Improving low-rank coal flotation using a mixture of oleic acid and dodecane as collector.

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Abstract. Low-rank coals (LRC) are abundant but underutilized due to their hydrophilic nature and high oxygen content, which hinder flotation efficiency. Traditional single-collector systems often result in low recovery rates and high reagent consumption. This study investigates the use of a mixed collector system comprising oleic acid (OA) and dodecane (D) to improve LRC flotation. Response Surface Methodology (RSM) was employed to optimize the dosing ratio of OA to D. Laboratory-scale flotation tests demonstrated that mixed collectors significantly enhance flotation efficiency, achieving recovery rates up to 65.5% and reducing ash values from 55.6% to 16.7%. Optimal conditions were identified at a dodecane dosage of 300 g/t and an oleic acid dosage of 255.5 g/t. The findings underscore the potential of mixed collectors to enhance coal hydrophobicity, thereby improving recovery and separation from gangue minerals. This approach offers a sustainable solution for LRC beneficiation, minimizing waste and enhancing economic viability.

Keywords: Low-rank coal, flotation, mixed collectors, oleic acid, dodecane, optimization

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1. Introduction

Low-rank coals (LRC) are the type of coal that have been subjected to the least metamorphic change during the coal-forming process, characterized by low carbon content, and high oxygen content (Sondreal & Wiltsee, 1984). LRC are abundant but underutilized energy resources, and the challenges in utilizing them results from their high reactivity, low calorific value, and difficulties in beneficiation processes due to their hydrophilic nature (An et al., 2021). Flotation is a widely used method for the separation of coal from gangue minerals, where the hydrophobicity of the coal surface is increased to facilitate its attachment to air bubbles and subsequent recovery (Liu et al., 2019). The use of collectors, such as oleic acid (OA) and dodecane (D), has been explored to enhance the flotation efficiency of low-rank

coals. These collectors modify the surface properties of coal particles, making them more hydrophobic and improving their floatability (An et al., 2021).

The traditional use of single collectors often results in low flotation efficiency, high collector consumption, and increased costs (Liu et al., 2019). This has led to the investigation of mixed collectors, such as a combination of D and OA, to exploit potential synergistic effects that could enhance the flotation performance of LRC (An et al., 2021). Research has shown that mixed collectors, such as OA and D can interact with the coal surface through hydrogen bonding, particularly between the polar groups of the collector and the oxygenated functional groups on the coal surface (Liu et al., 2019). This interaction increases the hydrophobicity of the coal particles, promoting their adhesion to air bubbles during the flotation process (Liu et al., 2019).

Despite advancements in using mixed collectors for low-rank coal flotation, there are still research gaps that need to be addressed. The utilization of mixed collectors, such as a combination of OA and D, presents a promising approach to enhance the flotation efficiency of low-rank coals, but the optimization of the dosing ratio of D-to-OA as mixed collectors remains a critical aspect to achieve maximum flotation efficiency and coal recovery rates (An et al., 2021). Additionally, understanding the interaction mechanisms between the mixed collectors and the coal surface, considering the presence of gangue minerals, and optimizing the process parameters are essential for improving the overall flotation performance of low-rank coals (Liu et al., 2019).

The aim of this research project is to enhance the flotation efficiency of low-rank coals through systematically optimizing dosing ratio of D to OA as mixed collectors. X-ray Fluorescence (XRF), X-ray diffraction (XRD), and Scanning Electron Microscopy/Energy-Dispersive X-ray Spectroscopy (SEM-EDS) were utilized to analyse the sample's composition, mineralogy, and morphology. Proximate analysis was conducted to determine the coal sample's properties, including moisture content, volatile matter, ash content, fixed carbon, calorific value, and sulphur content, which are important for evaluating the flotation efficiency. Ultimate analysis was performed to determine the elemental composition of the LRC sample, including carbon, hydrogen, nitrogen, sulphur, and oxygen content. Minitab was used as a tool for experimental design and optimization. Minitab is a powerful statistical software tool widely used for quality improvement and optimization. It provides various statistical tools, including regression analysis, Analysis of Variance (ANOVA), and Design of Experiments (DoE) capabilities, which can be employed to optimize reagent dosages in flotation processes. Minitab allows researchers to design experiments, analyse data, and visualize results effectively, making it easier to identify optimal reagent combinations (Dehghan & Dianati, 2015).

2. Materials and methods

2.1. Experimental procedure

Figure 1 represents the flowsheet (designed using Draw.io) which summarizes how the experiment was carried out.

