KSÜ Mühendislik Bilimleri Dergisi 21(2):107-120, 2018 KSU J Eng Sci, 21(2):107-120, 2018
Araştırma Makalesi Research Article

Kahramanmaras Sutcu Imam University
Journal of Engineering Sciences

Geliş Tarihi : 13.11.2017 Received Date :13.11.2017
Kabul Tarihi : 09.04.2018 Accepted Date :09.04.2018

Beneficiation of Fine Coal Tailings from Coal Preparation Plant by Enhanced Gravity Methods

İnce Boyutlu Kömür Hazırlama Tesisi Atıklarının Geliştirilmiş Gravite Yöntemleri ile Zenginleştirilmesi

Filiz ORUÇ ŞAPÇI[1], *Eyüp SABAH*[1*]

[1]Afyon Kocatepe University, Mining Engineering Department, Afyonkarahisar, Türkiye

*Sorumlu Yazar / Corresponding Author: Eyüp SABAH, esabah@aku.edu.tr

ABSTRACT

In the past, it was more economical to dispose fine coal without utilization. Nowadays, beneficiation of fine coal is a necessity due to increasing costs of mining, tailings disposal and storage problems. This research contains experimental studies devoted to beneficiation of <0.1 mm coal preparation plant tailings of Garp Lignite Enterprises (Tunçbilek- Kütahya/Turkey). It was found from the characterization studies that the coal tailings include clay minerals (kaolinite, mica/illite, and smectite group), quartz, siderite, pyrite and dolomite which are of higher density than lignitic coal. Concentration processes are proposed as preliminary and final. In the preliminary two-stage processing tests, hydrocyclone is used to separate clay minerals associated with coal. For this purpose, structural and operating parameters of hydrocyclone (hydrocyclone diameter, vortex diameter, apex diameter, feed inlet pressure, pulp solids ratio) and of Falcon concentrator (gravity force, feed rate, pulp solid ratio and wash water pressure) are optimized, and their influences on separation efficiency were discussed. Under optimum conditions, a fine clean coal concentrate assaying 35.66% ash and 1.63% total sulfur at a recovery of 34.60% was obtained.

Keywords: Fine Coal Tailings, Characterization, Hydrocyclone, Falcon Concentrator

ÖZET

Geçmiş yıllarda, ince kömürlerin değerlendirilmeden atılması daha ekonomikti. Günümüzde ise; madencilik, atıkların bertarafı ve stoklama maliyetlerindeki artış ince fraksiyonlardaki kömürün değerlendirilmesini gerekli kılmaktadır. Bu araştırma, Garp Linyitleri İşletmesi (Tunçbilek-Kütahya) -0,1 mm kömür hazırlama tesisi atıklarının zenginleştirilemesi için uygulanan deneysel çalışmaları içermektedir. Karakterizasyon çalışmaları sonucunda, kömür atıklarında linyit kömüründen daha yüksek yoğun değerlerine sahip kil mineralleri (kaolinit, mika/illit ve smektit grubu), kuvars, siderit, pirit ve dolomit bulunduğu belirlenmiştir. Zenginleştirme prosesi ön ve nihai proseslerden ibarettir. iki aşamalı ön zenginleştirme testlerinde, kömüre eşlik eden kil minerallerini ayırmak için hidrosiklon kullanılmıştır. Bu amaçla, hidrosiklon ve Falcon konsantratörünün yapısal ve operasyonel parametreleri (hidrosiklon çapı, vortex ve apex çapı, besleme giriş basıncı, pülp katı oranı; santrifüj kuvvet, besleme hızı, pülp katı oranı ve yıkama suyu basıncı) optimize edilmiş ve bu parametrelerin ayırma performansına etkisi tartışılmıştır. Optimum şartlarda elde edilen ince temiz kömürün kül ve kükürt oranı %35,66 ve %1,63 olup, kömür kazanma verimi ise %34,60'dır.

Anahtar Kelimeler: İnce Kömür Atıkları, Karakterizaston, Hidrosiklon, Falcon Konsantratörü

1. INTRODUCTION

Today, technology is the main source for progress in many industrial branches but also in mining industry. Therefore, it is necessary to make intensive investigations for creative solutions from exploration to production stage while fulfilling environmental concerns. Despite increasing environmental care, the problematic mining wastes worldwide estimated to be 173.64 billion tons in 2017 (Reportlinker, 2018) and are waiting for plausible solutions. In recent years and especially after second half of the 90's, due to full and semi-mechanized mining, coal production in Garp Lignite Enterprises (Turkey) generated coal with significant amounts of inorganic impurities and fine particles. The coal with minus 180 μm particle size group was accumulated in a waste tailings dam. Tunçbilek Coal Preparation plant with 700 ton/hour nominal capacity, including dewatering processes, consumes approximately 1000 m^3 water for processing of one ton of coal.

In the past, when traditional gravity methods (shaking table, water cyclone, spiral), were not effective, flotation and oil agglomeration were used for processing of fine coal. Flotation has been selected for removing clay and pyrite at finer sizes of coal. Fine coal is defined as minus 0.5 mm size fraction and this fine coal has been processed with conventional methods (flotation, shaking table, spiral, water cyclones, oil agglomeration etc.). Flotation reagents are generally more expensive than other physical beneficiation methods, some other methods are costly or not efficient and also, some have limitations in practice (Rastogi & Aplan, 1985; Dumm & Hogg, 1988; Adel et al., 1991; Ceylan & Küçük, 2004; Surkov et al., 2008; Xia & Peng, 2014). The particle sizes of coal and other inorganic impurities in the tailing make some of these methods unsuitable. Therefore, progress in processing technology has been observed in coal preparation industry as well. The development of new enhanced technologies has made it possible to utilize separation at ultra fine particle sizes. Among them are Mozley Multi Gravity separator, Knelson and Falcon concentrators (Rubiera et al.· 1997; Koca et al., 2000; Çiçek at al., 2002; Honaker & Das, 2004; Hirajima et al., 2005; Honaker et al., 2005; Majumder & Barnwal, 2006; Majumder et al., 2007a; Majumder et al., 2007b; Menendez et al., 2007; Özgen et al.,2009; Oney & Tanrıverdi, 2012; Boylu, 2013; Uslu et al., 2013; Sabah & Koltka, 2014; Boylu, 2014; İbrahim et al., 2014; Tozsin et al., 2016; Xiang-nan et al., 2016; Xiang-nan et al., 2017).

This paper describes a study performed on the chemical, physical and mineralogical characteristics of fine coal tailings and investigates the optimum process flowsheet to concentrate fine clean coal from the Tunçbilek coal preparation tailings having particle size < 0.1 mm using gravity based processing methods. The fine coal tailings were fed to hydrocylones for desliming before concentration tests. A semi-batch centrifugal concentrator manufactured by Falcon Concentrators Inc. was used to treat fine coal particles.

