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ORIGINAL PAPER

A NEW APPROACH FOR MODELLING OF STATIC STABILITY OF DENSE MEDIUM SEPARATOR

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ABSTRACT

In this study, effects of the feed density, coal slime content and magnetite particle size on static stability of a dense medium drum was investigated. In this paper, a parameter defined as the density differential value between the lower and upper portion of suspension is used to characterize the static stability. The actual data collected from the tests were used to construct the empirical model representing density differential as process responses to the independent variables. The significance test of model fit for density differential was performed using analysis of variance (ANOVA). The results showed that the density differential model was significant. The research has shown that with an increase in feed density and coal slime content stability of dense medium enhances.
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INTRODUCTION

Dense medium separation (DMS) process is one of the most effective coal cleaning methods due to its wide density adjustment range, high separation sensitivity and capacity. DMS is a float-sink process that ensures high-density impurities in the run of mine (ROM) sink in the dense medium and the lighter minerals float, thus increasing the coal quality (Wills and Napier-Munn, 2006; Honaker et al., 2000). Dense medium separation (DMS) is widely used in separation processing due to its high separation precision, large processing capacity, and good adaptability (Oteyaka, 2008). Compared to gravity separation, DMS enhances particle separation by introducing a suspension composed of fine particles and water (Douet al., 2019).

Dense medium drums (DMDs) are density separation machines commonly used in the coal and recycling industries. The medium typically consists of a suspension of high-density powder in water. As shown in Figure 1, objects with a density lower than that of the medium float and exit the drum through the light fraction outlet at the surface. Heavier objects sink and are removed from the drum by collectors or spirals, which are driven by the drum's rotation. The medium is supplied via inlet tubes, and a slight drum inclination ensures a steady flow toward the light fraction outlet (Eggers et al., 2017; Eggers et al., 2019).

Magnetite is commonly used to control medium density in dense medium drums. However, the inability to recover a portion of the magnetite leads to increased operational costs. Therefore, alternative materials such as sand, clay, quartz, steel slug, magnetite, and ferrosilicon are being tested as heavy media (Honaker and Bimpong, 2009; Mikołajczyk et al., 2022)

In coal preparation, the dense medium suspension comprises magnetite powder, water, and coal slime. Its rheological property is defined by the viscous resistance the suspension exerts on moving particles (Zhu et al., 2020). Key factors affecting these properties include the suspension concentration, the particle size, density, and shape of the slime (Yang and Aldrich, 2005). The high density and rapid sedimentation rate of magnetite powder often lead to instability in the suspension. Measuring the suspension density directly within the machinery during the actual separation process is challenging, complicating the study of dense medium suspensions (Majumder et al., 2006).

The dense medium suspension is a coarse-dispersed phase system, prone to sedimentation and stratification when static, leading to instability (Zhao et al., 2024). DMS plants do not typically operate at steady state and that set point changes should be tracked appropriately in terms of ash content and yield (Firth et al., 2011). That is, the appropriate density of

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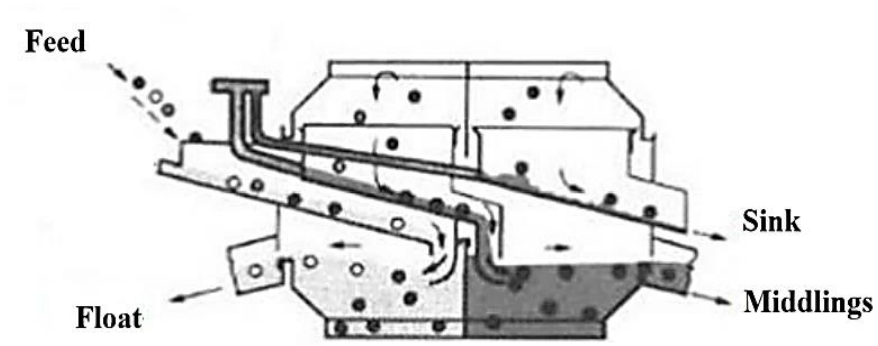

Fig. 1 Dense medium drum.

dense medium can efficiently separate low-ash coal from waste. Therefore, optimization and stability of dense media density are critical for clean coal production. (Dai et al., 2020).