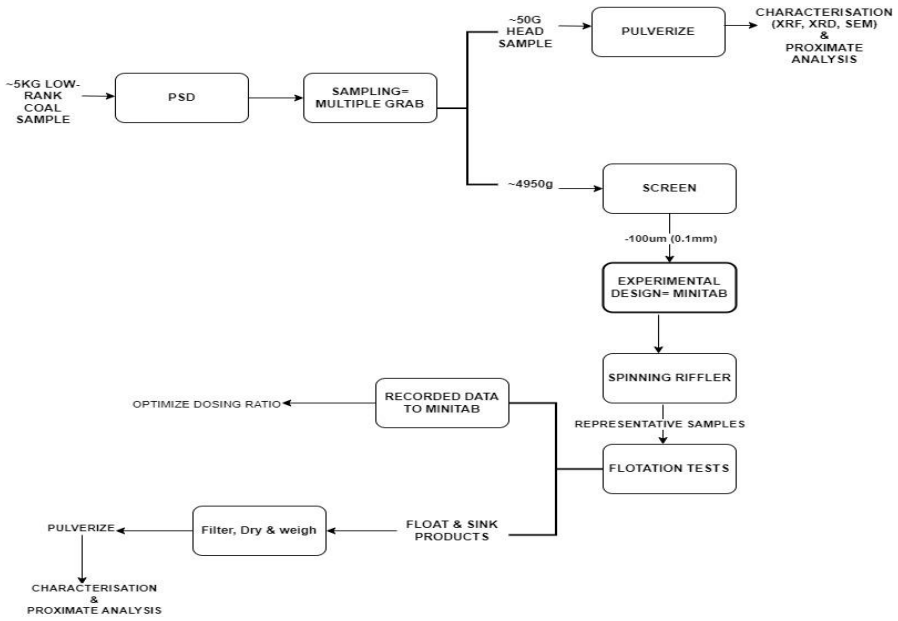

Fig. 1. Flowsheet summarizing experimental procedure

2.2. Flotation tests

Batch flotation tests were conducted in a 2.5L lab-scale flotation cell using ~500g of LRC sample, which was milled for 28 minutes to achieve 80% passing 75 microns, with a pulp concentration of 15% solids by weight. Methyl Isobuthyl Carbinol (MIBC) was used as a frother at a constant dosage of 100g/t. The air flow rate and agitation speed were kept constant at 2L/min and 1200rpm respectively. Using the DoE from Minitab (RSM), found in the appendix section, 25 flotation tests were carried out. For each test, ~500g of LRC sample and 2835mL of water were added first to the flotation cell and conditioned for 2 minutes. After conditioning, the pH of the pulp was adjusted using lime and sulphuric acid. The mixed collectors (at varying dosage and ratio) were then added into the pulp and agitated for 2 minutes. After that, sodium silicate (a depressant for present gangue) was added, followed by MIBC and each reagent addition was agitated for 2 minutes. Air was then injected, and the floated coal was collected after 4 minutes with 20 seconds scraping interval for 4 minutes. The sinks were also collected, filtered and dried at 50^{o}C overnight. The dried products were taken for analysis and used to calculate recoveries.

2.3. Sample characterisation

2.3.1 Characterisation

The XRF procedure was used to determine the trace elements present in the LRC sample, which was achieved using ZSX primus II Rigaku X-ray fluorescence. The XRD procedure was also used to reveal the structural information of the LRC sample, which was achieved using Ultima IV Rigaku X-ray diffraction. Finally, the SEM procedure was used to identify the maceral composition and mineral matters in the LRC sample.

2.3.2 Proximate analysis

The procedures and equations for determining the moisture content (Mo), volatile matter (V), ash (A), calorific value (CV), fixed carbon (F) and sulphur content (S) were used to determine their quantities in the head sample. The Standard practice methods ASTM D3172-13, SANS 17246:2011, and ISO 17246:2011 were used to conduct proximate analysis of the LRC to determine the percentage moisture, ash, volatile matter, and fixed carbon. The calorific value using E2K combustion was determined using SANS 1928:2009 and ISO 1928:2009 standard method procedures (SANS, 2009). The % sulphur was analysed using U-THERM TX-DL8300.

By leveraging controlled experiments and quantitative analysis, the study effectively examined the influence of various dosing ratios on coal recovery and flotation efficiency. The results obtained from this methodology lay the groundwork for optimizing the combination of OA and D, offering insights that could improve the beneficiation of LRC and contribute to more sustainable coal utilization practices.

3. Research results and discussion

3.1 Head sample results and discussion

3.1.1. Head XRF analysis

The head sample was taken for XRF analysis to identify the elemental composition, which is critical for understanding the gangue material present and optimizing the flotation process. The XRF results are summarized in Table 1.

Table 1. XRF head sample results

Component	Mass %
Al_2O_3	22.76
SiO_2	48.45
SO_3	5.42
CaO	4.61
TiO_2	2.71
Fe_2O_3	12.88
K_2O	1.42
P_2O_5	0.142
MgO	0.77

SiO_2 constitutes the largest portion of the sample at 48.46%, indicating a high concentration of silicate minerals. This implies that quartz or other silicates are present in the gangue, potentially impacting the flotation process due to their hydrophilic characteristics (Yang et al., 2013). Al_2O_3 makes up 22.77% and is likely sourced from aluminosilicate minerals such as kaolinite, indicating a substantial presence of aluminum-bearing minerals. Elevated levels of Al_2O_3 may suggest that coal ash exhibits refractory properties, complicating its removal during flotation. Meanwhile, Fe_2O_3 accounts for 12.88% and reveals that iron-bearing minerals like hematite are part of this LRC composition. These can

influence both magnetic properties and flotation efficiency depending on which reagents are used (Sloss, 2002).

The detection of CaO (4.61%) and MgO (0.78%) implies the possible presence of calcite or dolomite, which could influence both the overall ash content and the pH level in flotation slurry, thereby potentially affecting reagent performance (Zhao et al., 2015). Additionally, SO_3 at a concentration of 5.43% indicates sulfur presence, likely originating from pyrite or other sulfide minerals. These sulfur compounds pose environmental challenges during combustion, making their removal through flotation advantageous.

