



RESEARCH ARTICLE

Density cleaning for some Turkish lignites

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ABSTRACT

In the scope of this study, in order to determine the floatability characteristics of lignites, 5 samples were collected from various lignite reserves of Turkey namely Dursunbey, Çayırhan, Iğın, Ermenek, and Gürmin-Merzifon. Collected samples were analyzed in terms of float and sink analysis. As regards to float and sink analysis, the original samples were floated and sunk in 2 different $ZnCl_2$ solutions of densities 1.40 and 1.60 g cm^{-3} . Proximate analysis of each original sample for the corresponding lignite was carried out in the beginning of this study. In terms of proximate analysis performed, Dursunbey lignite sample has the lowest ash content of 24.86 % while Gürmin Merzifon lignite sample has the highest ash content of 45.02 %, respectively. Accordingly, 5 float and sink analysis graphic obtained and they would help one to understand and easily figure out the optimum medium density for cleaning.

Keywords: Turkish lignites, coal washability, float and sink, density cleaning, coal preparation

1. INTRODUCTION

Washability test for coals is carried out with float and sink analysis and the data obtained is used to understand which separation medium is optimum for coal cleaning. Coal preparation plants are cleaning the run of mine coals with density medium. More clearly, a solution with magnetites (due to its easy recyclability) is prepared and coal samples are faced with that specific solution. Some amount of coal and lower density materials are floating over the solution while other shales and high density materials are tend to sink. Although this method is environmentally disadvantageous and economically not feasible, it has been widely used in coal preparation plants in the world. Recent technologies are focusing on dry separation of coal and shale, but still this traditional method of cleaning is better in terms of efficiency and capacity.

Lignite reserves are widely present in Turkey and they constitute the major portion. In the study of Çakal et al [1], chemical and physical properties of some lignites were investigated. Çakal et al. [1] have studied 4 different lignite coal samples and they determined the ash contents between 18.6 % and 37.5 %. Sulfur content of lignites are also important in

terms of their utilization as fuel to power plants. Referring back to Çakal et al. [1] study, sulfur contents of the studied samples varies between 1.4 % and 4.4 %. As in the study of İnaner and Nakoman [2], Çan lignites were studied and their ash and sulfur content was determined as 29.67 % and 3% (as received basis) respectively. Same authors have provided a figure of hard coal and lignite deposits of Turkey and it is provided in Fig 1.

The tabulated regional reserve distribution and average chemical properties of Turkish lignites are provided in Table 1 (Adopted from the study of İnaner and Nakoman [3]).

Referring to the Table 1, Turkish lignites have the average of 21% ash content and 2.1% sulfur content, respectively. Moisture content is also high and it is between 20% and 50%. Turkish lignites are mostly utilized as fuel to power plants. There are mostly power plants located nearby these deposits. However referring back to the Table 1, lignites have lower calorific values than steam coals. The boilers of the power plants are designed with respect to coals with specific calorific value. In order to have the designed calorific specification, there should be coal preparation plants. These coal preparation plants utilize the run of mine coal and products are clean

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coals with higher calorific values and lower ash and sulfur content. Depending on the nature of the coals, density cleaning is sometimes hard. In this context, washability of the coal should have been investigated beforehand in order to have optimum usage of chemicals and optimum product properties. Ozbas et

al. [4] have investigated the effect of cleaning process on combustion characteristics of lignites in their study and they have summarized this fact: "reducing the ash and sulfur content by washing has become a compulsory process to obtain an environmentally friendly product".

