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## Efficiency evaluation of the bottom ash flotation collector by removed saturated fatty acids from soybean oil

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**Abstract:** Unburned carbon flotation is performed to investigate the separation efficiency of the collector containing poly unsaturated fatty acid on the bottom ash. The results of an experiment using soybean oil collector (S.O. collector) show the high recovery and enrichment ratio at the dosage of 9 kg/ton. In order to investigate the collector efficiency on poly unsaturated fatty acids, a collector is manufactured using the esterification reaction. Unsaturated fatty acid oil collector (U.F.O. collector) is manufactured in which removed saturated fatty acids and increased content of poly unsaturated fatty acid from the S.O. collector. The U.F.O. collector is showed high separation efficiency at 7 kg/ton. The U.F.O. collector concentrates the unburned carbon content of the concentrate and improves the recovery with a low dosage than the S.O. collector. By removing saturated fatty acids and increasing the content of unsaturated fatty acids, this investigation provides that 1) the dosage of a collector can be reduced up to 2 kg/ton difference, and 2) the poly unsaturated fatty acids shows the best performance for adsorption properties on the unburned carbon surface.

**Keywords:** bottom ash, flotation, unburned carbon, unsaturated fatty acid, linoleic acid

### 1. Introduction

Kerosene was used as a collector for coal flotation (Denby et al., 2002; Huang et al., 2003; Liu et al., 2013). Ucurum (2009) evaluated the jameson flotation kinetic model for unburned carbon recovery from fly ash using diesel as a collector. Zhang et al. (2015) conducted flotation experiments on the effect of diesel dosage, conditioning time and impeller rotation speed to separate carbon from fly ash. However, oxygen-containing groups such as C-O and O-C=O of unburned carbon in coal ash were formed during coal combustion and showed similar surface characteristic to oxidized coal and low-grade coal. It increased the polarity and reduced the hydrophobicity of the unburned carbon (Wang et al., 2009; Xing et al., 2019).

Hydration film formed on the surface of the oxidized coal, while mineral oils such as kerosene and diesel lacked groups capable of bonding with the hydration film, resulting in low separation efficiency (Wang et al., 2018). Also, mineral oils caused environmental pollution due to recalcitrant incompatibility in the waste water treatment process after flotation process. Wang et al. (2018) reported that oil with oxygen containing groups show excellent adsorption to the surface of oxidized coal. Choe et al. (2006) reported that unsaturated fatty acids with more double bonds have more oxygen containing groups. Oil with unsaturated fatty acids containing oxygen groups showed excellent adsorption at the surface of unburned carbon. Kim (2018) reported that adsorption between unburned carbon in bottom ash and collector is generated by the  $\pi$ - $\pi$  interaction. In general, a carbon atom bonds to four other atoms, with a double bond leaves one electron. The bond of electrons left behind by a double bond is called the  $\pi$ - $\pi$  bond. Oil containing unsaturated fatty acids with many double bonds is easily adsorbed by  $\pi$ - $\pi$  bonds with oxygen-containing groups such as O-C=O on the surface of unburned carbon.

The unsaturated fatty acids (oleic acid, linoleic acid, linolenic acid) of vegetable oil had double bonds, as shown in Table 1. To improve the flotation efficiency of unburned carbon with oxygen-containing groups, flotation studies were conducted using vegetable oil as a collector.

Table 1. Fatty acid structure

	Structure	Fatty acid
Saturated fatty acid	$\text{CH}_3(\text{CH}_2)_{14}\text{COOH}$	Palmitic acid
	$\text{CH}_3(\text{CH}_2)_{16}\text{COOH}$	Stearic acid
Mono unsaturated fatty acid	$\text{CH}_3(\text{CH}_2)_7\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOH}$	Oleic acid
Poly unsaturated fatty acid	$\text{CH}_3(\text{CH}_2)_4\text{CH}=\text{CHCH}_2\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOH}$	Linoleic acid
	$\text{CH}_3\text{CH}_2\text{CH}=\text{CHCH}_2\text{CH}=\text{CHCH}_2\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOH}$	Linolenic acid

Abidin et al. (2013) reported that vegetable oil composed of fatty acids and fatty acid methyl esters is a non-polar collector that is advantageous for the recovery of unburned carbon. Alonso et al. (2000) studied the soybean oil and olive oil used in food processing as a flotation collector to recover coal from fine coal waste. The results showed that by using vegetable oil as a collector, coal had higher calorific and lower ash content than mineral oil. Alonso et al. (2002) used colza oil as a collector to obtain high calorific and low ash coal from fine coal waste.

Some researchers reported the results of studies in which waste cooking oil was used as a more economical and eco-friendly collector than vegetable oils. The use of waste cooking oil as a flotation collector showed economic and environmental advantages in terms of reuse of waste cooking oil classified as waste. Valdes et al. (2006) conducted flotation study to recover high-calorific/low-ash content coal in fine coal waste generated from coal purification plants, and confirmed that an experiment using waste vegetable oil as a collector is obtained high-calorific/low-ash content coal. Yang et al. (2020) confirmed that waste oil is an excellent collector for unburned carbon removal from coal fly ash. They found that the oxygen groups contained in waste oil contribute to the hydrophobization of carbon, and confirmed the excellent separation performance of fly ash and unburned carbon. Guo et al. (2021) conducted a study on the flotation performance and adsorption properties of saturated and unsaturated fatty acids isolated from hogwash oil to determine which fatty acids have negative effect on the flotation performance. They performed quartz flotation to compare that unsaturated fatty acid shows the excellent adsorption properties on the surface of quartz.