3.1.2. Head SEM-EDS analysis

The head sample was then taken for SEM-EDS analysis. SEM coupled with EDS provides a powerful combination of techniques for investigating both the morphology and elemental composition of coal at the microscale (Zou et al., 2020). This analysis is critical for understanding the coal's microstructure and its association with minerals, which can significantly influence its behavior during flotation. The SEM analysis provided high-resolution images of the LRC sample at different magnifications. These images reveal important features that directly impact flotation performance, as seen in figure 2.

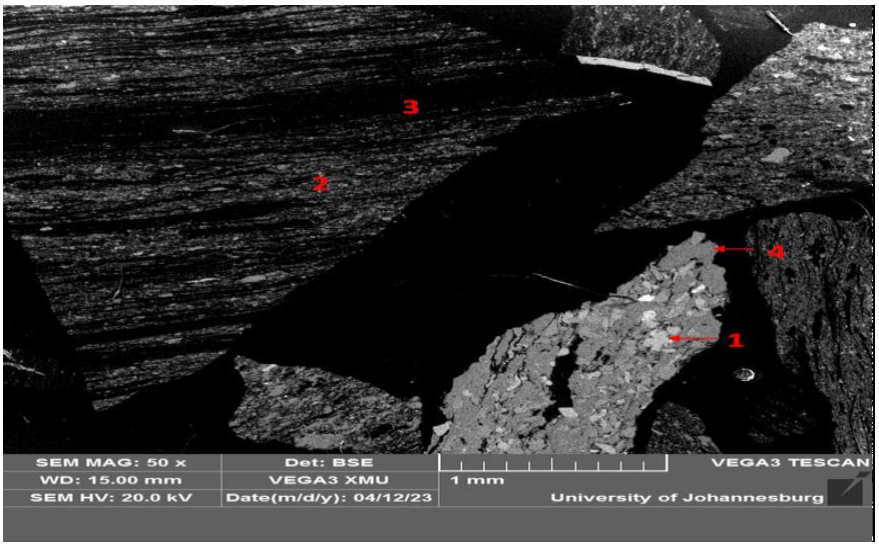

Fig. 2. Head sample SEM results

The SEM image reveals a heterogeneous surface morphology in the LRC sample, with both smooth, compact regions and more porous, fractured areas. These porous zones are often filled with mineral matter, particularly clays and silicates which are difficult to separate during flotation due to their hydrophilic nature. Additionally, such voids tend to trap moisture and air, hindering effective collector adsorption and reducing bubble-particle attachment efficiency (Wei et al., 2014). The irregular particle shapes, ranging from angular to rounded, indicate variability in surface area, which can influence how flotation reagents interact with the coal. While larger surface areas may enhance reagent coverage, the presence of both hydrophobic and hydrophilic regions complicates selectivity. These microstructural features observed through SEM-EDS provide valuable insight into the expected flotation behavior of the coal and should be more explicitly linked to the flotation results discussed in later sections.

The variability in particle size and shape suggests that further size reduction or classification might be necessary for an ideal flotation feed. The EDS results are summarized in Table 2.

Table 2. Head sample EDS results

Spectrum	C	Mg	Al	Si	P	S	K	Ca	Ti	Fe	O
1	21.03	-	5.02	6.21	-	-	0.03	-	0.04	0.04	67.60
2	25.72	-	1.37	1.37	0.02	0.07	0.02	-	-	-	71.42
3	27.23	-	-	-	-	0.07	-	0.01	0.02	0.02	72.67
4	20.04	0.10	6.01	6.91	-	-	0.06	-	0.04	0.04	66.74

The EDS spectra indicate the presence of carbon (20-27%) and oxygen (66-72%), aligning with the organic and mineral components typical of coal. Trace elements like Al, Si, and Fe corroborate the presence of aluminosilicates and iron oxides. This microstructural diversity, along with elemental analysis results, suggests that the surface of coal is heterogeneous, featuring both hydrophilic and hydrophobic areas. As a result, flotation reagents must be carefully optimized to selectively target carbon-rich zones while rejecting silicate and iron-containing minerals.

3.1.3. Head XRD analysis

The sample was also taken for XRD analysis to identify the mineralogical composition of coal. It provides information on crystalline phases present in the coal, such as quartz, pyrite, and clay minerals. Understanding the mineral content is essential for evaluating coal's combustion properties and potential for ash formation (Karacan & Olea, 2018). The XRD results are summarized in figure 3.