2. EXPERIMENTAL

2.1. Materials

The coal slurry sample used in the experiments was taken from the discharge and of fine tailings in Tunçbilek Coal Preparation Plant of G.L.I of Turkish Coal Enterprises (Kütahya-Turkey), as indicated in Figure 1. The sampling of coal tailings (400 kg) was made using the standard of Türk Standartları Enstitüsü (2002). After sampling process, the representative samples were transferred to the laboratory and tests were immediately started to preserve physical and chemical properties of the coal tailings.

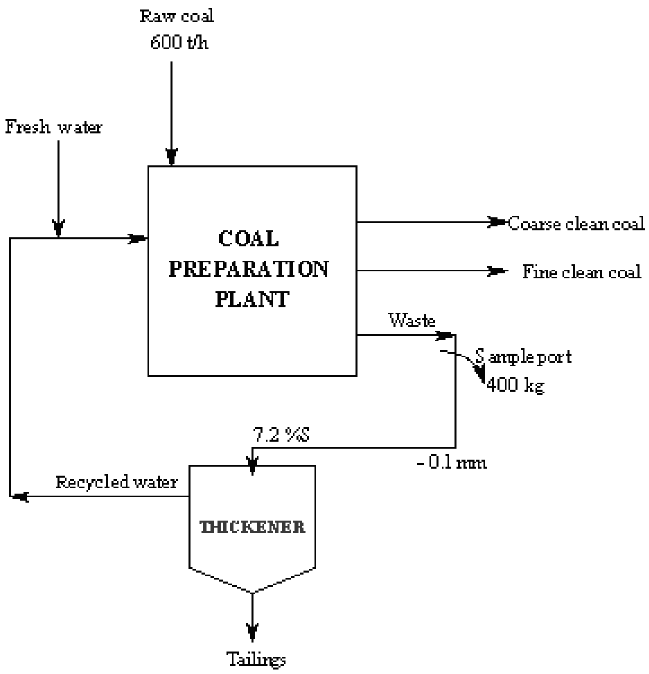

Figure 1. A Schematic Illustration of Coal Preparation Plant at which the Sample was taken

2.2. Methods

2.2.1. Characterization tests

The characterization studies were carried out using a number of qualitative and quantitative analysis techniques. While chemical composition of the fine tailings was made by X-ray fluorescence, thermal analysis (DTA-TGA) was performed by LINSEIS L 81. The particle size distribution was determined by Fritsch-Analysette 22 Particle Size Analyzer. The specific surface area of original tailings was measured by N_2 adsorption isotherm at 77.4 K, in a volumetric adsorption system, Micromeritics-Flowsorb II-2300. The samples were degassed before measurement at 60°C for 30 min. The mineral composition was determined by X-ray diffraction (XRD) using a Rigaku-Giger Flex. The ash and sulfur contents were analyzed according to ISO (2010) and (1996), respectively. Also the calorific value was determined based on ISO (2009). The density of coal tailing was measured using a pycnometer. Following the characterization tests, the beneficiation studies were immediately initiated before any physical and chemical decomposition of tailing.

2.2.2. Concentration tests

Concentration processes are given as preliminary and final processing. In the preliminary two-stage processing tests, the aim was to separate clay minerals associated with coal through hydrocycloning. For this purpose, a systematic study was performed using a pilot-scale hydrocyclone (22 and 44 mm in relatively small diameters) with an internal volume capacity of 200 liters and adjustable pressure of 0 to 10 bars. Under controlled process conditions, the effects of structural and operating parameters such as hydrocyclone diameter, vortex diameter, apex diameter, feed inlet pressure, and suspension solid ratio on separation performance were determined to identify optimum conditions for treating fine tailings. Optimum underflow product of hydrocylone was concentrated in Falcon SB-40 unit where parameters such as gravity force, feed rate, pulp solid ratio and wash water pressure were varied to determine their respective effects on the process response variables. The following relation was used for calculating combustible recovery (in percent) for the two-step coal beneficiation process:

$$Combustible\ recovery\ (\%) = \frac{M_c(1-A_c)}{M_f(1-A_f)} x100 \quad (1)$$

where A_c is ash content of clean coal, A_f is ash content of feed, M_c is mass of clean coal, and M_f is mass of feed.

3. RESULTS AND DISCUSSION

3.1. Characterization Studies of Fine Coal Tailings

XRD analysis of the coal preparation plant tailings indicated that the main mineral composition of the coal samples is quartz, kaolinite and contains a small amount of smectite clay minerals, mica/illite, dolomite and feldspar, and pyrite. The results are in agreement with the findings of Güngör and Türkmenoğlu (1993) who investigated the mineralogy of clays associated with coals in Beye area of Tunçbilek-Domaniç (Kütahya) Neogene basin. The main chemical components of the coal tailings measured by XRF method are presented in Table 1. The content of 13.34% Al_2O_3 and ferric oxide observed indicates of the presence of clay minerals in the tailings; mineralogical data together with chemical composition confirmed that also the tailings are composed of kaolinite, illite and mica. The low percentage of CaO and MgO is attributed to calcium- and magnesium-based carbonates such as dolomite in the tailings. As a result, the original tailings theoretically contain around 63% clay minerals (smectite, illite, kaolinite), 9% quartz and other minerals (dolomite, siderite, pyrite and feldspar) with the percentage of coal being about 20-35%.

Table 1. Chemical Analysis of Original Tailings.

Constituent	Weight (%)
MgO	3.68
CaO	1.53
Al_2O_3	13.34
SiO_2	35.53
Fe_2O_3	5.89
Na_2O	<0.11
K_2O	1.23
TiO_2	0.50
P_2O_5	0.10
MnO	0.13
SO_3	0.41
LOI	37.60

The maximum particle size of the tailings is 0.3 mm. Figure 2 presents the particle size distribution of the tailings with a d_{80} of 85.53 μm for tailings. According to the Wentworth classification (Wentworth, 1922), the percentage of particles in silt size is 64% (4–63 μm) while the percentage of particles in the clay size accounts for 35% (<4 μm), Those particles in sand size are 1% (>63 μm) and represented by larger quartz particles, other silicate minerals and coal particles.

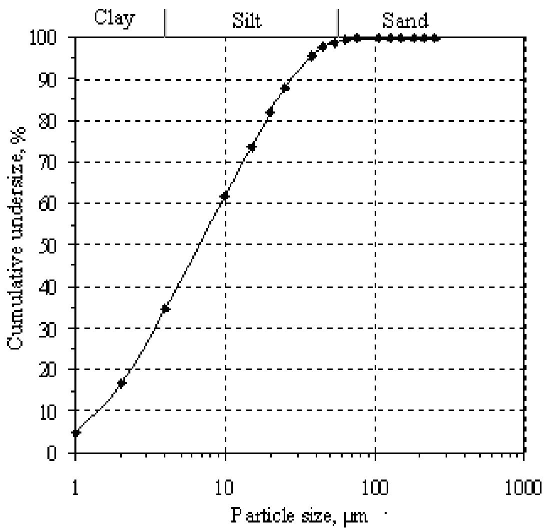

Figure 2. Particle Size Distribution of Coal Preparation Plant Tailings

Specific gravity determined by using pycnometer and the specific gravity of the pulp with 7.2% solids by weight is 1.88 g/cm^3. The specific surface area of the pulp identified by Quanto Chrome Monosorb and the value is 33.32 m^2/g. Qualitative and quantitative analysis results were used to identify the properties of the plant tailings as illustrated in Table 2.