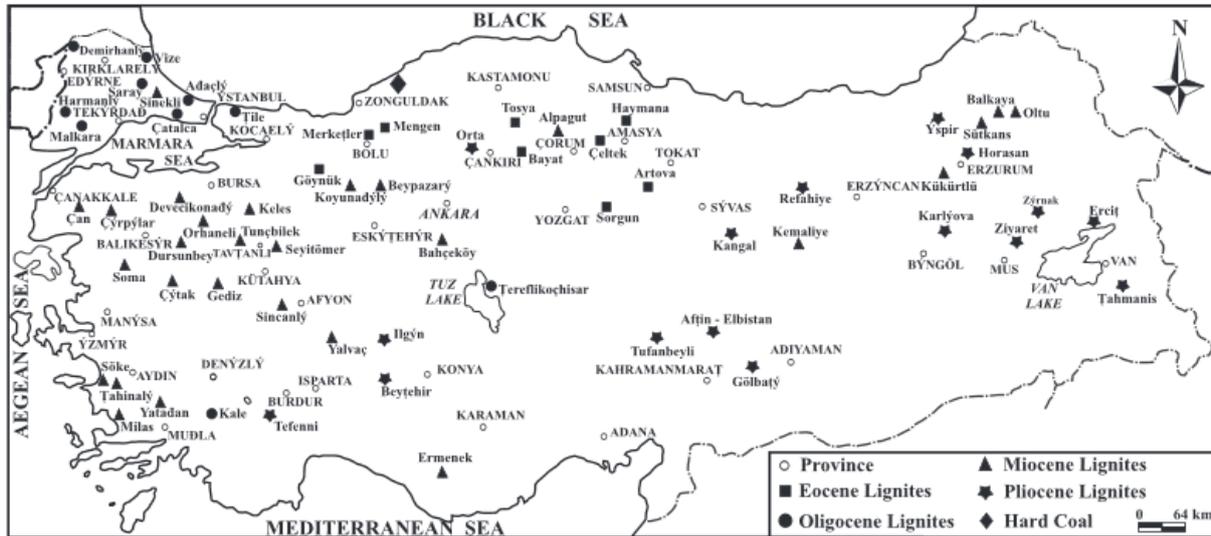


Fig 1. Hardcoal and lignite deposits of Turkey [3]

Table 1. Regional reserve distributions and average chemical properties of Turkish lignites [3]

REGIONS	AGE	RESERVE (109 tonnes)	MOISTURE (%)	S (%)	ASH (%)	CALORIFI C VALUE (kcal kg ⁻¹)
NORTH -WEST ANATOLIA REGION (Kütahya-Balıkesir- Bursa-Manisa-Çanakkale)	Miocene	2	20	1.7	20	3500
SOUTH - MIDDLE - ANATOLIA REGION (Adana- Kahramanmaraş)	Pliocene	4	50	2.0	20	1200
CENTER ANATOLIA REGION (Ankara-Çorum) (Konya-Çankırı- Sivas)(Yozgat)	Miocene Pliocene Eocene	1.45	30	3.2	25	3000
SOUTH WEST ANATOLIA REGION (Aydın-Muğla- Denizli-Isparta-Afyon) (Burdur)	Miocene Pliocene	0.9	30	2.0	20	2500
THRACE REGION (Tekirdağ-Edirne- Kırklareli-Istanbul)	Oli- gocene	0.4	30	3.0	20	2500
EAST ANATOLIA REGION (Bingöl-Erzincan-Van) (Erzurum)	Pliocene Miocene	0.2	20	1.2	20	3000
TOTAL		8.25	36.5	2.1	21	2240

Sivrikaya [5] has studied a low rank lignite and the author has applied dense medium, gravity-based and floatation techniques to evaluate the its cleaning potential. Aktas et al. [6] have studied centrifugal float and sink separation of fine Turkish coals in dense media and they have summarized the dependency of the float fraction grade on the “dense medium density”, “degree of liberation” and the “amount of submicron particles” in the coal samples. However either float and sink characterization of coal samples or the floatability in general depends strongly on the hydrophobicity of the coal samples and as stated by Sivrikaya [5] hydrophobicity changes with rank, petrographic composition and degree of oxidation [7, 8-11]. High ash content along with low carbon content, high content of polar groups (hydroxyl, carboxyl, carbonyl) are considered as the main reasons for the low floatability and hydrophilic nature of lignites [5, 11- 13].

Washability characteristics of coals are tested with float & sink tests. Based on the float and sink test results of a specific coal, extent of the washing conditions are determined [14, 15]. In addition to washability tests, Atesok et al. [16] have employed Reichert spiral to understand the cleaning characteristics of bituminous and lignitic coals. According to Aksoy et al. [17], in terms of lignite fines cleaning, physical processing methods are widely employed since they have lower costs and easier to employ. In order to employ the physical methods, corresponding requirements of each physical separation agent should be understood and this can be realized with washability characterization. However, there are some obstacle for physical separation and the major limiting factor for gravity separation is regarded as its dependency on particle size of coal [17]. So, determination of washability characteristics of lignites and understanding the physical separation requirements beforehand should include the consideration of particle size. Although fine coal cleaning is off great importance by many researchers [18-23], still the washability characterization of lignites has significance in terms of ash and sulfur reduction which are crucial in terms of the processes of further utilization. In addition to the abovementioned, Hacifazlioglu and Toroglu [24] have investigated the optimum design and operating parameters of slime coal cleaning in a pilot scale Jameson cell. Coal cleaning in terms of environmental and economical point of view has great significance. Assessment of cleaning requirements & conditions along with any possible improvements could only be understood with washability characteristics.