The fly ash of coal ash generated from thermal power plants in Korea is recycled as a cement admixture. In the case of bottom ash, it is used as a lightweight aggregate for construction materials, however, unburned carbon of bottom ash degrades quality of lightweight aggregate. Moon et al. (2016) conducted an experiment using bottom ash as an aggregate for concrete bricks. According to the authors results, the bottom ash which had been removed unburned carbon, reduced cement amount used, and were lighter specific gravity and dry weight compared to solid bricks. Sahbaz et al. (2008) separated unburned carbon of bottom ash discharged from a power plant by using the Jameson flotation machine. The effect of operating parameters was investigated using kerosene as a collector. Kim (2018) studied the effect of vegetable oil used as a collector in flotation to recover unburned carbon from bottom ash. He confirmed that vegetable oils which contain a lot of poly unsaturated fatty acids with two or more double bonds, show excellent adsorption for unburned carbon and high separation efficiency.

For this study, the separation efficiency of a collector containing poly unsaturated fatty acids proposed, as proposed by Kim (2018) is investigated. The purpose of this study is to study the separation efficiency of a collector with high content of poly unsaturated fatty acids having two or more double bonds. The collector is manufactured by the esterification reaction; soybean oil (S.O. collector) is used to remove saturated fatty acids and increase unsaturated fatty acids content. The manufactured collector is made with an inexpensive S.O. collector compared to other vegetable oils.

## 2. Materials and methods

### 2.1. Materials

Bottom ash is obtained from a thermal power plant in Gyeongsangnam-do region, Korea. The analysis result of the particle size of bottom ash is shown in Table 2. The weight ratio of the -0.043 mm sample is 4.7 % and the unburned carbon content is 0.4 %. Flotation is performed on bottom ash samples with a particle size of -0.54 mm or less. The raw sample of bottom ash contains unburned carbon of 15 %.

Table 2. Unburned carbon analysis of each size sample

Size fraction (mm)	Wt. (%)	Calorific value (kcal/kg)	Unburned carbon content (%)
Raw	100	979	15
+0.54	50.4	-	0.2
- 0.54 ~ + 0.27	10.3	1315	20.4
- 0.27 ~ + 0.15	21.4	2643	37.7
- 0.15 ~ + 0.074	10.3	1609	28.4
- 0.074 ~ + 0.043	2.9	782	14.4
-0.043	4.7	-	0.4

According to Kim (2018), XRF analysis showed that the  $\text{Fe}_2\text{O}_3$  content of bottom ash is approximately 11 %. Metal ions such as Fe in solid pulp interfere with the adsorption of the collector on the unburned carbon, which causes a decrease of flotation efficiency. Therefore, magnetic separation is carried out to remove impurities such as  $\text{Fe}_2\text{O}_3$  from bottom ash.

Table 3 shows the  $\text{Fe}_2\text{O}_3$  and unburned carbon content of ferromagnetic, weak magnetic, and non-magnetic samples produced by magnetic separation. Through magnetic separation, the  $\text{Fe}_2\text{O}_3$  content of the non-magnetic sample is reduced to 4.8%, and unburned carbon is concentrated to 38 %. In this study, flotation is performed with a non-magnetic sample of bottom ash.

Table 3. Analysis of  $\text{Fe}_2\text{O}_3$  and unburned carbon content of products by magnetic separation

	Wt. (%)	$\text{Fe}_2\text{O}_3$ content (%)	Unburned carbon content (%)
Feed	100	11.8	15
Ferromagnetic sample (1000 gauss)	2.6	85.3	-
Weak magnetic sample (2000 gauss)	28.7	16.1	-
Non magnetic sample	68.7	4.8	38

### 2.2. Flotation experiment methods

Flotation experiments are conducted in order to recover unburned carbon from bottom ash using a Denver sub-A flotation machine with a 0.2 L flotation cell. To improve the recovery of bottom ash flotation, the flow rate of the injected air is adjusted using an air flow meter as shown in Fig. 1.

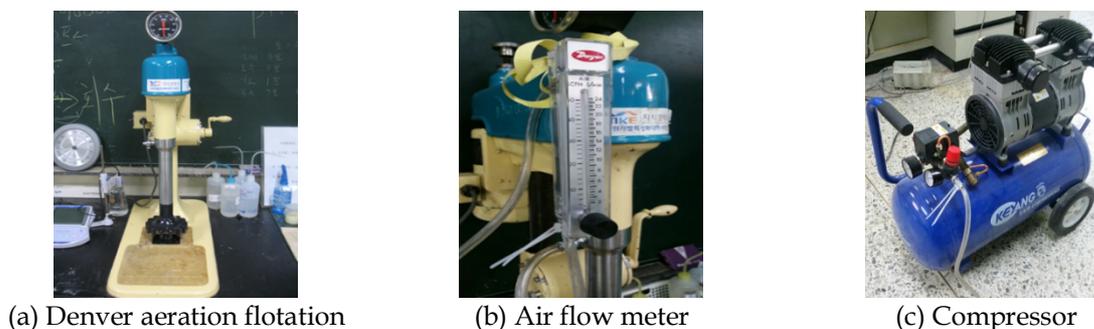


Fig. 1. Flotation machine

Bottom ash samples of 200 g are fed into the flotation cell. Distilled water is added to adjust the solid pulp density to 10 %, the mixture is stirred for 5 minutes, and pH of the solid pulp is adjusted to 7 using hydrochloric acid (HCl). Collector and frother are added and mixed for 3 minutes. Total flotation time is 5 minutes. The flowsheet of the flotation experiment is presented in Fig. 2.

