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INFLUENCE OF PARTICLE SIZE AND FEED RATE ON COAL CLEANING IN A DRY SEPARATOR

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Abstract: This research is concerned with the effects of particle size distribution and feed rate of feed on the coal cleaning performance of table type air separator. In tests, the lignite and hard coal samples from Mugla and Zonguldak districts in Turkey were used. The samples were tested in three different size distributions such as –38 + 6 mm, –19 + 6 mm and –9.5 + 6 mm. The effect of particle size was investigated together with the feed rate 2 Mg/(h·m^2), 1.68 Mg/(h·m^2) and 1.32 Mg/(h·m^2) and very important physical parameters of table type air separator such as, riffle height, table slope and table frequency. Results were analyzed by using the Tromp curve for indicating the effects in detail. Consequently, the results revealed that the particle size had remarkable effect on separation efficiency. The separation efficiency was, however, inversely affected as the particle size distribution became finer, and the best results were obtained in particle size distribution was –38 + 25 mm in both sample tested. The E_p value was 0.11 for the hard coal samples while it was 0.13 for the lignite samples.

Keywords: *dry coal cleaning, particle size effect, air separator*

Introduction

The classical wet coal cleaning techniques depend on density differences between coal and impurities such as, pyrite minerals and silicate minerals etc. Air-based separation technologies, like water-based methods, also separate coal and ash-bearing material according to their different relative densities (Frankland, 1995; Arslan, 2006; Chen and Wang, 2006). The pressure difference between two random points in the bed is almost equal to the difference between the hydrostatic heads of these two points, as shown in Eq. 1:

$$\Delta P = P_1 - P_2 = (h_1 - h_2)\,\rho, \tag{1}$$

where ΔP is the pressure drop (Pa), P_1 and P_2 are the pressures at point 1 and 2 (Pa), and ρ is the bed density (kg/m³), h_1 and h_2 (m), are height of point 1 and point 2,

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respectively. Particles with a density lower than the bed density will float to the top of the surface while higher density particles go to the bottom of the bed. This stratification process, which occurs according to density, follows Archimedes` law, as shown in equation

$$\rho 1 < \rho < \rho 2 \tag{2}$$

where ρ is the density of the fluidized bed (kg/m³), $\rho 1$ and $\rho 2$ the densities of float and sink particles (kg/m³), respectively (Zhenfu and Qingru, 2001).

Several of dry, density–based separators used throughout the twentieth century were developed in the period from 1910 to 1930 (Osborne,1986). The technologies shared the same basic principle mechanisms that are commonly employed in wet cleaning separation such as, dense medium separations, pulsated air jigging, riffled table concentration and air fluidized coal launders (Lochart, 1984; Donnelly, 1999; Sahu et al., 2009). One of the most successful applications of dry cleaning is the FGX separator which was developed by Tangshan Shengzhou Machinery Co., Ltd. in 1996. The separation principle is a combination of vibration and air and is used to develop a fluidized bed on the separator surface which is reflected in the unit's description as a "compound separator". The development of a fluidized bed eventually enhanced the separation process of the unit and the size range that can be treated (Zhenfu, et al., 2002; Kohmuench et al., 2005; Gongmin and Yunsong, 2006; Zhang et al., 2011). The apparatus which was used in tests is called "table type air separator" shares the same principles and similar design with the FGX separator with some innovative changes (Kademli and Gulsoy, 2013). The scheme of apparatus is given as Fig. 1.