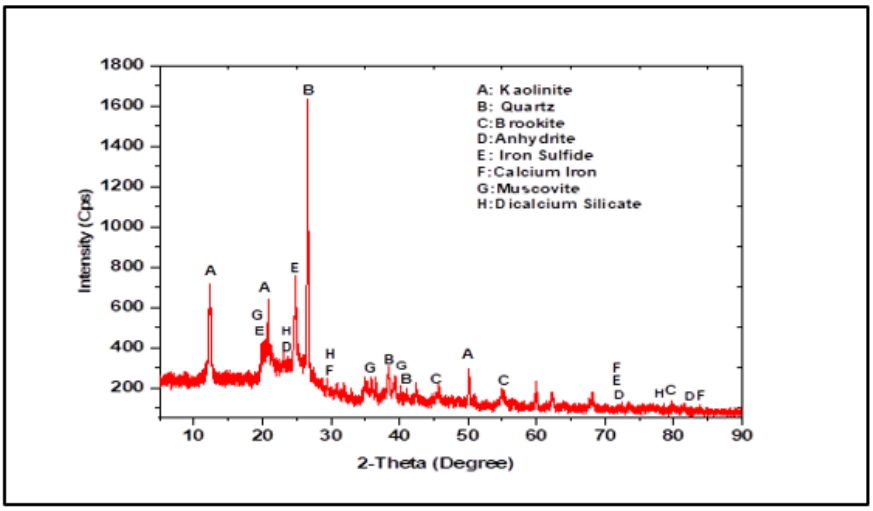

Fig. 3. Head sample XRD results

XRD analysis revealed the crystalline phases within the coal, shedding light on its mineralogical composition. The primary phases identified are quartz (SiO_2) and kaolinite ($Al_2Si_2O_5(OH)_4$), both of which contribute significantly to the high ash content in the coal. Pyrite (FeS_2) is also present as a common sulphur source, complicating flotation and combustion due to its tendency to form sulphur dioxide (SO_2) during burning (Rao & Gouricharan, 2016). These XRD findings align with results from XRF and SEM-EDS analyses, confirming that silicates and iron-bearing minerals are abundant in this coal sample. Such minerals pose challenges for flotation processes, indicating a need for specialized reagents to effectively separate carbon-rich material from gangue components.

3.1.4. Head proximate analysis

Proximate analysis was done on the head sample to achieve a deeper understanding of the thermal behavior of coal, including its moisture, ash, and volatile matter content, which directly impact flotation performance and energy output (Jiang et al., 2022). The proximate analysis results are summarized in table 3.

Table 3. Head proximate analysis.

	Moisture (%, ar)	Volatile (%)	Fixed Carbon (%)	Calorific Value (kJ/g)	Ash (%)	Sulphur (%)
Average	6.76	11.63	26.02	9.28	55.60	2.47

The proximate analysis results indicate that coal has air dried (ad) moisture content of 6.76%, which is relatively moderate but still affects flotation by impacting the hydrophobicity of coal particles. The ash value, at 55.60%, is notably high, suggesting a large proportion of non-combustible material that diminishes its calorific value and efficiency for energy production (Fan et al., 2010). With volatile matter at 11.63% and fixed carbon at 26.02%, these figures are typical for LRC, indicating their lower energy yield. Consequently, the calorific value stands at just 9.28 kJ/g; underscoring the need to reduce ash through flotation to enhance suitability for combustion and improve energy generation potential.

3.1.5. Ultimate analysis

The head sample was taken for ultimate analysis, and it provided a detailed breakdown of the elemental composition of the coal's organic matter. The ultimate analysis results are summarized in table 4.

Table 4. Ultimate analysis results

	Nitrogen %	Carbon%	Hydrogen%	Sulphur%	Oxygen %
Head sample	1.484	28.90	2.77	0.77	46.07

The analysis indicates that the sample is composed of 28.90% carbon, which is relatively low for coal and confirms its classification as a low-rank variety. The oxygen content stands at 46.07%, pointing to an abundance of oxygenated compounds These compounds are often hydrophilic and can negatively affect flotation efficiency. The levels of hydrogen (2.77%), nitrogen (1.48%), and sulphur (0.77%) align with typical characteristics found in low-rank coals, although the moderate amount of sulphur underscores the necessity

for removal processes to mitigate environmental impacts from combustion emissions. Additionally, the high level of oxygen suggests this coal type requires optimized flotation conditions to enhance recovery rates and energy efficiency.

3.2 Flotation product results and discussion

3.2.1 Recovery rates

After the flotation tests, the mass of the floats and sinks were recorded and used to calculate recovery rates (%wt., ad). The goal was to identify optimal combinations of OA, D, sodium silicate and pH levels for maximum coal recovery, using experimental design variations of four parameters based on the DoE. Figure 4 summarizes the recovery rates from different runs.

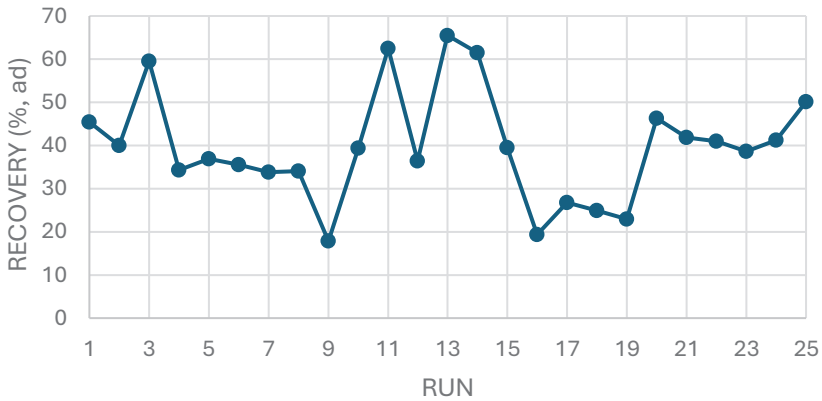

Fig. 4. Flotation recovery rates across 25 runs

The recoveries show the runs with the best reagent combinations and pH levels, which is why a direct trend in recovery values is not evident. The recovery rates, shown in Table 7 (see appendix) demonstrate a range of values between 17.84% and 65.51%, indicating that some reagent combinations were notably more effective than others. The highest recoveries were obtained with runs 13 (65.51%), 11 (62.45%), and 14 (61.46%), suggesting that these combinations likely achieved the optimal hydrophobicity needed for effective coal attachment to air bubbles during flotation. These findings support the hypothesis that systematically optimizing the dosing ratio of OA and D can enhance the flotation performance of LRC.