The stability of the medium as it passes through a DMS is an important issue for the separation capability and efficiency of the DMS (Firth et al., 2012). The homogeneity of a dense medium suspension consisting of solid and liquid is defined as stability. The stability of the medium determines the density gradient in the separation zone and thus directly affects the separation sensitivity (Bozzato et al., 2000).

Researchers investigated the viscosity of the suspension, using different research methods and experimental instruments. Studies showed that the viscosity is significantly directly correlated with the suspension stability (Shi and Napier-Munn,1996; He and Laskowski,2000). Further studies showed that the viscosity is relevant with the volume concentration of solids in the suspension (Mendoza 2017; Santamaría-Holek and Mendoza, 2010). To improve the stability of the suspension effects of of slime content and solid volume concentration investigated. Results showed that the stability of suspension is increased with the increase of slime content and solid volume concentration (Napier-Munn, 1990; O'Brien et al., 2014). However, limited studies found that addressed the effects of magnetite particle size and slime ratio at different medium densities on stability.

MATERIALS AND METHOD

In experimental studies, a copper tube was used to prevent self-magnetizing of magnetite particles. The copper tube of 120 cm length and 3 cm diameter was designed to simulate a dense medium drum (Fig. 2).

The potential components for the artificial medium mixtures were magnetite with 3 different particle size: -106 µm, -75 µm, -45 µm and fine coal slime with size less than 45 µm. The magnetite samples were prepared by grinding a 65.74 % Fe grade magnetite sample into 3 different particle size.

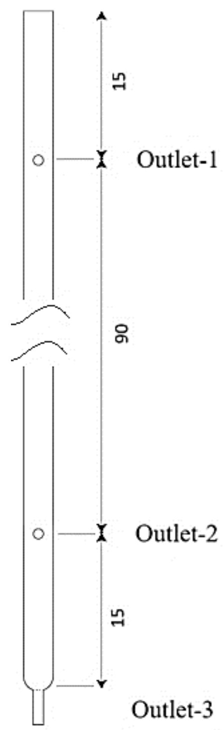

Fig. 2 Copper tube.

In the experiments, heavy media suspensions of three different densities were prepared using different proportions of coal slime and magnetite of different particle sizes. The medium compositions are given at Table 1.

According to the targeted feed density, the amount of coal slime and magnetite by weight was calculated and mixed with water. In the next stage, the suspension was transferred to the copper tube and turned upside down 10 times. At the end of 30 seconds, samples were taken from 3 outlets of the tube and densities were measured. The test duration was determined as 30 seconds to simulate the duration of inlet and outlet of heavy media in a dense medium drum.

Table 1 Medium compositions.

Variables	Low level	Medium level	High level
Feed Density (g/cm3)	1.4	1.6	1.8
Coal Slime (%)	0	10	20
Magnetite Particle Size (d_{100}) (μm)	53	75	106

Table 2 Test results.

