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Original Article

Determination of the effect of different gravity methods on the removal of ash and sulfur from Arguvan lignite

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Abstract

This study, it is aimed to find out the beneficiation of Malatya-Arguvan lignite by gravity methods. First of all, the washability of lignite has been investigated with sink-float experiments. It has been determined that lignite washability from washing curves is generally difficult but may be possible with controlled washing at a density of 1.68 g /cm^3. Then, to remove ash and sulfur from lignite by shaking table, spiral and Falcon concentrator tests were conducted. Clean coals are obtained from all other methods except Falcon were found to decrease in ash and sulfur content and increase in calorific value. Clean coals with the lowest ash and sulfur content were obtained with a spiral concentrator. Reichert spiral results showed that the ash content decreased from the lignite of 37.77% to 26.50% and the sulfur content from 3.85% to 2.08%. The calorific value increased from 2576 kcal/kg to 4590 kcal/kg. Arguvan lignite has very limited usage due to its lower calorific value, high ash and sulfur content. Although enrichment has been carried out, it has been concluded that lignite needs to be further improved by using different methods.

Keywords: Lignite, Falcon concentrator, Reichert spiral, Shaking table, Sink-Float tests

Arguvan linyitinden kül ve kükürt uzaklaştırılmasında farklı gravite yöntemlerinin etkisinin belirlenmesi

Özet

Bu çalışmada gravite yöntemleriyle Malatya-Arguvan linyitinin zenginleştirilmesi amaçlanmıştır. Öncelikle, yüzdürme-batırma deneyleriyle linyitin yıkanabilirliği araştırılmıştır. Yıkama eğrilerinden linyitin yıkanabilirliğinin genel olarak zor olduğu, 1,68 g/cm^3 yoğunlukta kontrollü olarak yıkanabileceği belirlenmiştir. Daha sonra, linyitten kül ve kükürdü uzaklaştırmak için sallantılı masa, spiral ve Falcon konsantratör deneyleri yapılmıştır. Falcon hariç diğer tüm yöntemlerden elde edilen temiz kömürde kül ve kükürt içeriğinin azalmış, kalorifik değer ise artmıştır. En düşük kül ve kükürt içeriğine sahip olan temiz kömürler spiral konsantratör ile elde edilmiştir. Reichert spirali sonuçları linyitteki kül içeriğinin %37,77'den %26,50'ye ve kükürt içeriğinin ise %3,85'den %2,08'e azalmış olduğunu göstermiştir. Kalorifik değer 2576 kcal/kg'dan 4590 kcal/kg'a yükselmiştir. Düşük kalorifik değeri, yüksek kül ve kükürt içeriği yüzünden Arguvan linyiti sınırlı bir kullanıma sahiptir. Her ne kadar zenginleştirme gerçekleşse de, farklı yöntemler kullanılarak linyitin daha da iyileştirilmesi gerektiği sonucuna varılmıştır.

Anahtar Kelimeler: Linyit, Falcon konsantratör, Reichert spiral, Sallantılı masa, Yüzdürme-Batırma deneyleri

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1. INTRODUCTION

Sulfur is one of the major undesirable constituents of coal; it contributes to air pollution and causes operational problems during combustion such as slagging, corrosion, equipment wear, etc. More importantly, the emission of sulfur dioxide into the atmosphere during coal combustion is of serious ecological concern. Therefore, sulfur dioxide emissions can be reduced by various preparation methods such as gravity concentration and flotation methods [1].

Gravity separation is a method based on the specific gravity difference between coal and impurities such as ash-forming substances and sulfur [2]. Gravity-based methods are much more efficient than flotation, especially for medium-sized particles. Methods based on specific gravity differences are widely used to separate coal and mineral substances from each other [3].

Coal washing is a process that depends on the density difference between coal and impurities [4]. In the float-sink analysis, heavy liquids of increasing density have to be prepared. For coal, they can be the solutions of $ZnCl_2$ of density ranging from 1.3 to 1.8 g/cm^3 as coal density is from 1.17 to 1.35 while for ash forming minerals from 1.8 to 5.2 g/cm^3. The sample of the material is first immersed in the lightest liquid (1.3 g/cm^3). The sinking particles were directed to another container of higher density (1.4 g/cm^3) and a subsequent density fraction was obtained. It contained particles within a density range from 1.3 to 1.4 g/cm^3. The procedure is repeated until the last separation provides two fractions: floating particles having a density from 1.6 to 1.8 g/cm^3 and sinking particles with a density higher than 1.8 g/cm^3 [5, 6]. Thus, in the prepared heavy environment, coal and other components can be easily separated by the floating of the coal particles containing lighter minerals and the sinking of the heavier mineral-containing materials [7].

The formation of stratified particles on the shaking table, is the result of many forces including gravity forces, the friction forces between particles and the table which are caused by the table plate movement and liquid movement, the force of liquid pressure on particles, and the force of inertia. The ordering force acting on particles is the sum of vectors representing the forces. This stratification force for heavy particles has a slightly different direction than that for light particles. This is caused by the fact that the stratification force for heavy particles is mainly determined by the inertia forces, while other forces (friction, gravity, and water pressure force) are of low values. The shaking tables can be used to process nonferrous metal ores containing particles smaller than about 3 mm. In the case of coal, because of its considerably lower density, larger particles (up to 6 mm in diameter) should be used. For fine particles of about 0.1 mm in size smooth surfaces of the shaking table are recommended. In other cases, the surface of the shaking table is modified by grooves and strips. An additional factor improving separation is the use of asymmetric shaking of the table [8, 9].

In the spirals, the centrifugal force is a result of the shape of the separator. The material travels down through a stationary spiral with many turns of a mean radius of 20 cm with a fall per turn of about 28 cm. The forces affecting particles in the spiral separator are centrifugal, gravity, friction, and liquid pressure. The forces which determine separation are friction and liquid pressure operate in the same direction as a horizontal component of the gravity forces, as well as the horizontal component of the centrifugal force. In the spiral separator, the tailing containing light particles is collected in the lowest coil. The clean coal is collected from the neighboring 2-3 coils through the holes in the coil surface bottom. Particles larger than about 0.05 mm diameter are suitable for separation [8].

