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OPTIMUM SEPARATION ROUTE FOR SEMI-BITUMINOUS COAL USING SEMI-PILOT SCALE PNEUMATIC STRATIFICATION JIG

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Abstract: Nowadays, dry beneficiation technologies with an air dense medium fluidized bed come into prominence in the field of coal preparation. In this study, the optimum conditions for different operational parameters such as discharge stargate rate, pulsation frequency, and superficial air velocity were investigated on separation of semi bituminous coal from Soma (Imbat) region using a semi pilot scale Allair jig unit. The experimental studies were carried out with two coal size fractions of -15+4 and -4+1 mm by applying rougher and scavenging stages. After the optimization of each parameter, the results for the rougher stages indicated that clean coal products could be obtained with 11.80% and 16.74% ash contents for -15+4 mm and -4+1 mm size ranges, respectively. In addition, discardable tailings with 65.44% and 60.95 % ash contents could be obtained as the result for the scavenging stages. Finally, the combination of these results for -15+1 mm size exhibited that 59.80% of the feed material with 37.70% ash content can be upgraded to clean coal products with low ash content as 19.80% while the remaining part was discarded as tailings with 68.60% ash content. These values suggested that optimizing the operational parameters of unit brings better results which are applicable in industrial application of dry processes compared to wet processes.

Keywords: *semibituminous coal, dry coal cleaning, Allair jig, optimization*

Introduction

In recent years, the scarcity of fresh water sources alleviated the need for coal producers to develop dry beneficiation techniques considering both technical and economic issues. It is obvious that coal will be an important energy source for many countries for many centuries. However, it is also clear that the enrichment of coal by wet methods results in drying which brings considerable cost and energy requirement.

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There is a great deal of work to make dry beneficiation of coal competitive with conventional wet beneficiation processes. Some technological measures and online data collection systems along with an optimum process design for specific coal types are required to make this competition realistic since physical properties of coal and its associated minerals play a major role on separation efficiency especially for dry processing (Mohanta et al., 2013).

Dry beneficiation techniques for coal processing such as hand picking, optical or X-ray sorting (Feil et al., 2012), crushing + size classification (accelerator) (Honaker, 2007), air jigs (Honaker, 2007; Sampaio et al., 2008; Snoby et al., 2009), air tables (Patil and Parekh, 2011), FGX technologies (Zhang et al., 2011), Akaflow aerodynamic separator (Weitkaemper and Wotruba, 2010; Wotruba et al., 2010; Boylu et al., 2012; Boylu et al., 2013), tribo-electrostatic separator (Soong et al., 2001; Dwari and Rao, 2007; Tao et al., 2011), air-dense medium fluidized bed (Chen and Yang, 2003), electrostatic separation etc., exhibit many advantages over wet processes in terms of economic aspects and environmental concerns.

Among these techniques, air jigs and air-dense medium fluidized bed for pneumatic beneficiation have been commercialized and being applied in many countries. These processes are basically depending on the differences in characteristics of coal and gangue minerals such as density, particle size, and shape factors. Stratification of coal is achieved through fluidizing and pulsating air, vibration, and an oscillating deck in gravity based dry separators.

There are a number of studies which showed successful uses of gravity based dry processing for coal cleaning. These studies indicated that dry beneficiation techniques can be well adapted to coals with different characteristics (Sampaio et al., 2008; Snoby et al., 2009; Patil and Parekh, 2011).

In a recent publication Dong et al. (2015) investigated the effect of feed characteristics on the fluidization of separating fluidized bed for dry coal separation by utilizing medium sized magnetite powder (-300+100 μm) and tracer particles for simulating coals with different densities, steel balls for simulating metal products, and large glass balls for large particles in system. They examined the effect of these components on separation fluidized bed (SFB) and bubbling fluidized bed (BFB) characteristics. They found that following the addition of large glass balls, the dominant frequency varied in different layers of bed between 0.125 Hz (suitable for SFB formation) to 3.25 Hz (not exactly suitable for SFB formation). These values suggested that by introducing large particles (as 50 mm which was simulated with large glass balls) into the system would severely damage the stability of SFB as well as separation.