Table 2. Characteristics of the Tunçbilek Coal Preparation Tailings

Parameters	Tailing
Specific gravity, gr/cm^3	1.88
Solids content, %	7.2
Specific surface area, m^2/gr	33.32
LOI, %	37.60
Particle size interval, µm	1………300
Ratio of slime size (< 20 µm) particles, %	81.97
Ratio of clay size particles, %	35
Ratio of silt size particles, %	64
Ratio of sand size particles, %	1
Mineral content	Clay minerals (kaolinite, smectite, illite) quartz, feldspar, siderite, pyrite, and dolomite
Total ash content, %	66.43
Carbon content, %	15.02
Total sulfur content, %	1.38
Loss on ignition, %	37.60
Calorific value, kcal/kg	1835

3.2. Hydrocycloning Tests

3.3.1. Effect of pulp ratio

The effect of pulp ratio on recovery and ash content of fine coal product was investigated at four different solid ratios as 2.5%, 5%, 7.2% and 10% with hydrocyclone diameter of 44 mm (Figure 3).

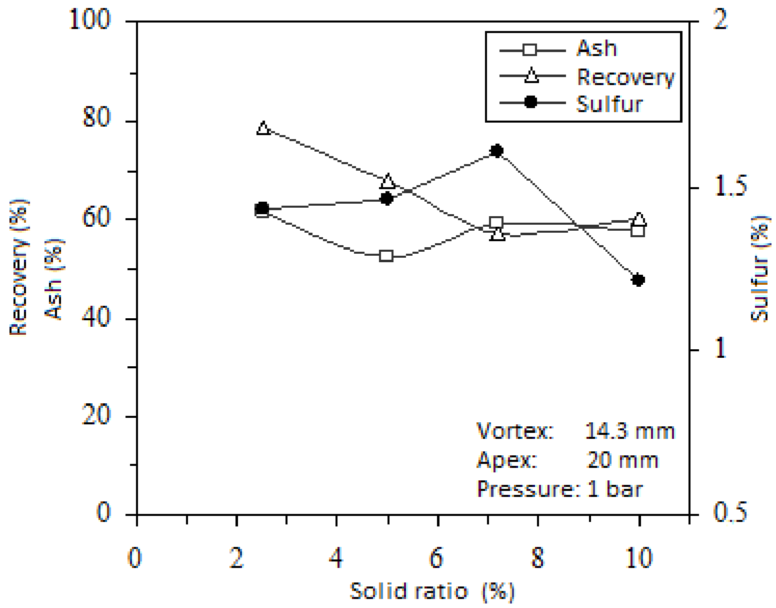

Figure 3. Effect of Percent Solids onto Separation

It can be seen that the recovery decreased with increasing percent solids while the ash content increased above 5% solids. The ash content and recovery were respectively calculated as 52.63% and 67.76% at 5% solids. Actually, the effect of pulp density on hydrocyclone separation is a complex matter. The presence of clay minerals causes an increase in effective viscosity of pulp. Because of this reason, hindered settling conditions existed and separation performance was adversely affected. Also, the classification tests were repeated at original solids ratio (7.2%). It is seen that the ash increased from 52.63% to 59.44% and the recovery value of clean coal decreased to 57.51% from 67.76% when compared to the results of 5% solids.

3.2.2. Effect of feed pressure

In this series of experiments, the influence of feed pressure (1, 2, and 3 bar) was investigated and the results are presented in Figure 4. Feeding at constant pressure and continuous state is the most critical parameter in hydrocyclone separation. Otherwise, classification is affected negatively. It has been determined that increasing pressure has rather little effect on recovery with hydrocyclone of 22 mm diameter. The coal product having the lowest ash content (52.63%) is achieved at 1 bar pressure. The main reason is ascribed to the large apex diameter. But when the apex diameter was decreased to 4.5 mm, the recovery increased sharply. The ash content and recovery at 3 bar pressure is respectively determined at 57.44% and 79.27%.

3.2.3. Effect of hydrocyclone diameter

The hydrocyclone optimization tests showed that the optimum results are achieved with hydrocyclone of 44 mm diameter at 1 bar pressure with 5% solids. The ash content of clean coal is 52.63% with a recovery of 67.76%.

The experiments were performed in order to identify the effect hydrocyclone diameter on classification under the same conditions (5% solids, 1-3 bar pressure) using 22 mm diameter hydrocyclone (Figure 5). A considerable increase in recovery was achieved at low feed pressure and small diameter of hydrocyclone. The cut point (d_{50}) for 22 mm hydrocyclone was found to be smaller than that of 44 mm diameter. Therefore, the clay minerals must have been partitioned in the overflow. If the recovery values of 22 and 44 mm hydrocyclone are compared, optimum results were obtained with 44 mm diameter cyclone at 1 and 2 bar pressures. The main reason is attributed to smaller apex diameter of 22 mm hydrocyclone than that of 44 mm diameter cyclone. Low pressure and small apex diameter dictate the concentration of underflow product. So, the percent solids in the underflow increased. The clean coal recovery (77.34 %) obtained with 22 mm diameter exhibits higher recovery that that of 44 mm hydrocyclone (67.76%).

3.2.4. Effect of apex diameter

A series of experiments have been performed at 2.0, 4.5, and 2.2 mm apex diameters and 20 mm vortex finder in order to determine the effect of apex diameter on 44 mm diameter hydrocyclone (Figure 6). Apex diameter affects the concentration in the underflow. Therefore, the apex diameter must be wide enough for separation of coarse particles in the underflow. Much larger apex diameter cyclone diverts fine particles to underflow. The classification performance is affected negatively by small apex (2.2 mm) and this causes high concentration of underflow product.

