*Proceedings of the 6th International Conference of Recent Trends in Environmental Science and Engineering (RTESE'22)*
*Niagara Falls, Canada – June 05-07, 2022*
*Paper No. 200*
*DOI: 10.11159/rtese22.200*

# The Impact of Frother Type on the Concentration of Coal by Flotation Process

**Tsumbo Nethamba, Willie Nheta**
University of Johannesburg
Mineral Processing and Technology Research Centre
P.O. Box 17011, Doornfontein 2028, Johannesburg, South Africa
nethambatsumbo1607@gmail.com; wnheta@uj.ac.za

***Abstract*** - In this paper, the interactive effect of three different frother types, particles size distribution and pH on the flotation performance of fine bituminous coal was investigated. A series of flotation tests were conducted with the objective to determine the frother that will influence the quality of the floated coal in terms of ash content and combustible recovery. The three frothers investigated were Methyl Isobutyl Carbinol and 4-Methilo-2-Pentanol which fall under aliphatic alcohols frother group and Dowfroth 200 which is in the polygycols frother group. The laboratory results showed that the maximum combustible recovery of 81.22% and low ash content of 21,2% was obtained using the following flotation conditions: Particle size distribution of 80% passing 75µm, Methyl Isobutyl Carbinol dosage of 40g/t and pH equal to 6. Sodium isobutyl xanthate and Diesel oil which were used as co-collectors were kept at a dosage 50g/t. Of the three collectors investigated, the order of better performance was Methyl isobutyl Carbinol > Dowfroth200 > 4-Methilo-2-Pentanol.

***Keywords*:** Flotation, Coal, Frothers, optimisation, Taguchi method

## 1. Introduction

Run-of-mine (ROM) coal can be processed using different technologies to achieve the desired product quality in terms of particle size, ash, sulfur and moisture content. To produce a high-quality coal product with the highest economic value, a number of coal preparation technologies acting in concert have to be applied. Which coal preparation technologies to be applied depends on ROM coal physical and chemical properties, such as coal rank (intrinsic ash and sulfur content) and particle size distribution (PSD). Nearly half of the world's coal reserves are low-rank coals. These low rank coals have high moisture and ash content, which have large effect on processes such as a reduction in plant reliability, higher transportation rates, higher $CO_2$ emissions and storage. To efficiently come up with solutions for the removal of moisture while producing less ash coal, it is very important to understand basic aspects of coal moisture and trace elements associated with the coal. Coal is the most widely available fossil fuel and energy resource worldwide and it accounts for around 30% of primary energy and 41% of global electricity production worldwide [1]. In many developing countries, electricity is generated by coal-fired power plants producing significant amounts of fly ash. Despite environmental concerns, coal will still play the most important role in the energy supply until 2050 [2] due to its abundance, relative ease of recovery, and low cost. The known coal reserves in the world are over 1140 billion tons, which is sufficient to satisfy global energy demands for more than 153 years at current rate of consumption [2]. Coal reserves reported by the World Coal Association (WCA) are significantly lower about 860 billion tons, which is equivalent to 112 years of coal output [3].

In the past, a common approach to treating coal fines (slimes) was to discard and direct them to the refuse ponds. According to a study conducted by the USA's National Research Council, over 70 to 90 million tons of coal fines were deposited in refuse ponds annually [4]. There are several techniques that have been investigated to try and recover coal from fines and froth flotation is considered to be one of the rare commercially available technologies for cleaning and recovering of coal fines [5]. Dense medium separation technologies are commonly used for treating coarse coal. On the other hand, coal flotation is widely used to treat fine coal – typically below 0.5 mm in size. According to [5], the maximum particle size the feed coal can have to be considered highly floatable is generally about 0.589 mm. Coal flotation is based on the difference in the surface properties between hydrophobic coal and hydrophilic mineral matter. It is a complex threephase process involving coal particles, reagents and air bubbles, whose behaviour is governed by a number of sub-processes. For a better understanding of the coal flotation process, the knowledge of the chemical composition, physical structure, surface characteristics, and floatability of coal is of great importance.

Coal is an organic sedimentary rock, which is composed of a variety of organic macerals and inorganic minerals. It is a very heterogeneous material, whose composition changes via coalification process. Organic and mineral matter in coal have different surface characteristics, typically expressed through their hydrophobicity level. It has been reported that the coal floatability varies widely depending on the coal rank [5]. The effect of feed particle size, pulp density and system pH on flotation process performance was investigated but the investigation on the impact of frother type on the recovery of coal has never been done [6]. This investigation seeks to investigate the effect of frother type on the recovery of coal by froth flotation process.

