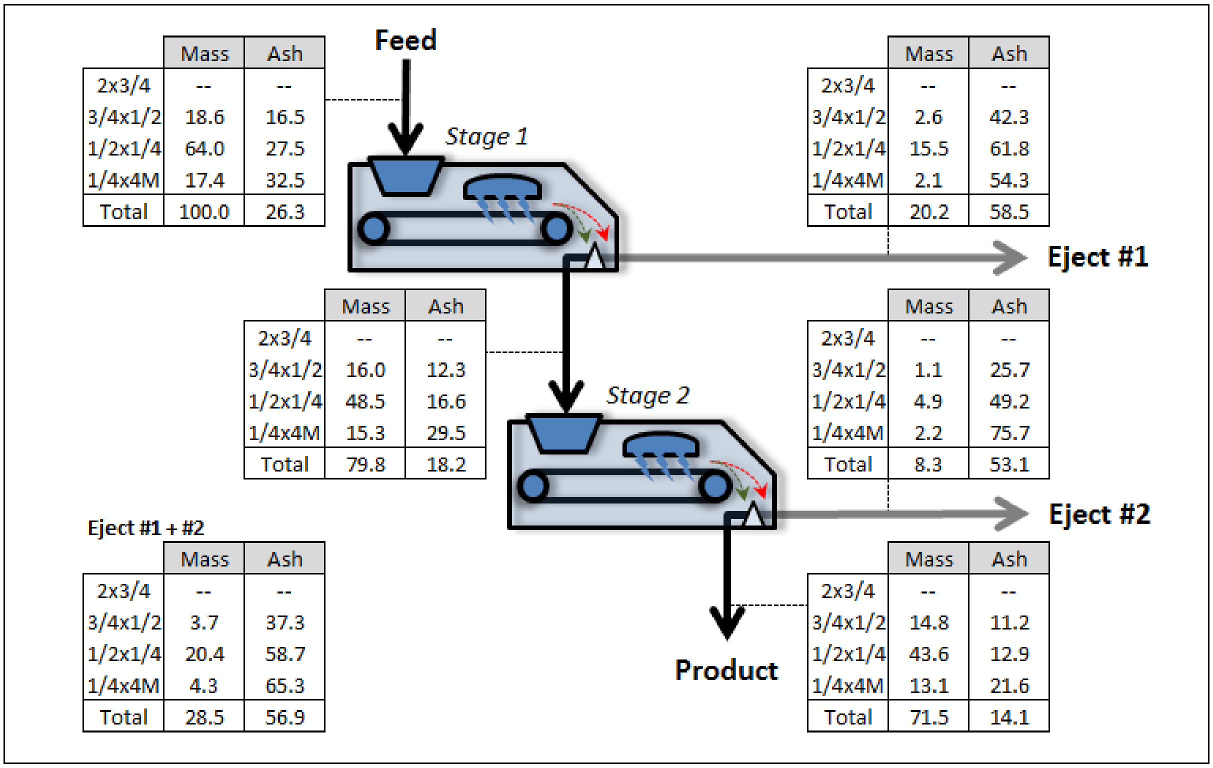


	Mass	Ash
2x3/4	35.0	17.2
3/4x1/2	23.2	16.9
1/2x1/4	32.9	27.5
1/4x4M	8.9	32.5
Total	100.0	21.9

	Mass	Ash
2x3/4	35.0	17.2
3/4x1/2	13.7	17.2
1/2x1/4	--	--
1/4x4M	--	--
Total	48.7	17.2

	Mass	Ash
2x3/4	--	--
3/4x1/2	9.5	16.5
1/2x1/4	32.9	27.5
1/4x4M	8.9	32.5
Total	51.3	26.3

Figure 6. Preparation of fine feed for round two testing by screening the first round clean product at ¾ inch.



	Mass	Ash
2x3/4	--	--
3/4x1/2	18.6	16.5
1/2x1/4	64.0	27.5
1/4x4M	17.4	32.5
Total	100.0	26.3

	Mass	Ash
2x3/4	--	--
3/4x1/2	2.6	42.3
1/2x1/4	15.5	61.8
1/4x4M	2.1	54.3
Total	20.2	58.5

	Mass	Ash
2x3/4	--	--
3/4x1/2	16.0	12.3
1/2x1/4	48.5	16.6
1/4x4M	15.3	29.5
Total	79.8	18.2

	Mass	Ash
2x3/4	--	--
3/4x1/2	1.1	25.7
1/2x1/4	4.9	49.2
1/4x4M	2.2	75.7
Total	8.3	53.1

Eject #1 + #2

	Mass	Ash
2x3/4	--	--
3/4x1/2	3.7	37.3
1/2x1/4	20.4	58.7
1/4x4M	4.3	65.3
Total	28.5	56.9

	Mass	Ash
2x3/4	--	--
3/4x1/2	14.8	11.2
1/2x1/4	43.6	12.9
1/4x4M	13.1	21.6
Total	71.5	14.1

Figure 7. Circuitry used in the second round of fine coal testing of the DriJet™ sorter.

coal product from the first round of testing at ¾ inch (see Figure 6). The plus ¾ inch material was collected and set aside, while the minus ¾ inch was then passed through two additional stages of sorting using the new set of operating conditions. The resultant test data is summarized in Figure 7.

