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Using an axial electromagnetic field to improve the separation density of a dense medium cyclone

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To produce an on-line control method to improve the separation density of a given suspension density of a dense medium cyclone, a thin solenoid coil was placed in the cylindrical part of a cyclone. The dense medium distribution test and −3 + 0.125-mm coarse slime separation tests for different electric currents were performed. Float-and-sink analysis was performed for the separation products. The magnetic force of the particles under a magnetic field was also simulated. The results indicated that the presence of a magnetic field can improve the separation density by increasing the “separation cone density” caused by the inward radial motion and the upward axial motion of the magnetic particles. This approach provided a new separation density manipulation method for dense medium cyclones via application of a magnetic field.

1. Introduction

Dense medium cyclones (DMCs), also known as heavy medium cyclones, were the most important cleaning units within coal preparation plants and were known to be efficient, high-tonnage devices suitable for upgrading particles in the 50–0.5 mm size range. The working principle of DMCs had been well documented (King and Juckes, 1984; Napier-Munn, 2005; Svarovsky, 1984). The research and application of three-product dense medium cyclones in China held a leading position in the world, and currently, the process that was widely used involves the simultaneous separation of three products using a single suspension density. However, this process had the following problems in practice: (1) to satisfy the second-stage separation requirement, the feed pressure of the first-stage must be improved, meaning that the materials, such as pipelines, should have better wear resistance; (2) the difficulties of second-stage density manipulation in a three-product dense medium cyclone for coal preparation represent a bottleneck to be solved: first, the actual effect was not made obvious by adjusting the second-stage overflow tube insertion depth to change the separation density, often due to the rusting of mechanical devices and slime blocking (Liu, 2006); second, production must be halted when replacing the bottom orifice. Thus, there was an urgent need to develop a novel method for adjusting the second-stage separation density of a dense medium cyclone.

In recent years, magnetic devices had been widely applied because of their functional diversification (Ali-Zade et al., 2008; Augusto et al., 2004; Premaratne and Rowson, 2003; Sripriya et al., 2003), and interest had also arisen in inventing a magnetic cyclone for use in a mineral processing plant with the aim of improving product grade and recovery. Currently, magnetic cyclone designs were mainly divided into two groups: overflow magnetic cyclones and underflow magnetic cyclones (Freeman et al., 1993). In designs belonging to the first group, an electromagnet produced a field pattern to attract magnetically susceptible particles to the centre of the cyclone and then through the overflow (Fricker, 1985). In designs from the second group, electromagnets were set on the outside of the cyclone, providing a magnetic field to attract particles to the side wall of the cyclone, and the flow subsequently removed them through the underflow (Shen and Finch, 1990; Watson and Amoako-Gyamphi, 1983; Watson and Li, 1999). The magnetic force in the two aforementioned types of magnetic cyclones was radial. The feasibility of enhancing the separation effect and the homogenisation degree of the suspension in a cyclone by using a magnetic force was demonstrated by Svoboda and his research group (Svoboda and Campbell, 1996; Svoboda et al., 1998). The main impact of the magnetic force that was generated by magnetic systems on the separation effect is axial and weak. By adjusting the magnetic field strength and position of the magnet, the Ep was noted to decrease from 0.05 to 0.01 in combination with a reduced cut-point density. In addition, further analysis was performed by Vatta et al. (2003) to determine the yield of the dense medium cyclone underflow with a sample

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Table 1
Sieve analysis of the raw coal.

Particle size (mm)	Weight (%)	Ash (%)
−3 + 1	35.00	46.39
−1 + 0.5	16.10	29.34
−0.5 + 0.25	21.98	28.92
−0.25 + 0.125	9.68	25.14
−0.125	18.03	26.74
Feed	100.00	34.57

consisting predominantly of quartzite material as a function of the magnetic field strength and solenoid position in the cone of the cyclone. For a specific magnetic field strength and solenoid position, the mass of material to be processed downstream was found to be reduced, but at the same time, a disruption in the ferrosilicon flow pattern inside the cyclone would occur beyond a certain magnetic field strength, leading to an impaired cyclone separation efficiency (Svoboda, 1994). The effect of this type of magnetic system was subsequently tested from 1996 to 2000 on DMCs at a diamond production plant with different cyclone sizes of 250 mm and 510 mm to supplement the work by IIana Katinka Myburgh (Myburgh, 2001), and the results indicated that the yield of the concentrate could be reduced by the application of a suitable magnetic field.

