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RESEARCH ARTICLE

ENRICHMENT OF SİVAS/GEMEREK LIGNITE COAL BY OIL AGGLOMERATION USING DIFFERENT VEGETABLE OILS

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ABSTRACT

The aim of this study was to investigate the use of various vegetable oils (almond oil, hazelnut oil, poppy oil, soybean (soya) oil, sunflower oil) for Sivas/Gemerek (in Turkey) lignite coal by oil agglomeration. The study examined the effect of bridging liquid type and dosage on oil agglomeration. Vegetable oil dosages of 2%, 5%, 10% and 20% were investigated in oil agglomeration experiments. The agglomeration of lignite coal with these bridging liquids was evaluated based on yield, combustible recovery and ash rejection. The agglomeration performances of these vegetable oils were compared. The highest ash rejection (70.30%) was observed by using soybean (soya) at 20% of the bridging liquid dosage. The yield and combustible recovery of lignite coal were achieved 36.46% yield and 38.05% combustible recovery in this soybean (soya) oil dosage, respectively. The lignite coal ash content was reduced from 19.08% to 15.54% under these optimum conditions.

Keywords: *Ash rejection, Combustible recovery, Lignite coal, Oil agglomeration, Vegetable oil, Yield.*

1. INTRODUCTION

Coal, petroleum and natural gas are fossil energy raw materials. Generally, rocks containing 50% combustible material are described as coal. Coal contains inorganic materials and moisture except organic materials. Coal is classified into four ranks by The American Society for Testing and Materials (ASTM): lignite, sub-bituminous, bituminous and anthracite. Lignite coal, also known as brown coal or low-rank coal, has the following characteristics: low calorific value, high moisture and ash content, proneness to spontaneous combustion, low friability.

Impurities in coal, which are important for both the use and cleaning of coal, are divided into three groups: moisture, ash and sulfur. The failure to reach the desired yield and ash ratios with classical methods for cleaning fine coals (-500 µm) has led to the emergence of many physicochemical methods. Among these methods, oil agglomeration is a method with advantages such as high efficiency, low ash concent, simple applicability and high selectivity. Oil agglomeration is a process for the enrichment of fine coals (-500 µm) and was developed as an alternative to flotation method. Also this method achieves beneficiation of low-quality coals such as lignite effectively [1,2].

In this method, differences in surface properties (hydrophobic (organic) and hydrophilic (inorganic)) between coal and gangue minerals are utilized to remove inorganic impurities. The oil agglomeration process involves intense mixing of an immiscible liquid (bridging liquid) and an aqueous suspension of fine coal. The hydrophobic (organic) coal particles readily coat with the bridging liquid, leading to the formation of agglomerates. On the other hand, hydrophilic (mineral matter) particles do not agglomerate upon collision. After the agglomeration process, the slurry is screened to separate the coal agglomerates (concentrate) from the non-agglomerated particles (tailings) [3,4].

Several studies have reported the use of various types of vegetable oils as bridging liquids in oil agglomeration. The study conducted by Alonso et al. [5] focused on obtaining high calorific value products from coal cleaning wastes. They achieved this by agglomerating the wastes with vegetable oils, including crude and refined sunflower and soybean oils. The study conducted by Asad et al. [6] focused on the beneficiation of Makarval coal. They investigated the use of soybean oil as an agglomerant in this process. The ash content of agglomerates has been reduced from 30% to 7.5% and sulfur content was reduced from 5.4% to 2.0%. The study conducted by Chakladar et al [7] found that turpentine oil is an effective bridging liquid for the beneficiation of Indian cooking coals by oil agglomeration. In the study, two high-ash coals of Indian origin, 26% and 34% ash, were selected. A wide range of particle sizes, pH, electrolyte type, agitation conditions and oil dosage were investigated. Both coals (-200 mesh) showed approximately 50% reduction in ash content. The study by Chary and Dastidar [8] examined the use of various oils as bridging liquids in the oil agglomeration of Indian bituminous coal. The oils investigated include: jatropha oil, karanja oil, rubber seed oil, cotton seed oil, sunflower oil, soya oil, castor oil, palm oil, sesame oil, coconut oil. The study conducted by Garcia et al. [9] found that refined sunflower and soybean oils were suitable for coal agglomeration with three Spanish anthracites. The study conducted by Ken and Nandi [10] focused on the desulfurization of high sulphur Indian coal by oil agglomeration using linseed oil. Experimental results showed that raw coal with 5.52% sulfur, 13.47% ash and GCV of 7038 kcal/kg can be beneficiated to produce clean coal with 2.18% sulfur along with 5.32% ash and 7769 kcal/kg GCV. The study by Malik et al. [11] investigated the use of edible and non-edible vegetable oils, including castor oil, soybean oil (soya oil), linseed oil, and mahua oil, for agglomerating five different types of Indian coals. Using different coal-oil combinations, agglomerate yields ranged from 40.0 to 87.5% and ash rejections from 13.5 to 62.0%. Valdés and Garcia [12] carried out agglomeration of coal fines cleaning wastes from two different Spanish coal cleaning plants with waste vegetable oils (WVO) from households. They recovered high calorific value and low ash coal with waste sunflower oil and olive oil.