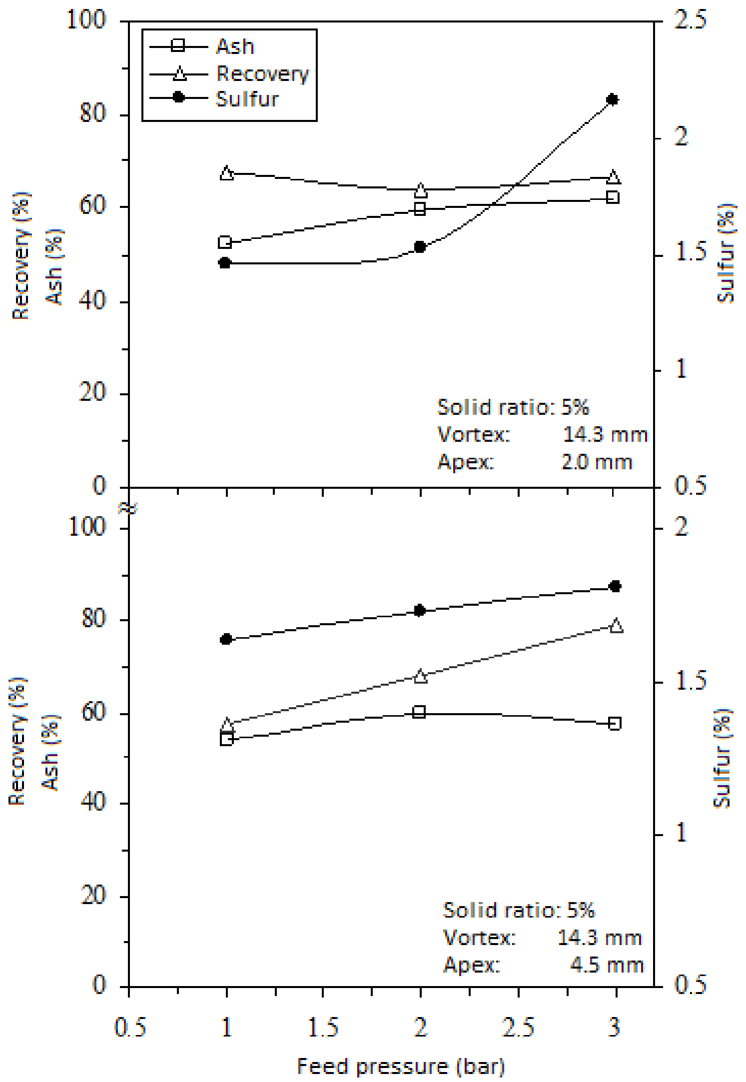

Figure 4. Effect of Feed Pressure of 20 mm and 4.5 Apex Diameters onto Hydrocyclone Classification

The high ash content is observed because of high pressure of 44 mm hydrocyclone with both 2.2 mm and 20 mm apex diameters. The ash percent of clean coal is calculated as 54.55% for 2.2 mm apex at 1 bar. At the same pressure, the ash value is determined to be 52.63% upon raising the apex diameter to 20 mm. The ash content increased due to a pressure increase for 2.2 mm and 4.5 mm apex diameters. The ash contents are less than that found for 20 mm apex diameter. This situation is explained by the presence of clay minerals (fine particles) that are carried to underflow; this causes high ash content in clean coal upon increasing the apex diameter. Another important result must be pointed out that the smaller apex diameter generates higher pulp concentration and in turn higher recoveries. This is especially more dominant at 2.2 mm apex diameter.

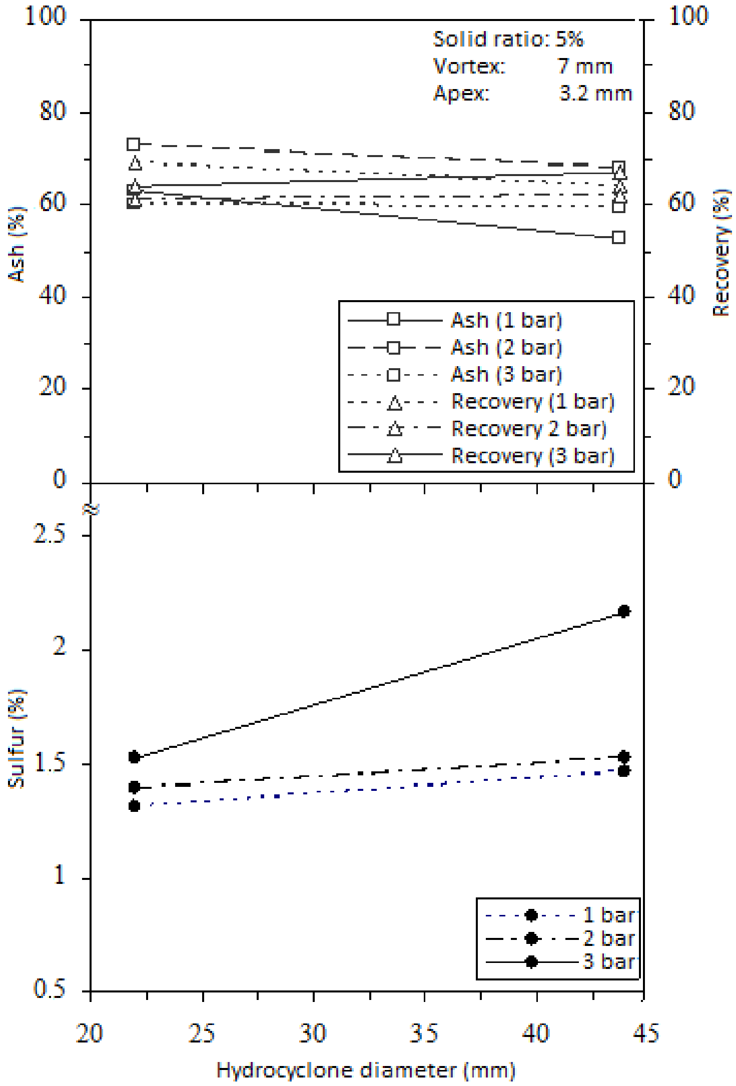

Figure 5. Ash and Sulfur Removal against Hydrocyclone Diameter; (a) Ash and Recovery Values, (b) Sulfur Contents

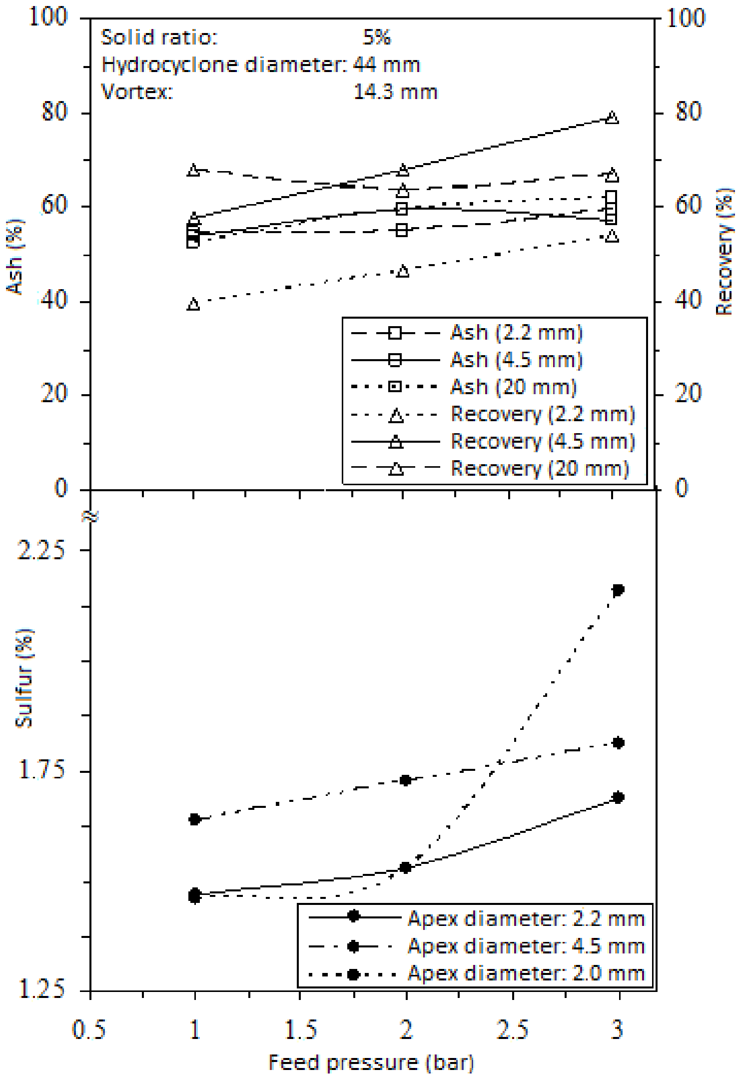

Figure 6. Variation of Ash and Sulfur Contents with Feed Pressure at Different Apex Diameters