Figures 8 and 9 provide plots of the recovery-ash and recovery-rejection data obtained from the testing of the finer coal feed. As expected, the separation of both of the finest size fractions (½ x ¼ inch and ¼ inch x 4 mesh) improved dramatically by reconfiguring the sorter electronic setting to conditions more suitable for treating finer solids. After the first stage of cleaning, the feed ash content for the ½ x ¼ inch fraction was reduced from 27.5% down to 16.6%. A second stage of recleaning further reduced the ash down to 12.9%. As expected, the ¼ inch x 4 mesh size did not respond as well, achieving clean coal ash values of 29.5% and 21.6%, respectively, after two stages of cleaning a feed stream containing 32.5% ash. Nevertheless, this level of performance was still considered to be good given that the sorter technology was primarily designed for upgrading plus ¼ inch solids.

DISCUSSION

The pilot-scale test program provided some important information regarding the operational characteristics of the dry sorter technology for coal cleaning applications. For example, the data indicate that the technology performs best when the unit has been configured to treat a specific narrow particle size fraction. In fact, the data suggest that high levels of

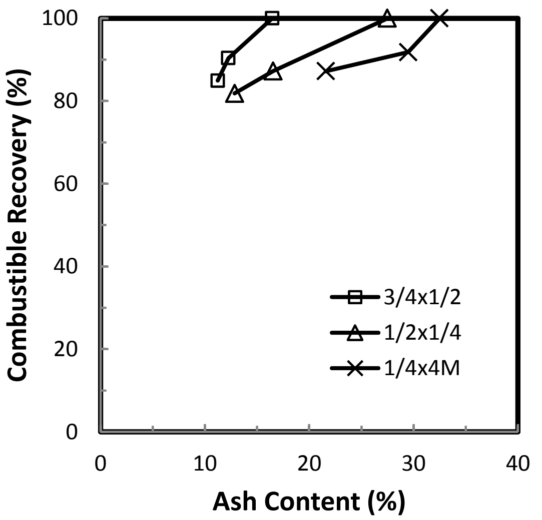


Figure 8. Size-by-size combustible recovery and clean coal ash obtained while the sorter was configured for fine coal cleaning.

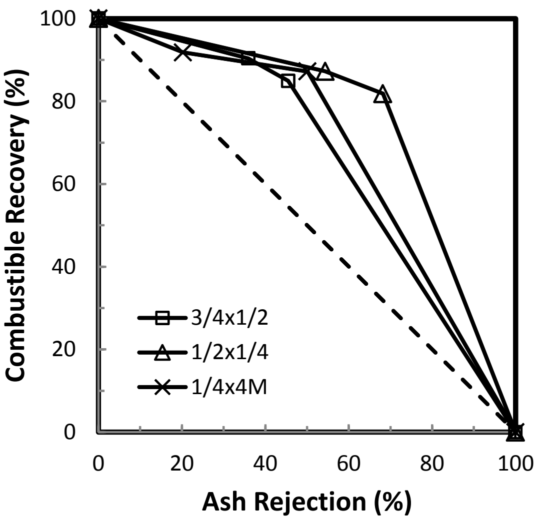


Figure 9. Size-by-size combustible recovery and ash rejection obtained while the sorter was configured for fine coal cleaning.

separation performance may be realized by prescreening the feed coal into different size classes then treating each size using a sort optimized for that particular particle size class. This upfront preprocessing step is not considered to be a serious issue; however, since coal sizing is a normal occurrence in all coal processing operations. Also, this type of size-by-size circuitry would allow each sorter to be optimized for a given size class so that maximum throughput capacity could be attained for the lowest overall investment in capital equipment.

