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Investigation and Comparison of Emulsified Diesel Oil and Flomin C 9202 as a Collector in the Beneficiation of Ultra-Fine Coal by Agglo-Flotation

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Abstract: Modern mechanized mining techniques produce enormous quantities of coal fines. Reagents regime (i.e. reagents usage and reagent type) is an important fundamental factor in the process of recovering and dashing of ultra-fine coals (coal fines). The other factors that are crucial for recovery and the purity of the final product obtained is the nature of the particle size of the solids as well as the adsorption of the reagent on the solid particles surface among others. Coal concentrators and mills have embark on the strategy of establishment fine coal benefaction reagents which are not only cheap but effective and efficient. In this study, the effects of both the Flomin C 9202 and Emulsified light diesel oil are investigated in regards to their performance on the combustible recovery as well as the ash remaining in the clean coal product. The study, further involves grinding the coal sample to obtain the fines sizes, flocculate the fines to get the agglomerates and finally float them, what is commonly referred to as Agglo-flotation. The results for both Flomin C 9202 and emulsified light diesel oil were analyzed and after obtaining the best collector (which in this case was Flomin C 9202) then the flowsheet was there after determined. The batch tests for collector determination showed that the Flomin C 9202 outperformed the emulsified diesel oil, and after conducting two stages flowsheet with the collector (Flomin C9202), the ash content was reduced from 22.78%(original coal sample) to 7.91% while the combustible recovery increased from 77.44% (original coal sample) to 92.85%.

Keywords: Flomin C9202, Emulsified Light Diesel Oil, Agglo-Flotation and Flowsheet

1. Introduction

The proportion of ultra-fine coal in run- of- mine, worldwide, drastically increases with increased mechanization, modernization of coal mining and cleaning methods [1, 2, 11].

The need for the production of super-pure concentrates to prepare water-coal fuel and deep cleaning so as to desulphurize power-generating coals is the second major reason as to why there is an increased coal slimes in the coal concentrators and mills [2].

Coal slimes in mineral processing facilities are further increased by mining coal of low ranks, as well as cleaning coal using convectional techniques such as dense medium separation among others [3]. Production of coal slimes has a devastating effect in overall coal upgrading due to slimes coating [10].

In many coal preparation plants, neutral hydrocarbon oil such as light diesel oil and kerosene are used as a collector for the floatation and flocculation processes in ultra-fine coal, which have a large consumption, and problems such as the special control of the aviation kerosene, there is also the issue of high price of diesel oil and the low efficiency of floatation [5, 6]. Light diesel oil as well as the kerosene are always used as coal slimes flotation collectors which at times cause thick oil film, high viscosity, the ineffective secondary enrichment, and consumption of such reagents in large amount [6, 18]. The performance of floatation reagents, is a fundamental factor for good flotation results as well [7, 8, 9]. It is therefore important to look for efficient and affordable reagents as a way to reduce flotation costs, improve on flotation performance effect as well as increasing its economic efficiency which is the main objective of any coal upgrading facility [9].

The various reagents studies on the effects of conventional hydrocarbons oils on performance in ultra- fine beneficiation, shows that their consumption in coal processing facilities is very high in addition to their increase price, however their efficiency is not that promising [11, 12]. Most coal upgrading industries are therefore embarking on cost cutting strategy and their focus is solely based on the reagents use where they want investigate reagents which could not be used in large volume, but where low quantities will be used with higher degree of efficiency [14].

There are numerous holes and cracks on the coal surface which may lead to high collector consumption for low rank coal flotation [11]. An alternative separation technique, which appears to have the potential to remove these limitations, is selective agglomeration using a high internal phase emulsion binder [8]. The poor flotation and high collector consumption are main obstacles to promote low rank coal flotation for industrialization. Flotation of lignite was studied using kerosene along with different types of surfactants like cationic, anionic, and non-ionic surfactants [15]. It was found that the presence of surfactant with oily collector improved the flotation of low rank coal [22]. It was further observed that the oxidized coal surface became hydrophobic after adding fatty alkyl propelene diamine, even when the oxidation was extensive [12].