A dominant increase is achieved at 2 bar pressure; the ash content decreased with increasing feed pressure, as seen Figure 7. It is well known from the literature that increase in pressure causes higher centrifuge forces (Olson & Omman, 2004) and thus the classification recovery gets increased. But, in practice the clean coal is obtained with ash content of 55.53% at 3 bar pressure and this at 1 bar pressure is better than the ash value of 57.88%.

The original tailings containing 66.43% ash is preconcentrated with 22 mm 44 mm hydrocyclones at two stages (Figure 8). The optimum result is achieved with 44 mm diameter hydrocyclone at percent solids of 5%, 2.2 mm apex diameter, 14.3 mm vortex diameter and 1 bar pressure.

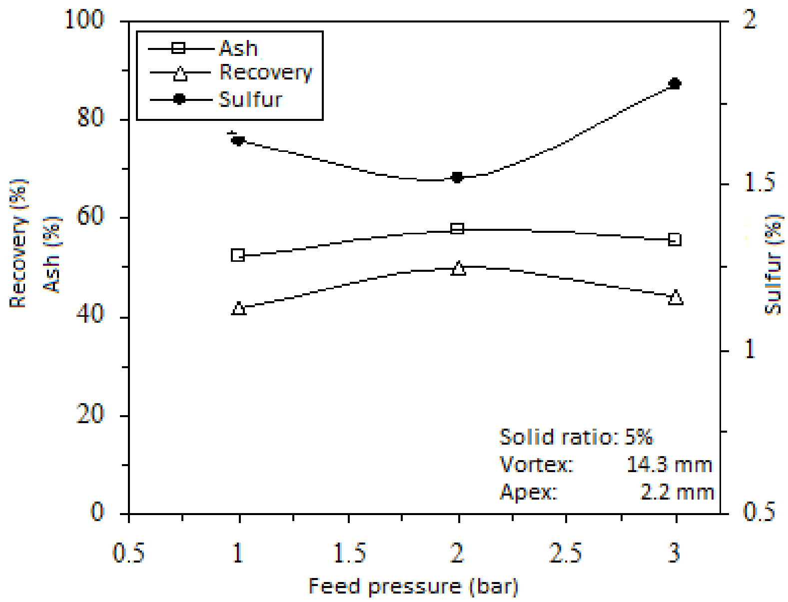

Figure 7. Ash/Sulfur Contents and Recovery Values of Hydrocyclone of 2.2 Mm Apex Diameter without Vortex Finder

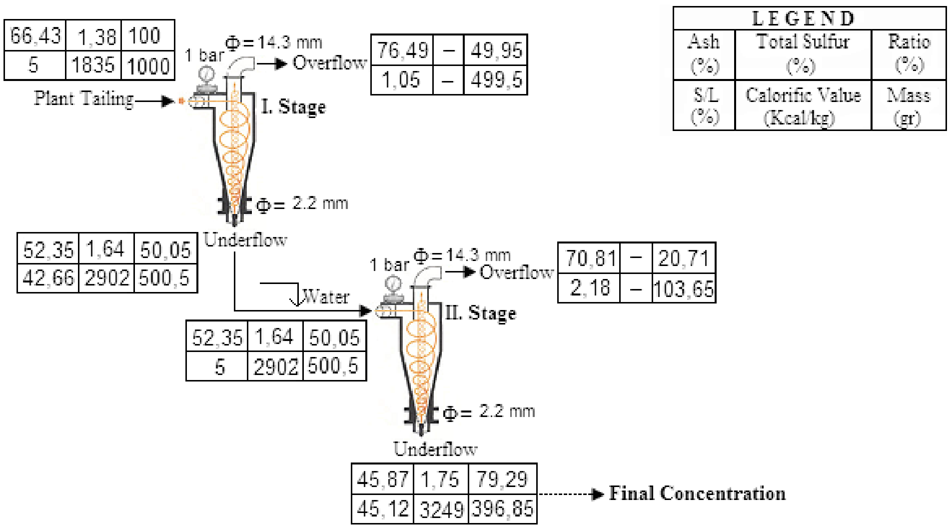

Figure 8. Material Balance for Two-Stage Hydrocyclone Classification

3.3. Falcon Concentrator Tests

The coal obtained with an ash content of 45.87% by two stage hydrocyclone classification was fed to a high capacity Falcon SB 40 unit which operates at low cut point specific gravity. The effects of main operating parameters, namely gravitational force, water pressure, percent solids and feed rate, on the combustible coal recovery, including ash and sulfur contents were investigated.

Figure 9 shows the effect of gravitational g-forces on ash/sulfur contents and recovery. The ash content and recovery decrease with increasing gravitational forces. The heavy particles have a tendency of being reported to overflow product over coal at lower g-force values. Under the greater gravitational force, the gravitational force acting on the particle is larger, and the possibility of particles entering into the overflow is lower. Therefore, the heaviest minerals associated with coal such as quartz, dolomite, siderite and feldspar have separated successfully at the concentration zone and this causes a decrease in ash contents at higher g-forces. The decrease in ash contents proves that the gravity force plays an important role in the concentration process as emphasized in the literature (Parekh & Khalek, 2002; Honaker et al., 2004). The combustible recovery obtained at lower and higher g-forces is the comprehensive reflection of the ash/sulfur content. As a results, an optimum gravity force provided by a 300*g force for minimizing the product ash content is shown in Figure 9.