The type and nature of the bridging liquid has a very important effect on the performance of the agglomeration process. It seems like various types of oils, such as diesel oil, fuel oil, kerosene, engine oil, vegetable oils and fish oil, have been effectively utilized as bridging liquids in the agglomeration

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process. Considered renewable are vegetable oils with negligible sulphur, nitrogen and metal content. There are also several environmental benefits to using vegetable oils, too. In this work, different virgin vegetable oils (almond oil, hazelnut oil, poppy oil, soybean (soya) oil, sunflower oil) have been tested as bridging liquid in oil agglomeration. These vegetable oils have a high density of approximately 0.9 g/cm^3 and they are less expensive than compared to hydrocarbons. The usage of vegetable oils for oil agglomeration appears to be an attractive bridging liquid that should be considered. In the present study, the influence of different vegetable oil types and dosages on oil agglomeration of Sivas/Gemerek lignite coal was investigated and the agglomeration performances of these vegetable oils were compared.

2. MATERIAL AND METHOD

2.1. Material

The coal sample from the Sivas/Gemerek region in Turkey was used for the agglomeration experiments. The proximate and calorific value analysis of the coal sample has been completed (Table 1). The X-ray diffractometer can be used to analyze the composition of lignite coal. In this case, it detected the presence of quartz (SiO_2) and pyrite (FeS_2) in the lignite coal sample. The particle size distribution of the lignite coal ground to -500 µm used in the agglomeration experiments is given in Table 2.

Table 1. Proximate and calorific value analyses of Sivas/Gemerek lignite coal.

Proximate Analysis		**Calorific Value Analysis**	
Parameters	**(%)**	**Parameters**	**(kcal/kg)**
Moisture in original coal	23.79	Upper calorific value of dry coal	3555
Moisture in air-dried coal	19.49		
Ash in dry coal	19.08		

Table 2. Particle size distribution of Sivas/Gemerek lignite coal.

Particle size (µm)	**Weight (%)**
-500 + 425	11.15
-425 + 300	12.70
-300 + 250	11.07
-250 + 180	10.54
-180 + 125	9.38
-125 +90	8.92
-90 +63	7.75
-63 +45	6.32
-45	22.17
Total	100

The study used the following vegetable oils: almond oil, hazelnut oil, poppy oil, soybean (soya) oil and sunflower oil. The vegetable oils used in the oil agglomeration experiments were obtained from the local market and used without any chemical or physical modification. The properties and densities of the bridging liquids used in this study are given in Table 3, where these are the data provided by the manufacturers.