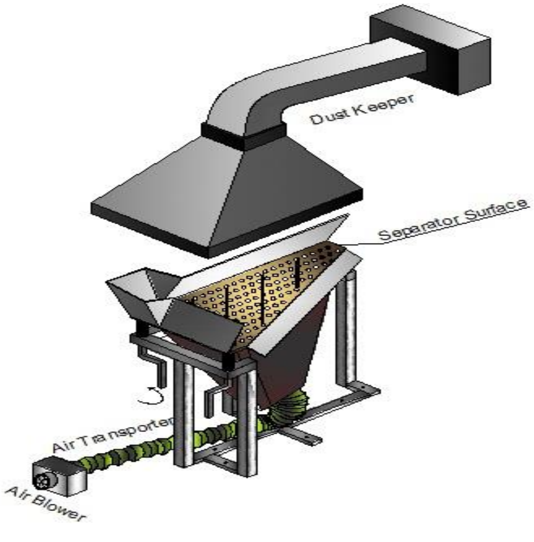

Figure 1. Scheme of apparatus

Materials and methods

The test apparatus have regular openings of 3 mm size on the table surface and air blower to supply stratification of the coal and tailings. The air blower provides air that passed holes on the table surface to fluidize and transport the light coal particles at different rates. The rate of vibration and air blowing were controlled by frequency controllers, and feed rate were controlled by an electromagnetic controller. It also has a vibrator to shake the table surface. The high-density particles (rock) move towards along riffles which direct the particles to the back of table for discharging. The riffles cause the high density particles to move towards discharge side of the table and allow the light ones to rise and to move towards concentrate. The table type air separator was chosen as an example of one simple application of dry separation methods in addition to ease of control and its ability to operate in batch mode.

In the present study, two different coal samples, lignite from Mugla and a hard coal from Zonguldak, were chosen as the test materials to indicate the effect of particle size distribution on dry coal cleaning. The proximity analyses of coal samples are given in Table 1.

Table 1. Proximate analysis of the tests samples

Samples	Original values (MJ/kg)	Dry values (MJ/kg)	Original ash content (%)	Dry ash content (%)	Original volatile material (%)	Dry volatile material (%)	Original moisture (%)
Lignite	6.17	6.82	42.56	45	37.79	40.41	6.7
Hard coal	15.65	15.94	47.32	48.08	20.04	20.36	1.59

The parameters were defined in pre-experiments as riffle height, table slope and table frequency. Besides, feed rate and particle size of feed.

According to the pre-experiments results, they were fixed their best values in accordance with results of chemical analyses. The steps of parameters that were tested in pre-experiments and fixed values are given in Table 2.

Table 2. The apparatus parameters

Name of parameter	Step 1	Step 2	Step 3	Fixed
Table frequency	45 Hz (2700 rpm)	42 Hz (2520 rpm)	39 Hz (2340 rpm)	45 Hz (2700 rpm)
Table slope	0.26 (14.6^0)	0.21 (11.8^0)	0.15 (8.5^0)	0.15
Riffle height	1.5 cm	2 cm	2.5 cm	1.5 cm

Test methodology

The test samples were fed to the surface by using an electromagnetic feeder and two products were collected as clean coal (middling was added in concentrate) and tailing from equipment discharge units. All tests were conducted in a batch mode for each run. For each test, the system was cleaned before using a new feed. The nine favourable experimental conditions were determined according to results of pre-experiments which are shown in Table 3. The products, clean coal and tailings, were ground to 250 μm by milling and were analyzed to find their thermal values and ash content. The influences of parameters on separation efficiency were indicated by using graphs that indicate the relationship between parameters and process recovery and also by using tromp curves to indicate the productivity. E_p and d_{50} values were calculated for different particle sizes of the samples.

Results and discussion

Analyses results of both samples are given as Table 3 and Table 4. The combustible recoveries of concentrate, total amount of removal ash contents and concentrate mass recoveries were calculated by using Eqs 3-5 respectively:

$$\text{combustible recovery} = \frac{Mc \cdot (1-Ac)}{Mf \cdot (1-Af)} 100 \tag{3}$$

$$\text{total amount of removal ash} = \frac{Mt \cdot At}{Mf \cdot Af} 100 \tag{4}$$

$$\text{concentrate mass recovery} = \frac{Mc}{Mf} 100 \tag{5}$$

where Mc is mass of clean coal (kg), Mf is mass of feed (kg), Mt is mass of tailing (kg), Ac is ash content of clean coal (%), Af is ash content of feed (%), At is ash content of tailing (%).