In this study washability characteristics of 5 different lignite samples was investigated and this was carried out with the help of float and sink analysis tests. In this context, results are not only tabulated but also corresponding graphical demonstrations of float and sink curves were provided. Based on the tabulated data and considering the corresponding plots of float and sink experiments, density requirement of the cleaning process could be estimated. Not only density of the medium of separation could be understood but also the corresponding ash content of the product at the end of cleaning/washing would be clear with the help of this study.

2. MATERIALS AND METHOD

Coal washability properties are determined by the evaluation of the float and sink test results. Float and sink analysis is carried out on a solution (at a density previously determined) and coal particles either float over or sink in this solution. More clearly, when a coal sample faced with high density medium, particles with lower density tends to float while particles with higher density tends to sink.

Float and sink analysis on the studied samples was carried out with the 1.40 and 1.60 g cm⁻³ solutions. These abovementioned solutions were prepared with ZnCl₂.

3. RESULTS & DISCUSSION

Ash content of run of mine coal samples and their density cleaned fractions were tabulated in Table 2. The most significant decrease in ash content is observed for Gürmin-Merzifon lignite sample while the lowest decrease is observed on İlgin sample.

Table 2. Ash content of run of mine coals and 1.60 gr cm⁻³ cleaned coals

Sample	Ash Content (%) (as received)	Ash Content (%) (cleaned with 1.60 gr cm ⁻³ medium)
Dursunbey	24.05	16.49
Çayırhan	26.29	17.06
İlgin	28.52	26.38
Ermenek	23.50	17.55
Gürmin-Merzifon	45.34	23.33

In this study, sieve analysis was carried out for the samples investigated. In order to evaluate the size orientation, samples are only crushed with primary crusher (jaw crusher). In this case, a quick understanding of the float and sink tendency of the samples was addressed and size dependency of washability characteristics was not considered in detail. Tabulated float and sink analysis results (Table 3-7) and float and sink analysis graphs (Fig 2-6) are provided.

Considering float and sink graph (Fig 2) and tabulated data of float and sink experiment (Table 3) for Dursunbey lignite sample, run of mine coal has 24.05% ash content. Fraction of 34.51% for this original sample (Dursunbey lignite) floats at 1.40 g cm⁻³ medium and ash content of this corresponding float is 7.96 %. Original sample has the weight percentage of 38.46 (%) which has the density of +1.40-1.60 gr cm⁻³, and ash content of this abovementioned fraction (middling) is 24.14 %. If Dursunbey lignite (run of mine) is floated at 1.60 g cm⁻³ density solution, 72.97% of it would be collected as float fraction and it would have 16.49 % ash content.

