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A.M. SALEH*, J. ISKRA**

EFFECT OF MOLECULAR WEIGHT OF POLYETHYLENE GLYCOL FROTHERS ON THEIR PERFORMANCE IN LOW RANK COAL FLOTATION

In this study, the effect of molecular weight of polyethylene glycol frothers on flotation of low rank coal was investigated. Four frothers of molecular weights equal to 400, 600, 1000 and 1500 were tested. These frothers were referred to, throughout the text, as PG400, PG600, PG1000 and PG1500, respectively. The obtained data showed that polyethylene glycol of molecular weight equal to 1000 or higher provided worse results. The best performance, i.e., high flotation recovery, rate and selectivity, was observed for PG600 while PG400 performed worse than PG600 and better than PG1000 and PG1500. The best performance of PG600 was attributed to its greater surface activity over all other tested frothers.

INTRODUCTION

Froth flotation is an interactive engineering system consisting of three major components: chemistry, equipment and operating conditions (Klimpel 1984). Frothers are considered as major variables in the chemical component. A frother molecule consists of polar and nonpolar groups which make it preferentially adsorbs and orients at the water/air interface and does not form stable bonds at mineral surfaces (Booth, Freyberger 1962). Leja and Schulman's (1954) experimental results have revealed the possibility of frother molecules to adsorb at collector-coated mineral surfaces. Interactions between frother and collector molecules are also well documented in the works of Leja (1956/1957). Since frother molecules accumulate preferentially at the water/gas interface, they actively interact with collector molecules at the moment of the particle/bubble collision and attachment. It is well established that frothers reduce induction time and hence, make flotation process more kinetic (Laskowski 1989). Some authors (Klimpel, Hansen 1987) still see the ability of frother to disperse air into fine bubbles, which helps in stabilizing the froth, is the most important characteristics of frother. Several approaches were suggested to improve frother performance in flotation process. First,

*Department of Mining, Faculty of Engineering, Alazhar University, Cairo, Egypt.
**Department of Mineral Processing and Waste Treatment, Silesian Technical University, Gliwice, Poland.

Kumar et al. (1986) indicated the synergetic effect of mixing frothers and stated that it is more advantageous than using any one of them. Mixing frother and collector or emulsification of collector with nonionic frothers was also reported (Read et al. 1989). Recently, flotation research was extended towards quantifying frother chemistry/particle size interactions. These studies led to new frothers that efficiently recover fine or coarse grains (Hansen, Klimpel 1986; Hansen et al. 1986; Klimpel, Hansen 1988).

This study investigates the effect of molecular weight of a polyethylene glycol frother on its performance in low rank coal flotation.

EXPERIMENTAL

Materials

Coal used in this study was of the steam type of the rank of 31.1 according to the Polish Classification Standards (Polish Standards 1950). According to ASTM Standards, it can be considered as lignite or as subbituminous coal. It was obtained from Paryz mine, Dąbrowa Górnicza, Poland. It contained 27% ash and 3.2% total sulphur. Commercial diesel oil was used as a collector. Four polyethylene glycols were applied and tested as frothers. The general chemical formula of the frothers is:

$$HO{-}C_2H_4O(C_2H_4O)_n\,C_2H_4{-}OH$$

The frothers applied are characterized by molecular weights equal to 400, 600, 1000 and 1500. These frothers were referred to, throughout the text, as PG400, PG600, PG1000 and PG1500, respectively. All these reagents were prepared and supplied by Institute of Organic Chemistry, Faculty of Chemistry, Silesian Technical University, Gliwice, Poland.