2.2. Method

The coal sample was grinded using ball mill by closely controlled and sieved the particle size -500 µm. Heidolph RZR 2051 speed-controlled mechanical stirrer was used for performing the agglomeration tests. Agglomeration experiments were undertaken in 1000 mL glass beaker. Three-blade metal portable baffles were inserted to beaker as a turbulence generator. 15 g coal-400 mL distilled water mixtures were agitated to provide complete wetting of coal particles. Bridging liquid (vegetable oil) was then added, and mixture of coal-bridging liquid-water was agitated at 400 rpm for 15 min of agglomeration time. The experiments were carried out at the ambient pH of the mixture, which was measured to be pH 5.50. After agglomeration, the slurry was transferred to a sieve with an aperture of 500 µm. This separation process helps to separate the agglomerates from the tailings. The agglomerates were washed with distilled water. Then acetone washing was performed to remove the bridging liquid and again washed with distilled water. The oil agglomeration process schematic representation is shown in Figure 1.

Table 3. Bridging liquids used in this study and their properties.

Bridging Liquids	Properties	Density (g/cm^3)
Almond oil	It is a yellowish vegetable oil that contains unsaturated oil acids of oleic and linoleic acid, saturated oil acids myristic and palmitic acid glycerides obtained by pressing Rosaceae seeds	0.912
Hazelnut oil	It is a vegetable oil that contains oil acids such as oleic acid and linoleic acid which is not chemically processed and is obtained by physical processes and extraction from hazelnut fruits	0.914
Poppy oil	It is a vegetable oil containing oleic acid, linoleic acid and lower amounts of stearic acid and palmitic acid glycerides which is obtained from pressing the seeds of Papaver somniferum varieties (containing 47-51% oil).	0.922
Soybean (soya) oil	It is a vegetable oil that is obtained by extraction or pressing from the seeds of soybean (Glycine max) species	0.917
Sunflower oil	It is a vegetable oil that contains oleic acid and linoleic acid obtained from the seeds of the plant Helianthus annuus with an oil content of 39-45%.	0.912

The agglomerates were dried at 105 ± 5 °C. At the end of drying, the agglomerates were weighed and analyzed for ash content. The standard ASTM-3174 method has been used for ash determination [13].

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The yield (%), combustible recovery (%) and ash rejection (%) of the agglomerates were calculated by formulas as below:

$$Y(\%) = \frac{Wt_a}{Wt_f} * 100 \quad (1)$$

$$CR\ (\%) = \left(\frac{Wt_a}{Wt_f}\right) * \left(\frac{100 - A_a}{100 - A_f}\right) * 100 \quad (2)$$

$$AR(\%) = \left[\frac{A_f - \left(A_a * \frac{Wt_a}{Wt_f}\right)}{A_f}\right] * 100 \quad (3)$$

Where, Y= yield (%), Wt_a= weight of agglomerate (g); Wt_f= weigh of feed coal (g); CR= combustible recovery (%); A_a= ash of agglomerate (%); A_f= ash of feed coal (%); AR = ash rejection (%).

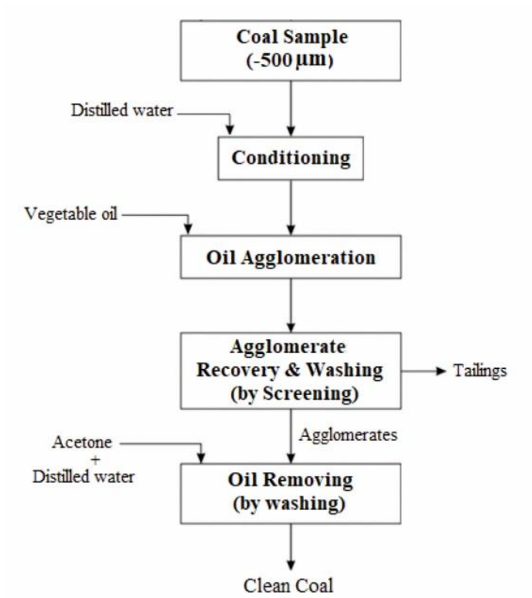

Figure 1. The oil agglomeration process schematic representation.

3. RESULTS AND DISCUSSION

The choice of liquids as bridging liquid in oil agglomeration is indeed crucial for the success of the process. It can significantly impact the efficiency and effectiveness of oil agglomeration. The bridging liquid acts as a medium to facilitate the agglomeration of coal particles. Bridging liquids have different properties, such as density, viscosity, surface tension and functional groups, which can

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affect the agglomeration process. Therefore, careful consideration should be given to choosing the right liquid for successful oil agglomeration.