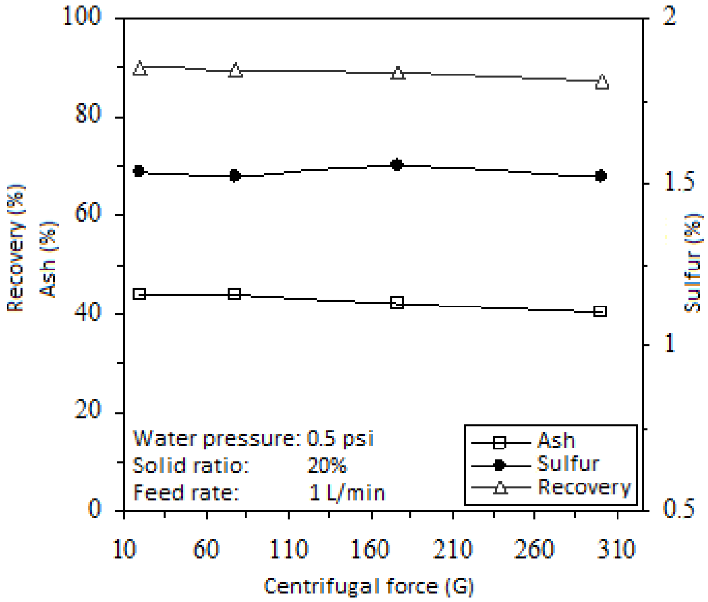

Figure 9. Experimental Results Showing the Effect of Applied G-Force on Ash-Sulfur Content and Recovery

The effect of wash water pressure on ash/sulfur contents and recovery was investigated. At fixed gravitational force of 300*g, the tests results of changing the wash water pressure performed at 0.5, 1.0 and 1.5 psi are given in Figure 10. As it can be seen from Figure 10, the optimum ash content (40.26%) was found at 0.5 psi. Decreasing the wash water pressure resulted in lower ash and sulfur content at 300*g due to particles being rejected by fluidizing water. Lower fluidizing flow assists in removing clay but also adversely affects combustible recovery; this greater wash water pressure provides greater fluid drag force for particles in the settling process, which leads to more light particles into the overflow.

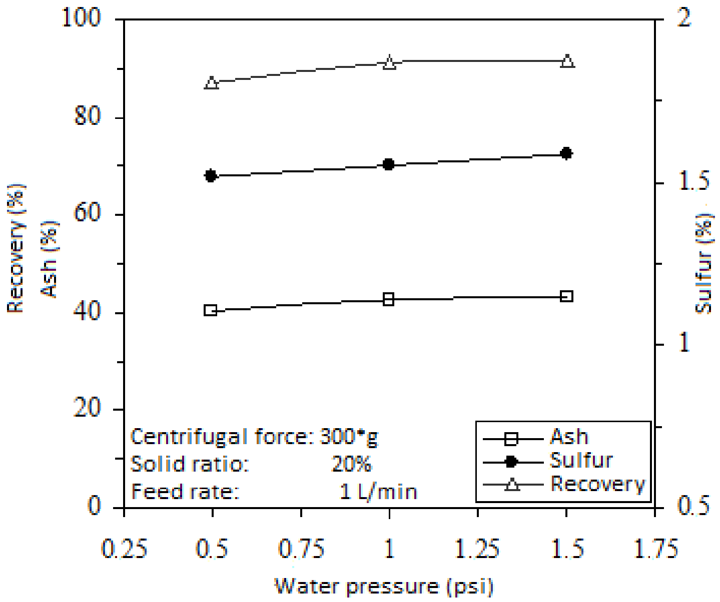

Figure 10. Effect of Water Pressure on Separation Performance of Coal with Falcon SB 40

Figure 11 gives the optimization results of feed rate on ash and recovery. It is clear that increasing the feed rate has a negative effect on separation performance. Falcon concentrator performance is limited by the ability of the heavy particles to settle to the bowl wall during retention time. So, increasing the feed rate increased the feed material at short time and led to insufficient separation. This behavior is similar to those results reported by other investigators (Honaker et al. 1996; Parekh & Khalek 2002). An optimum feed rate of 1 L/min was found for the minimum ash content of 40.26% with a recovery of 87.19%.

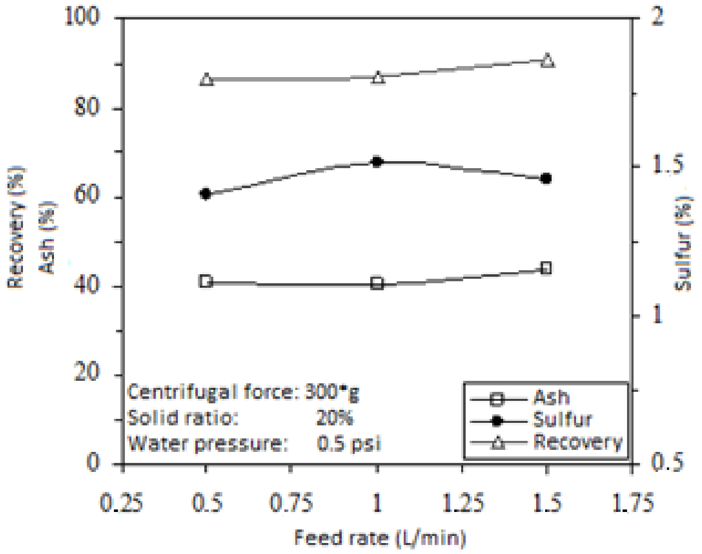

Figure 11. Effect of Feed Rate on Ash, Sulfur Content, and Recovery

The effect of percent solids on recovery and ash reduction was conducted over a range of 10% to 30% solids by weight is shown in Figure 12. It was found that increasing solids content from 10% to 20% resulted in an increase in the product ash value from 40.26% to 43.59%. The high feed solid ratio reduces the particle settling time and thus, maintains a high separation performance.

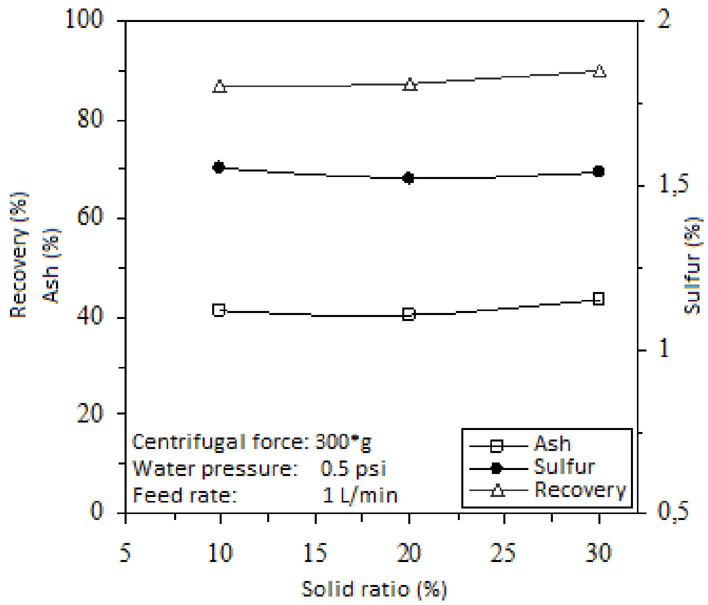

Figure 12. Effect of Solid Rate on Ash/Sulfur Contents and Recovery

Finally the coal was obtained at a maximum centrifugal force of 300*g under the feed rate of 1 L/min and minimum water pressure of 0.5 psi. As seen in Figure 11, lower water pressure causes a decrease in ash content. Because of this reason, optimum experimental parameters were repeated with water pressure of 0.25 psi. After optimization of Falcon concentration tests, the coal was decanted in order to reduce ash (40.26%) and total sulfur (1.52%) content. The clean coal exhibited 35.66% ash and 1.63% total sulfur with a recovery of 34.60% after decantation (Figure 13).