In the view of above situation, Flomin C 9202 and emulsified light diesel oil is investigated with objective of the study being to investigate the effects of Flomin C 9202 reagent as the main alternative to traditional light emulsified diesel oil and compare the best results between the two main collectors and establish the best in coal cleaning and upgrading. The result of surfactants on froth flotation of unburned carbon from coal fly ash, according to [4].

The sample is taken through the flocculation process before being subjected to flotation so as to enhance the efficiency of the separation of coals containing the coal slimes

The collector introduced in this research is a sort of emulsified oil which contains surfactant. On the one hand, the collector can achieve directional adsorption on oil-water interface and form hydration shell to prevent oil droplets from merging and decrease the surface tension of oil drops, therefore the constituent of diesel in the collector can be well dispersed among the ore pulp, and the chances of contact between coal surface and non-polar hydrocarbon-type oil can be increased.

By using Emulsified Diesel Oil (EDO), the surface tension between oil phase and water phase would drop by tens of times, making it easier for micro particles of oil to disperse among water and form oil-in-water type emulsion. Therefore, the chances of contact between the collector and coal surface would be increased. After emulsification, dispersion of EDO in water would be improved, and the size of oil drops would be minified, which, on the one hand, reduces the amount of collector adsorbed on the surface of coal particles as well as the total quantity of collector required in the floatation; and on the other hand, increases the probability of collision between coal particles and collector, and shortens the attachment period, thus improving the efficiency and general performance of floatation.

Most coal preparation plants in our country have been used neutral hydrocarbon oil such as light diesel and kerosene as collector of the floatation, which have a large consumption, and problems such as the special control of the aviation kerosene, the high price of diesel oil, the low efficiency of floatation are serious as well [13].

The floatation agent is made of environmental protection renewable natural oils, high efficiency, low cost and good stability, and can reduce floatation clean coal pollution from high-ash slime.

More of the oil collector was adsorbed on the surface of coal particles pretreated by grinding with a collector compared with grinding alone, and the contact angle of long flame coal increased by grinding with a collector compared with that pretreated with grinding directly at any given collector dosage [9].

2. Experimental Materials and Methods Details

2.1. Main Raw Materials and Equipment

The coal sample was obtained from Haosheng coal mining mine China. Coal slimes characteristics and equipment for batch tests are discussed in this section.

2.1.1. Properties of Coal Slime Sample According to Particle Sizes Fraction

The size composition of coal samples are given in Table 1.

Table 1. *Particle size distribution in the original coal sample.*

Particle size (mm)	Yield (%)	Ash (%)	Combustible matter (%)	Combustible matter distribution (%)
+0.9	1.1	23.86	76.14	1
-0.9+0.45	5.8	19.62	80.34	6
-0.45+0.154	30.7	15.86	84.14	33
-0.154+0.105	16.8	17.94	82.06	18
-0.105+0.074	11.00	23.10	76.9	11
-0.074	34.6	29.11	70.89	31
Total feed	100	22.78	77.22	100

As can be seen from the tabulated data above, the coal sizes range from –0.45+0.15mm showed the higher percentage of coal yield in the feed (30.7%) and the lowest ash content present (15.86%). As the size reduced further and further so do increase of the Ash content and decreased amount of solid combustible matter. The smallest size (-0.074mm), contained the highest amount of ash content and the lowest percentage of the combustible matter, this was in the justification from several researchers that as the coal sizes reduces the more the Ash content due to slimes present. The coal particles in their small sizes contains lot of fines probably of gangue minerals. Again particle sizes (+0.9mm), has got a very high ash content compared to others, this could be attributed to the fact that at coarser coal particles the degree of liberation was too low, hence coal still remained inter-locked together with ash forming mineral matter [18]. This may indicate that increasing the apparent size can be very helpful for obtaining a better flotation performance [12].

