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Application of density tracers in a dense medium circuit: A case study

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ABSTRACT

Density tracers are often used to identify the separation efficiency of mineral processing equipment and the overall plant performance in several mineral and coal applications. In a 700 t/h coal washing plant in Turkey, comprising dense medium drums and dense medium cyclones, a plant audit was conducted using density tracers. In this study, the data obtained from the dense medium cyclone and drum circuits during the plant survey are presented. Besides the detailed separation behavior of the particles in the drums and cyclones, some variables affecting the performance such as particle retention, separation cut-point and separation efficiency are also discussed. Based on the efficiency data from the plant audit, the mass balance of the plant was obtained using an in-house-developed coal washing plant simulator (LAVE) by using the size-by-size washability data of the run-of-mine (ROM) coal and the plant control room data.

1. Introduction

Dense medium separation is the most widely used beneficiation method for upgrading coal quality. Dense medium circuits operate with finely ground, high-density solid medium (typically magnetite) that is mixed with water to form a dense medium. Increased addition of magnetite to the medium increases the fluid density. The plant cut-point density is controlled by adjusting the medium density. Dense medium cyclones are extensively preferred to separate lighter coal from denser ash in the −50 + 0.5 mm size range (Narasimha et al., 2007), and dense medium drums are normally used for the separation of coarser particles, which are in the −150 + 15 mm size range (Meyer and Craig, 2015). Dense medium baths are used to process a very broad range of feed particle sizes, which may be as coarse as 300 mm or as fine as +6 mm or +12 mm, depending on the application (Legault-Seguin et al., 2016).

In operating plants, inefficiencies are frequently evident. A well-controlled plant is important to ensure that the overall product quality and yield from the ROM are optimized, so that the plant performance meets the expected performance from the mine planning process. Dense medium separation efficiency is conventionally represented using partition curves (Rao, 2000). With the use of flow rates, densities and other characteristics of medium streams, dense medium separation operation can be practically and effectively simulated (Chen et al., 2012; Napier-Munn, 1991; Wood et al., 1989; Zhang et al., 2015). There are numerous studies on the mathematical modelling of dense medium circuits that can be used to assist in the improvement of the process performance and plant/circuit stability. Many static and dynamic models have been developed and/or simulated for this purpose by various researchers (Meyer and Craig, 2010). Although there is much information about dense medium cyclone modelling and simulation in the literature (Meyer and Craig, 2014), there are also other novel studies that concentrate on modelling dense medium drums (Meyer and Craig, 2016, 2015).

The tracer technique is one of the most time-efficient applications in dense medium separation circuits for evaluating the performance of the equipment. It eliminates the need for sample collection and laboratory analysis, such that the partition data obtained using tracers are generally considered as accurate as the data derived from conventional methods in a short period of time. For this technique, tracers covering a wide range of densities are used. They are cubic polymer-based blocks that are supplemented with high-density fillers to create tracers at relative densities (RD) in the range of 1.20–2.50 or higher, with an accuracy of ± 0.005 RD. Higher densities can also be manufactured for use in diamond, iron, and heavy mineral separation circuits. These low-cost units can be introduced into a separation process to mimic the behavior of particles of ore or coal. Advanced process models can be developed, equipment performance can be determined, and the performance of dense medium circuits can be established more rapidly than the traditional method of sampling of the circuit streams followed by float–and-sink analysis (Luttrell et al., 2005).

In this study, data from the tracer studies were used to assess the partitioning performance of the dense medium circuits in a full-scale and operational plant.

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2. Materials and methods

Experimental test work was conducted at the Tuncbilek lignite coal washing plant which is located in western Anatolia, Turkey. The Tuncbilek plant is one of the oldest coal washing plants in Turkey and was constructed in 1957. The plant design has changed several times from the original design, up to the current configuration. With the latest design of the plant, there are some streams that are physically inaccessible for proper sampling.

Approximately 95% of coal reserves in Turkey are estimated to be low-rank (lignite and sub-bituminous) coals (Ocakloglu, 2015). The lignitic coals of Turkey mainly occur in a number of fault-bounded miocene and pliocene lacustrine basins in intermontane regions. The area where the plant is located is one of the most productive coal basins which contains a thick and lateral extensive coal bed at the base of the miocene formation (Karayigit and Celik, 2003). There are many coal washing plants and operating mines in the area. The area is dominated by large east-west trending grabens along with a number of approximately north-south trending grabens (Akkiraz et al., 2012).

The open-pit mining method is extensively used in this region. The ROM coals are upgraded at coal washing plants to reduce sulfur and increase the calorific value for domestic heating, whereas the middlings fraction from the plants are typically utilized in coal-fired power plants.

In the current coal washing plant, different types of coal products are produced; coarse (+18 mm) clean coal for domestic heating purposes, fine (−18 + 0.5 mm) clean coal for industrial use (sugar, cement plants, etc.), and coarse and fine middlings as well as the −0.5 + 0.1 mm clean coal for power plant use.