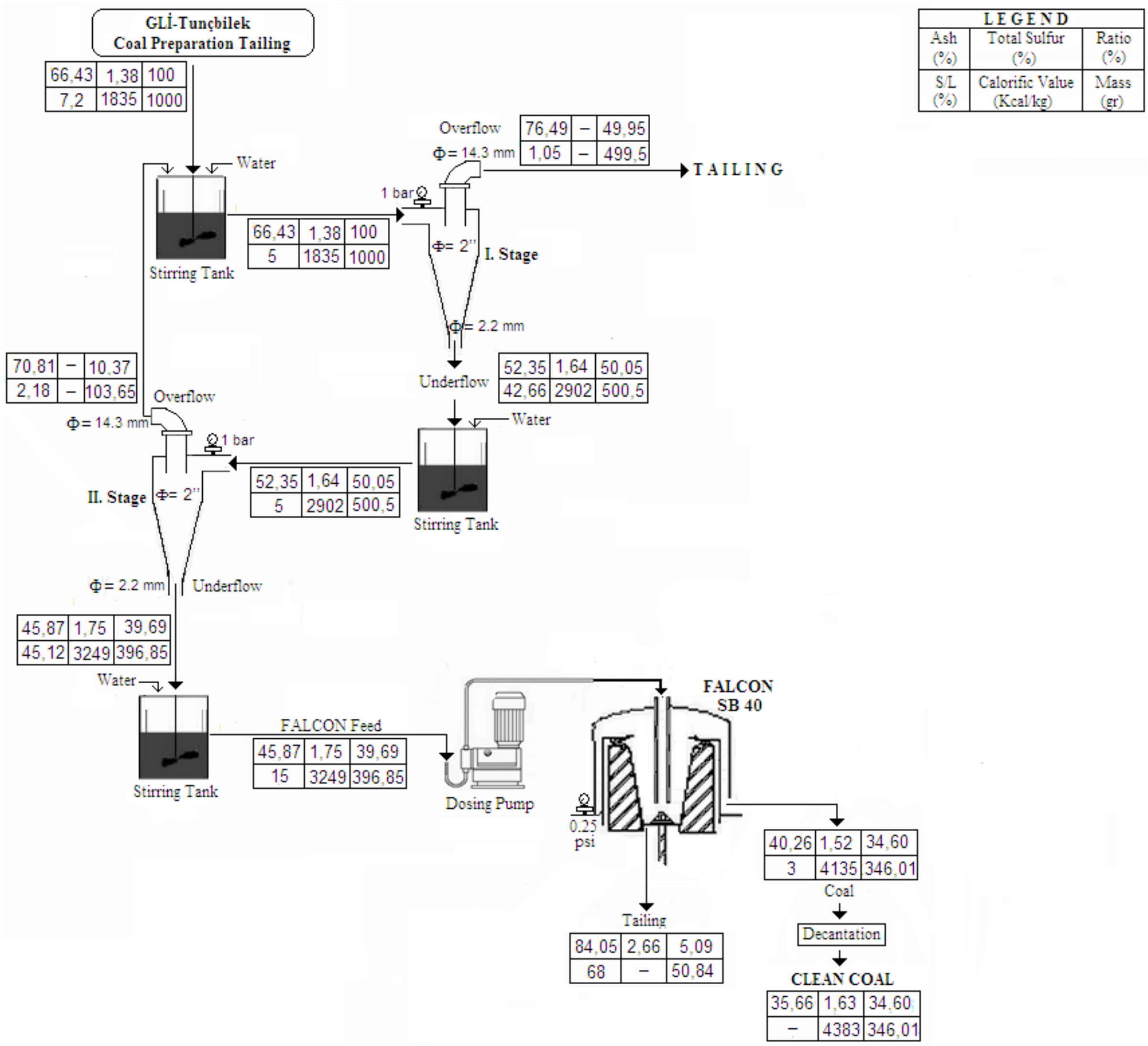

Figure 13. Processing Flowsheet for Beneficiation of Fine Coal Tailings

4. CONCLUSIONS

The classification studies were conducted in hydrocyclones of small-diameters (D = 22 and 44 mm) for desliming of ultrafine coal tailings with size less than 0.1 mm. Structural parameters like vortex diameter, apex diameter, and hydrocyclone diameter were optimized along with the operating parameters like feed inlet pressure and suspension solid ratio. The deslimed product was obtained in two stages with an ash content of 45.87% and recovery of 74.02% using 44 mm hydrocyclone with an apex diameter of 2.2 mm and vortex diameter of 14.3 mm at 1 bar optimum pressure.

Following classification tests, optimum underflow product of hydrocylone was fed to Falcon SB 40 concentrator. Influence of the key operation parameters, namely gravity force, water pressure, pulp solid ratio and pulp feed rate, on the separation efficiency were investigated. Optimum results were obtained at 20% solids, water pressure of 0.5 psi, feed rate of 1 L/min with a maximum g-force of 300*g. The ash content of Falcon feed (optimum hydrocyclone underflow product) decreased to 40.26% from 45.87% with a recovery of 34.60%. The clean coal obtained from Falcon tests was processed by decantation in order to reject some of the ash content.

The clean coal was obtained with an ash value of 35.66% with 1.63% total sulfur content after beneficiation studies of coal tailings containing ash value of 66.43% and total sulfur content of 1.38%. The calorific value was increased to 4383 kcal/kg from 1835 kcal/kg with a recovery of 34.6%. This investigation revealed that beneficiation of fine coal tailings is possible by using gravity based processing methods with a combination of hydrocyclone circuit and Falcon concentrator.

The benefit of utilizing ultrafine coal tailings of Tunçbilek could provide 90.000 tons/year clean coal which could be used at thermal power plant, cement industry and brick factories. This means that a major amount of economic gain is obtained particularly by this recycling process.

5. ACKNOWLEDGEMENTS

The investigation presented in this publication was funded by TUBITAK (Turkish Scientific and Technical Research Council) with the project number 1041080.

6. REFERENCES

Adel, T., Wang, D., Yoon, H. (1991). Washability Characterization of Fine Coal, *Proceedings of 8th Annual International Pittsburgh Coal Conference*, University of Pittsburgh, 204–209.

Boylu, F. (2013). Modeling of Free and Hindered Settling Conditions for Fine Coal Beneficiation through a Falcon Concentrator, *International Journal of Coal Preparation and Utilization*, 33(6), 277–289.

Boylu, F. (2014). Autogenous Medium Fine Coal Washing Through Falcon Concentrator, *Separation Science and Technology*, 49, 627–633.

Ceylan, K., Kücük, M.Z. (2004). Effectiveness of the Dense Medium and the Froth Flotation Methods in Cleaning Some Turkish Lignites, *Energy Conversion and Management*, 45(9-10), 1407–1418.