2.1.2. XRD-Analysis

The mineral composition for this sample was determined by X-Ray Diffraction (XRD). The figure 1, clearly shows that kaolinite, quartz, montmorillonite, calcite and siderite are the major mineral matter (gangue minerals) in this particular coal sample. This provided a clear knowledge on how best to clean this coal slimes. As without the knowledge of the coal composition some problem might be difficult to solve especially when you come across anomaly. In addition to that the XRD analysis shows that Kaolinite and Quartz are the main mineral impurities with minor traces of montmorillonite, calcite and siderite respectively.

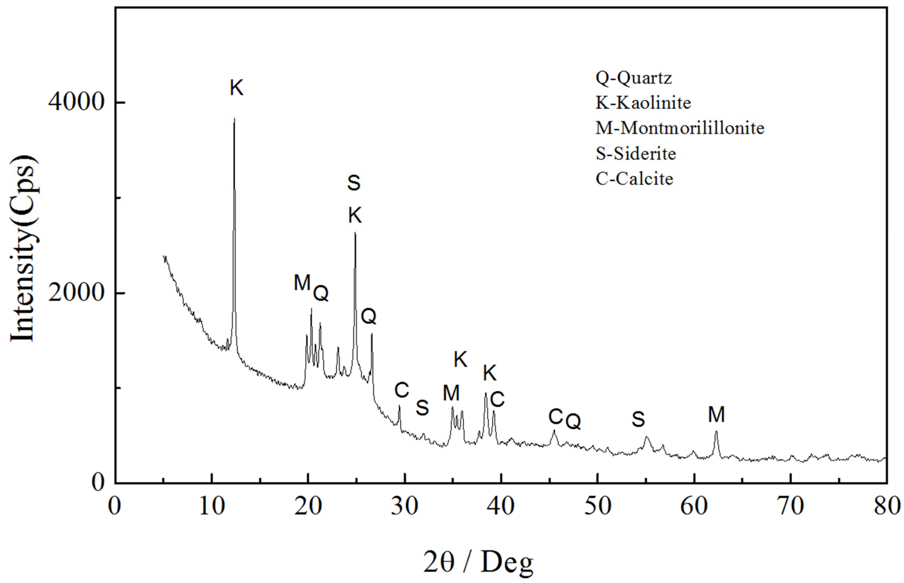

Figure 1. *X-ray diffraction pattern of the coal sample.*

2.1.3. Chemical Reagents

Collectors: Flomin C9202 and Emulsified diesel oil. Frother: Flomin F422, Dispersant: Sodium silicate, both tap and deionized water was used throughout the experiment period.

2.2. Experimental Methods

The coal sample was obtained in its finer sizes as shown in according to the table 1 above and as such, there was no need for crushing. 50g of the sample was placed in ball mill with 65% concentration by volume.

After, the grinding operation, then the ground sample was placed in flocculation cell with four baffle and a volume of 670ml. The coal-water suspension was subjected to intensive stirring at 2000rpm for 10 minutes with sodium Hexametaphosphate for adequate dispersion to take place before the speed being varied for several tests. Flomin C9202 was added to slurry for induced hydrophization and agglomeration process to take place. This process was allowed for 30 minutes for allow enough time for proper agglomeration. Thereafter the speed and other parameters were varied to obtain the optimum conditions.

The agglomerates was taken to mechanical flotation cell for separation, after which the Recoveries and ash contents after the coal samples were flocculated and floated were analyzed as per the below equation:

$$\text{Combustible matter recovery},(\%) = \left(\frac{mc(1-Ac)}{Mf\,(1-Af\,)}\right)*100 \quad (1)$$

Whereas Ac, is the ash content of the clean coal, Af, is the ash content of the feed. Mc, is the mass of the clean coal, whereas mf is the mass of the feed. CR=Combustible recovery. The figure below show the experimental flowsheet.