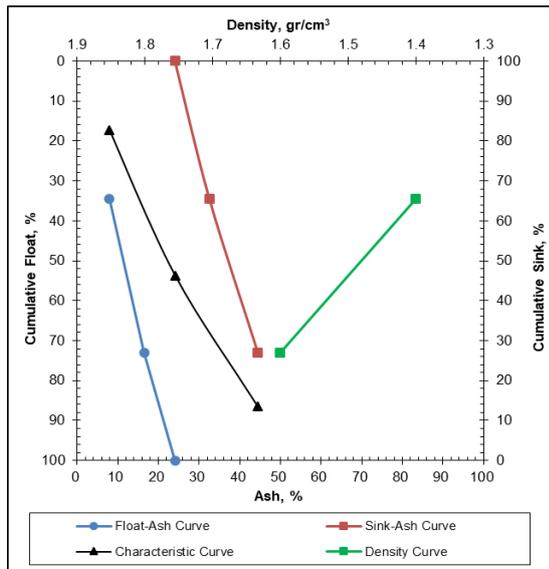


Fig 2. Float and sink graph for Dursunbey lignite sample

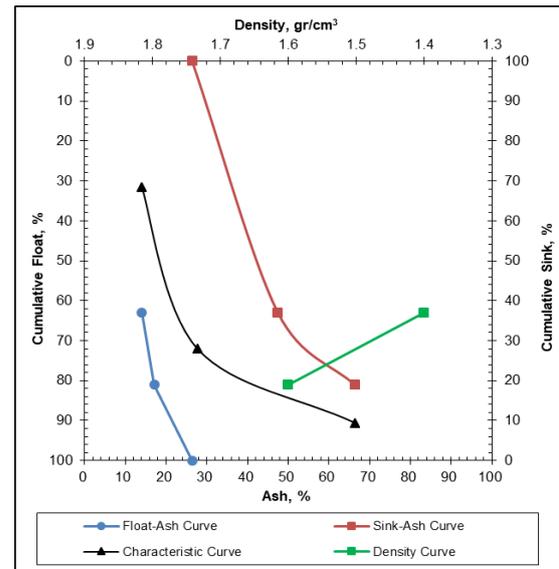


Fig 3. Float and sink graph for Çayırhan lignite sample

Table 3. Float and sink analysis results for Dursunbey lignite sample

Density gr cm ⁻³	Float		Cumulative Float			Cumulative Sink			
	%Amount	%Ash	Content	%Amount	Content	%Ash	%Amount	Content	%Ash
-1.40	34.51	7.96	274.70	34.51	274.70	7.96	100.00	2404.61	24.05
+1.40 - 1.60	38.46	24.14	928.42	72.97	1203.12	16.49	65.49	2129.91	32.52
+1.60	27.03	44.45	1201.48	100.00	2404.61	24.05	27.03	1201.48	44.45
Total	100.00	24.05	2404.61						

Table 4. Float and sink analysis results for Çayırhan lignite sample

Density gr cm ⁻³	Float		Cumulative Float			Cumulative Sink			
	%Amount	%Ash	Content	%Amount	Content	%Ash	%Amount	Content	%Ash
-1.40	62.98	14.02	882.98	62.98	882.98	14.02	99.77	2628.69	26.35
+1.40 - 1.60	17.97	27.71	497.95	80.95	1380.93	17.06	36.79	1745.71	47.45
+1.60	18.82	66.30	1247.77	99.77	2628.69	26.35	18.82	1247.77	66.30
Total	100.00	26.29	2628.69						

As regards to tabulated data (Table 4) and corresponding float and sink graph (Fig 3), Çayırhan lignite sample, which has originally has 26.29 % ash content, can rather be cleaned with 1.40 g cm⁻³ solution. The float fraction of 63.02 % has been collected at the end of 1.40 g cm⁻³ float and sink experiment and corresponding ash content of this collected fraction is 14.02%. A total amount of 81.06% can be collected as float and the ash content would be 17.07 % considering the 1.60 g cm⁻³ cumulative float. The fraction collected as sink for the 1.60 g cm⁻³ (+1.60 g cm⁻³) solution is 18.94 %, which is a little bit more than the middling (+1.40-1.60 g cm⁻³) i.e. 18.04%, and their ash contents are 66.30 % (sink 1.60) and 27.71 % (middling), respectively. It can be claimed that high percentage of float fraction can be collected with only 1.40 g cm⁻³ as an initial evaluation.

In terms of the Ilgin sample, amount of the float fraction (1.40 g cm⁻³) is 78.45 % and ash content of the corresponding is 21.63 %. Referring to tabulated data (Table 5) and graphical representation (Fig 4) of float and sink experiment, Ilgin sample has 28.52 % ash content originally and cumulative float of 1.60 g cm⁻³ has the ash content of 26.38 %. The negligible difference between ash contents for cumulative float of 1.60 g cm⁻³ and original (abovementioned, 26.38 % and 28.52 % respectively) is actually because of the high mass fraction collected as cumulative float, i.e. 94.20 %. In this case, there would be no meaning for the 1.60 g cm⁻³ density cleaning for Ilgin sample, rather it should be cleaned with 1.40 g cm⁻³ solution. Still, 1.40 g cm⁻³ solution did not contribute much since the ash percentage was 28.52 (%) in the beginning and after this test (1.40 g cm⁻³ float and sink) it only decreased to 21.63 %, which can be

interpreted as Ilgin sample does not favor density medium separation.