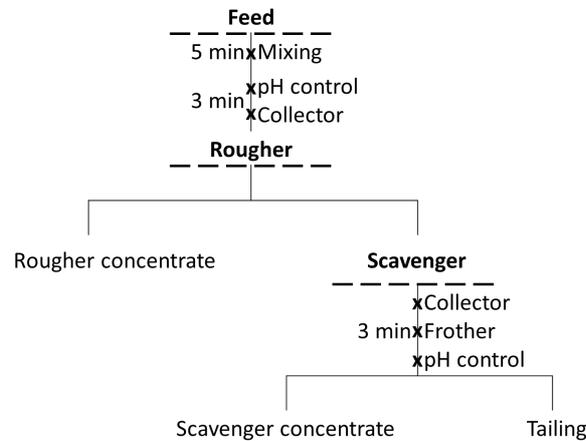


Fig. 2. Flowsheet of bottom ash flotation

The oil collector does not emulsify into the solid pulp, with the result that oil does not adsorb to the surface of unburned carbon. In particular, larger dosage of collector, the more acute this phenomenon tend to be.

Therefore, in this study, flotation experiments are conducted as a rougher and scavenger process. The rougher concentrate is recovered by adding half of the collector. The scavenger concentrate is recovered by adding a collector and frother and adjusting pH. The recovered unburned carbon is dried at 90 °C for 24 hours. Weighted samples are prepared and analyze. Temperature of solid pulp is maintained at 25 °C, and the operating conditions of the flotation experiments are shown in Table 4.

Table 4. Operating conditions of flotation

Operating conditions	Values
Solid pulp density	10 %
Collector	S.O. collector
Frother dosage	M.I.B.C 450 g/ton
Stirring speed	900 rpm
Air flow rate	16 L/min
pH of the solid pulp	7
Froth collection time	5 minute

The separation efficiency of flotation is defined as recovery and enrichment ratio. The recovery is expressed in terms of the weight (C) and unburned carbon content (c) of the concentrate, and the weight (F) and unburned carbon content (f) of the feed can be defined as:

$$R = \frac{C \cdot c}{F \cdot f} \times 100 \quad (1)$$

In this study, the weight and grade of the concentrate used the average value of the rougher and scavenger concentrates.

The enrichment ratio can be defined as the ratio of the concentrate grade to the feed grade.

$$ER = \frac{c}{f} \quad (2)$$

### 2.3. Collector preparation

The saturated fatty acid of the S.O. collector is removed by using the esterification method. The preparation flowsheet is presented in Fig. 3.

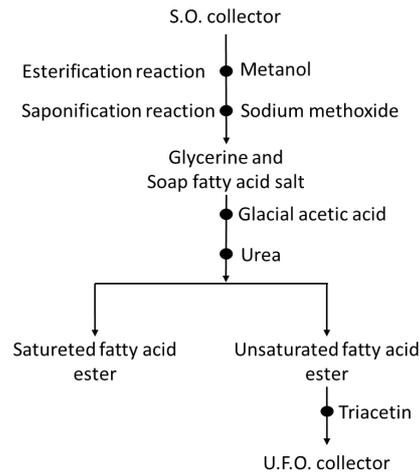


Fig. 3. Flowsheet of collector preparation of unsaturated fatty acid oil collector (U.F.O. collector)

(1) The S.O. collector of 50 g dehydrated under reduced pressure in a silicone oil bath heated to 105 °C for 30 minutes is mixed with anhydrous ethanol, to which 28 % sodium methoxide is added. Esterification proceeds by stirring for 5 minutes with a magnetic heated stirrer.

(2) To stop the esterification reaction of fatty acid esters, glacial acetic acid adds to neutralize, and it is mixed with urea + anhydrous ethanol solution. After leaving it to cool for one day, the formed saturated fatty acid ester crystals are removed.

(3) The unsaturated fatty acids are extracted by destroying the unsaturated fatty acid-urea complex by adding water and hydrochloric acid to the solution from which the crystals are removed.

(4) The glycerine-triacetate and sodium methoxide solution are mixed together, the ethyl acetate is removed, after which triglycerides composed of unsaturated fatty acids formed, resulting in the production of the unsaturated fatty acids collector (U.F.O. collector).

## 2.4. Analysis methods

The calorific value of the concentrate and tailing is measured using a calorimeter (IKA C2000 basic) by the lower heating value. In order to minimize the effect of the calorific value of a collector on the concentrate and tailing, the concentrate and tailing are washed with alcohol to remove oil on the surface. In the case of unburned carbon, ignition loss is analyzed according to the value for the diminished weight under the Korean Industrial Standard KS L 5405. The fatty acid content of the collector is analyzed using the gas chromatograph-mass spectrometer (GC-MS) analysis, and the GC-MS analysis is requested by the Food Analysis Center of Pukyong National University, Korea.

## 3. Results and discussion

### 3.1. Flotation circuits study

The emulsification of oil in solid pulp is important for flotation using oil as a collector. Oil with a large dosage does not emulsified in solid pulp, so it is not adsorbed to unburned carbon in solid pulp, but is adsorbed and floated to some unburned carbon on the surface of solid pulp.

The unburned carbon content of flotation feed in this study is at 38 %, which is used a collector of large dosage. Therefore, the flotation circuits for emulsification of the collector in solid pulp are very important. In this study, the separation efficiency of the rougher and rougher & scavenger processes is compared for emulsification of a collector in solid pulp. In the rougher & scavenger process, only half of collector dosage is added to recover the rougher concentrate. The scavenger concentrate is floated by adding a collector and a frother. The dosage of the S.O. collector is 9 kg/ton, M.I.B.C of 450 g/ton is used as a frother. The solid pulp is maintained at pH 7, density 10 %, temperature 25 °C, mixed at 900 rpm, and adjust air flow rate at 16 L/min.