The study investigated the usage of five different vegetable oils (almond oil, hazelnut oil, poppy oil, soybean (soya) oil, and sunflower oil) in agglomeration experiments. The effects of these oils at different dosages (2%, 5%, 10%, and 20%) on the oil agglomeration process were examined.

Figure 2 illustrates the agglomeration performance of lignite coal with different almond oil dosages. Figure 3 illustrates the agglomeration performance of lignite coal with different sunflower oil dosages. Figure 4 illustrates the agglomeration performance of lignite coal with different poppy oil dosages.

As seen in Figures 2 and 3; the lowest yield and combustible recovery values in the examined vegetable oils were obtained at very low bridging liquid dosages (2% and 5%) for almond oil and sunflower oil. When almond oil and sunflower oil were used at low liquid dosages, an adequate liquid bridge could not form between the coal particles, resulting in low yield and combustible recovery. Increasing the doses of almond oil and sunflower oil resulted in higher yields and combustible recovery values of the agglomerates. Similarly, both yield and combustible recovery values of the agglomerates were increased by increasing the dosage of poppy oil. (Figure 4). This can be explained by the improved contact of coal pores with bridging liquids and the increased formation of larger spherical agglomerates due to an increase in the number of bridging liquid droplets [14]. However, the increase in combustible recovery is accompanied by a decrease in ash rejection. This can be explained to a reduced in the selectivity of the bridging liquid droplets. Similarly, Shukla and Venugopal [15] observed that there was a decrease in ash rejection as the oil dosage increased.

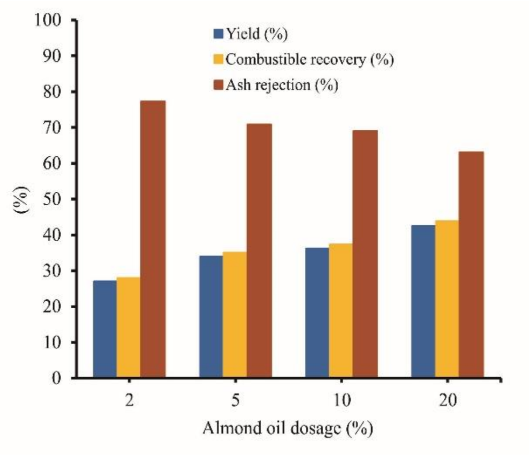

Figure 2. Agglomeration performance of lignite coal with different almond oil dosages.

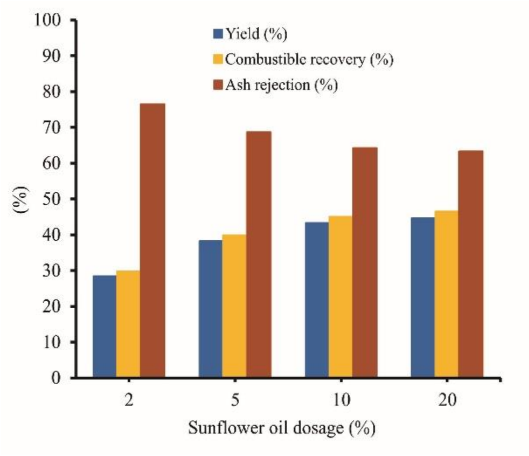

Figure 3. Agglomeration performance of lignite coal with different sunflower oil dosages.

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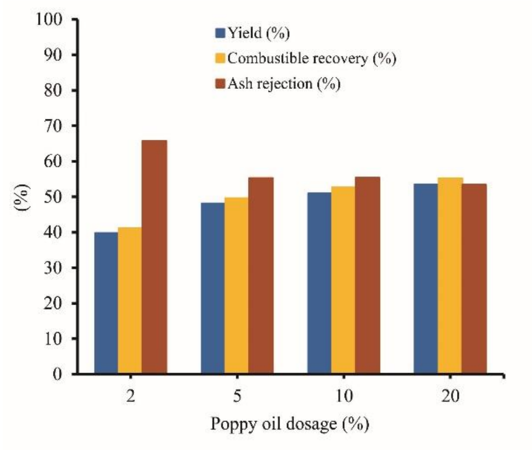

Figure 4. Agglomeration performance of lignite coal with different poppy oil dosages.