Zhang et al. (2014) utilized air-dense medium fluidized bed dry separating system for preparing low-ash coal. For this aim, they used fine magnetite powder and fine coal samples in order to make up the separation layer. They obtained the optimum conditions for producing clean coal products from raw coal in -80+6 mm size with 15.8% ash content. In conclusion, they obtained clean coal products with 3.71% ash content while the yield was 67%. Meanwhile, the E_p value was as 0.055. In another study performed with a similar unit, the effect of separation density on the characteristics of the products was discussed in term of ash contents of products. It was found that clean coal with ash content of 18.21% and tailings with 63.81% ash content can be produced at a low separation density of 1.44 g/cm^3 with E_p value of 0.055. However, at high separation density value of 1.76 g/cm^3, the quality of the products increased, and clean coal and tailings with 16.35 and 67.50 % ash content values were produced (Zhenfu et al., 2001).

In addition to coal processing, these dry processing methods are also suitable for beneficiation of different minerals such as sand, ferrous minerals (Weitkaemper and Wotruba, 2010; Wotruba et al., 2010) or coal-like materials such as leonardite (Boylu et al., 2012). In some applications, gravity based dry processing methods were also developed to utilize modified systems with different dense media (Luo et al., 2007; Luo et al., 2008; Fan et al., 2009) such as sand (Kretzschmar, 2010), magnetite (Chen and Yang, 2003), magnetite+fly ash (Fan et al., 2009), magnetic pearl (Zhen-Fu et al., 2007), and paigeite (Zhao et al., 2011) for separation of both inorganics (Snoby et al., 2009), pyrite (Sampaio et al., 2008; Snoby et al., 2009), and Hg (Snoby et al., 2009). It was also reported that for proper use of air table or fluidized bed separators, optimum separation of these impurities requires the optimization of operational parameters such as vibration amplitude, frequency, air volume, superficial air velocity, transverse angle, longitudinal angle, and coal properties such as size and shape factor with careful control (Sahan and Kozanoglu, 1997; Haibin et al., 2011).

Haibin et al. (2011) examined the separation performance of 0-25 mm size South African coal while considering the effect of different parameters as vibration frequency, air volume, transverse, and longitudinal angle. Their results indicated that the optimum conditions can be listed as 3 mm of amplitude with a motor frequency, an air volume of 50%, and transverse and longitudinal angles of 7º and -2º, respectively. With the light of these findings, in this study, we investigated the effect of other operational parameters such as discharge stargate rate, pulsation frequency, and superficial air velocity for producing a clean coal concentrate and tailings.

Experimental

Material and methods

Coal sample

Semi bituminous coal from Soma (Imbat) Region, Turkey was used in the tests. According to the proximate analyses the run-of-mine (ROM) sample contains 43.00% ash, 42% volatile matter, and 10.04 MJ/kg calorific value on moisture free base. Several tests were conducted to determine the optimal feed size before optimizing the moisture effect for an effective separation. The coal samples were initially crushed to -15 mm, and classified as -15 mm, -15+4 mm, -15+1 mm, -4 mm, and -4+1 mm. Allair jig was utilized for each fraction in two stages. During these tests, all the separation conditions were optimized manually by randomly checking the product quality and followed by fine tuning before collecting the products. The separation performance at each size fractions indicated that the coal sample should be classified into two fractions that are -15+4 mm and -4+1 mm for the optimal separation. While the separation efficiency of -15 mm fraction was 35.6%, the split fractions of -15+1 mm and -15+4 mm exhibited much higher efficiencies of 40.8% and 49.6 %, respectively. Furthermore, the ash contents of the clean products were reduced down to 17.21% from 29.69% by applying the cut size at 4 mm. On the other hand, the ash content of the clean products on these split fractions of -15+1 mm was reduced down to 16.83% from 23.36%. It was also noticed that the presence of -1 mm in the size distribution of coals significantly deteriorates the separation (Boylu et al., 2015). Therefore, the ROM coal sample was crushed into -15 mm which was also the maximum size for semi pilot scale Allair stratification jig. Based on our experience on effective dry coal processing through Allair jig, the screening was performed to classify the -15 mm coal sample to the size fractions of -15+4 mm and -4+1 mm.