To investigate the effect of the magnetic characteristics on dense medium distribution in DMCs for coal preparation, Ma Tingting et al. performed a series of tests and analytical studies (Ma et al., 2013). The results indicated that in cases in which a magnetic field was applied at the top of the cyclone cylinder, the separation density increased slightly when using a lower magnetic induction.

The findings outlined above indicate that if this magnetic manipulation method could be applied to the coal preparation process, it would certainly introduce significant changes to the dense medium cyclone separation process and significantly improve the efficiency and automation level of the coal preparation plant. The purpose of this experimental study was to determine, in detail, the separation effects as a function of magnetic field strength and solenoid position.

2. Materials and methods

2.1. Samples

2.1.1. Sieve analysis

The coal sample used in for testing was obtained from the Tun-Lan Coal Preparation Plant and was passed through a 3-mm vibrating screen. The sieve results were listed in Table 1. Coal particles measuring −3 + 1 mm accounted for 35.00 wt.% of the total sample, which had an ash content of 46.39%. As the coal particle size decreased to −0.25 + 0.125 mm, the ash content decreased as well. Finally, the fraction of coal particles measuring −0.125 mm was found to increase to 18.03%, and the ash content increased slightly to 26.74%.

2.1.2. Washability study

All experimental procedures followed the Chinese National Standard Method for the float-and-sink analysis of coal. The float-and-sink test of coal samples with different ranges of particle size was performed using the gravity separation method, in which a $ZnCl_2$ solution of various densities (1.3, 1.4, 1.5, 1.6, 1.7, 1.8, and 2.0 g/cm^3) was used as the heavy liquid. The results of the float-and-sink test for coal samples with particle sizes ranging from 3 to 0.25 mm were presented in Tables 2–4.

The portion of the coal samples that floated in media with densities of 1.3 and 1.4 g/cm^3 was mostly composed of particles measuring −3 + 0.25 mm, whose ash content was lower than 9.0%. The raw coal was considered to be relatively difficult to float or difficult to float at lower separation densities and easy to float at higher separation densities.

Raw coal has a lower elementary ash content, and the light component accounted for a large proportion; thus, it was easy to

Table 2
Float-and-sink test of raw coal for the −3 + 1 mm size fraction (%).

Density range (g/cm^3)	Float		Cumulative float		Cumulative sink		±0.1 specific gravity distribution	
	Yield γ	Ash A_{ad}	Yield γ	Ash A_{ad}	Yield γ	Ash A_{ad}	Mean density δ	Content $\delta \pm 0.1$
<1.3	9.06	4.23	9.06	4.23	100.00	45.49	1.30	26.86
1.3–1.4	17.80	8.54	26.86	7.09	90.94	49.73	1.40	26.62
1.4–1.5	8.82	17.67	35.69	9.70	73.14	59.79	1.50	15.27
1.5–1.6	6.45	26.95	42.14	12.34	64.31	65.59	1.60	9.91
1.6–1.7	3.46	35.17	45.60	14.08	57.86	69.91	1.70	7.55
1.7–1.8	4.09	42.10	49.69	16.38	54.40	72.13	1.80	7.14
1.8–2.0	6.10	52.55	55.79	20.34	50.31	74.58	1.90	6.10
+2.0	43.97	77.64	100.00	45.49	44.21	77.64		
Feed	100.00	45.49						

Table 3
Float-and-sink test of raw coal for the −1 + 0.5 mm size fraction (%).

Density range (g/cm^3)	Float		Cumulative float		Cumulative sink		±0.1 specific gravity distribution	
	Yield γ	Ash A_{ad}	Yield γ	Ash A_{ad}	Yield γ	Ash A_{ad}	Mean density δ	Content $\delta \pm 0.1$
<1.3	5.57	2.16	5.57	2.16	100.00	31.23	1.30	47.01
1.3–1.4	41.44	6.84	47.01	6.29	94.43	29.63	1.40	55.65
1.4–1.5	14.21	16.20	61.22	8.59	52.99	47.59	1.50	20.35
1.5–1.6	6.14	25.75	67.36	10.15	38.78	59.22	1.60	9.70
1.6–1.7	3.56	34.11	70.92	11.35	32.64	65.60	1.70	5.84
1.7–1.8	2.28	41.00	73.20	12.28	29.08	69.51	1.80	4.69
1.8–2.0	4.83	51.63	78.03	14.71	26.80	71.98	1.90	4.83
+2.0	21.55	76.53	100.00	27.97	21.97	76.53		
Feed	100.00	27.97						