Gravity separators such as the enhanced Multi-Gravity Separator (MGS), Falcon, and Knelson concentrators are suitable for removing ash and sulfur from coal grains <0.25 mm in size [3]. Falcon is a centrifugal gravity concentrator with similar features to the Knelson concentrator. The concentration is achieved in a fast-spinning bowl (up to 300 G). The device is fed from its bottom and employs centrifugal force to drain the slurry as a thin flowing film at its wall. The heavier particles are retained inside the bowl while the lighter minerals flow out with the fluid [10, 11].

There are some studies on the removal of coal from ash and sulfur by gravity methods. Özgen et al. (2011) enriched two lignite ores containing 66% and 53% ash with Multi-Gravity Separator (MGS) [12]. As a result, they obtained clean coal containing approximately 23% ash with a recovery of 49-60%. Honaker et al. (1996) using the Falcon concentrator, 60-70% of the ash in the fine coal was removed with a gain greater than 85% [13]. In another study, Honaker et al. (1995) using the Falcon concentrator, removed about half of the ash and sulfur content in the fine coal, with a recovery of 90% [14]. Rath et al. (2011) used the Falcon concentrator and the flotation method to remove ash from the coal [15]. They concluded that the Falcon concentrator was not as effective as flotation in reducing ash content. While the Falcon removed a maximum of 47.5% of the ash with 35% efficiency, they removed 60% ash with 23% efficiency by flotation. Das et al. (2010) tried a combination of gravity separation and Jameson cell separation to clean fine coal that does not show good floatability [16]. As a result, they managed to reduce the ash content from 30.4% to 12%. Özbakir et al. (2017) used a combined optimization of hydrocyclone and multi-gravity separation device to remove ash and sulfur from the coal preparation plant tailings [17]. As a result, they managed to reduce the ash content from 54.82% to 24.52%.

Malatya Arguvan lignite used in this study is one of the less-studied lignites. Only sink-float, flotation and agglomeration enrichments of this lignite have been studied, and there are no studies on gravity methods. Therefore, this study, made with Arguvan lignite, will be a first in its field. The results obtained from the experiments will give an idea especially for other researchers who will work with this lignite. In the present study, to remove ash and sulfur from lignite, sink-float, shaking table, spiral, and Falcon concentrator tests were conducted.

2. MATERIAL AND METHODS

2.1 Material

The original lignite samples used in this study were provided by Arguvan Coşkunlar Coal Management. Representative samples of lignite were reduced by coning and quartering sampling methods. The samples were prepared according to the Astm Standards for proximate, total sulfur, gross calorific value, XRD, and FTIR. All analyses for the samples were carried out in triplicate and mean values have been reported.

Results of the proximate analysis of Arguvan lignite are given in Table 1. As seen in Table 1, that the total sulfur content is 3.85%, ash content is 37.77% and the lower heating value is 2576 kcal/kg (on the air-dried basis).

Table 1. Proximate analysis results of Arguvan lignite [18]

Components	As received	Air-dried	Dried
Moisture (%)	22.67	7.96	-
Ash (%)	31.73	37.77	41.04
Volatile matter (%)	21.56	25.66	27.88
Fixed C (%) (by difference)	24.04	28.61	31.08
Total S (%)	3.23	3.85	4.18
Upper calorific value (kcal/kg)	2116	2624	2899
Lower calorific value (kcal/kg)	2068	2576	2851

XRD and FTIR results for Arguvan lignite are shown in Figure 1 and Figure 2, respectively. As seen in Figure 1, the main inorganic impurities existing in lignite include montmorillonite, gypsum, pyrite, and clay minerals.

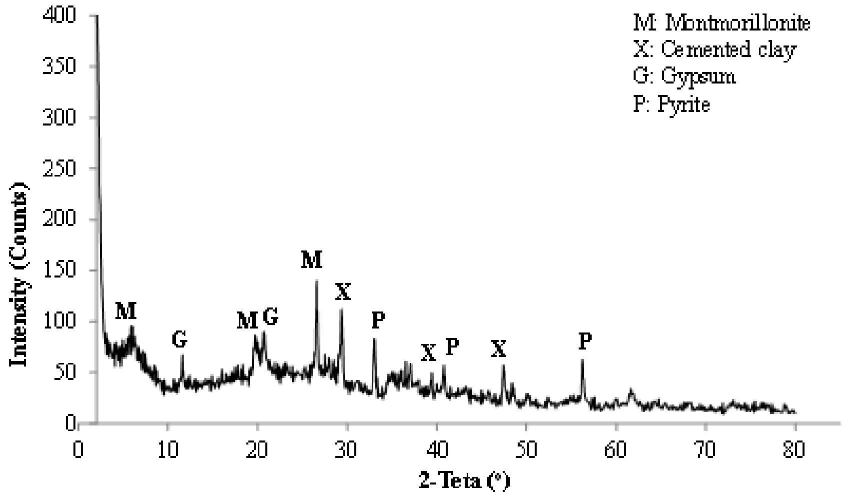


Figure 1. XRD pattern of Arguvan lignite [18]

The FTIR spectrum was recorded in the region of 4000 to 400 cm^{-1} (Fig. 2). The peaks approximately at 3413 cm^{-1} and 2920 cm^{-1} are due to –OH stretching and the existence of aliphatic groups in coal samples, respectively. Just about at 1618 cm^{-1} peak corresponds to aromatic C=C ring stretching structure. The aliphatic –CH deformations are observed at 1436 cm^{-1}. The peak at 1038 cm^{-1} is due to aliphatic ether C-O and alcohol. The complex bands at 915 cm^{-1} and 799 cm^{-1} indicate the aromatic structures within the coal. The band at 524 cm^{-1} is because of Si-O deformations [19-21].