Air jigging

The dry beneficiation of the coals was performed using semi pilot scale Allair Jig (Allmineral, Germany) which runs at a maximum capacity of 650 kg/h (Fig. 1). The Allair jig unit consists of feeding (Mohanta et al., 2013; Feil et al., 2012), separation (jigging) (Sampaio et al., 2008), and powder filtering units (Boylu et al., 2012) as shown in Fig. 1. In this study, discharge stargate rate, pulsation frequency, and fluidizing air rate (superficial air velocity) were the main parameters investigated. All stratification tests were performed at the fixed bed and discharging heights (in jigging cell) of 11 cm and 8.5 cm, respectively.

Fig. 1. Lab scale Allair stratification jig facility (1-feed chute, 2-belt conveyor, 3-feed chute, 4-jigging cell, 5-pulsed air production and distribution mechanism, 6-fluidized air tank, 7-dense particle discharge channel, 8-ligth particles discharge, 9-ventilation pipe, 10-filter unit)

Optimization studies were performed at two separate size fractions involving two separation stages of rougher and scavenging. The flow sheet on the optimization studies is presented in Fig. 2. The fixed and tested parameters and accompanying capacities and retention times (RT) of the -15+4 mm size fraction in jigging cell are illustrated in Table 1.

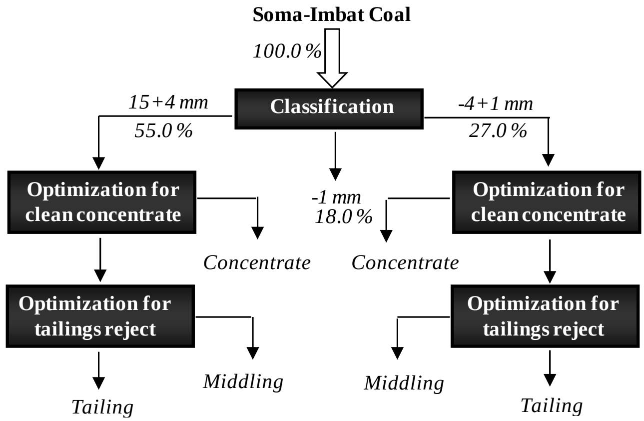

Fig. 2. Flow sheet showing percent material flow and mode of optimization studies

Table 1. The operational conditions of rougher stage separation of -15+4 mm size fraction and accompanying retention times and capacities

FSR (rpm)	DSR (rpm)	PF (s^{-1})	SAV (cm/s)	RT (min)	Capacity (kg/h)
10	14.0	3.2	1083	4.13	152.40
15	21.0	3.2	1083	2.95	213.64
20	28.0	3.2	1083	2.27	277.71
25	34.9	3.2	1083	1.89	332.82
30	44.8	3.2	1083	1.59	396.86
35	64.8	3.2	1083	1.50	420.46
20	28.0	2.8	1083	1.56	404.80
20	28.0	3.0	1083	1.78	354.38
20	28.0	3.3	1083	2.22	283.20
20	28.0	3.5	1083	2.26	278.40
20	28.0	3.7	1083	2.28	276.60
20	28.0	3.8	1083	2.23	282.77
20	28.0	3.2	1083	2.23	282.00
20	28.0	3.3	1035	2.72	231.75
20	28.0	3.3	1083	2.34	269.40
20	28.0	3.3	1131	2.33	270.90
20	28.0	3.3	1179	2.35	267.90
20	28.0	3.3	1228	2.39	264.00
20	28.0	3.3	1276	2.28	276.32

FSR: feed stargate rate, DSR: discharge stargate rate,
PF: pulsation frequency, SAV: superficial air velocity, RT: retention time

Float and sink tests

The characterization of the feed material in both size ranges (-15+4 mm and -4+1 mm) was utilized with float-sink tests. $ZnCl_2$ solutions were prepared at different densities ranging between 1.3-1.9 g/cm^3. The results were evaluated based on the degree of ash removal, combustible recovery, and separation efficiencies as calculated using Eqs. 1, 2, and 3:

$$R_{comb.}(\%) = \frac{C(100-c)}{F(100-f)} \tag{1}$$

$$R_{ash}(\%) = \frac{T\,t}{F\,f} \tag{2}$$

$$Eff_{sep.} = R_{comb.} - (100 - R_{ash}) \tag{3}$$

where R_{comb}, R_{ash}, and Eff_{sep}. are the combustible recovery, ash removal, and separation efficiency, respectively. *C*, *T*, and *F* represent the yields, and *c*, *t*, and *f* stand for the ash contents of concentrate, tailing, and feed, respectively.