Çiçek, T., Cöcen, İ., Engin, V.T., Demir, Ş. (2002). Recovery of Fine Coal from Tailings of Coal Washing Plants. *Proceedings of IXth International Mineral Processing Symposium*, 198–205.

Dumm, T.F., Hogg, R. (1988). Washability of Ultrafine Coal, *Minerals & Metallurgical Processing*, 5(1), 25–32.

Güngör, P., Türkmenoğlu, A. (1993). The Mineralogy of Clays Associated with Coals in Beye Area of Tunçbilek-Domaniç (Kütahya) Neogene Basin, *Proceedings of 6th National Clay Symposium*, 95–109.

Hirajima, T., Kubo, Y., Suzuki, K. (2005). Recovery of Fine Combustible Matter from Coal Washery Waste by Multi-Gravity Separator, *Shigen-to-Sozai*, 121(9), 456–460.

Honaker, R.Q., Paul, B.C., Wang, D., Huang, M. (1995). Application of Centrifugal Washing for Fine-Coal Cleaning, *Minerals and Metallurgical Processing,* 8(10), 80–84.

Honaker, R.Q., Das, S. (2004). Ultrafine Coal Cleaning Using A Centrifugal Fluidized-Bed Separator, *Coal Preparation*, 24, 1–18.

Honaker, R.Q., Sad, A., Nombe, M. (2005). Improving the Separation Efficiency of the Knelson Concentrator Using Air Injection, *Coal Preparation*, 25, 99–116.

ISO (1996). Solid Mineral Fuels-Determination of Total Sulfur-High Temperature Combustion Method (Standard No ISO 351), International Organization for Standardization, Geneva, Switzerland.

ISO (2009). Solid Mineral Fuels-Determination of Gross Calorific Value By The Bomb Calorimetric Method and Calculation of Net Calorific Value (Standard No ISO 1928), International Organization for Standardization, Geneva, Switzerland.

ISO (2010). Solid Mineral Fuels-Determination of Ash (Standard No ISO 1171), International Organization for Standardization, Geneva, Switzerland.

İbrahim, S.S., El-Anadoly, E.E., Farahat, M.M., Selim, A.Q., Xei-Menshawy, A.H. (2014). Separation of Pyritic Sulfur from Egyptian Coal Using Falcon Concentrator, *Particulate Science and Technology*, 32, 588–594.

Koca, K., Koca, S., Karaoğlu, M. (2000). Recovering of Fine Coal Particles from Tailing Ponds of TKİ Alpagut-Dodurga Coal Washing Plant. *Mineral Processing on the Verge of the 21st Century: Proceedings of the 8th International Mineral Processing Symposium*, 427–431.

Majumder, A.K., Barnwal, J.P. (2006). Modeling of Enhanced Gravity Concentrators – Present Status, *Mineral Processing & Extractive Metallurgy*, 27, 61–86.

Majumder, A.K., Bhoi, K.S., Barnwal, J.P. (2007a). Multi-Gravity Separator: An Alternate Gravity Concentrator to Proses Coal Fines, *Minerals & Metallurgical Processing*, 24(3), 133-138.

Majumder, A.K., Tiwari, V., Barnwal, J.P. (2007b). Separation Characteristics of Coal Fines in a Knelson Concentrator – A Hydrodynamic Approach, *Coal Preparation*, 27, 126–133.

Menendez, M., Gent, M., Torano, J., Diego, I. (2007).Optimization of Multi-Gravity Separation for Recovery of Ultrafine Coal, *Minerals* & *Metallurgical Processing*, 24(4), 253–263.

Olson, T., Omman, R.V. (2004). Optimizing Hydrocyclone Design Using Advanced CFD Model, *Minerals Engineering,* 17(5), 713–720.

Oney, Ö., Tanrıverdi, M. (2012). Optimization and Modeling of Fine Coal Beneficiation by Knelson Concentrator Using Central Composite Design (CCD), *The Journal of Ore Dressing,* 14(27), 11–18.

Özgen, S., Türksoy, V.O., Sabah, E., Oruç, F. (2009). Process Development Studies on Recovery of Clean Coal from Ultra Fine Hardcoal Tailings Using Enhanced Gravity Separator, *The Canadian Journal of Chemical Engineering*, 87(5), 715–725.

Parekh, B.K., Khalek, M.A.A. (2002). Using Falcon Concentrator as a New Technology for Removal of Environmental Pollutants of Egyptian Coal, *Journal of Ore Dressing,* 7, 20–28.

Reportlinker (2018). Global Mining Waste Management Market 2017-2022, https://www.reportlinker.com/p05288513 (erişim tarihi 18.03.2018).

Rastogi, R.C., Aplan, F.F. (1985). Coal Flotation as a Rate Process, *Minerals* & *Metallurgical Processing*, 2, 137–147.

Rubiera, F., Hall, S.T., Shab, C.L. (1997). Sulfur Removal by Fine Coal Cleaning Processes, *Fuel*, 76(13), 1187–1194.

Sabah, E., Koltka, S. (2014). Separation Development Studies on The Beneficiation of Fine Lignite Coal Tailings by The Knelson Concentrator, *Energy & Fuels*, 28, 4819–4827.

Surkov, A.V., Samykina, E.V. Eppelbaum, L.V., Semenov, S.V. (2008) The Main Reason for Mineral Loss in Gravity Dressing, *The Open Mineral Processing Journal*, 1(1), 37–44,

Tozsin, G., Acar, O., Sivrikaya, O. (2016). Evaluation of a Turkish Lignite Coal Cleaning by Conventional and Enhanced Gravity Separation Techniques, *International Journal of Coal Preparation and Utilization*, 38(3), 135–148.

Türk Standartları Enstitüsü (2002). Water Quality- Sampling-Part 10: Guidance on Sampling of Waste Waters (Standard No TS ISO 5667-10), Türk Standartları Enstitüsü, Ankara, Turkey.

Uslu,T., Sahinoglu, E., Yavuz, M. (2013). Desulphurization and Deashing of Oxidized Fine Coal by Knelson Concentrator, *Fuel Processing Technology*, 101, 94–100.

Wentworth, C.K. (1922). A Scale of Grade and Class Terms of Clastic Sediments, *The Journal of Geology,* 30(5), 377–392, 1922.

Xia, Y., Peng, F.F., 2014. Effect of Structured Plates on Fine Coal Gravity Separation in a Liquid Fluidized Bed System, *Engineering Applications of Computational Fluid Mechanics*, 1(3), 164–180.

Xiang-nan, Z., You-jun, T., Qi-xiao, S. (2016). Separation of Flocculated Ultrafine Coal by Enhanced Gravity Separator, *Particulate Science and Technology*, 35(4), 393–399.

Xiang-nan, Z., You-jun, T. Qi-xiao, S. and Zhong-pei, M. (2017). Enrichment and Migration Regularity of Fine Coal Particles in Enhanced Gravity Concentrator, *International Journal of Mineral Processing*, 163, 48–54.