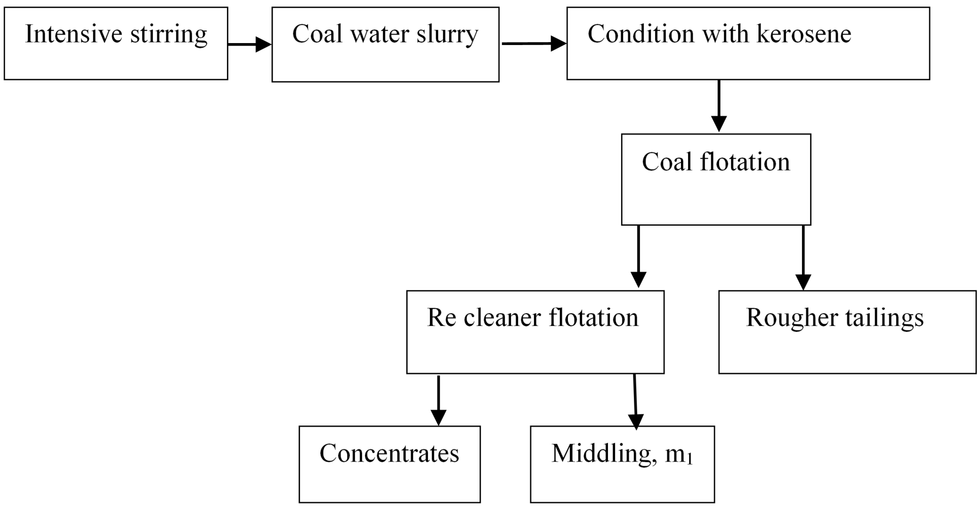

Figure 2. *The concept of ultra-fine coal flow sheet.*

This is a test conducted in coal mineral processing industries to ascertain the maximum achievable performance of coal froth flotation. It measure the possible selectivity that could be achieved in froth floatation of the coal. Flowsheet determination in coal industries is treated as analogous to the float and sink analysis in the coal wash ability by the dense medium separation.

This experiment was conducted performed in two stages, the first one was the rougher floatation, the concentrate from the rougher was re-floated once, so as to remove any mineral matter (kaolinite and quartz), that might have either entrained or entrapped in the clean coal product during the flocculation process. Sodium hexametaphosphate and Flomin F422, was used as the dispersant during this study.

The collector was not used in this Process because it was only to eradicate mechanically entrained mineral matter. The figure.1 above illustrates the whole procedure of the experiment. The coal –water suspension from the ball mill was subjected to intensive stirring to de-agglomerate it in case of hetero-coagulation during the grinding process. Sodium hexametaphosphate was added in right dosages to disperse coal particles and gangue minerals. It was then conditioned for 30 minutes of flocculation process, the flocs were transferred to Denver mechanical cell for flotation process. The flocs were floated in two stages of one rougher and one re-cleaners, it was then taken for dewatering and thermal drying before being analyzed for ash content and solid combustible recovery. The results for this experiment are plotted and discussed in the figure 4.

3. Results and Discussions

3.1. Effects of Collector Concentration (Dosages) on Agglomerates from Both the Diesel Oil and Flomin C 9202

The figure 3 show the results for both Flomin C 9202 and emulsified light diesel oil respectively, it is clearly shown that as, the dosages increased from 0.2kg/ton to 1.6kg/ton for both collectors the recovery of the coal also increased.

For Flomin C 9202 the recovery increased from the initial dosage of 0.2-1kg/ton, the recoveries were 43% to 90%, and thereafter there was no significant change. On side of emulsified light diesel oil, the trend seems to be the same, that in the initial dosage loading that is from, 0.2-1kg/ton, the solid combustible recoveries increases rapidly from 38% to 86%, any further increase on dosage did not bring out any noticeable increase, this increase could be due to the fact that, at low collector dosage there was insufficient adsorption of all ultrafine coal particles, thus there was competition between particles with different surface properties and the only strongly hydrophobic particles were floated, hence resulting to a lower, combustible recovery). In addition, with the increased dosages on both the Flomin C9202 and The emulsified light diesel, there was the formation of larger flocs/agglomerates with increasing coal size. As the dosages increased beyond the optimum, however there was a trend where the ash content kept on increasing, higher reagents loadings seems to increase the ash of concentrate and that could be attributed to the high ash content indicating that there was an increase in mineral entrainment and entrapment.