Results and discussion

Effect of discharge stargate rate

The effect of discharge stargate rate values on the separation efficiency and the ash contents of the products were evaluated for the rougher and the scavenging stages. The results of these tests are shown in Figs. 3a-c. It can be clearly seen from Fig. 3a that no direct relationship was observed between the separation efficiency and the discharge stargate rate for the separation of -15+4 mm size coal to obtain a clean coal product. Nevertheless, a maximum value of 42.2% of separation efficiency was achieved at 20 rpm discharge stargate rate. In addition, any increase on this value resulted in the mixing of concentrate to the tailings stream which was formed after stratification of material inside the jig. Especially at 35 rpm, the separation efficiency decreased to a level of 22.8%. Similar behavior was also obtained for the beneficiation of -4+1 mm size coal samples where over 10 rpm discharge stargate rate, the separation efficiency decreased down to 20.4% from the peak value of 32.7%. Meanwhile, the reason for obtaining optimum separation at lower discharge stargate rates for -4+1 mm size fraction can be attributed to the lower amount of ash forming materials which in turn resulted in a thinner shale (dense ash forming particles) layer. In addition, the speed of shale particles was observed to be relatively higher in the fine fractions, and therefore lower discharge stargate rates were found sufficient for the -4+1 mm size fraction.

The effect of the discharge stargate rate on the ash contents of concentrate, middlings, and tailings are presented in Figs. 3b-c. The results revealed no significant changes in the rougher stage for the effect of discharge stargate rate on the ash contents of concentrates. Contrary to this, the ash contents of tailings yielded distinct changes. Thus, considering different size fractions of -15+4 mm and -4+1 mm, the ash contents of concentrates were found to be varied in the range of 8.47%-12.49% and 17.45%-18.45%, respectively. However, at the optimum discharge stargate rates of 10 and 20 rpm per each fraction, the ash contents of tailings were found as 55.74% and 50.28%, respectively. It is interesting to note that these values decreased to 48.99% and 42.00% at lower discharge stargate rates, respectively.

The effect of discharge stargate rate on the separation efficiency in a series of tests for the -15+4 mm size fraction yielded no significant effect during the scavenging stages (for discharging tailings). Interestingly, under the same conditions, the experiments adopted for -4+1 mm size fraction gave high separation efficiencies at 10 rpm for both rougher (for obtaining clean coal) and scavenging stages. Evidently, the separation efficiency decreased from 28.09% to 8.7% with increasing this value to 50 rpm.

Similar dependencies for -15+4 mm size fraction for the ash contents of tailings at the scavenging stages varied in the range of 63.92%-65.46 %. On the other hand, the tests adopted for -4+1 mm sized coals resulted in 62.45% ash content with the application of optimum discharge stargate rate at 10 rpm. However, increasing this value to 50 rpm resulted in much lower ash contents of 55.00% which also gave the same trend with the concentrates.

In addition, while the ash contents of concentrate (middlings) revealed no significant effect for -15+4 mm size coals (30-35%), -4+1 mm sized coals produced a significant effect above 40 rpm because the ash content increased from 33.52% to 45.19%.

Similar studies were also reported considering the discharge stargate rate which directly controls the distribution of feed material across the bed. Weinstein and Snoby (2007) studied the effect of varying speeds of stargate rate for enrichment of bituminous coal (-4+1 mm) and obtained a clean coal product with 6.86% ash content by enriching the coal feed to 14.81% ash at a constant speed of stargate rate.