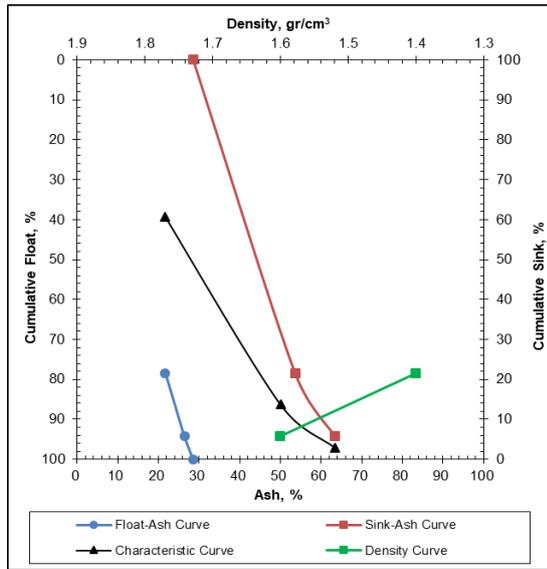


Fig 4. Float and sink graph for Ilgin lignite sample

In terms of the Ilgin sample, amount of the float fraction (1.40 g cm⁻³) is 78.45 % and ash content of the corresponding is 21.63 %. Referring to tabulated data (Table 5) and graphical representation (Fig 4) of float and sink experiment, Ilgin sample has 28.52 % ash content originally and cumulative float of 1.60 g cm⁻³ has the ash content of 26.38 %. The negligible difference between ash contents for cumulative float of 1.60 g cm⁻³ and original (abovementioned, 26.38 % and 28.52 % respectively) is actually because of the high mass fraction collected as cumulative float, i.e. 94.20 %. In this case, there would be no meaning for the 1.60 g cm⁻³ density cleaning for Ilgin sample, rather it should be cleaned with 1.40 g cm⁻³ solution. Still, 1.40 g cm⁻³ solution did not contribute much

since the ash percentage was 28.52 (%) in the beginning and after this test (1.40 g cm⁻³ float and sink) it only decreased to 21.63 %, which can be interpreted as Ilgin sample does not favor density medium separation.

As regards to float and sink graphical representation (Fig 5) and the tabulated data (Table 6), Ermenek lignites which has a 23.51 % ash content (run of mine) can be cleaned with density separation. In terms of float fraction for 1.40 g cm⁻³, ash content of 13.36 % can be obtained at an amount of almost one third (33.59 %) of the total mass. Cumulative float fraction of 1.60 g cm⁻³ on the other hand resulted as an amount of 81.43% with an ash content of 17.85 %. Middling in this case (for Ermenek lignite) is resulted as the highest amount out of the lignite samples investigated, i.e. it has 47.84 % mass fraction for the fraction of +1.40-1.60 g cm⁻³. Higher the amount of the middling fraction is not actually desired in terms of float and sink tests and it can be attributed as the limitation of the floatability of the corresponding sample. Further evaluations as regards to higher amounts of middling can be associated with the less liberation of particles at the specific size orientation tested. In the scope of this study, float and sink analysis was not performed on the samples which are sieve analyzed or size classified. Rather, in order to have an idea about the size orientation of the samples, they were objected to primary crushing. So, initial assessment of lack of the liberation for Ermenek sample can be made in this case considering its high amount of middling. Size reduction would be claimed to contribute float and sink separation of each sample investigated, but the most contribution of size reduction would be observed for Ermenek sample. In order to understand the possibility of density separation of a sample, size distribution should also be questioned.

Table 5. Float and sink analysis results for Ilgin lignite sample

Density gr/cm ³	Float		Cumulative Float			Cumulative Sink			
	%Amount	%Ash	Content	%Amount	Content	%Ash	%Amount	Content	%Ash
-1.40	78.45	21.63	1696.87	78.45	1696.87	21.63	100.00	2852.29	28.52
+1.40 -1.60	15.75	50.02	787.82	94.20	2484.69	26.38	21.55	1155.42	53.62
+1.60	5.80	63.38	367.60	100.00	2852.29	28.52	5.80	367.60	63.38
Total	100.00	28.52	2852.29						