Fig. 4 shows the results of the comparison of the two processes according to changes in the air flow rate. Fig. 4 (a) is the unburned carbon content of the concentrate for the two processes. The unburned

carbon content in the rougher & scavenger process is higher than in the rougher process at various air flow rate. Fig. 4 (b) is the unburned carbon content of the tailings of the two processes. It can be seen that the unburned carbon content of the tailing in the rougher & scavenger process is lower than in the rough process. This means that the unburned carbon in the solid pulp does not floated because the collector is not emulsified at the rougher process. Fig. 4 (c) shows the results of the comparison of the recovery for the two processes, the recovery of the rougher & scavenger process is relatively higher. Also, the recovery increases as air flow rate increased. However, the recovery and unburned carbon content of the concentrate decrease at more than 16 L/min, which means that the bottom ash in the solid pulp is floated with the froth. Therefore, bottom ash flotation using oil as a collector improves the separation efficiency by recovering unburned carbon at the rougher & scavenger process.

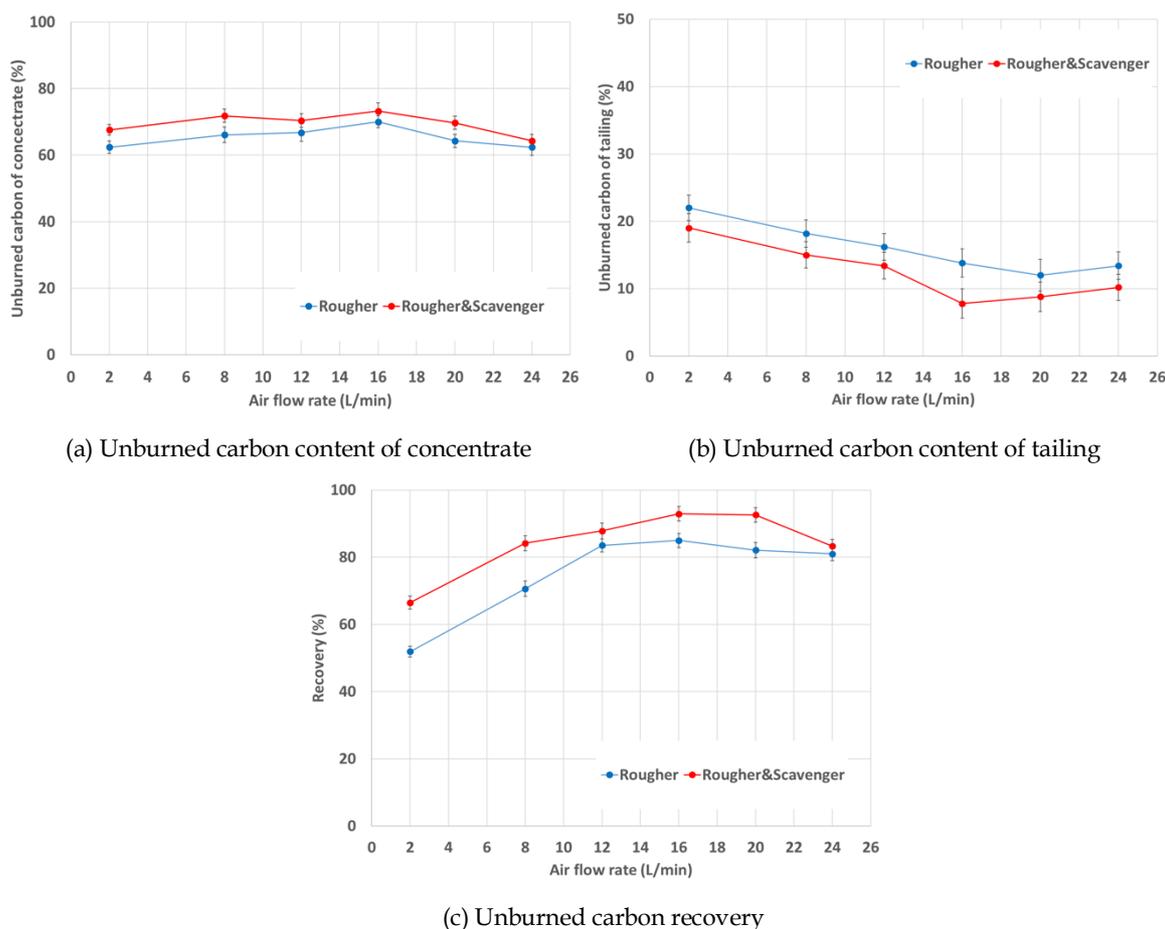


Fig. 4. The effect of recovery and unburned carbon content with rougher and rougher & scavenger process

### 3.2. Separation efficiency of flotation with S.O. collector

Kim (2018) used four vegetable oils as collectors for bottom ash flotation in order to compare separation efficiency. According to the authors results, the recovery was highest in the order of canola oil, soybean oil, sunflower oil, and safflower oil. Fig. 5 shows the results of the GC-MS analysis of vegetable oils used as a collector. The vegetable oils used in this study is the same as those used in the study by Kim (2018).

In the vegetable oils shown in Fig. 5, the contents of poly unsaturated fatty acids of soybean oil, sunflower oil, and safflower oil are higher than that of canola oil. The poly unsaturated fatty acids such as linoleic acid and linolenic acid have more double bonds than oleic acid. Vegetable oils containing linoleic acid and linolenic acid occur adsorption with oxygen-containing groups such as O-C=O on the surface of unburned carbon by  $\pi$ - $\pi$  interaction reaction. Therefore, safflower oil, which has a high poly unsaturated fatty acid content, shows excellent adsorption on the surface of unburned carbon. However, safflower oil has the disadvantage of being too expensive for use as a collector in a large-scale flotation system.