Effect of pulsation frequency

The effect of the pulsation frequency on the separation efficiency of dry process and the ash contents of concentrate and tailings are illustrated in Figs. 4a-c. As it can be seen from Fig. 4a that the optimal pulsation frequency at rougher stages was found as 3.17 s^{-1} for the separation of coal at -15+4 mm but interestingly no effective separation was found at scavenging stages and finer size fractions of -4+1 mm. Therefore, at that pulsation frequency value, these results can be explained by the coal characteristics because the samples taken from Soma-Imbat region exhibit an easy to wash character and consists of material at near gravity values. It should also be noted that the pulsation frequency varies upon the type of coal and its size distribution in feed for separation. These findings are also supported by Feil et al. (2012) who used -16+6.3

mm and -6.3+2 mm size fractions, and correlated the jig bed height with the pulsation frequency. They found that the increasing the pulsation frequency from 80 min^{-1} to 88 min^{-1} resulted in better performance when the jig bed level was ≤125 mm. Meanwhile, they also showed that this value depends on the mineral matter in the ROM coal, and can be lowered to 100 mm if there are significant amounts of mineral matter in the ROM. On the other hand, there is a critical pulsation frequency for samples exhibiting difficult to wash character and consisting of high amounts of near gravity material. Wotruba et al. (2010) reported similar dependencies, and suggested a critical pulsation frequency for coals of low washability index.

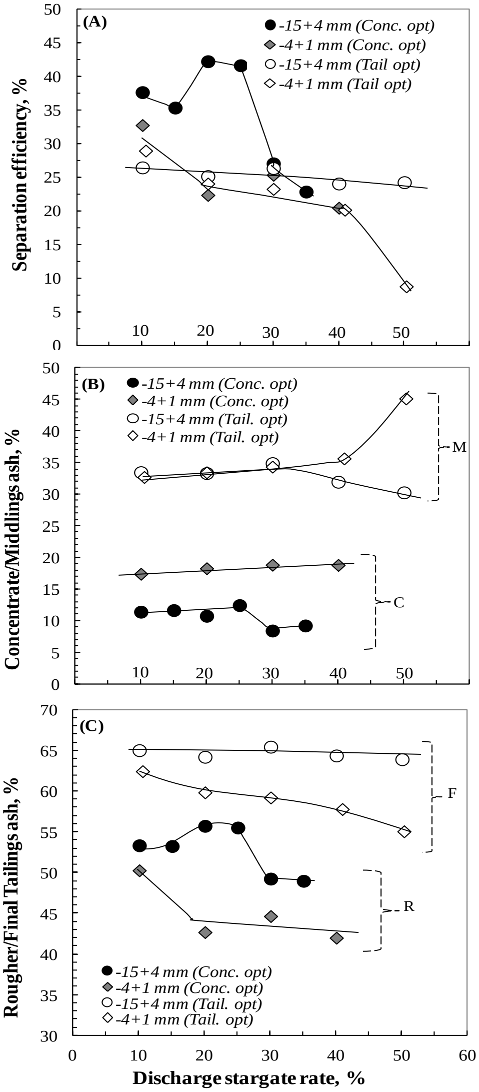

Fig. 3. Effect ofdischarge stargate rate on separation (M: middlings, C: concentrates, R: rougher tailings, F: final tailings)

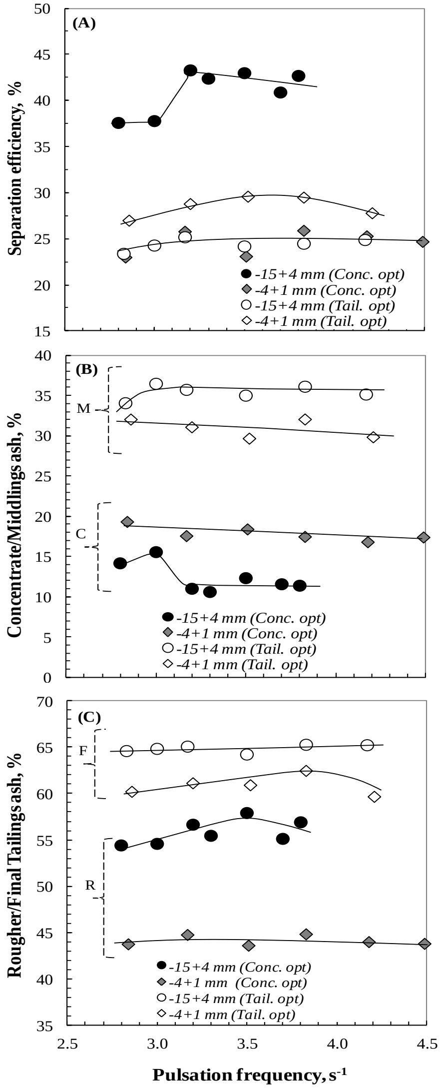

Fig. 4. Effect of pulsation frequency on separation (M: middlings, C: concentrates, R: rougher tailings, F: final tailings)