## 2. Material and methods

### 2.1 Materials

A South African low ranking coal sample (bituminous coal) sampled from Wonderfontein (WFN) colliery seam 3 was used for this study. The reagents used were Methyl Isobutyl Carbinol (MIBC), Dowfroth 200 and 4-Methyl-2-pentanol as frothers, Sodium isobutyl xanthate (SIBX) and Diesel as collectors and sulphuric acid as pH regulator. All reagents were sourced from Merck, South Africa and of AR grade.

### 2.2 Methods:  Coal characterization

The as received coal sample was prepared by spinning riffle and cone and quartering method to obtain the required sample for characterization. 1 kg was obtained from the spinning riffle for the purpose of particle size distribution (PSD) by Sieve shaker. 20g was obtained by spinning riffle and pulverized, from the pulverized sample, 10g was taken for X-ray fluorescence (XRF) using a RIGAKU Ultimate IV machine to determine the chemical composition. Furthermore, the remaining pulverized 10g sample was characterized by X-ray diffraction (XRD) with a Rigaku machine to determine the mineralogy of the feed sample. Proximate analysis to determine the amount of ash, moisture and volatile matter present in the coal sample was done according to procedure by [7].

### 2.3 Size reduction experiments

Coal sample was milled to obtain a PSD required for flotation. Dry milling was performed using a rod mill. 13 rods were placed in a rod mill with a coal sample with the aim of obtaining 80% passing 100, 75, 50 and 38 µm respectively.

### 2.3 Flotation experiments

Forward flotation was conducted, the coal was recovered on the float while the gangue minerals were recovered in the sinks. Distilled water and 500g of the sample were added in a 1.5-liter Leeds Barker flotation cell shown in Fig. 1 to create a slurry for the flotation experiments.

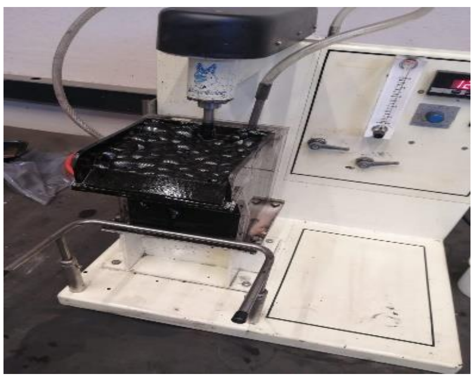

Fig. 1: Leeds Barker flotation cell

Flotation experiments were designed using Taguchi method of optimisation and major flotation parameters investigated were frother dosage and particle size distribution [8]. Different flotation reagents used and their functions are shown in Table 1 and different experimental conditions investigated are shown in Table 2. For all the flotation tests work, a Leeds Barker flotation cell was used. Flotation tests were carried out on samples milled to 80% passing of 100, 75, 50 and 38µm and the %solids was kept constant at 30%. The slurry was agitated with a top driven variable speed impeller at 1200rpm. Sodium isobutyl xanthate (SIBX), Diesel oil and pH were kept constant throughout all the flotation experiments. SIBX and Diesel were kept at a dosage of 50 g/t and the pH at 6. The PSD was varied between 80% passing 100µm to 80% passing 38%µm and frothers were varied between 30 – 60 g/t for all 16 runs. After flotation process, the concentrates were taken to the muffle furnace for further analyses of ash content.

Table 1: Summary of flotation reagent schemes investigated.

| Reagent no. | Reagent name | Function | Typical reagent dosage | Conditioning time in minutes |
|---|---|---|---|---|
| 1. | Sulphuric acid | pH controller | - | |
| 2. | SIBX | Collector | 50 g/t | 2 |
| 3. | Diesel oil | Collector | 50 g/t | 2 |
| 4. | MIBC | Frother | 30-60 g/t | 2 |
| 5. | 4-Methilo-2-pentanol | Frother | 30- 60 g/t | 2 |
| 6. | Dowfroth 200 | Frother | 30-60 g/t | 2 |

Table 2: Taguchi Design of flotation Experiments Summary

| Experiment No. | 80% passing PSD (µm) | Frother type and dosage (g/t) |
|---|---|---|
| 1 | 38 | 30 |
| 2 | 75 | 40 |
| 3 | 100 | 50 |
| 4 | 50 | 60 |
| 5 | 50 | 30 |
| 6 | 38 | 40 |
| 7 | 75 | 50 |
| 8 | 100 | 60 |
| 9 | 38 | 30 |
| 10 | 75 | 40 |
| 11 | 50 | 50 |
| 12 | 100 | 60 |
| 13 | 50 | 30 |
| 14 | 100 | 40 |
| 15 | 75 | 50 |
| 16 | 38 | 60 |