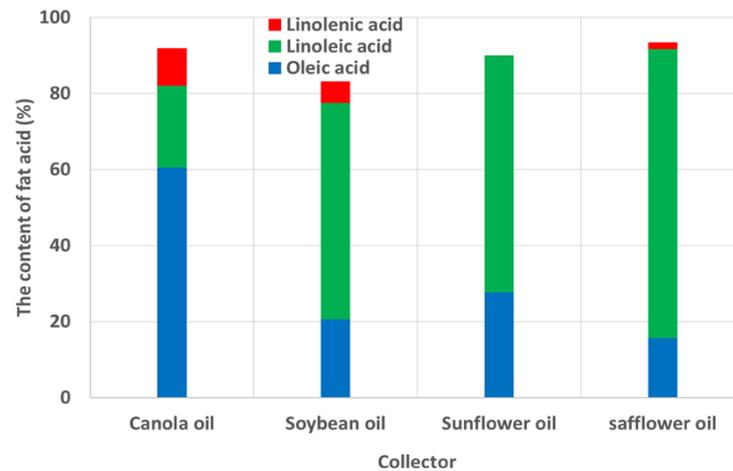
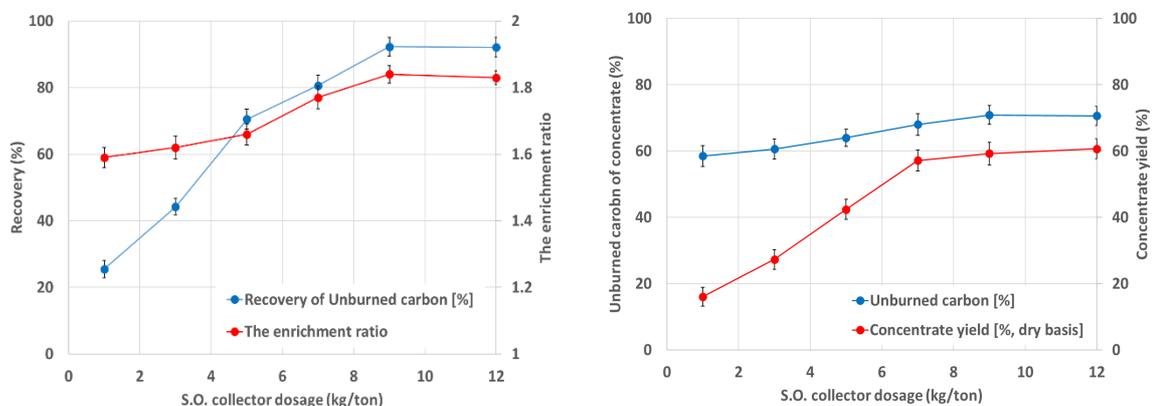


Fig. 5. Comparison of unsaturated fatty acids of collectors

In this study, the collector prepares in which increased the poly unsaturated fatty acids content from S.O. collector by the esterification reaction. The manufactured collector is used to investigate the effect of poly unsaturated fatty acids on the separation efficiency of bottom ash flotation. Prior to manufacturing the collector, bottom ash flotation experiment is performed using S.O. collector.

Fig. 6 (a) is the recovery and enrichment ratio of the flotation concentrate according to the S.O. collector dosage. The experiment is conducted with solid pulp density of 10 %, pH 7, stirring speed of 900 rpm, air flow rate of 16 L/min, and M.I.B.C of 450 g/ton. The recovery and enrichment ratio increase as the S.O. collector dosage increases. The recovery and enrichment ratio of 12 kg/ton are similar to 9 kg/ton. Fig. 6 (b) shows the results of the unburned carbon content and the concentrate yield according to the S.O. collector dosage. The concentrate yield and unburned carbon content is the highest at 9 kg/ton. The recovery of 92 %, enrichment ratio of 1.84 and unburned carbon content of 70.9% are obtained with S.O. collector at dosage 9 kg/ton.



(a) The recovery and the enrichment ratio

(b) The unburned carbon content and yield of concentrate

Fig. 6. The effect of the separation efficiency according to the S.O. collector dosage

### 3.3. Collector preparation

In this study, a collector is manufactured by removing saturated fatty acids and increasing unsaturated fatty acids by the esterification reaction. Fig. 3 shows the preparation process of the collector, and Fig. 7 shows a schematic diagram of the removal of saturated fatty acids.

The soybean oil contains in the form of triglycerides, as shown in Fig. 7 (a), to which methanol is added to induce the esterification reaction. Then, sodium methoxide is added to produce glycerin and soap fatty acid salts through a saponification reaction. Glacial acetic acid is added to stop the saponification reaction, resulting in the production of an ester of fatty acids. After urea is added and cooled, saturated fatty acid ester and unsaturated fatty acid ester are formed a complex with urea, respectively, as shown in Fig. 7(b). The saturated fatty acid ester precipitated as crystals is removed,