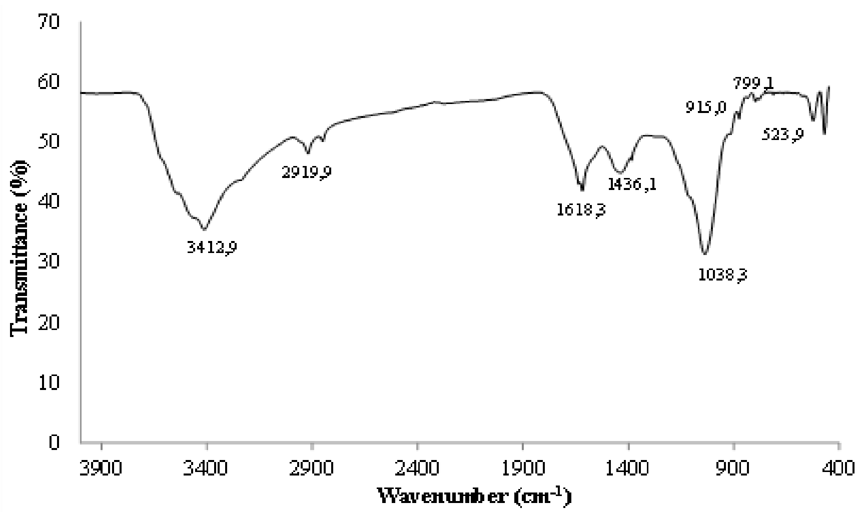


Figure 2. FTIR spectrum of Arguvan lignite [18]

The petrographic analysis results of Arguvan lignite carried out in MTA laboratories. According to the results of the petrographic analysis (Figure 3 a, b, c), it was seen that the maseral distribution was 59% vitrinite (huminite), 7% exinit (liptinite), and 6% inertinite group. Mineral distribution was determined to be composed of 6% framboidal pyrite and 22% other mineral substances. Microlitotype distribution; 31% clarite, 21% duroclarite, 12% vitrite, 29% carbominerite and 7% other microlithotypes. According to these results, it was found that Arguvan lignite was composed of 15% monomaseralic, 34% bimaceralic, 22% trimaseralic, and 29% carbominerite groups. These results are compatible with the work of Abakay Temel & Majumder (2016) [22].

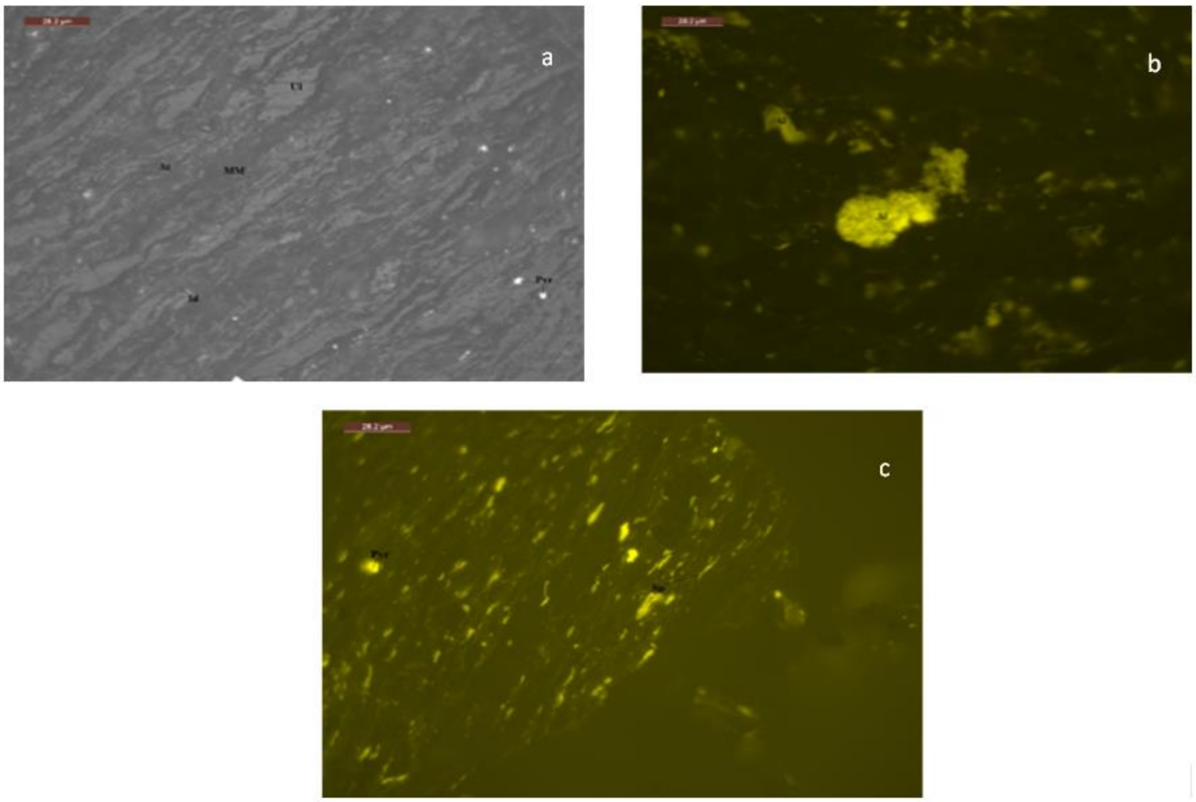


Figure 3 (a, b, c). Polarized microscope image of Arguvan lignite
(Ul: Ulminite, At: Atrinite, Id: İnertodetrinite, Pyr: Framboidal pyrite,
MM: Mineral matter, Sp: Sporinite, Al: Alginite)

In Figure 3, it is seen that the impurities in the lignite (clay, limestone, etc.) are very finely dispersed. This suggests that the impurities are contaminated during coalification (syngenetic). In Figure 3, significant amounts of framboidal (spherical) pyrite have been observed to be distributed at a very fine size (less than about 30 microns). Also, the amount of mineral matter together with pyrite is 28% by volume, suggesting that beneficiation will be difficult.

2.2 Method

The experimental flow chart is given in Figure 4. Removal of lignite, whose characteristics were determined, from ash and sulfur, was carried out with Sink-Float, Shaking Table, Reichert Spiral, and Falcon Concentrator.