The variation in recoveries across different runs, alongside the lack of a distinct trend, suggests that flotation response is highly sensitive to adjustments in mixed collector ratios as well as depressant and pH levels. This observation is consistent with previous research by Liu et al. (2019) and Kadagala et al. (2021), which noted that using mixed collectors enhances performance by improving interactions between collectors and coal surfaces through hydrogen bonding. Specifically, studies like those conducted by Liu et al. demonstrated increased recovery rates when utilizing mixed collectors due to enhanced hydrophobicity of coal particles. The findings from this study support these conclusions, indicating that combining OA and D improves LRC floatability.

Furthermore, the findings from runs 13 and 11 reinforce An et al. (2021) conclusions on how mixed collector systems can enhance recovery rates by optimizing reagent combinations. In contrast, research centered on single collectors, such as Liu et al. (2021), frequently reported lower recovery rates due to limited interaction between the collectors and hydrophilic coal surfaces. This study's results underscore the critical role of optimizing mixed collectors for LRC flotation processes. The validity of this study is strengthened by a robust experimental design employing a DoE framework, a standard statistical approach used to optimize and analyze multiple factors simultaneously. Utilizing Minitab for DoE allowed systematic variation in dosages and pH levels to examine their effects on recovery rates, thereby enhancing result reliability.

3.2.2 Proximate analysis, CV & Sulfur

The proximate analysis of the flotation products was carried out to verify the improvement in coal quality after flotation and to determine whether the optimized collector mixtures achieved the desired reduction in ash content and enhancement in energy content. The overall proximate results (including CV and sulfur) of the floats and sinks are summarized in figure 5 and 6 respectively.

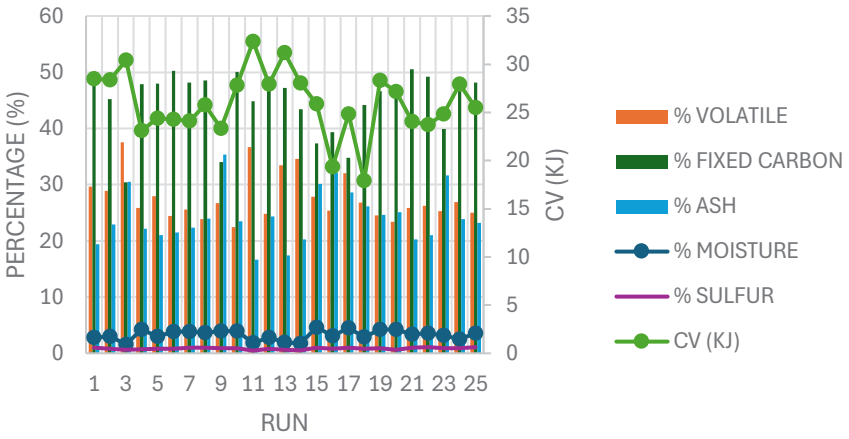

Fig. 5. Overall proximate analysis of the floats

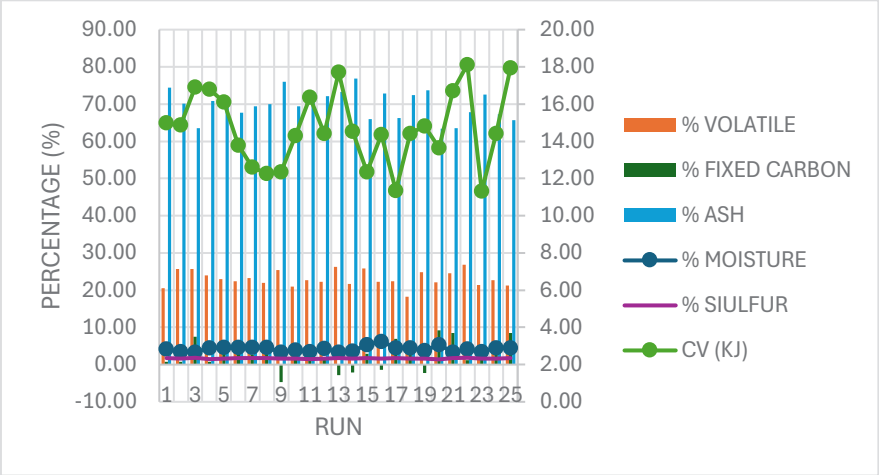

Fig. 6. Overall proximate analysis of the sinks

From the results, it can be observed that the floats generally exhibited lower moisture (%, ad), sulfur and ash values, higher volatile matter, CV and fixed carbon content compared to the sinks. For example, in run 1, the floats had an ash content of 19.38% and a fixed carbon content of 48.19%, compared to the sinks, which had an ash value of 74.43% and a fixed carbon content of 25.17%. This trend is consistent throughout most runs, indicating that the flotation process effectively separated the carbon-rich material from the high-ash gangue minerals. The reduction in ash and increase in fixed carbon and CV in the float fractions imply that the mixed collector system successfully targeted and separated the hydrophobic coal particles, while rejecting the more hydrophilic, ash-forming gangue minerals.