Test	Feed Density (g/cm^3)	Coal Slime (%)	Magnetite Particle Size (d_{100}) (μm)	Outlet-1 Density (g/cm^3)	Outlet-2 Density (g/cm^3)	Outlet-3 Density (g/cm^3)	Density Differential (g/cm^3)
1	1.4	0	53	1.30	1.40	1.48	0.18
2	1.4	0	75	1.30	1.33	1.81	0.51
3	1.4	0	106	1.05	1.20	2.62	1.57
4	1.6	0	53	1.53	1.60	1.65	0.12
5	1.6	0	75	1.48	1.55	1.93	0.45
6	1.6	0	106	1.18	1.47	2.54	1.36
7	1.8	0	53	1.77	1.79	1.87	0.10
8	1.8	0	75	1.70	1.76	2.07	0.37
9	1.8	0	106	1.25	1.68	2.79	1.54
10	1.4	10	53	1.33	1.40	1.45	0.12
11	1.4	10	75	1.35	1.36	1.63	0.28
12	1.4	10	106	1.15	1.25	2.30	1.15
13	1.6	10	53	1.57	1.59	1.67	0.10
14	1.6	10	75	1.55	1.57	1.78	0.23
15	1.6	10	106	1.28	1.51	2.27	0.99
16	1.8	10	53	1.77	1.80	1.82	0.05
17	1.8	10	75	1.76	1.77	1.97	0.21
18	1.8	10	106	1.54	1.72	2.38	0.84
19	1.4	20	53	1.37	1.40	1.42	0.05
20	1.4	20	75	1.36	1.38	1.53	0.17
21	1.4	20	106	1.20	1.32	1.93	0.73
22	1.6	20	53	1.58	1.60	1.62	0.04
23	1.6	20	75	1.57	1.58	1.72	0.15
24	1.6	20	106	1.42	1.52	2.12	0.70
25	1.8	20	53	1.79	1.80	1.81	0.02
26	1.8	20	75	1.77	1.78	1.92	0.15
27	1.8	20	106	1.68	1.71	2.32	0.64

RESULTS AND DISCUSSION

A total of 27 experiments were conducted to investigate the effects of magnetite particle size, feed density and coal slime content on dense medium stability. Test results given at Table 2. Density differential values has calculated as difference between densities of last and first outlet. The density differential shows the stability of dense medium.

The actual data collected from the tests were used to construct the empirical model representing density differential as process responses to the independent variables. The actual model equation for density differential was as in Equation 1.

$$\text{Density differential} = 1.88 - 1.74\,X + 0.0154\,Y - 0.01740\,Z + 0.556\,X{*}X + 0.000506\,Y{*}Y + 0.000308\,Z{*}Z + 0.00458\,X{*}Y - 00403\,X{*}Z - 0.000674\,Y{*}Z \quad (1)$$

X: Feed density (g/cm^3)
Y: Coal slime (%)
Z: Magnetite particle size (μm)

The significance test of model fit for density differential was performed using an analysis of variance (ANOVA). The results showed that the model was significant as the F values were high and the Prob > F (p-value) were lower than 0.05 (Table 3). The predicted R^2 value of density differential model (0.9884) is in reasonable consistency with the adjusted R^2 value (0.9822), the difference between these two values are less than 0.2 for both models.

The effect of feed density and coal slime on density differential at the center level of the magnetite particle size is shown in Figure 3. As can be seen, a lower density differential was obtained at higher levels of feed density and coal slime. This may be explained by that at the higher solid concentration, the viscosity of the dense medium increases. Therefore, the settling rate of magnetite particles are becoming slower and results in an increase stability of the dense medium.

Table 3 ANOVA table derived for the density differential model.

	Degree of freedom	Sum of square	Mean square	F-value	Prob > F
Model	9	5.907	0.656	160.44	<0.001
Linear	3	5.055	1.685	411.88	<0.001
X	1	0.041	0.041	10.04	0.006
Y	1	0.770	0.770	188.25	<0.001
Z	1	4.244	4.244	1037.36	<0.001
Square	3	0.280	0.093	22.80	<0.001
X*X	1	0.003	0.003	0.72	0.407
Y*Y	1	0.015	0.015	3.75	0.07
Z*Z	1	0.262	0.262	63.92	<0.001
2-Way	3	3.000	0.393	0.13	32,05
X*Y	1	0,001	0,001	0.25	0,626
X*Z	1	0.006	0.006	1.35	0.262
Y*Z	1	0.387	0.387	94.56	<0.001
Error	17	0.070	0.004		
Total	26	5.977			