On the issue of ash content increased with increasing collector dosage. As the Flomin C9202 dosage increased from 0.2kg/ton to 1.6 kg/ton, the ash content reduced from 14.5% to 10.2%. For diesel collector, as the oil dosage increased from 0.3kg/ton to 2kg/ton kg/ton, the ash content reduced from 13.6% to 11%. The ash content in the product obtained from the kerosene collector was slightly higher than from the diesel collector, which may be related to its hetertoms nature.

In summary Flomin C9202 produced superior performance of ash content of 12.5% and the corresponding recovery of 90%, and it was therefore selected as the best collector compared to emulsified light diesel oil.

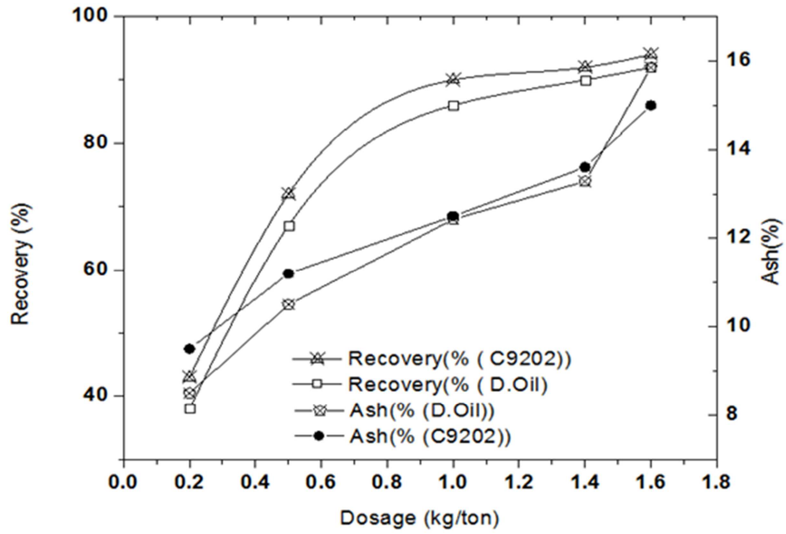

Figure 3. *Effect of Dosage on combustible recovery and ash.*

3.2. Determination Flow Sheet of for Coal Slimes Using the Collector Flomin C9202

The experimental study was carried out under the following conditions: Dispersant Sodium Silicate, 3kg/ton, Collector: Flomin C9202 dosage of 1.0kg/ton, Frother: Flomin F 422 was used at 200g/ton, the sample was ground 20 minutes, to allow for total liberation of gangue from the valuable coal. The impeller stirring speed of 2000rpm. A natural ph. for the slurry pulp was maintained and the normal tap water was used throughout the experiment.

After the several batch tests using the above mentioned conditions obtained, were used to carry out the final coal slimes processing flow sheet. In this experiment, the first step was intensive stirring (2000rpm) of the coal-water slurry suspension with the stirrer which was made to destroy any impurities here referred to as hetero-coagulation during grinding process in the ball mill, then, it was followed by addition of Flomin F422 as a dispersant, which was conditioned for ample time, and then the collector Flomin C9202, was added to induce the hydrophobity of the selected coal particles, the speed was then reduced from that of 2000 Rpm to allow gentle flocs formation, as well, to avoid the flocs degradation. The final process was the flotation of the already obtained agglomerates above with two stage flotation of one rougher and one re-cleaner flotation. The aim of this test was to remove the entrained and entrapped gangue minerals resulting from the possible hetero flocculation.