## 3. Results and discussions

### 3.1. Characterization of raw clay material

The chemical composition of the coal sample determined by XRF is shown in Table 2. Major impurities are Si, Al, Fe, and Ca at 21.35, 11.30, 9.45 and 4.75 % wt respectively. The XRD pattern shown on Fig. 2 revealed that the major crystalline mineral phases in the coal were quartz, kaolinite and basanite. Kaolinite and bassanite are clay minerals which lead to high ash content. The most common mineral matter that occur in coal are: clay minerals (kaolinite and montmorillonite), carbonates (dolomite, calcite, siderite), oxides (quartz) and sulfides (pyrite) [5]. Coal flotation is dependent on the surface properties of high-ash mineral matter. Pyrite has hydrophobic surface property, while the other minerals are generally hydrophilic. Coal flotation can be drastically affected by oxidation and by the presence of various inorganic materials.

From proximate analysis conducted, average moisture, ash and volatile matter content for the coal sample were 2.45, 49.19, and 21.29% respectively. A moisture content of 2.45% reflects that the coal sample was bituminous coal since it is bituminous coal that has % moisture range of 0.5–14% [9].

Table 3: Chemical composition of the feed sample

| Element | Al | Si | Ca | Ti | Fe |
|---|---|---|---|---|---|
| % Wt | 11.30 | 21.35 | 4.57 | 2.45 | 9.45 |

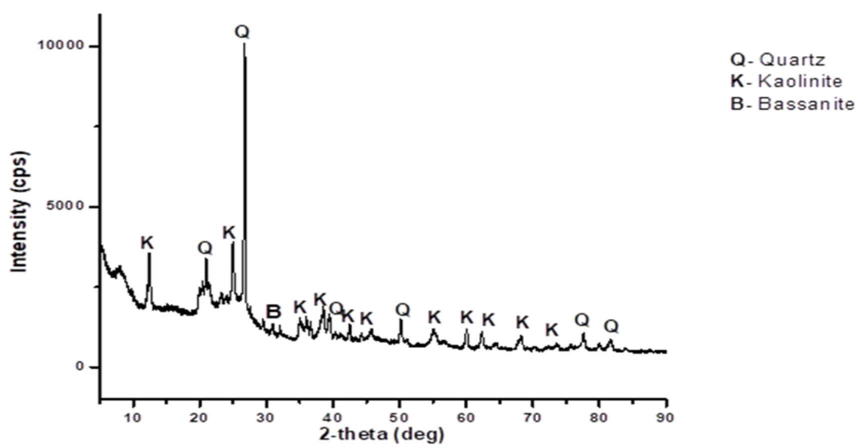


Fig. 2: Mineralogical composition of the coal sample

### 3.2 Size reduction experiments results

The milling experiments of the coal sample revealed that to obtain 80% passing 100, 75, 50, and 38µm, the sample was milled for 92, 134, 183, and 212 minutes respectively. According to [10], it was found that the finest and coarsest particles are less susceptible to flotation than intermediate particles. The flotation recovery of fines is lower in comparison with other particle sizes, primarily as a result of the decreased probability of collision between particles and bubbles and course particles leads to detachments of particles from the bubble [11].