Table 3. Lignite sample test results

Test Number	Particle Size (mm)	Feed (Mg/h)	Concentrate (MJ/kg)	Mass of concentrate (%)	Ash of concentrate (%)	Ash of tailing (%)	Combustion recovery (%)	Removal ash (%)	Tailing (MJ/kg)
1	–38+6	1.32	14.20	55.4	38.04	51.40	62.42	50.94	3.29
2		1.68	14.16	60.5	37.41	52.09	68.85	45.72	2.94
3		2.00	12.63	65.1	38.03	53.14	73.35	41.21	2.61
4	–19+6	1.32	10.11	63.4	41.56	48.56	67.37	39.50	4.14
5		1.68	9.86	67.7	41.95	46.00	71.45	33.02	3.92
6		2.00	9.50	73.9	42.52	51.38	77.23	29.80	3.59
7	–9.5+6	1.32	7.57	71.2	45.56	50.97	70.45	32.62	5.39
8		1.68	7.46	78.7	45.73	51.39	77.66	24.33	6.72
9		2.00	7.35	85.4	45.91	52.02	83.99	16.88	3.93

Table 4. Hard coal sample test results

Test Number	Particle Size (mm)	Feed (Mg/h)	Concentrate (MJ/kg)	Mass of concentrate (%)	Ash of concentrate (%)	Ash of tailing (%)	Combustion recovery (%)	Removal ash (%)	Tailing (MJ/kg)
1	–38+6	1.32	21.07	54.2	33.27	71.92	69.55	68.62	5.48
2		1.68	20.90	59.6	33.97	73.65	75.68	61.99	5.27
3		2.00	20.15	61.5	33.98	74.42	78.08	59.69	4.85
4	–19+6	1.32	17.23	60.1	36.91	75.56	74.06	61.78	5.05
5		1.68	16.61	64.7	37.56	77.32	78.90	55.93	5.39
6		2.00	15.90	66.9	39.42	78.18	79.15	53.02	5.41
7	–9.5+6	1.32	15.09	70.8	40.16	78.87	83.21	47.19	5.50
8		1.68	14.87	76.2	41.63	80.11	89.72	39.07	5.82
9		2.00	14.21	82.9	42.01	82.26	96.72	28.82	6.37

The influences of particle size and feed rate of feed on coal cleaning process were shown in Figs 2 and 3. These figures indicate that increasing the feed rate caused a decrease in thermal values and total amount of removal ash content while mass recovery of concentrate increased. Controversially, increasing the maximum particle size of feed caused an increase in thermal values and total amount of removal ash content while mass recovery of concentrate decreased. Although different thermal values and ash contents were obtained from both coal samples with different efficiencies, the effects of parameters on the separation process were similar in both samples. In these figures, the net thermal values of clean coal were also shown in graphs to emphasize its behavior with the change in parameters.

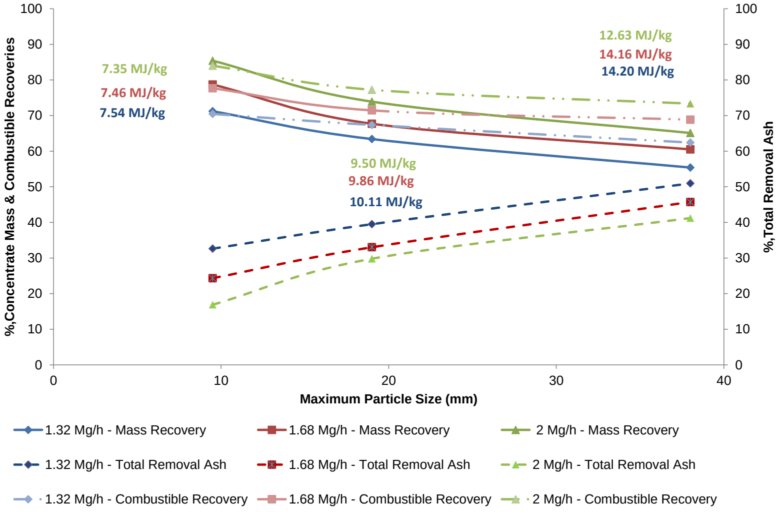

Fig. 2. Relationship between maximum particle size, feed rate and separation process of lignite sample