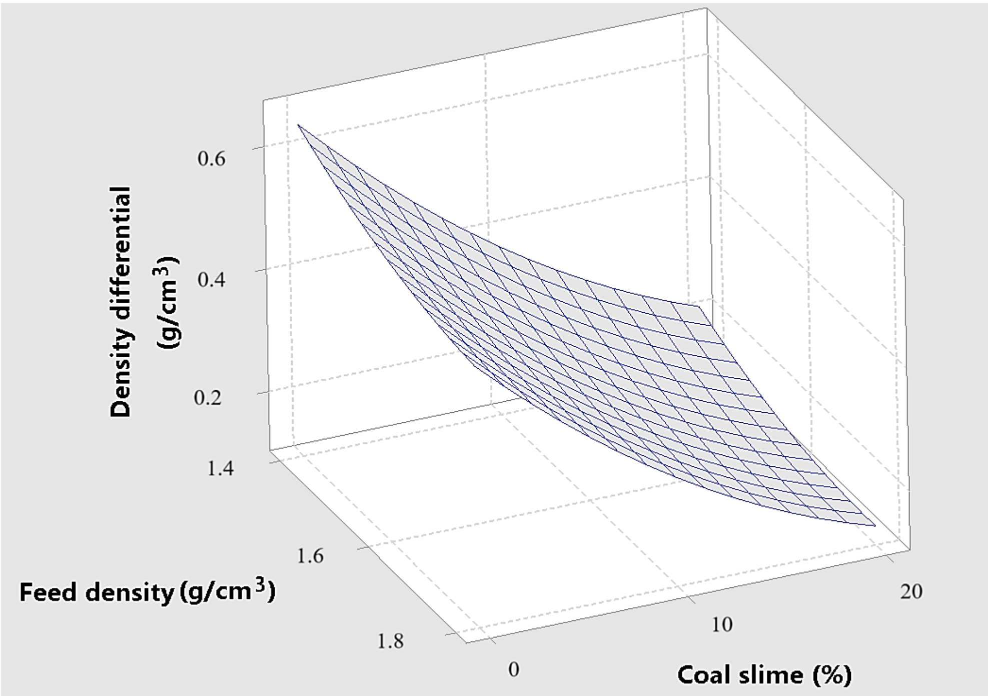

Fig. 3 The effect of feed density and coal slime on density differential at the magnetite particle size of 75 µm as the center level.

THE EFFECT OF FEED DENSITY AND MAGNETITE PARTICLE SIZE

Figure 4 illustrates the effect of feed density and magnetite particle size on the density differential at the center level of coal slime. As the magnetite particle size increases, the settling rate of the particles increases, which causes the density difference in the lower and upper outlets to increase. These effects were consistent with the results obtained in some previous studies (Gustafsson et al., 2005; He and Laskowski, 1995).

THE EFFECT OF COAL SLIME AND MAGNETITE PARTICLE SIZE

Figure 5 represents the effect of the coal slime and magnetite particle size on the density differential at the center level of feed density. It can be observed in Figure 4 that the minimum density differential value was found at the maximum levels of coal slime and minimum levels of magnetite particle size. This may be attributed to the fact that increased viscosity and decreased settling velocity.