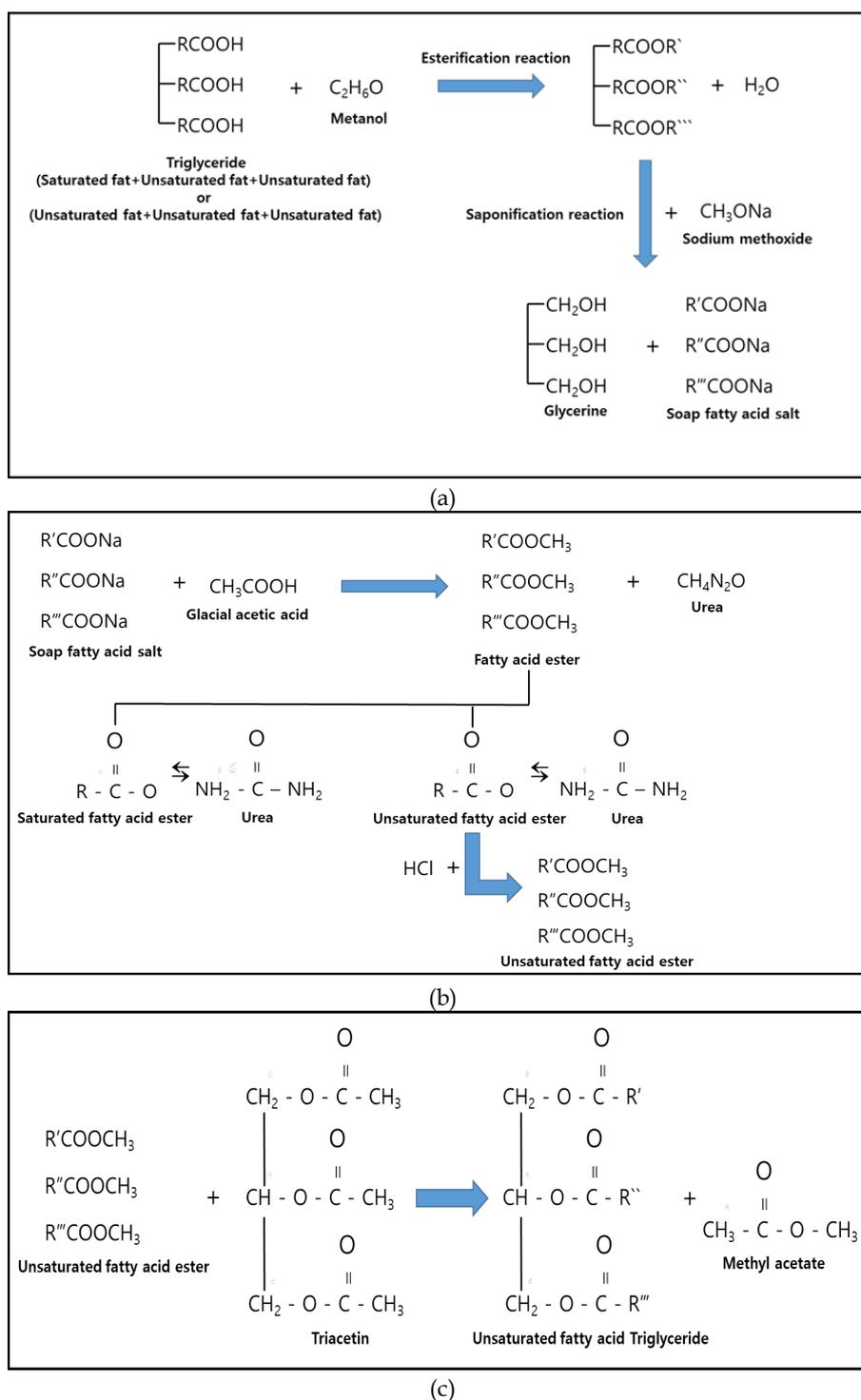


Fig. 7. The schematic diagram on the removed mechanism of saturated fatty acids of S.O. collector

and hydrochloric acid is added to the unsaturated fatty acid ester-urea complex to destroy the complex. A solution of triacetine and sodium methoxide is added to the unsaturated fatty acid esters in order to synthesize unsaturated fatty acids in the form of triglycerides. After heating in a silicone oil bath and reducing the pressure, ethyl acetate is removed and triglycerides composed of unsaturated fatty acids are produced. The GC-MS analysis performed to analyze the fatty acid content of the U.F.O. collector. Table 5 shows the results of the GC-MS analysis of the S.O. collector and U.F.O. collector. The saturated fatty acid content of the U.F.O. collector is decreased by the esterification reaction. In particular, most of the stearic acid of the U.F.O. collector is removed. In the case of unsaturated fatty acids, the oleic acid and linoleic acid content are increased. The U.F.O. collector has the highest content of linoleic acid with

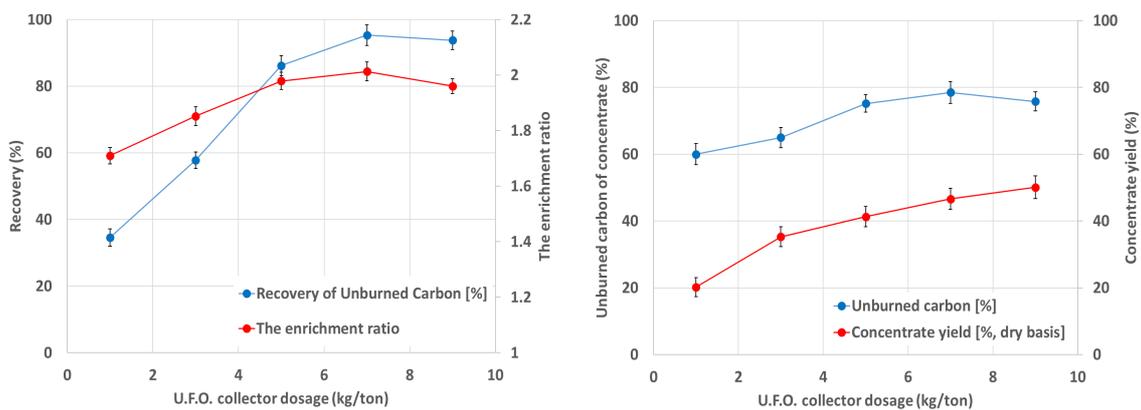
two double bonds, and the poly unsaturated fatty acid content is higher than that of the S.O. collector, while saturated fatty acid content is low.