Similar results are shown in Figs. 4b-c considering the variations of the ash contents for concentrate and tailings. As mentioned before, the experimental studies at -15+4 mm size, upon increasing the pulsation frequency to 3.17 s^{-1} at the rougher stages, the ash content of concentrate decreased from 15.60% to 11.00%. However, no significant change was observed in the scavenging stages for -4+1 mm size. In summary, the tailings with highest ash content of 57.95% from the rougher stages were obtained at 3.5 s^{-1} of the pulsation frequency.

Effect of superficial air velocity

The effect of superficial air velocity on the separation efficiency and ash contents of concentrate and tailings are presented in Figs. 5a-c. Significant differences were found for optimum superficial air velocities for separation/stratification of ROM coal and tailings at both rougher and scavenging stages. Thus, it was found that while the optimum superficial air velocity was found to be >1080 cm/s at the rougher stages for the separation of -15+4 mm size fractions, it increased to >1200 cm/s at the scavenging stages. These results can be attributed to the ratio of density of feed material to the tailings (ROM/tailings) or the bulk density of stratified material. Similar results were also obtained for the tests carried out with coal samples of -4+1 mm size fraction that the optimal separation was obtained at 950 cm/s at the rougher stages where it was proportionally increased to 1030 cm/s at the scavenging stages.

Considering the specifications of the products at -15+4 mm size fraction, a concentrate with 11.00% ash content was obtained in the rougher stage whereas the tailings product with 56.90% ash content was discarded. Re-processing of the tailings taken from the rougher stage, a concentrate (middlings) assaying 33.01% ash content with the final tailings of 63.64% ash could be obtained at 1220 cm/s of the superficial air velocity (Figs. 5b-c).

Likewise, the separation tests on -4+1 mm size fraction yielded a clean coal concentrate with 16.70% ash and tailings with 46.40% ash in the rougher stage. Additionally, by re-processing of tailings taken from the rougher stage, a concentrate (middlings) and final tailings were obtained with the ash contents of 29.67% and 60.65%, respectively at 950 cm/s of the superficial air velocity (Fig. 5c).

Consequently, it can be suggested that there is an optimum superficial air velocity for each size fraction to achieve the critical onset of segregation. In this manner, the excess air produces bubbles that divide the bed into particulate and bubble phases. Thus, in the case of smaller bubble sizes, the space becomes unsufficient for particle setting in the disturbed region below the rising bubbles. Meanwhile, in the case of bigger bubble sizes, the bubble rise velocity becomes faster for providing enough time for particle setting in the disturbed region (Yang et al., 2013). He et al. (2013) investigated the separation performance of South African raw coal by dense gas-solid fluidized bed beneficiation technique. They found that depending on the increase on superficial gas velocity (0-25 cm/s), the bed pressure drop fell slowly to the stable point. Therefore, this situation indirectly gave an idea about the rising bubbles with a well distributed size fraction to display steady conditions on the kinetic behavior of fluidization which then resulted in better density based coal beneficiation.

Similar results were obtained by Yang et al. (2013) in a vibrated gas-fluidized bed for superficial air velocity. They studied the effects of some process parameters such as vibration intensity, bed height, fluidizing time, and superficial air velocity on dry coal beneficiation. They concluded that the peak value of superficial air velocity shifted from 0.2 to 0.15 for feed size range of −6+3 mm and −3+1 mm, respectively.

Das et al. (2010) studied the hydrodynamic characteristics of dry beneficiation of iron and coal while considering the gas velocity and solids circulation rate with ash contents of the products. They used a mixture of coal samples with 43.00% ash content. In these studies, they performed separation processes by performing gas velocities of 3.55 m/s and 4.02 m/s, solids concentration rates of 9.7-11.3 kg/m^{2}s, and 6.87-10.11 kg/m^{2}s. As a result, they obtained clean coal products with low percentage 7-8% to the feed material. From that point of view, they suggested that increasing the gas velocity resulted in more mixing and less segregation of macerals depending on similarities in densities which in turn less beneficiation of coal.