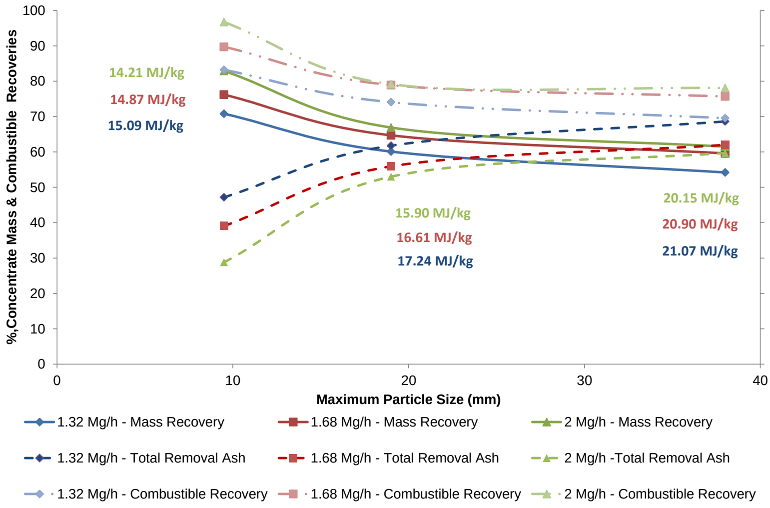

Fig. 3. Relationship between maximum particle size, feed rate and separation process of hard coal sample

Having completed all tests, the sink-float tests were carried out with clean coal and tailings to measure the process efficiency of separation. The E_p values, which are used as a measure of the misplacement of particles in the product streams, and d_{50}, separation densities, are calculated while keeping frequency and table slope at constant values of 45 Hz and 0.15 respectively. These test conditions were chosen according to the results of tests that have low ash content and high thermal values. Also the Tromp curves for different feed rates were used to analyzed the relationship between the feed rate and separation efficiency. The best results were obtained at 1.32 Mg/(h·m^2) feed rates. That is why, the test condition which has 1.32 Mg/(h·m^2) feed rates had divided five particle size fractions for analyzing the relationship between particle size and separation efficiency. The E_p values and d_{50} (cut points) of both samples are given as Table 5. The differences of E_p values of both samples in different feed rates and different particle sizes are shown in Figs. 4 and 5, respectively. The E_p values were calculated by using Eq. 6:

$$E_p = \frac{\boldsymbol{d_{75} - d_{25}}}{\mathbf{2}} \tag{6}$$

where d_{25} and d_{75} are densities of the particles with 25% and 75% of dispersion factor, which is the probability of elutriation. E_p is the misplacement of particles in the product streams.

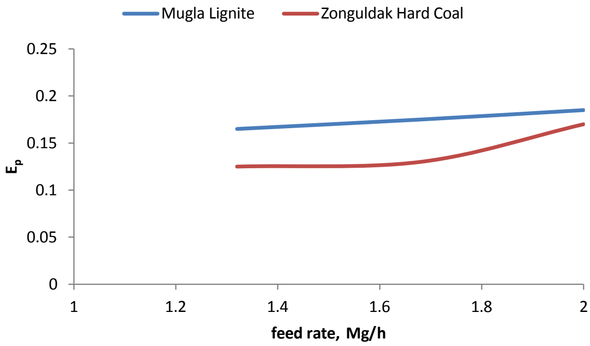

Fig. 4. A relationship between *E*p and feed rate

Table 5. *Ep* and d_{50} values of both samples versus feed rate

Feed Rate (Mg/h-m^2)	Lignite		Hard Coal	
	E_p	d_{50}	E_p	d_{50}
1.32	0.165	1.66	0.125	1.67
1.68	0.175	1.63	0.13	1.64
2.00	0.185	1.64	0.17	1.67