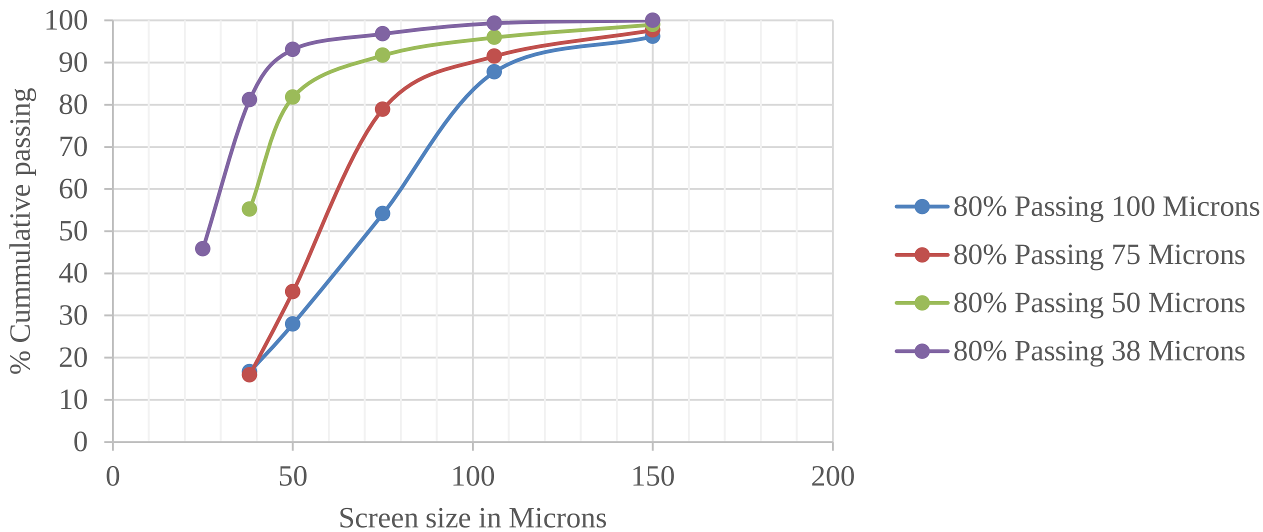


Fig. 3: Particle size distribution of milled coal sample

**3.3 Optimisation of flotation experiments results**

The interactive effect of MIBC dosage and particle size distribution was investigated using Taguchi method and the results are shown in Fig. 3.

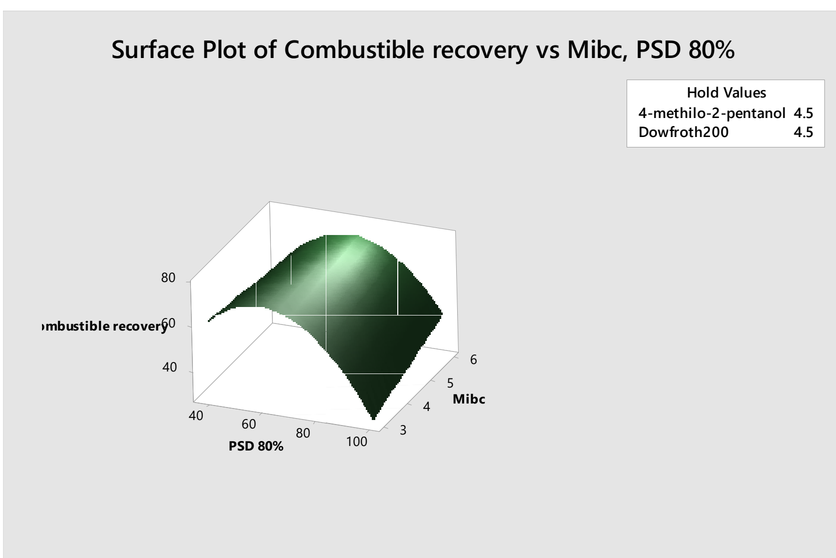


Fig. 3: Effect of particle size on combustible recovery.

From Fig. 3, the surface plot predicted that a high combustible recovery can be obtained from flotation of coal with a PSD of 80% passing 75µm and MIBC dosage 40g/t. This can be explained by the fact that fine and coarse particles are less susceptible to flotation than intermediate particles. The more one increases the frother dosage in an attempt to maximize recovery the more the process becomes less selective. The overdose of alcohol frothers leads to a slow rate of flotation due to excess frothers' tendency to disrupt the froth.

### 3.4 Flotation experiments results

Batch rougher flotation tests were carried out using a Leeds Barker flotation cell and the results are shown in Table 4. During flotation tests, reagents dosage was kept consistent for all laboratory test work as obtained using Mini Tab18 software (Taguchi design). The maximum coal flotation combustible recovery of 81.22% and 21.3% ash (dry basis) was obtained from Test no.10 using the following conditions: PSD of 80% passing 75µm, pH equal to 6, SIBX and Diesel oil dosage of 50g/t each and MIBC dosage of 40g/t. According to [12] the MIBC addition reduce the surface tension at the liquid–vapour interface, which results in the production of finer bubble size distribution and thus improves flotation rates and recovery values. However, a finer bubble size distribution also increases water recovery, which results in a greater recovery of entrainable coal particles. The interaction between OH group of MIBC and hydrated mineral matter improves floatability of high ash coal particles.

