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Multi component modelling of an air classifier

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ABSTRACT

This paper focusses on investigating the classification behaviours of the components having different densities and flow characteristics then developing preliminary model structure where these properties are considered. Such a study can improve the prediction accuracy of the existing models since material characteristics are of crucial importance. Within the scope of this study, laboratory scale experimental tests were undertaken on clinker, copper ore, magnetite and coal samples, at different operating conditions. The results concluded that, increasing the density decreased the cut size in the meantime increased the bypass of the classification operation. In addition, the sharpness and the fish hook parameters were found to be correlated with the flow characteristics of the material e.g., the higher the fluidity the higher the sharpness and the lower the fish-hook. As a conclusion of the study, the correlations presented in the paper were integrated into an existing air classifier model and preliminary multi component model structure for air classifiers was developed.

1. Introduction

Air classification is a process of separating particles into two or more groups according to their shapes, sizes and specific gravities. The process has been utilized by different industries i.e., cement, food, coal, where water interaction is avoided. Up to date, different types of air classifiers e.g., static and dynamic classifiers, have been developed. Static air classifiers adjust the target product size only by changing the magnitude and the direction of the airflow. On the other hand, dynamic classifiers have a rotating cage that is used both to disperse the feed and adjust the product size distribution. Dynamic air classification technology has been evolving since 1885 when the first generation air classifiers were introduced. Briefly, first-generation classifier has a dispersing plate on which the material is poured then thrown towards the separator wall where the final classification is performed with the introduction of the air. Within the technology, air is generated inside the separator body. Following the first-generation technology, second generation air classifiers were developed. The second-generation classifiers are operated with cyclones in order to increase the fines collection efficiency. Additionally, fan that is generating air for the classification is mounted outside of the separator body that also improved the overall efficiency of the machine. Finally, the third generation air classifiers or high efficiency classifiers (HES) were introduced and improved performances have been reported (Duda, 1985; Yardi, 2005). Improved efficiency of HES can be attributed to mounting of the fan outside of the classifier body, using the cyclones to collect the fines and using the rotor cage structure that enabled the forces participating in the classification well defined (Klumpar et al., 1986). Table 1 compares the performances of the above-mentioned generations regarding to their sharpness of separation parameters. As can be understood, the third generation classifier has sharper separation means the technology has improved classification efficiency.

During the classification operation of the HES, the particles are under the influences mainly of centrifugal (F_c), drag (F_d) and gravity (F_g) forces. The centrifugal force is generated by rotor, which accelerates the particles towards the outside edge of the distribution plate. Air enters the classification zone tangentially and creates a drag force that performs the final separation. The mathematical definitions of the forces (Klumpar et al., 1986; Duda, 1985) are given in Eqs. (1)–(3).

$$F_c = \frac{4}{3} * \pi * r_p^3 * \rho_p * \frac{V^2}{r} \tag{1}$$

$$F_d = c_D * \rho * \pi * r_p^2 * \frac{V_a^2}{a} \tag{2}$$

$$F_g = m * (\rho - \rho_{air}) * g \tag{3}$$

where;
r_p: particle radius
ρ_p: particle density

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Table 1
The variation of the sharpness of separation parameter with the classifier design (Yardi, 2005).

Sharpness (d_{25}/d_{75})	Classifier type
0.25	Static
0.30–0.35	Static to generation 1
0.40–0.45	Generation 1–2
0.50–0.55	Generation 2–3
0.60–0.70	Generation 3 (HES)

V: peripheral velocity of the rotor
r: rotor radius
c_D: drag coefficient
ρ: gas density
V_a: air velocity
m: mass of particle
g: gravitational constant.

As can be understood from Eqs. (1)–(3), the magnitudes of the forces depend both on the diameters and the densities of the particles. The coarser and the denser particles will be affected most by the gravitational and the centrifugal forces. Consequently it can be concluded that, as the feed gets denser, the cut size of the classification is to decrease and vice versa.

The literature reports that the material properties have influence on the performance of the classification operation. It is a well-known fact that, different components exhibit different behaviours and the models should be developed accordingly so as to improve the predicting capabilities of the models. Within the scope of the study, density and agglomeration tendencies of the bulk material were considered in mathematical modelling of a laboratory scale air classifier. Initially, experimental studies were undertaken with different samples. Afterwards, mass balancing studies were performed and the size-by-size efficiencies were calculated then inputted to the Whiten's efficiency curve equation (Napier-Munn et al., 1996; Benzer et al., 2001; Altun and Benzer, 2014). Finally, the parameters exist in the Whiten's equation (Eq. (4)) were correlated with the operating conditions of the air classifier as well as the material characteristics. The study contributes to the literature regarding explaining the behaviour of the components in the air classification operation that is then used in developing the multi-component modelling structure.

$$E_{oa} = C * \left[\frac{\left(1 + \beta * \beta^* * \frac{d}{d_{50c}}\right) * (\exp(\alpha) - 1)}{\exp\left(\alpha * \beta^* * \frac{d}{d_{50c}}\right) + \exp(\alpha) - 2} \right] \quad (4)$$

where;

E_{oa}: The actual efficiency to overflow
C: Fraction subjected to real classification; (100-Bypass)
β: Parameter that controls the initial rise of the curve in fine sizes (fish-hook)
β^*: Parameter that preserves the definition of d_{50c}; $d = d_{50c}$ when $E = (1/2)C$
α: Sharpness of separation
d: Size
d_{50c}: Corrected cut size.

2. Materials and methods

2.1. Description of the experimental apparatus

Within the study, experimental tests were undertaken with Alpine 100 MZR Classifier (Fig. 1) having the features given in Table 2. In this machine, the target size is adjusted by changing the wheel speed and the air flow rate used in the classification. Once the material is fed, the particles entering the classification zone are under the influence of drag, centrifugal and gravity forces thus either subject to the coarse or the fine stream. Fig. 2a–c illustrates the cross sectional views of the classifying chamber, rotor structure and the influencing forces in the classification operation.

Fig. 1. Alpine 100 MZR air classifier.

Table 2
The features of the Alpine 100 MZR classifier.

Wheel speed (rpm)	1000–15,000
Air volume (m^3/h)	5–50

The operational range of the classifier is reported as between 2 and 80 μm and the feed rate is between 2 and 6 kg based on the density of the material. As can be seen from Fig. 2, feeding is performed from the screw feeder. The air enters the classifier and reaches to the rotor. It flows through the rotor from the outside to the inside and leaves the classifier, taking the fine particles with it. Coarse material that is flung by the centrifugal force is taken from one point on the circumference of the housing and collected for weighing. The classifier has a rotor with zigzag, radially arranged channels (Fig. 2b). The influencing forces in classification operation are illustrated in Fig. 2c.

2.2. Experimental and mass balancing studies

Experimental studies comprise the air classification tests that are followed by characterization works and the weighing of the fine and coarse products of the classifier. Within the context of the study, coal, magnetite, clinker and copper ore samples were subjected to the classification tests of which the test plan is given in Table 3.

Regarding to the characterization, the density and the particle size measurements were undertaken. Within the study, the densities of the feed samples were determined by pycnometer method (TS EN 1097-7) where mass and volume measurements were undertaken with a glass container having the specified volume (Table 4). It should be emphasized that the densities determined within the study represent the overall density of the samples for a given size distribution. The particle size measurements were