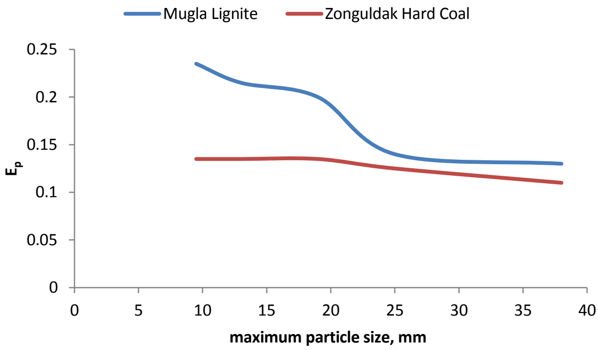

Fig. 5. Relationship with E_p values and maximum particle size

The figures and tables have shown that the particle size of the feed had more influence on separation process than the feed rate. The hard coal sample has lower E_p values than the lignite sample and the separation efficiency of lignite sample was inversely more influenced when the particle size fraction became finer than the hard coal sample. The E_p values and d_{50} (cut points) of both samples are given in Table 6 for each fraction. Also Fig. 5 shows the relationship between E_p values and maximum particle size for both samples. The figures indicated that the d_{50} (cut points) values, obtained in experiments, are similar with the wet coal cleaning methods whereas *E*p values are higher than wet coal cleaning methods which are currently used by industry. These classical wet methods usually have under 0.1 *E*p values. However, other dry coal cleaning methods such as, air jigs have 0.3 *E*p and 2.0 g/cm^3 d_{50} values with the particle size fraction of 50–13 mm and under 13 mm (Weinstein and Snoby, 2007; Snoby et al., 2009). The FGX is a dry coal cleaning system which consists of a deck, vibrator, air chamber and hanging mechanism (Honaker et al., 2008). It is reported that the FGX system has the performance of 0.15 – 0.25 *E*p and 1.78 g/cm^3 – 1.98 g/cm^3 d_{50} values (Gongmin and Yunsong, 2006). The results of specific study on the FGX showed that, for sub-bituminous coal, ash content was reduced from 20.79% to 8.40%. Also the low rank coal was upgraded by pneumatic table concentrator and ash content was reduced from 26% to 7% with a combustible matter recovery of 83% (Ghosh et al., 2014), whereas the table type air separator results showed that ash content was reduced 71.92% to 22.56% for hard coal with a combustible matter recovery of 78.08% while the ash content of lignite sample was reduced from 51.40% to 25.22% with a combustible matter recovery of 73.35%. The feasibility of dry cleaning system results showed that it is not suitable for lignite coal from Husamlar for the fractions of 8–5 mm and 5–3 mm (Cicek, 2008; Xia et al., 2015). Table type air separator shows similar results in the size fraction of 9.5–6 mm. The efficiency is inversely influenced with the particle size of feed in dry coal cleaning. The performance of table type air separator was slightly lower than the classical wet methods while it was higher than other dry coal cleaning methods performances. That is why it may be used in arid areas or as a pre-concentration unit in hard coal separation, especially for coarse grain sizes. All tests were repeated twice, and no meaningful differences in results were evident. So, the arithmetical averages of results are shown in paper.

Table 6. *E*p and d_{50} values of both samples versus particle size fractions

Particle Size Fractions (mm)	Lignite		Hard Coal	
	E_p	d_{50}	E_p	d_{50}
–38 + 25	0.130	1.68	0.110	1.68
–25 + 19	0.140	1.69	0.125	1.65
–19 + 13	0.200	1.69	0.135	1.61
–13 + 9.5	0.215	1.66	0.135	1.72
–9.5 + 6	0.235	1.65	0.135	1.73

Conclusion

All samples used in the experiment were investigated under the same test conditions. In the lignite sample it was observed that the clean coal increased its calorific value from 6.82 MJ/kg, which is the value of the original feed, to 14.20 MJ/kg, while the value for tailing was 3.29 MJ/kg. In the hard coal samples, the values of clean coal increased from 15.94 MJ/kg, which is value of the original feed, to 21.07 MJ/kg, while for tailing it was 5.47 MJ/kg. It was also observed that increasing the feed rate caused a decrease in concentrate values and the total amount of ash removal while the combustible recovery increased. Controversially, the increasing particle size caused an increase in concentrate values and the total amount of removal ash while combustible recovery decreased. Although, other dry coal cleaning systems provide similar results with the table type air separator, E_p values of these methods, which represent the performance of equipment, are higher (0.15, 0.25 and 0.3) than for the table type air separator. It means that table type air separator has higher performance with the lower E_p values like 0.11 for hard coal and 0.13 for lignite. It has slightly lower performance than classical wet methods while it has higher performance than other dry coal cleaning methods.

Consequently, it could be stated that the table type air separator can be used as a dry separator with high separation efficiency and high feeding capacity not only for lignite separation but also for hard coal separation process. Besides, it could use as pre-concentration unit in hard coal separation because of high quality of tailing.

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