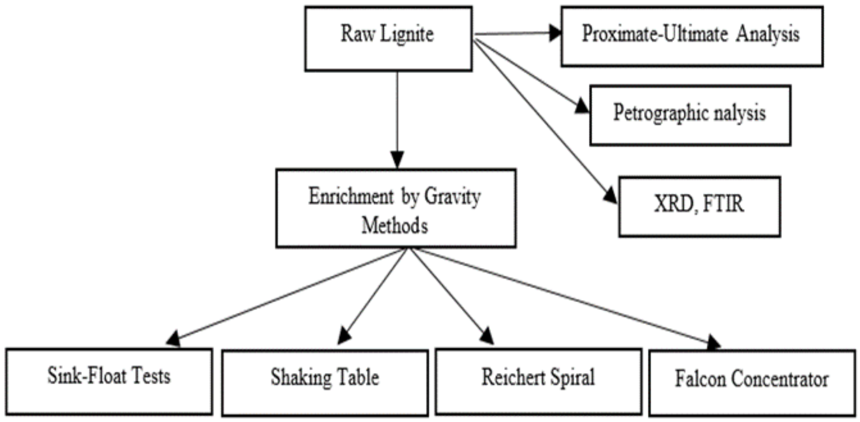


Figure 4. The experimental flow chart

For sink-float tests, the original lignite samples were air-dried, screened, and fractionated into three different particle sizes. The size fractions labelled as coarse (-31.5+19 mm), medium (-19+4.75 mm) and fine (-4.75+0.5 mm). The lignite samples which were -0.5 mm have been disregarded because of very fine particles. Float-sink tests were carried out in above size fractions using $ZnCl_2$ (Zinc chloride), at densities of 1.4, 1.5, 1.6, 1.7 and 1.8 g/cm^3. After the sink-float test, both floating (-1.4, -1.5, -1,6, -1.7 and -1,8 g/cm^3) and sinking fractions (+1.8 g/cm^3) were washed, air dried, weighed and analyzed for ash and sulfur content. The ash and sulfur contents of Arguvan lignite for sink-float tests by combining different size fractions are shown in Table 2. It is seen that the ash contents range from 15.77 to 65.98, sulfur contents range from 2.52 to 4.83.

Table 2. Ash content of Arguvan lignite size fractions for sink-float tests (on a dry basis)

Fractions	Particle size (mm)	Weight (%)	Ash (%)	Sulfur (%)
Coarse size	19-31.5	5.52	30.13	2.52
Medium size	4.75-19	32.70	36.86	3.66
Fine size	0.5-4.75	61.78	38.93	4.83

Shaking table and spiral tests were performed in -3.35+2, -2+1.18 and -1.18+0.15 mm size fractions. The lignite samples which were -0.15 mm have been disregarded because of very fine particles. The ash and sulfur contents of different particle sizes are shown in Table 3.
The shaking table tests were performed using a Wilfley table. The tests were done at different shaking frequencies (100, 150 and 200 rpm) and a different table slope (2, 4 and 6°).

The spiral tests were performed using a Reichert spiral with 5-launders. The spiral tests were done at different solid/liquid ratios (7.5, 15, 25 and 35% solid by wt.) and different splitter settings (90, 120 and 150°).

Table 3. Ash content of Arguvan lignite size fractions for shaking table and spiral tests (on a dry basis)

Particle size (mm)	Weight (%)	Ash (%)
2 -3.35	29.34	35.91
1.18 -2	29.60	35.39
0.15 -1.18	31.27	34.97
Below 0.15	9.79	59.48
Feed	100.00	37.77

For the Falcon tests, the lignite sample was first broken down to 30 mm with a jaw crusher, then down to 3 mm with a hammer crusher. Then, the crushed sample was milled with a ball mill and screened to below 500 µm, 212 µm and 150 µm. Falcon tests were carried out in -500, -212 and -150 µm size fractions and different speeds of rotation (20, 78, 176 and 300 G) using a laboratory-scale Falcon L40 concentrator. The water pressure and the solid concentration were maintained at 4 psi and 30% by wt., respectively.

The products obtained as a result of all these experiments are dried air, weighed and ground to below 106 µm to analyze for ash, sulfur and calorific values.

Combustible recovery and ash/sulfur removal efficiencies were calculated according to the following equations [23, 24];

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

$$R_{ash/S.}(\%) = \frac{T\times t}{F\times f} \quad (2)$$

where R_{comb} and $R_{ash/S}$ are the combustible recovery and ash/sulfur removal, respectively. C, T, F, and c, t, f represent the yields and the ash contents of the concentrate, tailings, and feed, respectively.

3. RESULTS AND DISCUSSION

3.1 Sink-Float tests

The washability data by combining different size fractions are given in Table 4. As seen in Table 4, in the medium with a density of -1.4 g/cm^3 for the coarse size, the floating part by weight is about 22% and the ash content is 16.3%. The floated product from the media of 1.4-1.5 g/cm^3 comprises the majority of coarse size coal sample and accounts for 42.4%, however, its ash content increases to 29.1%.

Table 4. Coal washability data obtained float-sink tests

	1	2	3	4		5		6	7
Size (mm)	Sp. grav. (g/m^3)	Wt (%)	Ash (%)	Cumulative float		Cumulative sink		Ordinat z	±0.1 dens. fract.
				%Wt	%Ash	%Wt	%Ash		
Coarse size (-30+19)	-1.4	21.9	16.3	21.9	16.3	100.0	32.6	11.0	
	+1.4-1.5	42.4	29.1	64.3	24.8	78.1	37.2	43.1	61.0
	+1.5-1.6	18.6	39.5	82.9	28.1	35.7	46.8	73.6	25.1

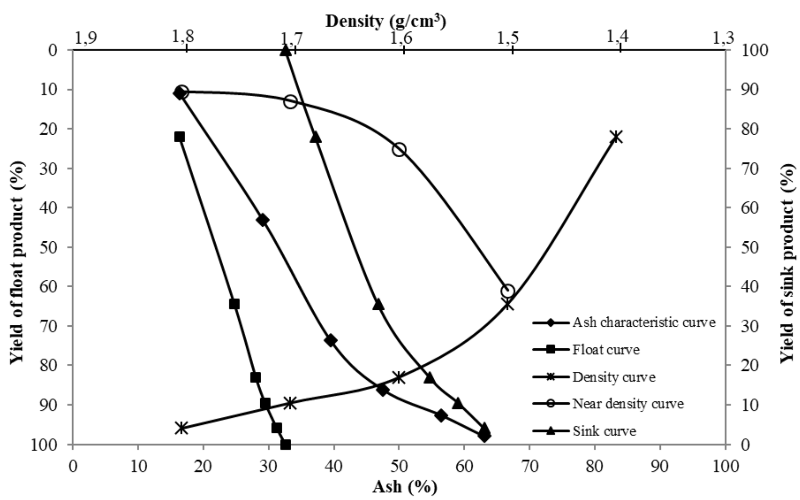
	+1.6-1.7	6.5	47.6	89.4	29.5	17.1	54.7	86.2	12.9
	+1.7-1.8	6.4	56.5	95.9	31.3	10.6	59.1	92.7	10.6
	+1.8	4.1	63.1	100.0	32.6	4.1	63.1	97.9	
Medium size (-19+4.75)	-1.4	10.0	14.5	10.0	14.5	100.0	37.0	5.0	
	+1.4-1.5	35.7	24.3	45.7	22.1	90.0	39.6	27.9	50.5
	+1.5-1.6	14.9	34.0	60.6	25.0	54.3	49.6	53.1	28.3
	+1.6-1.7	13.4	40.0	74.0	27.7	39.5	55.5	67.3	20.4
	+1.7-1.8	6.97	48.5	81.0	29.5	26.0	63.5	77.5	
	+1.8	19.1	69.0	100.0	37.0	19.1	69.0	90.5	
Fine size (-4.75+0.5)	-1.5	17.9	17.3	17.9	17.3	100.0	39.4	8.9	
	+1.5-1.6	15.8	23.5	33.8	20.2	82.08	44.2	25.8	32.1
	+1.6-1.7	16.3	29.7	50.0	23.3	66.25	49.2	41.9	25.7
	+1.7-1.8	9.4	34.9	59.4	25.1	49.97	55.5	54.7	
	+1.8	40.6	60.3	100	39.4	40.58	60.3	79.7	