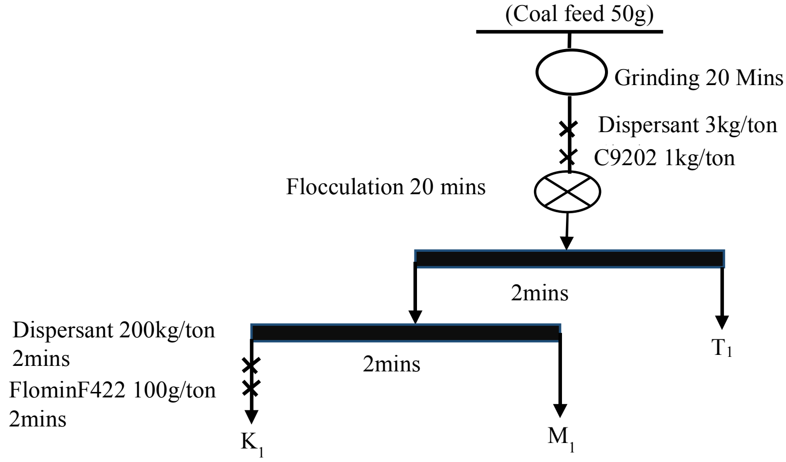

Figure 4. *Two stage Coal Floatation.*

Table 2. *Two stage coal slime flotation.*

Sample	Yield%	Ash%	The combustible matter%	Recovery%
K_1	80.40	7.91	92.09	92.85
M_1	3.83	50.68	49.31	3.83
T_1	3.52	80.27	19.73	3.52
Feed	100	21.75	78.25	100

In this test work after the sample was subjected to several flow sheet determination, the optimum results was obtained in 2 stage flow sheet with combustible recover of 86.28% and corresponding ash content of 6.39% respectively. Table 2 shows the tabulated results.

4. Conclusion

This research focused on the agglo-floatation technique to clean the ultra-fine coal (slime) and obtain very clean coal product devoid of environmental pollution and other hazards associated with coal burning.

The objective of study was to improve on coal upgrading by comparing the two main collectors (Flomin C9202 and Emulsified Diesel Oil). The following conclusions were drawn;

The highest ash contents were found on the most coarse coal particles>0.9mm and the smallest size coarse slimes<0.074mm (Table 1). The particles which are>0.99mm are not well liberated from gangue minerals while in small particles<0.074mm there was small particles of gangue minerals in the main coal product.

The Flomin C 9202 is the best collector compared to emulsified light diesel oil. When the sample was subjected to Agglo-flotation of two stage flow sheet; of one rougher and one re-cleaner stage the combustible recovery was 92.85% and the ash remaining in the clean coal product was 7.91% from 22.78% of the original coal sample. Flomin C 9202 makes the coal surface more hydrophobic as compared to EDO.

Flomin C9202 produces superior performance of ash content of 12.5% and the corresponding recovery of 90%, and it is therefore selected as the best collector compared to emulsified light diesel oil.

The mechanism of high-ash particle contamination in the oil agglomeration process will be further investigated from thermodynamic or kinetic aspects in future studies. Some test methods may also be introduced to explore the structure of agglomerates.

The combustible recovery increased and the ash content of agglomerates decreased with increasing stirring time up to 30 minutes, after which the ash content increased slightly due to the entrapment of particles with high ash content. The results indicated that 80% of the coal could be recovered as a 7% ash product under optimum conditions.

The effect of coal particles finer than 20 μm on the oil agglomeration process was investigated. It was concluded that fine coal particles with lower ash content were transferred from small agglomerates to large ones with increasing stirring time. However, some particles with high ash content may contaminate the agglomerates with excessive stirring time [6].

Flotation results indicated that the F C9202 had stronger collecting ability than emulsified diesel oil. Over 90% combustible matter recovery can be obtained and the quality of the concentrate was acceptable as the concentrate ash content just slightly increased compared with that in the presence of emulsified diesel oil [21].

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