Figure 5 shows the agglomeration performance of lignite coal with different hazelnut oil dosages. As shown in Figure 5, the yield and combustible recovery values of hazelnut oil tended to decrease with increasing bridging liquid dosage. At lower dosages of hazelnut oil, i.e. 2% and 5%, this indicates that there is enough oil to coat all the coal particles. Increasing the dosage of hazelnut oil makes the agglomerates pasty, which in turn makes it difficult for them to agglomerate. This decrease in agglomerate formation leads to a lower yield and reduced recovery of combustible materials. However, the ash rejection values of hazelnut oil increase with an increasing dosage of bridging liquid. The high content of inorganic minerals in the agglomerates has caused a decrease in yield, resulting in increased ash rejection. Asad et al. [6] and Ken and Nandi [10] also reported that increasing the dosage of oil had a negative effect on ash rejection.

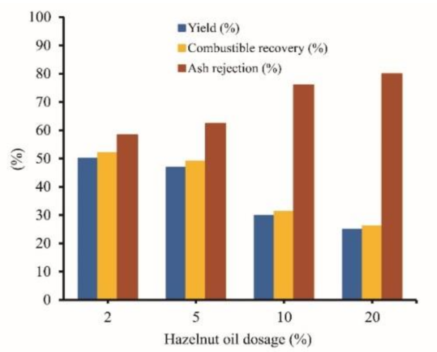

Figure 5. Agglomeration performance of lignite coal with different hazelnut oil dosages.

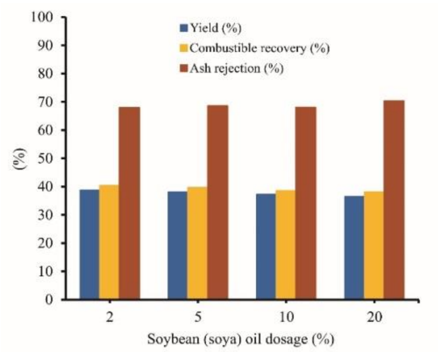

Figure 6. Agglomeration performance of lignite coal with different soybean (soya) oil dosages.

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Figure 6 shows the agglomeration performance of lignite coal with different soybean (soya) oil dosages. As seen in Figure 6, the values for yield, combustible recovery, and ash rejection did not change significantly with increasing dosage of soybean (soya) oil. At all soybean (soya) oil dosages, the bridging liquid effectively covers the coal particles. Under these conditions, there is sufficient contact between hydrophobic coal particles and agglomerate formation, resulting in higher yield and combustible recovery. This also caused high ash rejection.

Figure 7 illustrates the results obtained with vegetable oil type and dosage for yield in oil agglomeration. Figure 8 illustrates the results obtained with vegetable oil type and dosage for combustible recovery in oil agglomeration. Figure 9 illustrates the results obtained with vegetable oil type and dosage for ash rejection in oil agglomeration.

As can be seen in Figure 7 and Figure 8, almond and sunflower oil dosages of 2% had the lowest yields and combustible recoveries. For example, using almond oil these values were 27% and 27.99%, using sunflower oil these values were 28.46% and 29.75%, respectively. By increasing the dosages of these oils, the yield and combustible recovery were improved but ash rejection was decreased. Similarly, when poppy oil dosages were increased from 2 to 20%, both the yield and the combustible yield increased, but the ash rejection decreased. As can be seen in Figure 9, the maximum ash rejection (79.97%) was achieved at a hazelnut oil concentration of 20%. However, as the hazelnut oil concentration increased from 2 to 20%, the yield decreased from 50.06% to 24.93% and the combustible recovery decreased from 52.03 to 26.08%.