Table 5. Comparison of the fatty acids of collectors

Collector	Saturated fatty acid		Mono unsaturated fatty acid	Poly unsaturated fatty acid	
	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid	Linolenic acid
S.O. collector	9.3 %	3.3 %	20.7 %	56.8 %	8.5 %
U.F.O. collector	2.2 %	-	25.3 %	67.1 %	5.26 %

### 3.4. Separation efficiency of flotation with U.F.O. collector

In order to investigate the separation efficiency of the U.F.O. collector from which saturated fatty acids are removed by the esterification reaction, bottom ash flotation is carried out using U.F.O. collector of 1~9 kg/ton. The experimental condition are follows: frother is M.I.B.C 450 g/ton, pH 7, stirring speed of 900 rpm, air injection amount of 16 L/min, and the solid pulp density of 10 %. Fig. 8 (a) shows the effect of the U.F.O. collector dosage on the recovery and enrichment ratio. The recovery and enrichment ratio of the concentrate increase continuously, but decrease at 9 kg/ton. Fig 8 (b) shows the unburned carbon content and concentrate yield according to the U.F.O. collector dosage, which increase as U.F.O. collector dosage increased. However, the unburned carbon content of the concentrate decreases at 9 kg/ton of the U.F.O. collector dosage while the concentrate yield increases continuously.



(a) The recovery and the enrichment ratio

(b) The unburned carbon content and yield of concentrate

Fig. 8. The effect of the separation efficiency according to the U.F.O. collector dosage

Fig. 9 shows the calorific value of the concentrate and the unburned carbon content of the tailing according to the U.F.O. collector dosage. Unburned carbon concentrate of 5800 cal/g and clean bottom ash of unburned carbon content of 0.7 % are obtained at the dosage of 7 kg/ton. The unburned carbon concentrate of 5800 cal/g can be reused as coal fuel in a thermal power plant that uses anthracite (4500 cal/g). Clean bottom ash can be recycled as a lightweight aggregate for construction materials.

The S.O. collector obtains the recovery of 92 % and unburned carbon content of 70.9 % at collector dosage of 9 kg/ton. The U.F.O. collector obtains the recovery of 95.3 % and unburned carbon content of 75.8 % at collector dosage of 7 kg/ton. The U.F.O. collector, which removed saturated fatty acid and increased the content of poly unsaturated fatty acid from S.O. collector, increases the recovery, enrichment ratio, and the unburned carbon content of the concentrate. In addition, the dosage of the U.F.O. collector is reduced up to 2 kg/ton difference, which has economic advantages in terms of the cost of reagent in large-scale flotation system.

The increase in poly unsaturated fatty acid caused by esterification reaction contributes to improving the flotation separation efficiency, and the poly unsaturated fatty acid is shown to be the fatty acid with the best adsorption properties on the surface of unburned carbon.

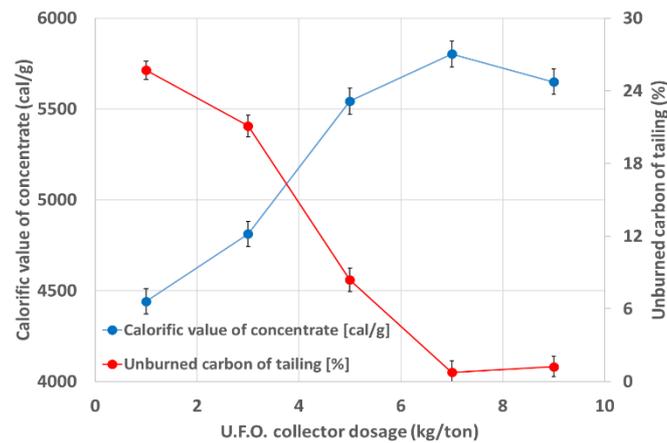


Fig. 9. Calorific value of concentrate and unburned carbon content of tailing according to the dosage of the U.F.O. collector

The schematic diagram of the interaction between the collector and the unburned carbon surface is shown in Fig. 10. While kerogen is adsorbed by  $\pi$ - $\pi$  bonding with the unburned carbon surface, S.O. collector and U.F.O. collector containing oxygen groups are adsorbed on the unburned carbon surface by the hydrogen bonding and  $\pi$ - $\pi$  bonding with the hydration film on the unburned carbon surface. Therefore, U.F.O. collector with a high content of linoleic acid having two or more double bonds provides an advantage in  $\pi$ - $\pi$  bonding.

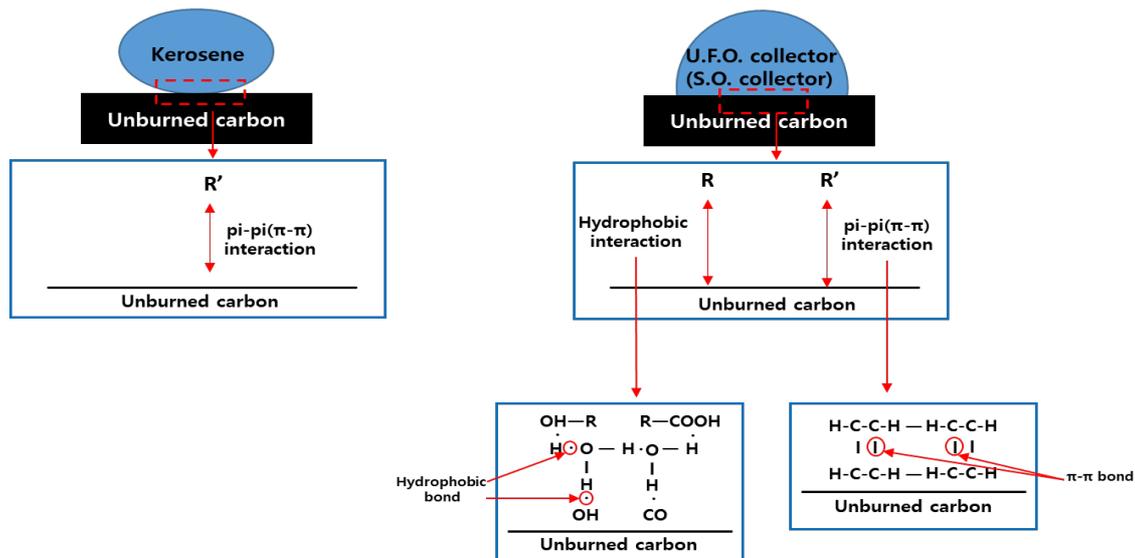


Fig. 10. The interaction schematic diagram between collectors and unburned carbon

### 3.5. The characterization of the U.F.O. collector

The FTIR spectroscopy is used to investigate the functional mechanism and flotation performance of the U.F.O. collector when saturated fatty acids are removed. Fig. 11 (a) is the result of FTIR spectrum for U.F.O. collector. The peaks at  $2854 \sim 2923 \text{ cm}^{-1}$  correspond to the vibration absorption peaks of  $\text{CH}_3$  and  $\text{CH}_2$  (Li et al., 2019).