According to Table 4, in the medium with a density of -1.4 g/cm^3 for the medium size, the floating part by weight is 10% and the ash content is 14.5%. The floated product from the media of 1.4-1.5 g/cm^3 comprises the majority of medium-size coal samples and accounts for 35.7%, however, its ash content increases to 24.3%. The material with a density of +1.8 g/cm^3 is 19.1% by weight, and the ash content is 69%.

For the fine size, at a density of -1.4 g/cm^3, the entire material is floated. In the medium with a density of -1.5 g/cm^3 for the fine size, the floating part by weight is 17.9% and the ash content is 17.3%. The material with a density of +1.8 g/cm^3 is 40.6% by weight, and the ash content is 60.3%. As expected, the ash content of the coal increased as the density of the medium increased in all particle sizes.

Since ±0.1 density fraction values are greater than 20 for all grain sizes at +1.4-1.5 and +1.5-1.6 g/cm^3 densities in Table 4, it can be said that separation at these densities will be very difficult. It was determined that although the separation in coarse size was moderately difficult at densities of +1.6-1.7 and +1.7-1.8 g/cm^3, it would be very difficult to separate for other sizes.

Belonging to coarse, medium and fine sizes of Arguvan lignites washability curves were given in Figure 5a, 5b and 5c, respectively.



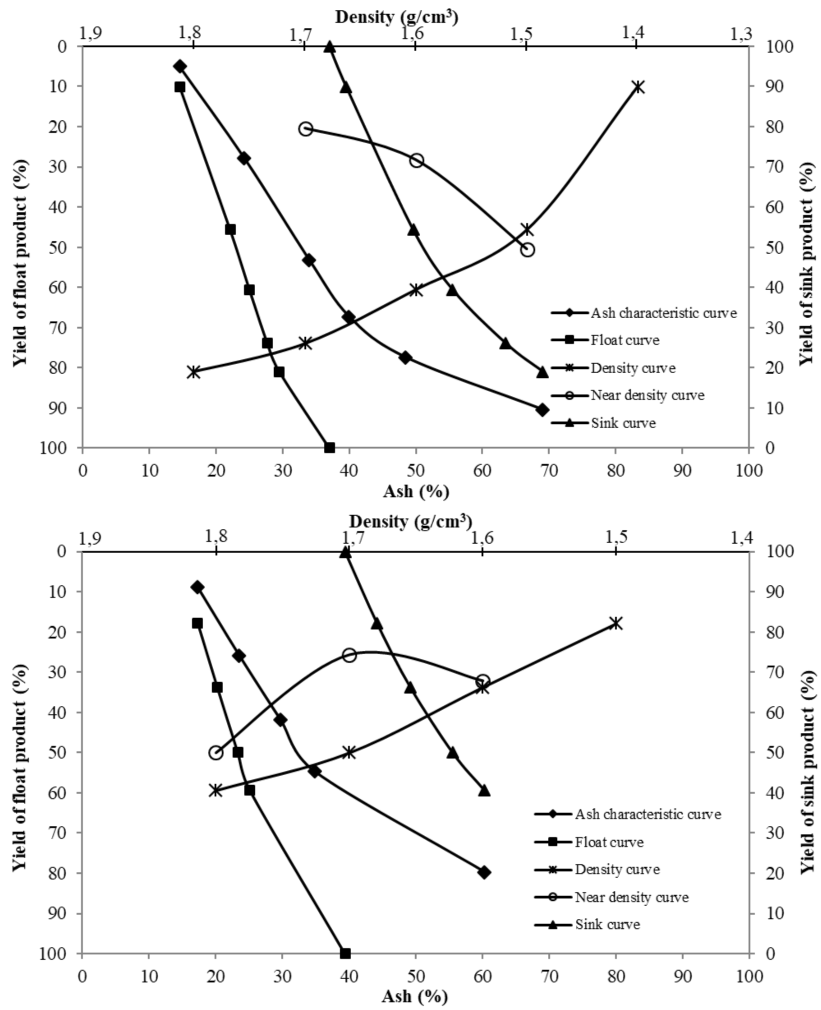


Figure 5. Coarse (a), medium (b) and fine (c) sizes of Arguvan lignites washability curves [18]

As can be seen in Figure 5, neither the shape of ash characteristic curves nor the shape of float curves is 'L' shaped rather, they seem like a slightly right inclined straight line for all sizes tested. This indicates the difficulty of washing Arguvan lignite at a certain density. These results are compatible with the literature [18, 25, 26]. Therefore, as a washing method, heavy-medium cyclone or equivalent device (spiral/table) for +0.5 mm coal can be used [27]. It is known from various studies in the literature that lignites can be floated in a narrow density range [28, 29].

3.2 Shaking table tests

The slope of the table and frequency of stroke were optimized to obtain clean coal. The slope was maintained as 4° and the effect of shaking table amplitude was studied 100, 150 and 200 rpm stroke frequency (shaking speed) for all size fractions. The effects of the variation of stroke frequency on the ash and combustible recovery according to different size fractions are given in Figure 6a.