Another interesting observation obtained from the test data is that the performance begins to deteriorate significantly below a critical particle size. This finding supports the manufacturer's recommendations that only particles coarser than about ¼ inch are best suited for upgrading using the current configuration of the coal sorter technology. From an engineering perspective, the particle size constraint is not surprising considering the requirement that a single layer of particles needs to be presented to the X-ray scanner. The limitation imposed by particle presentation makes it possible to estimate the theoretical maximum production that can be attained using the new sorter technology. The effective spatial volume (Q) moving through the scanner can be calculated using:

$$\mathrm{Q} = \mathrm{W} \times \mathrm{Dp} \times \mathrm{V} \times \beta \qquad [3]$$

where W is the width of the scanner belt, D_p is the particle diameter (bed height), V is the belt velocity and β is the particle packing efficiency. For spherical mono-sized particles placed back-to-back along the conveyor, β cannot exceed a value of π/6 (i.e., ratio of sphere-to-cube volume). From these expressions, the maximum mass flow rate (M) that can be passed as a single layer of particles through the separator is given by:

$$\mathrm{M} = \rho \times Q \qquad [4]$$

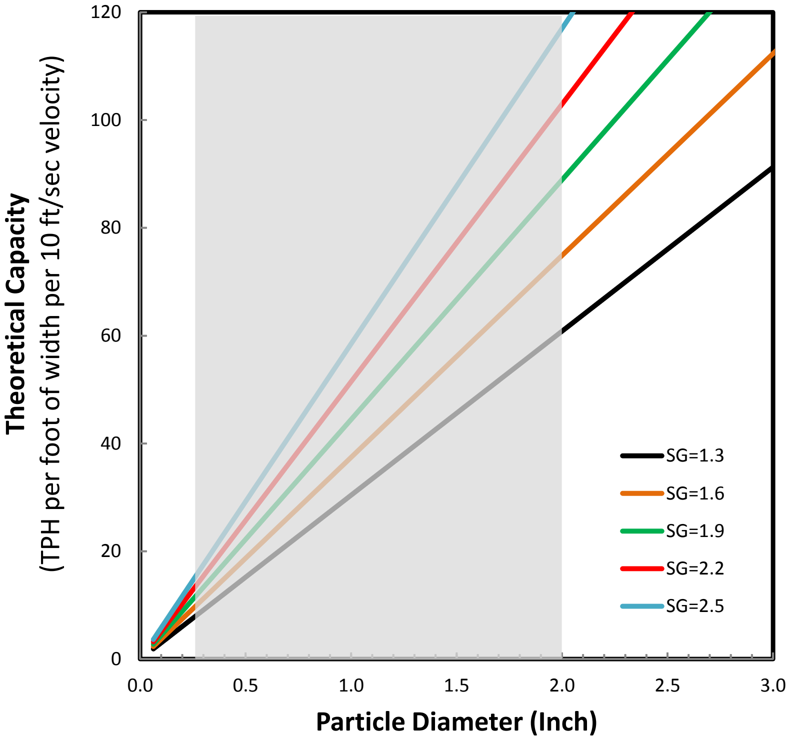


Figure 10. Theoretical maximum sorter capacity for mono-sized particles of different densities.

where ρ is the composite density of particles passing through the separator. Typically, this density value would correspond to specific gravity values of 1.5 to 1.9 SG for ash levels observed in typical eastern feed coals.

A plot of the theoretical sorter capacity as a function of particle diameter for different feed densities is provided in Figure 10. The plot was generated using a nominal belt velocity of 10 ft/sec. According to the plot, the theoretical maximum capacity for the larger 2-inch particles would fall in the range of 60 to 120 TPH per foot of scanner belt width, depending on the specific density of the feed solids. The theoretical capacity would fall sharply to 7-14 TPH per foot of belt width for particles smaller than ¼ inch in diameter. These finer particles can be easily missed when intermixed with coarser particles that are being separated at much higher production rates.

CONCLUSIONS

Several series of experimental test runs were conducted to evaluate the potential of an electronic coal sorter for upgrading of run-of-mine coal from an eastern U.S. mining operation. The test data indicate that this novel sorting technology can effectively remove unwanted mineral matter impurities contained in coarse (2 x ¼ inch) coal feeds. Due to inherently low capital and operating costs, this unique technology has the potential to serve as a viable coal cleaning alternative for sites that are water constrained or that have too low tonnage to justify a full-scale coal preparation facility (e.g., highwall miner applications, small contract mines with long truck haulage routes, etc.). More importantly, as a dry process, this method of separation avoids issues related to water usage and waste disposal that typically occur using traditional water-based separation processes. The compact footprint of this process may also allow the technology to be integrated into mining production units in underground mines, thereby reducing the demand for transporting and disposing wastes in dedicated surface refuse areas. The process is moving rapidly into the commercial sector as evidenced by a recent production-scale installation of this new technology (see Figure 11).

Figure 11. Photograph of a recent production-scale installation of the DriJet™ sorter technology.

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