Additionally, the peak around  $1218 \text{ cm}^{-1}$  corresponds to the stretching vibration of  $\text{CH}_3$ . The peak at  $1741 \text{ cm}^{-1}$  indicates the presence of a  $\text{C}=\text{O}$  functional group (Li et al., 2019, Xing et al., 2017). The FTIR spectrum result of U.F.O. collector shows that U.F.O. collector has a lot of polar groups, and the interaction between hydrophilic groups on the surface of unburned carbon and polar functional groups of U.F.O. collector are expected to ~~can~~ enhance the flotation of unburned carbon. These hydrophilic oxygen-containing groups can be adsorbed into the active site of an unburned carbon surface to achieve hydrophobization because the hydrophobic carbon-chain groups are oriented outward.

Fig. 11 (b) is the result of FTIR spectrum of bottom ash feed and flotation concentrate using kerosene and U.F.O. collector. The peak around  $1035\text{ cm}^{-1}$  is the expansion and contraction vibration of the Si-O group (Yang et al., 2020, Pizarro et al., 2015, Dhokte et al., 2011), and the peak intensity of the concentrate using kerosene is higher than that of the concentrate using U.F.O. collector. This can be explained by the increase of ash contents of the flotation concentrate, which means that the U.F.O. collector affects the functional groups of unburned carbon.

In addition, the C-H vibrational peak around  $2362\text{ cm}^{-1}$  of the concentrate using U.F.O. collector means that the U.F.O. collector is adsorbed on the unburned carbon surface.

The oxygen-containing group of the U.F.O. collector promotes the adsorption of the collector on the unburned carbon surface, which is advantageous for the hydrophobization of the carbon particles in the bottom ash. This shows an agreement with the results of flotation experiments.

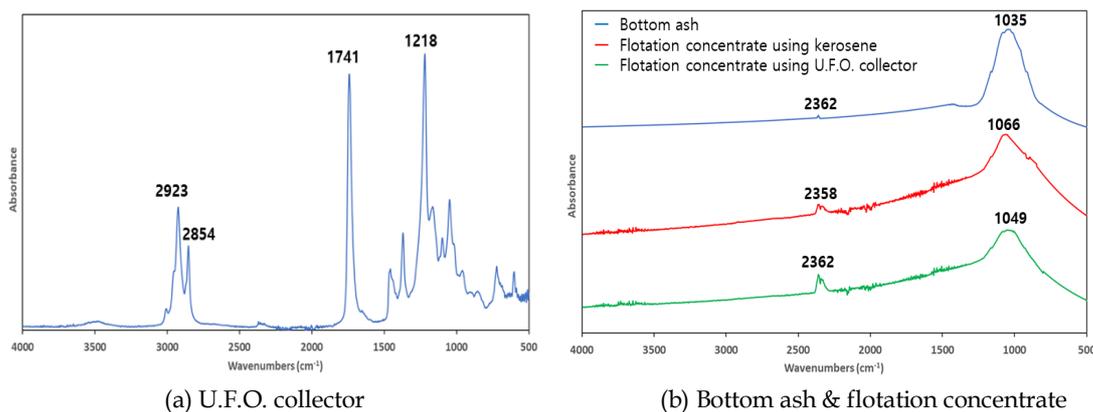


Fig. 11. FTIR spectrum of bottom ash, U.F.O. collector and flotation concentrate using collector

#### 4. Conclusions

Oil containing poly unsaturated fatty acid is used as a collector to improve the recovery of unburned carbon in bottom ash flotation. The aim of this study was to investigate the efficiency of the prepared collector, which is manufactured to remove saturated fatty acids and increase the content of poly unsaturated fatty acids from the S.O. collector. The recovery and the unburned carbon content of concentrate from a rougher & scavenger process are higher than a rougher process.

The flotation experiment is conducted using an S.O. collector as a collector, which is observed to increase the recovery, enrichment ratio and unburned carbon content of the concentrate as the collector dosage is increased. Thus, the recovery of 92 %, enrichment ratio of 1.84 and unburned carbon content of 70.9 % are obtained using S.O. collector of 9 kg/ton.

The U.F.O. collector is manufactured by removing the saturated fatty acids (palmitic acid, stearic acid) and increasing poly unsaturated fatty acids (oleic acid, linoleic acid) of S.O. collector. The fatty acid contents of U.F.O. collector through the esterification reaction are analysed by GC-MS, and chemical adsorption is confirmed by FTIR analysis.

The U.F.O. collector increases the recovery, enrichment ratio, and unburned carbon of the concentrate compared with the S.O. collector. The separation efficiency is maximized with the unburned carbon content of 75.8 %, the enrichment ratio of 2.01 and the recovery of 95.3 % at the U.F.O. collector dosage of 7 kg/ton.

The U.F.O. collector shows high separation efficiency than the S.O. collector and the dosage of a collector is reduced up to 2 kg/ton difference. Also, this study confirms that poly unsaturated fatty acid with many double bonds shows the excellent adsorption on the surface of unburned carbon. In addition, the unburned carbon concentrate of 5800 cal/g can be reused as coal fuel in a thermal power plant, and that clean bottom ash can be recycled as a lightweight aggregate.

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