Table 6. Float and sink analysis results for Ermenek lignite sample

Density gr/cm ³	Float		Cumulative Float			Cumulative Sink			
	%Amount	%Ash	Content	%Amount	Content	%Ash	%Amount	Content	%Ash
-1.40	33.59	13.36	448.76	33.59	448.76	13.36	100.00	2350.52	23.51
+1.40-1.60	47.84	21.00	1004.64	81.43	1453.40	17.85	66.41	1901.76	28.64
+1.60	18.57	48.31	897.12	100.00	2350.52	23.51	18.57	897.12	48.31
Total	100.00	23.50	2350.52						

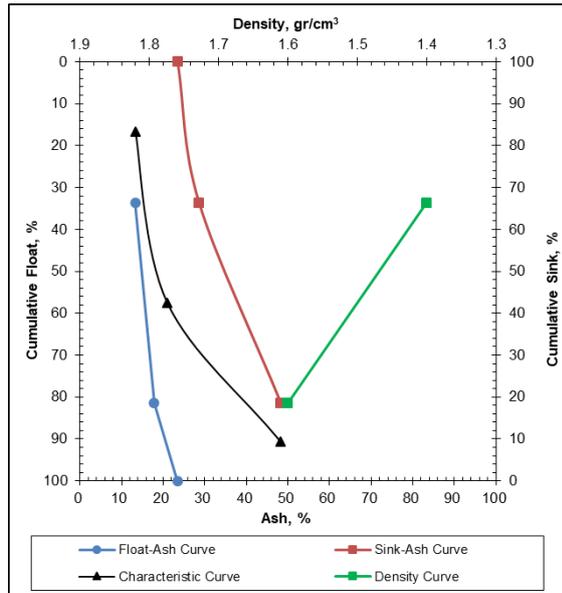


Fig 5. Float and sink graph for Ermenek lignite sample

As it is presented in Fig 6, and as it is tabulated in Table 7, Gürmin Merzifon lignite sample has the highest ash content (45.34 %) among the samples studied and corresponding amount of sink fraction of 1.60 g cm⁻³ is also the highest, i.e. 75.00 %. Although this abovementioned high amount of sink fraction for 1.60 g cm⁻³ can be regarded as not desired for a coal sample to be utilized further, still it can be interpreted as an achievement of the density separation of the specific sample. To be better clear in this context, Gürmin Merzifon lignite sample was observed to be successfully cleaned with density medium. Removal of this 75.00 % of high ash containing fraction would lead a production of clean fraction which has a ash content of 21.47 % (See Cumulative float of 1.60 g cm⁻³). Employment of 1.40 g cm⁻³ density in terms of float and sink test resulted as an amount of 9.89 % with an ash content of 11.00 %. Although the amount of the corresponding float fraction (1.60 g cm⁻³) varies for each of the samples investigated in the scope of this study, clean fraction of Gürmin-Merzifon lignite sample has almost half of the original (run of mine) ash content.

Table 7. Float and sink analysis results for Gürmin Merzifon lignite sample

Density	Float			Cumulative Float			Cumulative Sink		
gr/cm ³	%Amount	%Ash	Content	%Amount	Content	%Ash	%Amount	Content	%Ash
-1.40	6.63	11.00	72.93	6.63	72.93	11.00	98.00	4534.19	46.27
+1.40-1.60	16.37	28.33	463.76	23.00	536.69	23.33	91.37	4461.26	48.83
+1.60	75.00	53.30	3997.50	98.00	4534.19	46.27	75.00	3997.50	53.30
Total	100.00	45.34	4534.19						

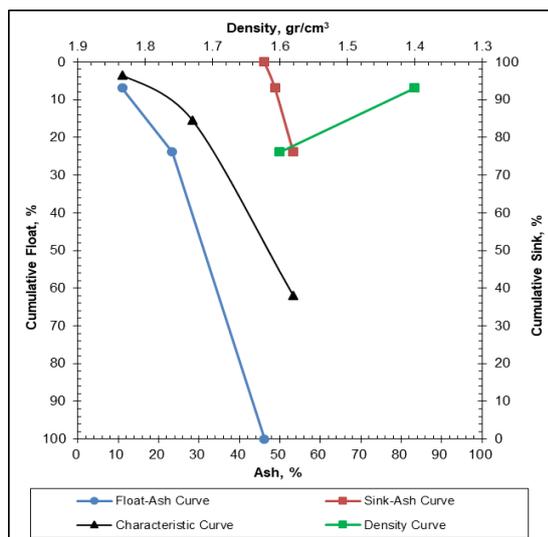


Fig 6. Float and sink graph for Gürmin-Merzifon lignite sample.