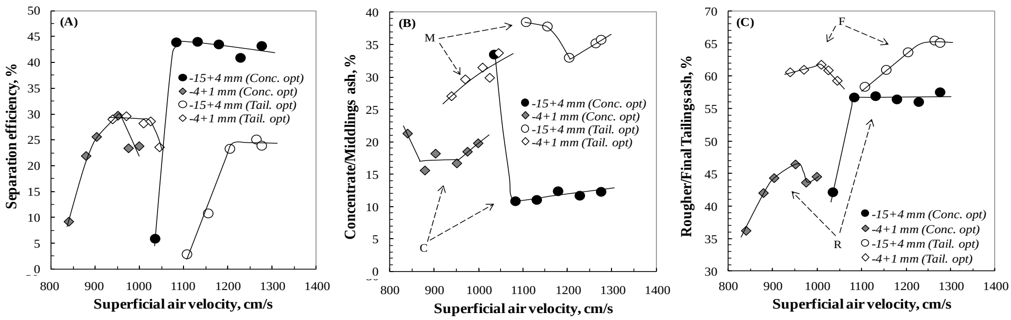

Fig. 5. Effect of superficial air velocity on separation
(M: middlings, C: concentrates, R: rougher tailings, F: final tailings)

Summary of results

Optimization of the rougher and the scavenging stages for the dry beneficiation of the Soma Imbat coal samples at two size fractions yielded the optimal conditions presented in Table 2. Additionally, the results of two-stages dry separation tests carried out at the optimum conditions are summarized in Tables 3, 4, and 5.

According to the results given in Table 3, approximately 36.9% of the feed material can be obtained as concentrate assaying 11.80% ash (25.56 MJ/kg) and 54.4% combustible recovery by performing one rougher stage for dry beneficiation of coal at -15+4 mm. In addition, the results of second stage (rougher) for the same size group showed that about 18.1% of the feed material can be obtained as middlings assaying 35.23% ash (15.8 MJ/kg) and about 45.0% of the feed can be discarded as tailings with 65.44% ash (3.22 MJ/kg) at 73.3% ash removal rate.

Table 2. Optimal conditions for each size fraction and processing stages

Parameters	-15+4 mm		-4+1 mm	
	Rougher	Scavenging	Rougher	Scavenging
DSR (rpm)	20.0	30.0	10.0-10.2	10.2-10.5
FSR	28.0	52.0	8.4-8.5	12.0-13.3
Puls. Freq. (s^{-1})	>3.17 (3.33)	3.50	4.18	3.52
SAV (cm/s)	>1083 (1131)	>1204 (1264)	951	970

DSR: discharge stargate rate (rpm), FSR: feed stargate rate (rpm), SAV: superficial air velocity

Table 3. Summary of separation results for rougher and scavenging stages

	Products	Weight (%)	Ash (%)	Comb. Rec. (%)	Ash Rem. (%)
-15+4	*Concentrate*	36.9	11.80	54.4	10.8
	Middling	18.1	35.23	19.6	15.9
	Tailing	45.0	65.44	26.0	73.3
	Feed	100.0	40.18	100.0	100.0
-4+1	*Concentrate*	50.7	16.74	62.6	26.0
	Middling	19.0	29.67	19.8	17.3
	Tailing	30.3	60.95	17.6	56.7
	Feed	100.0	32.59	100.0	100.0

For upgrading of the samples at -4+1 mm size range, following a dry beneficiation process in two-stages, 50.7% of the feed material was obtained as concentrate assaying 16.74% ash (23.50 MJ/kg) and 62.6% combustible recovery in the rougher stage. Meanwhile, 19.0% of the feed material of this stage was obtained as middlings with 29.67% ash (18.12 MJ/kg). In addition, 30.3% of the feed material was discarded as tailings with 60.95% ash (5.09 MJ/kg) and 56.7% ash reduction ratio.