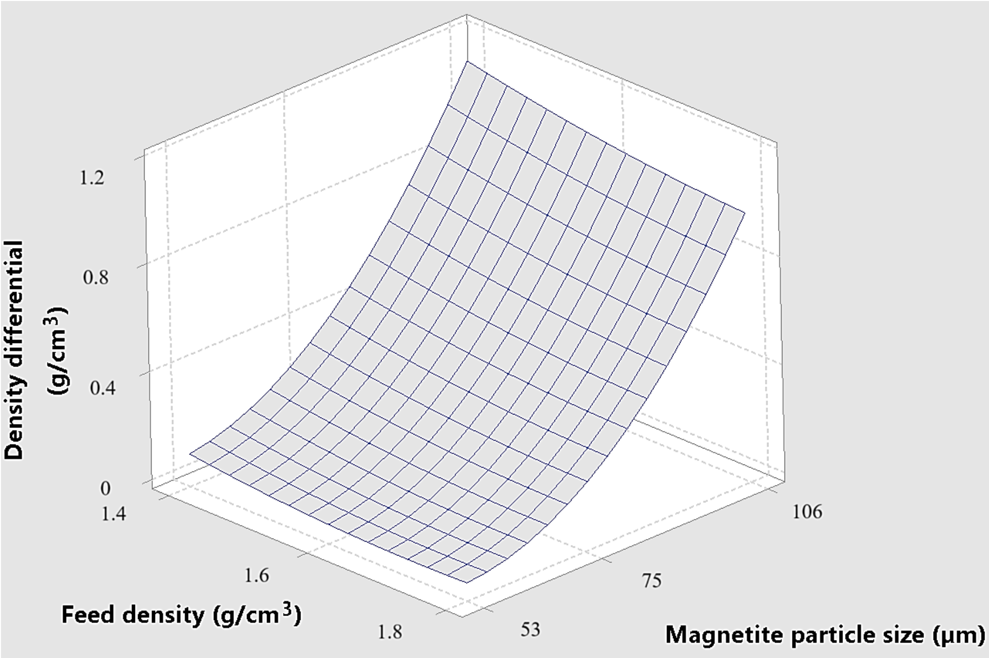

Fig. 4 The effect of feed density and magnetite particle size on the density differential at coal slime of 10 % as the center level.

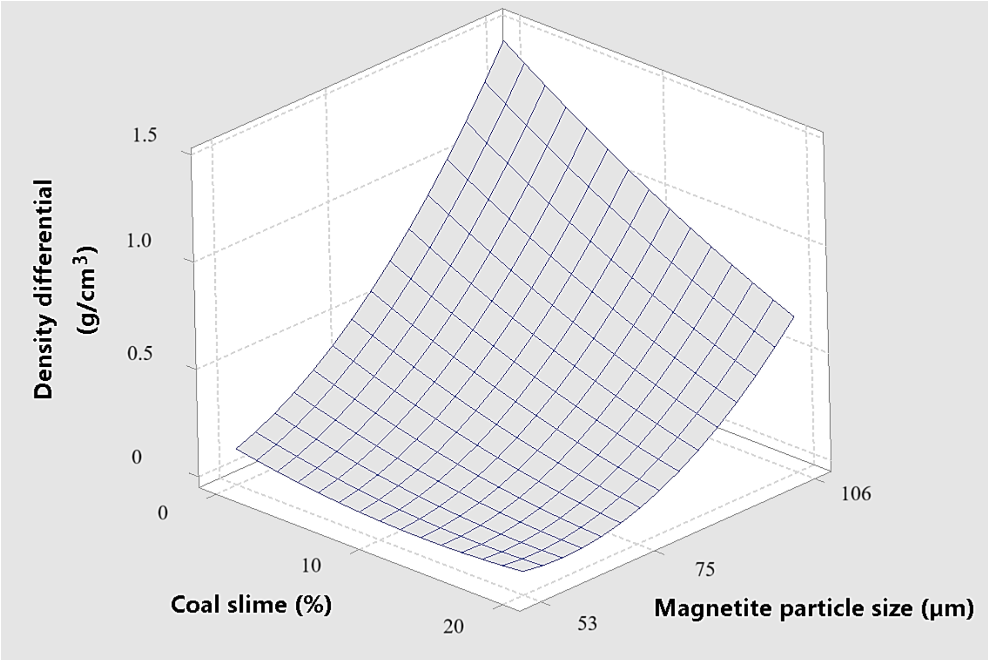

Fig. 5 The effect of the coal slime and magnetite particle size on the density differential at feed density of 1.6 g/cm^3 as the center level.

CONCLUSION

In this study, the effects of feed density, coal slime content and magnetite particle size on the density differential for a dense medium drum was investigated. Mathematical model equations were derived using experimental data and mathematical software package Minitab 17. The ANOVA results indicated that coal slime content and magnetite particle size were more effective independent variables on the density differential. The results suggested that all main parameters affected the density differential to some degree. The significance order of the effect of the variables on the density differential was found as magnetite particle size > coal slime content > feed density. Coal washing plants where densities of clean coal and waste rock are very close, and high amount of near density materials, use -45 μm (grade A or B) magnetite in common practice. However, the results of the numerical optimization in the range of the experimental data showed that it is possible to sustain dense medium stability by using slightly coarser magnetite at higher coal slime contents in a dense medium separator.

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