Run 11 achieved the lowest ash content (16.69%) and a high calorific value (32.36 kJ/g), indicating effective separation of ash-forming minerals and suitability for energy generation. This suggests optimal collector and depressant dosage, and pH in targeting hydrophobic, carbon-rich particles. Run 13 also demonstrated a favorable combination with slightly higher ash content but maintained a high calorific value (31.21 kJ/g). The proximate analysis findings align with the recovery results, showing that the highest recovery rates (in runs 11, 13, and 14) correspond to floats with lower ash and higher fixed carbon content. This suggests that the optimized mixed collector system not only increased coal floatability, but also effectively separated ash-forming minerals, resulting in higher-quality flotation products.

The outcomes of the proximate analysis are consistent with previous studies on mixed collector systems. For example, Liu et al. (2019) reported that the use of mixed collectors improved the separation efficiency of LRC by increasing their hydrophobicity, leading to reduced ash content in the concentrate. Similarly, An et al. (2021) found that the combination of OA and D as collectors resulted in lower ash content and higher fixed carbon in the floated products. This study's results support these findings, demonstrating the efficacy of mixed collectors in enhancing the flotation performance of LRC.

Deviations were, however, observed in runs where the sink fractions exhibited lower-than-expected ash values or higher calorific values, indicating potential challenges in fully rejecting all gangue materials. This could be attributed to either lost coal, and/or the presence of hydrophilic gangue minerals with properties like coal particles, as noted by Liu et al. (2021). Despite these positive results, further investigation is needed on the effect of PSD on ash separation efficiency, as different size ranges may influence reagent attachment and affect

ash content and calorific value. Additionally, varying reagent interaction times should be studied to determine the impact on ash, fixed carbon, and calorific value, helping to identify optimal conditions for improving coal quality.

3.2.3 Minitab contour plots

Using the same DoE, the percentage recovery and ash were input into Minitab software to generate contour plots and optimize the response for maximizing recovery while minimizing ash content. The contour plots help visualize the combined effects of OA and D, enabling the identification of optimal conditions for high recovery and low ash content. The analysis is, however, limited to two factors, potentially oversimplifying the flotation system, which involves additional variables like pH and sodium silicate dosage. Figures 7 and 8 represent the contour plots of recovery and ash vs. OA-D (g/t), respectively.

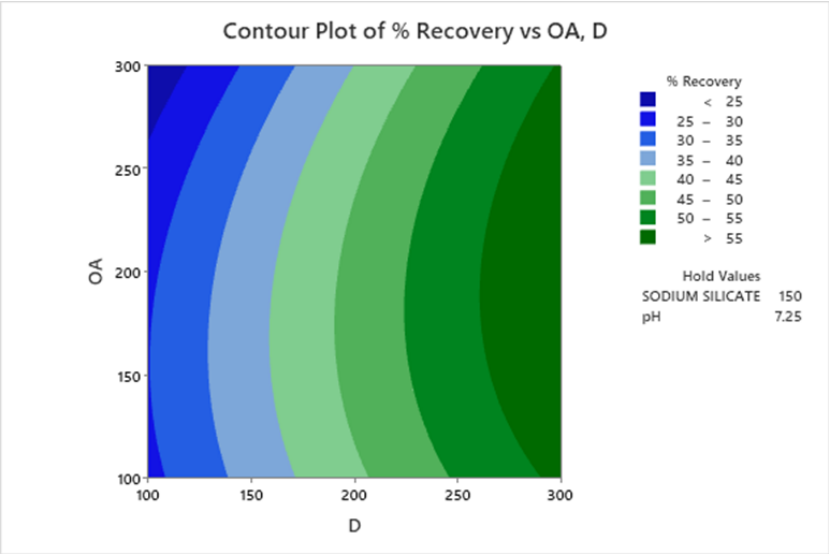

Fig. 7. Contour plots of flotation recovery vs. OA & D

The contour plot of recovery suggests that higher dosages of both OA and D lead to increased flotation recovery, but the effect of OA is less than that of D. The maximum recovery (>55%) is observed when D is at its upper dosage limit (300g/t) and OA, ranging from 100-300 g/t. This outcome supports the hypothesis that mixed collectors improve their flotation performance by enhancing the hydrophobicity of the coal surface, allowing for better attachment to air bubbles. The increase in recovery with higher dosages aligns with literature, such as Liu et al. (2019), who demonstrated that mixed collectors significantly improve LRC flotation by increasing the hydrophobicity of the coal surface.