If the middlings of the dry beneficiation processes performed for each size group were added to the concentrate at -15+4 mm size, 55% of the feed material was obtained as concentrate with 19.51% ash (22.36 MJ/kg) and 74% combustible recovery while the amount, ash content, and combustible recovery of concentrate at -4+1 mm size were 69.7% of feed material, 20.27% (22.03 MJ/kg), and 82.4 %, respectively (Table 4).

Consequently, if a wide range of -15+1 mm (in the case of combination of fractions) was considered, 59.8% of the feed material having 19.80% ash (22.23 MJ/kg) and 77% combustible recovery was obtained as concentrate while 40.2% of the feed material was discarded as tailings with 64.32% ash (3.69 MJ/kg) and 68.6% ash reduction ratio.

A comparison between theoretical and experimental results (Fig. 6) carried out at two different sizes considering the amount and the ash contents of concentrate and tailings are shown in Table 5.

Table 4. Summary of separation combined results for rougher and scavenging stages

Size Fraction (mm)	Products	Weight (%)	Weight * (%)	Ash (%)	Comb. Rec. (%)	Ash Rem. (%)	Separation Efficiency (%)
-15+4	Concentrate	55.0	36.9	19.51	74.0	26.7	47.3
	Tailing	45.0	30.2	65.44	26.0	73.3	
	Feed	100.0	67.1	40.18	100.0	100.0	
-4+1	Concentrate	69.7	22.9	20.27	82.4	43.3	39.1
	Tailing	30.3	10.0	60.95	17.6	56.7	
	Feed	100.0	32.9	32.59	100.0	100.0	

*Based on the feed

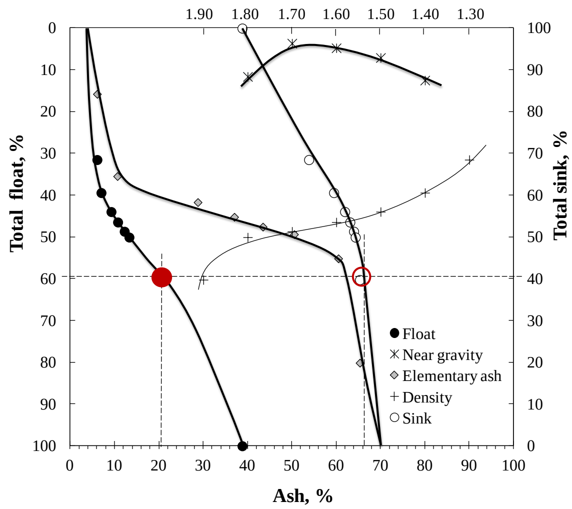

Fig. 6. Washability characteristics of the tested coal and product properties after optimized separation (red filled and circled for concentrate and tailings respectively)

Table 5. Summary of combined separation results for rougher and scavenging stages at -15+1 mm

Products	Weight (%)	Ash (%)	Comb. Rec. (%)	Ash Rem. (%)	Separation Efficiency (%)
Concentrate	59.8	19.80	77.0	31.4	45.6
Tailing	40.2	64.32	23.0	68.6	
Feed	100.0	37.70	100.0	100.0	

It was clearly shown that ideal values indicated in the washability tests can be obtained by detailed optimization of parameters. This can possibly be attributed to the easy washability feature of coal. Although the performance curves for the products obtained at the optimum conditions have not been drawn, it is clear that the separation density was about 1.9 g/cm^3 which well correlates with the concept of dry beneficiation processes.

Conclusion

Dry beneficiation process has many advantageous in terms of economic and environmental aspects. However, as revealed in this paper, there are some limitations that should be taken into account related to coal properties and process parameters. Although the tested coal sample was easily washable, at least two-stage beneficiation is required for obtaining clean coal products and tailings at an adequate quality with dry beneficiation processes. In addition, especially for that type of coals, it is important to perform beneficiation tests in two relatively narrow size ranges as -15+4 mm and -4+1 mm instead of applying one stage with a wide size range as -15+1 mm. Since the results of these tests showed that optimum discharge speed, frequency of pulsation, and fluidized air speed obtained for different sizes showed different characteristics. Even in the same size group, differences were observed for optimum values at the rougher and the scavenging stages. Finally, the processing of Soma Imbat coal on pneumatic Allair jig was found to yield products in high quality and proportional to the theoretical expectations.

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