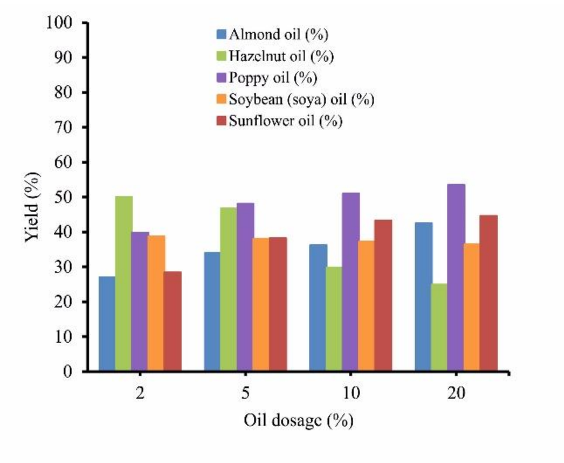

Figure 7. The results obtained with vegetable oil type and dosage for yield in oil agglomeration.

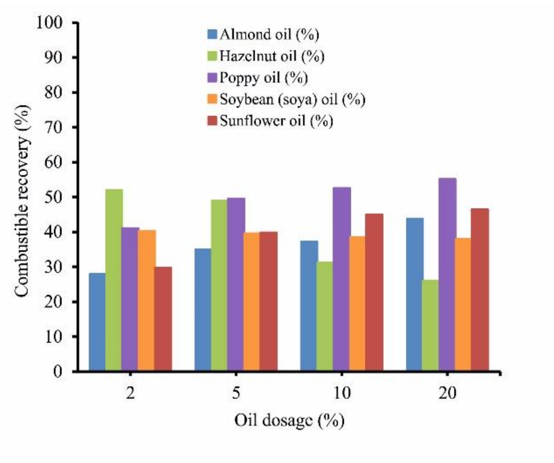

Figure 8. The results obtained with vegetable oil type and dosage for combustible recovery in oil agglomeration.

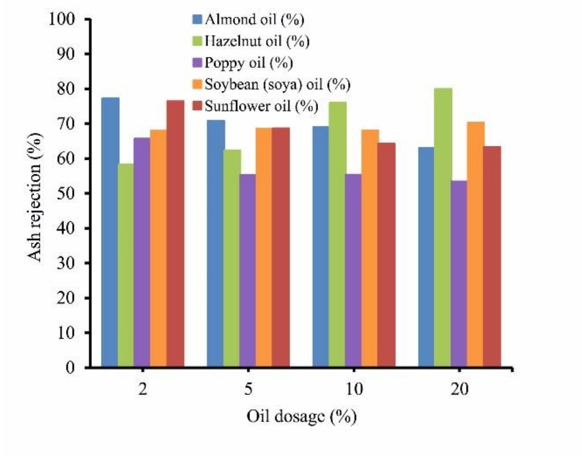

Figure 9. The results obtained with vegetable oil type and dosage for ash rejection in oil agglomeration.

As shown in Figure 9, the highest ash rejection of 70.30% was observed at a 20% soybean (soya) oil bridging liquid dosage. This bridging liquid achieved a yield of 36.46% and a combustible recovery of 38.05% (Figure 7 and Figure 8). Oil agglomeration experiments were evaluated together with yield, combustible recovery and ash rejection values to select the most suitable bridging liquid. The results of the present oil agglomeration study have shown that soybean (soya) oil has better bridging properties compared to other vegetable oils investigated. Based on the experimental results, soybean (soya) oil was selected as the most effective bridging liquid.

4. CONCLUSIONS

The focus of our present study is the enrichment of Sivas/Gemerek lignite by oil agglomeration using different vegetable oils. The following results have been reached:

i. Almond oil, hazelnut oil, poppy oil, soybean (soya) oil, and sunflower oil were used as bridging liquids at different dosages.
ii. The most effective results were obtained with a 20% dosage of soybean (soya) oil, which resulted in an ash rejection of 70.30%.
iii. Using a 20% dosage of soybean (soya) oil, the agglomeration yield was 36.46% and the combustible recovery was 38.05% for lignite coal.
iv. Under the optimum oil agglomeration conditions achieved, the ash content of the Sivas/Gemerek lignite was reduced from 19.08% to 15.54%.
v. Experimental studies showed that Sivas/Gemerek lignite coal was enriched through the oil agglomeration process using soybean (soya) oil.

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