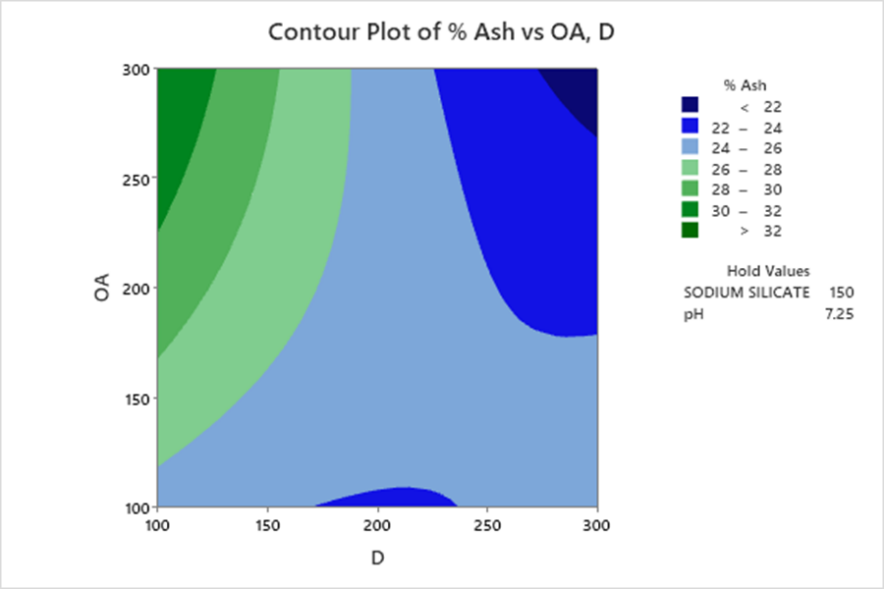

Fig. 8. Contour plots of flotation concentrate ash vs. OA & D

The contour plot for flotation concentrate ash (Figure 8) reveals that higher dosages of OA and D generally correspond to lower ash values in the floated product. The minimum ash value (~16.66%) is achieved at high dosages of D (300 g/t) and moderate dosages of OA (250-300 g/t). This result indicates that the mixed collector system is effective, not only in recovering coal particles, but also in rejecting ash-forming gangue minerals. The decrease in ash values with optimized collector dosages corroborates findings from An et al. (2021), who reported that mixed collectors improve the selectivity of flotation processes, leading to lower ash content in the concentrate. These results align with the recovery rate and proximate analysis results, where the highest recovery rates and lowest ash content were observed at high D and moderate OA dosage.

These results affirm the importance of optimizing the dosing ratio of OA and D to achieve maximum recovery and minimal ash, filling a gap in the literature concerning the optimal collector combinations for LRC. The contour plot findings are validated by the systematic DoE and Minitab's statistical analysis, which rigorously tested the effects of OA and D under controlled conditions. The use of RSM further improved reliability by optimizing multiple factors. The results are, however, limited by the small-scale flotation tests and specific coal sample characteristics, though they still provide valuable insights for optimizing mixed collectors in future studies.

3.2.4 Minitab response optimisation

This section presents the optimal response obtained from the Minitab software, focusing on maximizing coal recovery while minimizing ash content. The goal of this optimization is aligned with the project's aim of improving the flotation efficiency of LRC by optimizing the dosing ratios of OA and D, as outlined in the project objectives. Table 5 summarizes the optimal response generated through Minitab.

Table 5. Minitab optimal response

Solution	D	OA	SODIUM SILICATE	pH	% Ash Fit	% Recovery Fit	Composite Desirability
1	300	255.50	100	6.88	16.66	58.34	0.921708

The optimal solution from Table 5 suggests that the best recovery and lowest ash content are achieved at a dodecane dosage of 300 g/t, an oleic acid dosage of approximately 255.50 g/t, a sodium silicate dosage of 100 g/t, and a pH of 6.9. Under these conditions, the model predicts a coal recovery rate of 58.34% and an ash content of 16.66%. Interestingly, although the model predicts an optimal recovery of 58.34%, this value is lower than some of the actual recoveries achieved in individual experimental runs. This apparent contradiction may be attributed to the model's objective of optimizing multiple responses simultaneously—namely, maximizing recovery while minimizing ash content. In doing so, the model identifies a compromise solution that does not necessarily yield the highest possible recovery, but rather provides the most desirable overall outcome when both recovery and ash content are considered together. The high composite desirability of 0.92 indicates that these conditions provide a near-optimal balance between the competing goals of maximizing recovery and minimizing ash content.

These results align well with the previous experimental data, where higher dosages of D and moderate dosages of OA led to the highest recovery rates and lowest ash contents. Specifically, runs 11, 13, and 14 achieved the best recovery results, with corresponding low ash contents, further validating the optimal conditions proposed by the model. The optimal response from Minitab effectively addresses the research problem of enhancing LRC flotation efficiency by optimizing the mixed collector dosage. The study successfully identified optimal conditions, achieving a desirable balance between recovery and ash content, which supports the research aim of improving LRC flotation through a systematic approach. These outcomes also confirm the hypothesis that an optimized dosing ratio of D to OA can significantly improve flotation performance.

4. Conclusion

In conclusion, this study successfully optimized the flotation efficiency of LRC by determining the ideal dosing ratios of OA and D as mixed collectors. Our findings revealed that the highest recovery rates—65.51% in particular—were achieved with specific dosages, which also resulted in the lowest ash content (16.7%) and highest calorific values (32.4 kJ/g) for the floated coal products. The contour plot analysis from Minitab reinforced the significance of using mixed collectors, indicating that high dosages of D and moderate levels of OA are crucial for maximizing recovery and minimizing ash. The optimal conditions identified—300 g/t of D, 255.5 g/t of OA, 100 g/t of sodium silicate, and a pH of 6.88—not only confirm our model’s robustness but also predict a competitive recovery rate of 58.34% with minimal concentrate ash. This research offers valuable insights that could contribute to improving flotation processes and coal recovery efficiency in industrial applications.