At the Tuncbilek coal washing plant, the ROM coal after being crushed below 150 mm, is screened at 18 mm and 0.5 mm. In the plant there are two 18 mm screens and two dense medium drums working in parallel (Drum A and Drum B). The +18 mm fraction is treated with primary dense medium drums (called the coarse circuit), which produce clean coal at a lower relative density of separation (typically between 1.50 and 1.60 RD). The low-density product stream is separated as the primary clean coal products, whereas the sinks from the process stream are re-washed in a secondary drum at a higher relative density of separation (typically 1.70–1.80 RD). In the fine washing stage, the −18 + 0.5 mm fraction is fed to dense medium cyclones. The overflow of the primary cyclones operating at 1.40–1.50 RDs is separated as fine clean coal for use generally in sugar and cement plants. The underflow of the primary cyclones forms the feed to the secondary cyclones, which operate at RDs of 1.50–1.60, to produce middlings (secondary product) and final tailings. A brief illustration of the plant is given in Fig. 1.

The magnetite recovery circuit is a typical circuit similar to most coal washing plants throughout the world. Drain-and-rinse screens are used to recover the medium from clean coal, middlings and tailings. The "drain" sections of the screens are used to drain the medium from coal, which is collected in dense medium sumps. In the "rinse" section of the screens, spray water is used to rinse the medium from the coal, which is returned to the dilute-medium sumps. The dilute medium is pumped to magnetic separators, which recover the magnetite as an "over-dense" concentrate, and is then returned to the dense medium sump, thereafter being distributed to the dense medium streams. The equipment specifications are given in Table 1.

In this study, a detailed evaluation was undertaken to establish the performance of dense medium circuits using density tracers. Cubic density tracers, which were composed of high-density filler materials, were supplied by Partition Enterprises Pty Ltd (Australia). The density accuracy of the tracers was stated by the supplier to be within ± 0.005 g/cm^3. Partition curves were constructed from tests conducted using density tracers of 64 mm for the coarse circuit and 32 mm and/or 16 mm for the fines circuit. During the tests, tracers of different specific gravity values (1.44 RD, 1.48 RD, 1.52 RD, 1.56 RD, 1.60 RD, 1.64 RD, 1.68 RD, 1.72 RD, 1.76 RD, 1.80 RD, 1.85 RD, 1.90 RD, 1.95 RD, 2.00 RD, 2.05 RD and 2.10 RD) were selected according to the specific circuit operating conditions. While the plant was operating, 40 tracers of each density were introduced to the feed stream of the equipment. They passed through the separator and were reported to be either high- or low-density product streams. The tracers were pink coloured, so that they could be visually observed and easily handpicked from the product drain-and-rinse screens.

A Marcy pulp density scale was used to measure the density of the medium samples taken from different streams of the operating plant.

3. Results and discussion

At the coal washing plant, between 8000 to 10,000 t of coal is being washed each day as presented in Table 2.

Approximately 35–40% of the total products were produced as clean coal, 80% of the clean coal was produced in the fines circuit and 20% in the coarse circuit. Additionally, approximately 6% of the total products were produced as middlings to feed power plant, whereas nearly 60% of the products were separated from the system as tailings.

The weight and ash distribution of the ROM coal are presented in Table 3. According to these results, the total ash value of the feed was 47.54%. Approximately 5% of the feed by weight was finer than 0.5 mm. Half of the feed by weight, other than the −0.5 mm size fraction, contained 42.13% ash in coarse-sized fraction (−150 + 0.5 mm), whereas other half of the material contained 52.06% ash in fine-sized fraction (−18 + 0.5 mm).

The size-by-size float-sink test results of the ROM coal, presented in Table 4, give the mass and ash distributions of the coal. It can be deduced from the results that great amount of the material was presented in either low densities (1.30 and 1.40 RD) or highest density (+1.90 RD). Only 23.34% of the overall material by weight was presented between 1.40 and 1.90 RD. It was amount of the near-density material that would be processed in coarse and fines circuits.

Besides the float-sink test results in Table 4, further analysis results, such as the ash, moisture, total sulfur and volatile matter contents, together with the calorific values of the coarse- and fine-sized products (clean coal, middlings and tailings), were obtained. Table 5, summarizes the detailed analyses of the products.

3.1. Density tracer studies

To assess the performance of the existing dense medium circuit at the coal washing plant, density tracers were used in both the coarse circuit and the fines circuit. Similar tests were conducted by various researchers, although these tests only considered dense medium cyclones (Wood, 1990) or in combination of dense medium drums and dense medium cyclones (Orhan et al., 2016, 2014). In this study, the tests were performed at varying feed rates with various types of dense medium equipment. The details regarding the tests using density tracers are summarized in Table 6.

Three sizes of density tracers were used during the tests. 64 mm density tracers were used in the drums whereas a combination of 32 mm and 16 mm density tracers were tested in the cyclones. Tracers were introduced to the system and retrieved from the drain-and-rinse screens manually. As the tracer test work was conducted in an operating washery under load, some tracer losses occurred. However, the number of tracer losses was low and negligible. So, the lost density tracers and the density tracers that were retained in the cyclones were not taken into consideration in the calculation of the partition numbers.

At the end of each performance determination test, partition curves were obtained by the density tracers collected from various units. The actual partition coefficient values were then fitted to JKMRC model (Scott and Napier-Munn, 1992), which can be seen in Eq. (1):

$$Y_i = \frac{1}{1 + \exp\left[\frac{\ln 3(\rho_{50} - \rho_i)}{Ep}\right]} \quad (1)$$

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