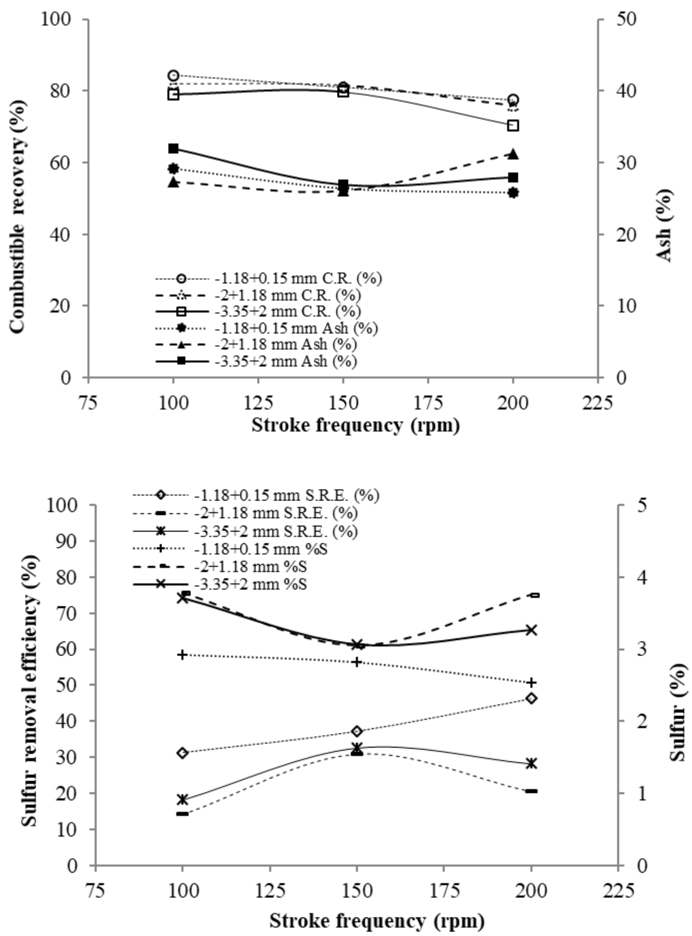
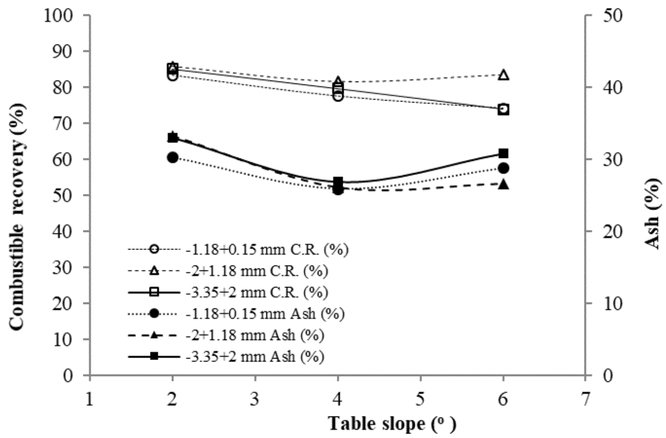


Figure 6. The effect of table stroke frequency change (at 4° table slope) on ash & combustible recovery (a) and sulfur & sulfur removal (b) efficiency according to different size fractions, respectively

According to Figure 6a, it has been found that is appropriate to work at high table speeds (150 rpm) in fine size fractions and low table speeds in coarse size fractions. A stroke frequency of 150 rpm with the lowest ash content was determined as optimum. These results are consistent with the literature [30, 31]. In the same way, it has been determined that there is an inverse relationship between clean coal ash and combustible recovery [31]. As optimally, the ash content of 37.77% in raw lignite was reduced to 25.87% with 77.5% combustible recovery and the calorific value is increased from 2576 kcal/kg to 4315 kcal/kg for -1.18+0.15 mm size fractions. Aydin et al. (2018), reduced the ash content of the -4+2 mm Seyitömer lignite from 44.69% to 24.26% with 46.7% combustible recovery by the shaking table [32].

When the shaking table speed is evaluated in terms of total sulfur removal, Figure 6b is obtained. As seen in Fig. 6b, shaking table speed is not very effective in total sulfur removal. As optimally, the sulfur content of 3.85% in raw lignite was reduced to 2.54% with 46.4% S removal efficiency for -1.18+0.15 mm size fractions.



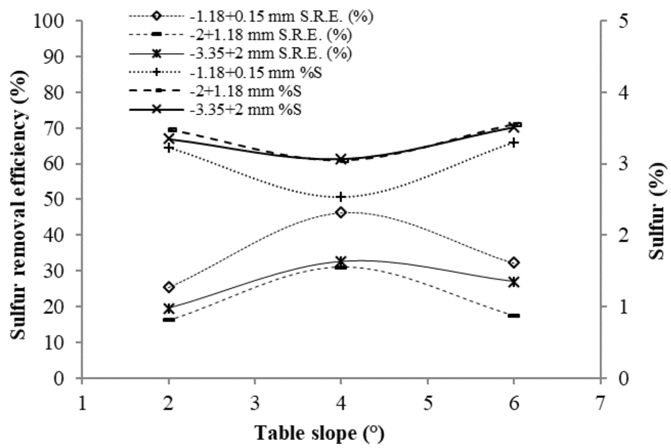


Figure 7. The effect of table slope change (at optimally stroke frequency) on ash & combustible recovery (a) and sulfur & sulfur removal efficiency (b) according to different size fractions, respectively

For all size fractions, the shaking table results obtained by varying the table slope are shown in Figure 7. From Figure 7a, it has been understood that all fractions should be worked at a 4° slope. When assessed from the point of view of clean coal ash, the table speed results are better than the table slope results. This shows that table speed is a more effective parameter for separation. According to Fig. 7b, it has been found that shaking table tests are not a significant influence on total sulfur removal efficiency.

As a result of the shaking table experiments, ash content of 37.77% in raw lignite has been reduced to 25.87% with 77.5% combustible recovery for -1.18+0.15 mm, 26.05% with 81.5% combustible recovery for -2+1.18 mm, 26.89% with 79.8% combustible recovery for -3.35+2 mm size fractions. The calorific values are increased from 2576 kcal/kg to 4315, 4148 and 4119 kcal/kg, respectively. Sulfur contents of 3.85% has been reduced to 2.54% with 46.4% sulfur removal efficiency for -1.18+0.15 mm, 3.05% with 31% sulfur removal efficiency for -2+1.18 mm, 3.07% with 32.6% sulfur removal efficiency for -3.35+2 mm size fractions.