Table 4: Rougher flotation results of on yield, ash content and combustible recovery

| Test no. | Yield, % Wt | Ash content, % | Combustible Recovery, % |
|---|---|---|---|
| 1. | 25.6 | 26.5 | 48.62 |
| 2. | 29.8 | 21.3 | 60.60 |
| 3. | 33.5 | 22.1 | 67.43 |
| 4. | 21.8 | 31.2 | 38.76 |
| 5. | 31.8 | 25.3 | 61.38 |
| 6. | 36.3 | 21.7 | 73.44 |
| 7. | 26.8 | 23.8 | 52.77 |
| 8. | 23.6 | 28.7 | 43.48 |
| 9. | 26.7 | 28.1 | 49.61 |
| 10. | 39.89 | 21.2 | 81.22 |
| 11. | 36.6 | 22.6 | 73.20 |
| 12. | 30.2 | 23.7 | 59.54 |
| 13. | 30.6 | 29.7 | 55.59 |
| 14. | 33.5 | 28.3 | 62.07 |
| 15. | 27.5 | 33.8 | 47.04 |
| 16. | 25.2 | 29.6 | 45.84 |

## 4. Conclusion

The current study confirmed that frother type plays a vital role during flotation of fine bituminous coal. The order of the flotation efficiency of the tested frothers is MIBC > Dowfroth200 > 4-Methilo-2-Pentanol. The best combustible recovery and ash content was obtained when floating bituminous coal with a PSD of 80% passing 75 µm using MIBC as a frother, SIBX and diesel as co-collectors at pH 6. Major clay minerals in the coal sample were Kaolinite and Bassanite. Taguchi method of optimisation proved to be suitable for optimisation of coal flotation process. The effectiveness of MIBC proved that it is the best frother when floating fine bituminous coal.

## Acknowledgements

The authors acknowledge the financial support from the National Research Foundation of South Africa [Grant number **132291]** and University Research Committee (URC) of University of Johannesburg. Wonderfontein (WFN) colliery is acknowledged for providing the coal samples.

## References


[1] World Energy Council. (2016, October 10). World energy resources. [Online]. Available: https://www.worldenergy.org/wp-content/uploads/2016/10/World-Energy-Resources-Full-report.

[2] B Dudley (2017, August 6). BP statistical review of world energy. [Online]. Available: https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review-2017/bp-statistical-review-of-world- energy-2017-full-report.pdf.

[3] World Coal Association (2012, ). Coal – energy for sustainable development. [Online]. Available: http://www.worldcoal.org/blog/coal-%E2%80%93-energy-for-sustainable-development/ .

[4] Orr, F. M. " Coal Waste Impoundments: Risks, Responses and Alternatives," *National Academy Press*, 2002.

[5] M. Ramudzwagi,N. Tshiongo-Makgwe, and W. Nheta. "Recent developments in beneficiation of fine and ultra-fine coal-review paper," *J. Clean. Prod.*, vol. 276, pp. 122693, 2020.

[6] Y. Li, W. Xia, Y. Peng, Xie, G., "A novel coal tar-based collector for effective flotation cleaning of low rank coal," *J. Clean. Prod.*, vol. 273, pp. 123172, 2020.

[7] C.J. Donahue, and E. A. Rais., "Proximate analysis of coal," *J. Chem. Educ.*, vol. 86, no. 2, pp. 222, 2009. 86, no. 2 (2009): 222.

[8] T. Masiya and W. Nheta. "Flotation of nickel-copper sulphide ore: optimisation of process parameters using Taguchi method." In *Proceedings of the International Conference on Mining, Material and Metallurgical Engineering, Prague (Czech Republic)*, 2014, vol. 113, pp. 1-11.

[9] P.J. Hancox and A.E. Götz., "South Africa's coalfields—A 2014 perspective," *Int. J. Coal Geol.*, vol. *132*, pp.170-254, 2014.

[10] J. Drzymala and P. B. Kowalczuk, "Classification of flotation frothers," *Minerals*, vol. 8, no.2, pp. 53, 2018.

[11] S. Muganda, M. Zanin and S. R. Grano, "Influence of particle size and contact angle on the flotation of chalcopyrite in a laboratory batch flotation cell," *Int. J. Miner. Process.*, vol. 98, no. 3-4, pp. 150-162, 2011.

[12] P. K. Naik, R. S. Reddy and V. N. Misra, "Interpretation of interaction effects and optimization of reagent dosages for fine coal flotation," ," *Int. J. Miner. Process* ., vol. 75, no 1-2, pp. 83-90, 2005.