In order to evaluate the availability of each coal samples for the density separation, corresponding decrease of ash contents (original to float) can be revisited. In this context of abovementioned, highest rate of ash content decrease was observed with Gürmin-Merzifon sample, i.e. it was originally with an

ash content of 45.34 % and 1.60 g cm⁻³ float fraction has 21.47% ash content, respectively. Accordingly lowest rate of ash content decrease was observed with Ilgın lignite sample and it does not favor density separation. However in this context, combustible recoveries of the each lignites were considered in order to have a correct comparison. Combustible recovery values (%) were tabulated in Table 8 along with ash and amount percentages respectively for -1.40 g cm⁻³ and -1.60 g cm⁻³ for each lignites studied.

Referring to Table 8, combustible recoveries of Ilgın and Çayırhan samples are the highest ones and Gürmin Merzifon sample has the lowest combustible recovery for both fraction, i.e. -1.40 and -1.60 g cm⁻³, respectively. Lignite utilization in terms of thermal energy production purposes would question the combustible recovery. Density cleaning increases the combustible recovery percentage and float fraction of 1.60 g cm⁻³ has the higher combustible recoveries. Ilgın lignite sample has the highest combustible recoveries while Gürmin Merzifon has the lowest. Based on this finding abovementioned, density cleaning should be employed for Ilgın samples as regards to have higher combustible recoveries and combustion efficiency but it might not as much considered as for Gürmin-Merzifon sample. Increase in the density resulted in an increase in combustible recoveries, but higher density of mediums require

more chemicals involvement and that means higher pollution potential for environment.

Float and sink tests are employed mostly in order to understand the cleaning requirements of the run of mine coals. Further utilization of coal always requires lower ash content and lower amount of sulfur. Initial cleaning of coals in the course of coal preparation

plants are rather easier and cheaper. However, not every coal has the same characteristics in terms of their washability tendency. Prior to cleaning at a specific density in coal preparation plants, float and sink tests were carried out in order to have initial idea about the product amount and ash content.

Table 8. Combustible recoveries of the studied lignites

Coal sample	-1.40 g cm ⁻³			-1.60 g cm ⁻³		
	%Amount	%Ash	% Combustible Recovery	%Amount	%Ash	% Combustible Recovery
Dursunbey	34.51	7.96	41.62	72.97	16.49	80.23
Çayırhan	63.02	14.02	73.61	81.06	17.07	88.51
İlgin	78.45	21.63	86.01	94.20	26.38	97.02
Ermenek	33.59	13.36	38.05	81.43	17.85	87.44
Gürmin-Merzifon	9.89	11.00	16.10	25.00	21.47	35.92

4. CONCLUSIONS

In this study, 5 different lignite samples were collected and analyzed in terms of their washability characteristics. Washability of lignites is important since Turkish lignites have respectively high ash content (>20 %). Coal preparation plants clean coals with some specific high density mediums. High density mediums are prepared with some chemicals or recyclable minerals such as magnetites. However still optimization for the density of the medium should be realized since the more the usage of density making chemicals the more pollution to environment and the more the economic loss is. Although recent technologies try to develop systems with less or no usage of water/chemicals, there are still issues like capacity and efficiency which are not overcome yet.

In this study, some characteristics data have been evaluated for some of Turkish lignites. One could easily decide either use of 1.40 or 1.60 g cm⁻³ or in between (-1.60+1.40) solution to reach the desired amount of clean coal with desired ash content. Considering only low ash content should not mean that lignites with high sulfur content are acceptable. Coal preparation plants operators or field engineers should not only question ash content but also sulfur content as regards to density separation characteristics.

In addition to the ash content comparison based on the results obtained (Dursunbey lignite sample has the lowest ash content of 24.86 % while Gürmin Merzifon lignite sample has the highest ash content of 45.02 %), combustible recoveries of each lignite and each separation density (1.40 g cm⁻³, 1.60 g cm⁻³) has been tabulated in this context. It was observed that İlgin lignite sample has the highest combustible recoveries while Gürmin Merzifon has the lowest.

Lignite deposits in Turkey is widely encountered and utilization of these lignites should better carefully considered in terms of environmental and economic reasons. With further studies about characterization of lignite utilization would help to have more developed technologies in this field.

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