3.3 Reichert spiral tests

To optimally determine the solid/liquid ratio, which is an important parameter, the fixed position of the splitter is maintained at 150°. For all size fractions, the spiral results obtained by varying the solid/liquid ratio are shown in Figure 8.

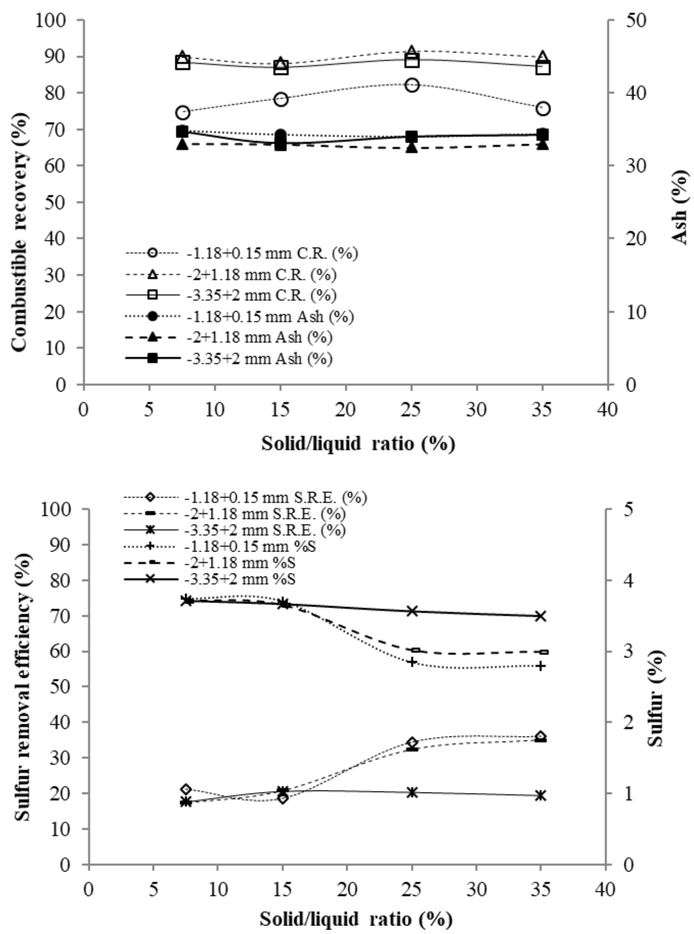


Figure 8. The effect of solid/liquid ratio change (at 150° position of splitter) on ash & combustible recovery (a) and sulfur & sulfur removal efficiency (b) according to different size fractions, respectively

According to Figure 8a, the lowest ash contents were obtained as 15% solids ratio for -3,35+2 mm size fraction, 25% solids ratio for -1,18+0,15 mm and -2+1,18 mm size fractions. The experimental data were compatible with the literature [33, 34]. As a result of solid/liquid ratio experiments, ash content of 37.77% has been reduced to 33.94% with 82.2% combustible recovery for -1.18+0.15 mm, 32.50% with 91.4% combustible recovery for -2+1.18 mm, 33.16% with 86.9% combustible recovery for -3.35+2 mm size fractions. The calorific values are increased from 2576 kcal/kg to 3201, 3366 and 3197 kcal/kg, respectively. As can be seen from Figure 8b, as the particle size decreased, the sulfur content decreased and the sulfur removal efficiency increased. Sulfur contents of 3.85% has been reduced to 2.85% with 34.4% S removal efficiency for -1.18+0.15 mm, 3.02% with 32.3% S removal efficiency for -2+1.18 mm, 3.67% with 20.7% S removal efficiency for -3.35+2 mm size fractions. Kangal et al. (2018), reduced the ash content of the +0.7 mm coal preparation plant tailings from 61.48% to 36.33% with 25.4% combustible recovery by the Reichert spiral [35]. Uçar et al. (2021) enriched the slime coal of the Garp Lignites

Enterprise with spirals. They obtained clean coal with a size of -1+0.212 mm, containing 81.74% carbon with a combustible recovery of 93.09% [36].

After the solid/liquid ratio was determined, the experiments were continued by changing the position of splitter settings to 90° and 120°. The results obtained by changing the position of splitter settings are shown in Figure 9.

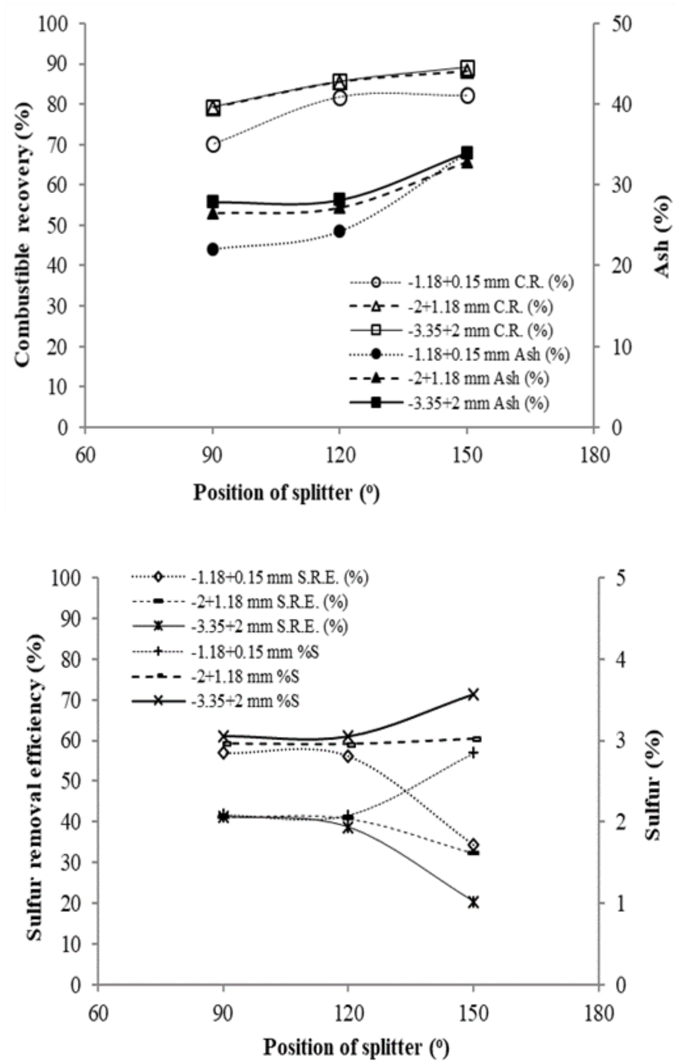


Figure 9. The effect of the position of splitter change (at optimally feed rate) on ash & combustible recovery (a) and sulfur & sulfur removal efficiency (b) according to different size fractions, respectively

From Figure 9a it is seen that the lowest ash values in all size fractions are in the 90° position of the splitter.