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5. Appendix

Table 6 shows the complete DoE

Table 6. Design of Experiments

RunOrder	D (g/t)	OA (g/t)	SODIUM SILICATE (g/t)	pH
1	200	300	100	7.25
2	200	300	200	7.25
3	300	200	200	7.25
4	200	200	100	8.5
5	300	300	150	7.25
6	200	200	200	6
7	200	200	100	6
8	200	100	100	7.25
9	100	200	150	6
10	100	100	150	7.25
11	300	200	150	6
12	200	200	200	8.5
13	300	200	100	7.25
14	300	200	150	8.5
15	200	100	150	8.5
16	100	300	150	7.25
17	100	200	150	8.5
18	100	200	100	7.25
19	100	200	200	7.25
20	200	200	150	7.25
21	200	100	200	7.25
22	200	100	150	6
23	200	300	150	8.5
24	200	300	150	6
25	300	100	150	7.25

Table 7 shows the recovery rates

Table 7. Recovery rates

RUN	FLOATS (g)	SINKS (g)	FEED (g)	RECOVERY (%)
1	226.30	271.30	497.60	45.48
2	199.30	298.30	497.60	40.05
3	296.30	201.30	497.60	59.55
4	169.90	326.20	496.10	34.25
5	182.60	311.50	494.10	36.96
6	176.30	319.30	495.60	35.57
7	167.00	327.30	494.30	33.79
8	168.30	325.30	493.60	34.10
9	87.10	401.10	488.20	17.84
10	193.80	298.60	492.40	39.36
11	308.70	185.60	494.30	62.45
12	183.30	320.30	503.60	36.40
13	323.30	170.20	493.50	65.51
14	303.30	190.20	493.50	61.46
15	195.30	298.70	494.00	39.53
16	95.30	397.70	493.00	19.33
17	133.60	365.30	498.90	26.78
18	122.60	370.50	493.10	24.86
19	113.60	382.30	495.90	22.91
20	228.30	265.40	493.70	46.24
21	205.70	286.10	491.80	41.83
22	203.40	293.40	496.80	40.94

23	190.60	302.30	492.90	38.67
24	203.30	290.20	493.50	41.20
25	248.30	247.60	495.90	50.07

Figures 9 shows the PSD of the feed sample.

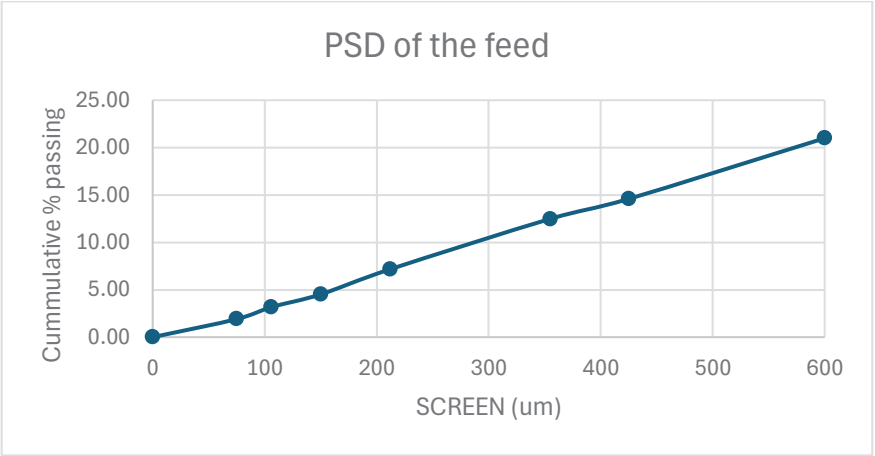

Fig. 9. PSD of the feed

Figure 10 shows the milling curve, where 80% passing 75 microns was the target grind. To achieve this, the sample was milled for 28 minutes, as per the milling curve.

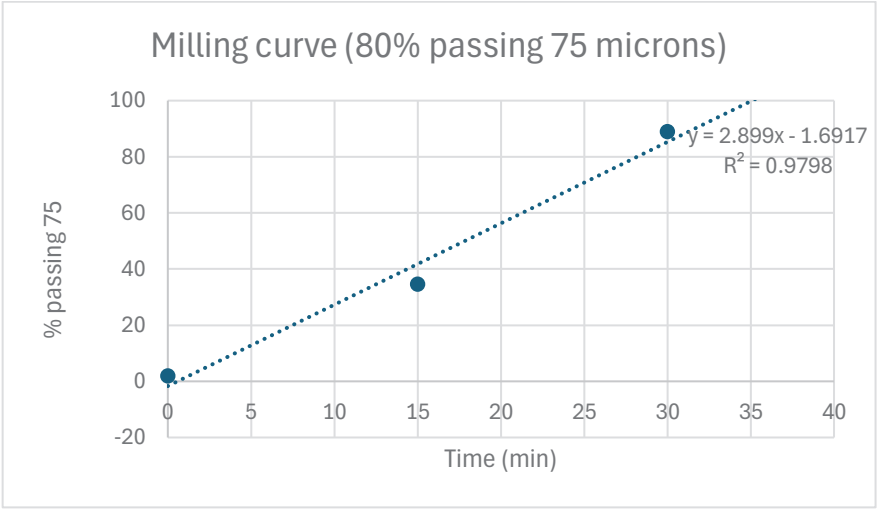

Fig. 10. Milling curve