However, it has been decided that the choice of 120° position of the splitter is appropriate due to the low combustible recovery. It has been determined that the splitter setting position is an important parameter for separation. As a result of the spiral experiments, the ash content of 37.77% has been reduced to 22.10% with 70.1% combustible recovery for -1.18+0.15 mm, 26.50% with 79.2% combustible recovery for -2+1.18 mm, 27.9% with 79.3% combustible recovery for -3.35+2 mm size fractions. The calorific values are increased from 2576 kcal/kg to 4590, 4110 and 3925 kcal/kg, respectively. As can be seen from Figure 9b, it was determined that the position of the splitter is effective in sulfur removal as well as in ash removal. As the position of the splitter decreased, the sulfur content decreased and the sulfur removal efficiency increased. Sulfur contents of 3.85% has been reduced to 2.08% with 45.4% S removal efficiency for -1.18+0.15 mm, 2.96% with 41.2% S removal efficiency for -2+1.18 mm, 3.05% with 41.3% S removal efficiency for -3.35+2 mm size fractions. Based on these results, it can be assumed that the results of desulfurization are relatively successful.

3.4 Falcon concentrator tests

Falcon concentrator test results are presented in Figure 10. As it can be seen from Figure 10, the ash content of 37.77% was reduced to 32.57% with 70.36% combustible recovery at a particle size of -500 µm and a force of 300 G. Clean coal was obtained with the highest combustible yield (97.1%) at 20 G. However, the desired reduction in ash content was not achieved (36.14%). However, it has been determined that sufficient ash reduction cannot be achieved in all G forces operating at -500 µm particle size.

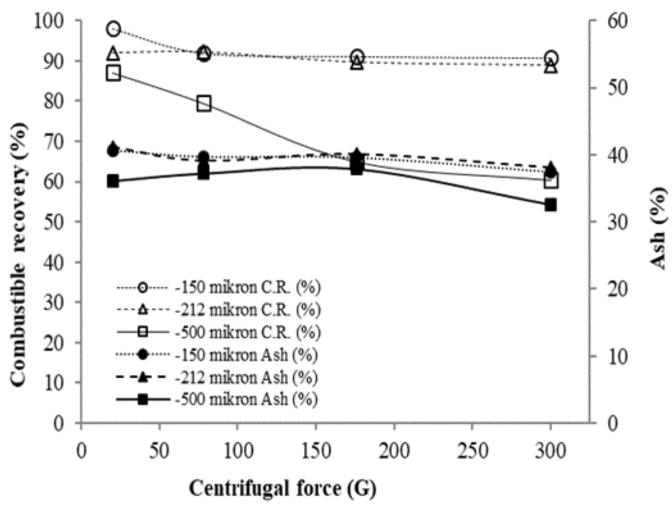


Figure 10. Effect of gravity force on ash and combustible recovery according to different size fractions

Falcon experiments were continued at -212 and -150 µm particle sizes. The ash content varies between 38.10% and 41.11% for all G forces studied with a particle size of -212 µm. These results show that as the particle size decreases, the clay minerals are combined with clean coal and therefore no separation occurs. Falcon concentrator experiments performed below the size of 150 µm are similar to the previous experiments.

Falcon concentrator results are consistent with coal studies in the literature [37-41]. On the other hand, there are also studies that the Falcon concentrator is successful in hard lignite [42-45]. The total sulfur content of clean coal obtained from the Falcon concentrator ranged from 3.76 to 3.80%. This showed that the removal of sulfur with the Falcon concentrator was not successful.

4. CONCLUSIONS

The beneficiation of Arguvan lignite has been investigated with sink-float, Wilfley table, Reichert spiral and Falcon concentrator. The following results were obtained:

The amount of floating material in ±0.1 density values indicates that for Arguvan lignite washability is very difficult. In sink-float experiments (at 1.7 g/cm^3), the ash content decreased from 37.77% to 28.42% and the sulfur content from 3.85% to 2.64%. The calorific value increased from 2576 kcal/kg to 3780 kcal/kg.

The best results of the table tests have been observed with a particle size of -1.18+0.15 mm. The ash content decreased from 37.77% to 26.27% and the sulfur content from 3.85% to 2.54%. The calorific value increased from 2576 kcal/kg to 4192 kcal/kg.

The best results of the spiral tests have been observed with a particle size of -1.18+0.15 mm, too. The ash content decreased from 37.77% to 26.50% and the sulfur content from 3.85% to 2.08%. The calorific value increased from 2576 kcal/kg to 4590 kcal/kg. The Arguvan lignite is estimated to have about 50% pyritic sulfur and up to about 50% sulfite by chemical analysis and enrichment tests. According to this, 45.4% sulfur removal efficiency with Reichert spiral means that almost all of the pyritic sulfur can be removed. It is thought that the content of 2.69% S in clean coal is caused by the sulfur content.

Falcon concentrator experiments did not provide the desired distinction in terms of both ash and sulfur removal.

In the experiments, it was observed that the fine clay minerals coalesced with the coal. It is thought that separation did not occur for this reason. Therefore, this study has shown that physical methods are insufficient in removing ash and sulfur from Arguvan lignite. It was determined that lignite should be ground to finer sizes and liberated. Then, its enrichment with chemical methods such as acid and alkali leaching, solvent extraction, etc. should be investigated. Thus, it has been concluded that it is beneficial to carry out detailed studies by considering different enrichment methods.

In the literature review, it has been determined that such a detailed study has not been done on Arguvan lignite. Therefore, it will be important for this study to inform researchers who will work with Arguvan lignite and similar coal.

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