Methods

Flotation tests were carried out in a mechanical subaeration laboratory flotation machine equipped with a 1-liter capacity cell. Raw coal was received from the mine as coarse lumps. These lumps were crushed with a jaw crusher to 1 mm size. The product from the jaw crusher was dry ground, using a ball mill (70% filling), to a size of −0.2 mm. After each run, the product was dry screened on a 0.2 mm large scale sieve. The −0.2 mm size fractions obtained from different runs were collected while +0.2 mm fractions were combined and returned to the mill until all material passed through the 0.2 mm screen. A representative sample of the flotation feed was wet sized using a Ro-Tap shaker and a set of laboratory sieves. The ash content in the obtained different size fractions was determined. Also, small samples were collected by a riffle sampler from the flotation feed and delivered directly to ash analysis. The size distribution of the considered flotation feed as well as the ash content are shown in Table 1. All flotation tests were carried out using tap water at 10% pulp density (solids by weight). The coal sample (100 g) was agitated for 5 min to ensure complete wetting of the coal surface, then the pulp was conditioned with diesel oil collector for 5 min and for 1 min with the considered frother. For the kinetic tests, the concentrate was collected after the following time periods: 0.15, 0.25, 0.50, 1.00, 2.00 and 4.00 min. Otherwise, one concentrate was collected after 4 min flotation time. The time was measured from the moment when the air was introduced into the cell. The pulp level was kept constant by adding more water during flotation. The pulp density, aeration rate (5 dm^3/min), speed of the flotation machine impeller (3800 r.p.m) and paddle velocity (10 runs/min) were kept constant during all tests. All flotation tests were carried out at the neutral pH range of 5.9–6.1. pH was adjusted using HCl and NaOH solutions. The concentrate as well as the tailings were filtered in a vacuum filter and dried in an electric drier at 80–100 °C, weighed with an electric balance and analyzed for ash content. The surface tension of the aqueous solutions of the considered frothers was determined with a stalagmometer.

Table 1. Size distribution of the considered flotation feed

Size mm	Wt %	Ash %
–0.200 + 0.150	08.04	18.86
–0.150 + 0.102	20.32	18.10
–0.102 + 0.075	10.69	17.90
–0.075 + 0.060	07.48	25.29
–0.060	53.47	33.37
Total	100.00	26.29

RESULTS AND DISCUSSION

It is worth to mention that dosages of reagents (diesel oil and considered frothers) were expressed in kg of frother per ton of coal.

Figures 1 and 2 illustrate the effect of diesel oil dosage on coal flotation as a function of the frother type with regard to coal recovery and concentrate ash content respectively. In all cases, constant frother dosage equal to 1.5 kg/t was applied. It is clear that increasing molecular weight of the polyethylene glycol to 1000 or more leads to a worse results, in particular, with respect to coal recovery. Also, while PG400 has a better performance than PG1000 and PG1500 with regard to coal recovery, it showed a lower coal recovery and higher concentrate ash content than PG600. PG1000 showed better performance than PG1500. The best coal recovery and concentrate grade is obtained with PG600. For all investigated frothers, the coal recovery increases as diesel oil dosage increases. With regard to concentrate ash content, there is a trend indicating decreasing ash content with the increase of diesel oil dosage increases in the case of PG1000 and PG1500, while opposite effects are observed in the case of PG400 and PG600.

Figures 3 and 4 illustrate the effect of frother dosage on coal recovery and concentrate ash content, respectively. In all cases, a constant diesel oil dosage equal to 2.93 kg/t was applied. It is clear that both a high frother dosage and a low one have

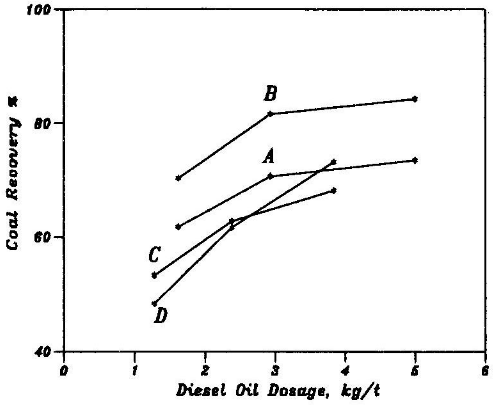

Fig. 1. Effect of diesel oil dosage on coal recovery
as a function of frother type. 1.5 kg/t frother dosage, flotation time 4 min.
A – PG400, B – PG600,
C – PG1000 and D – PG1500

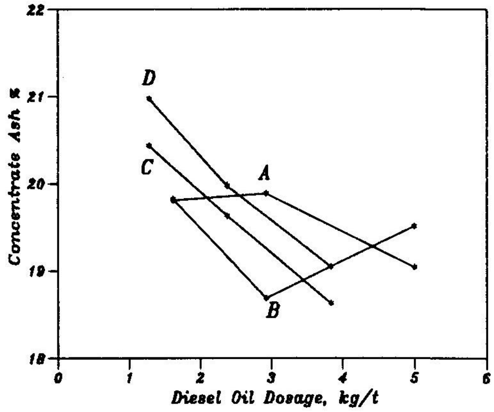

Fig. 2. Effect of diesel oil dosage on concentrate
ash content as a function of frother type.
1.5 kg/t frother dosage, flotation time 4 min.
A – PG400, B – PG600,
C – PG1000 and D – PG1500

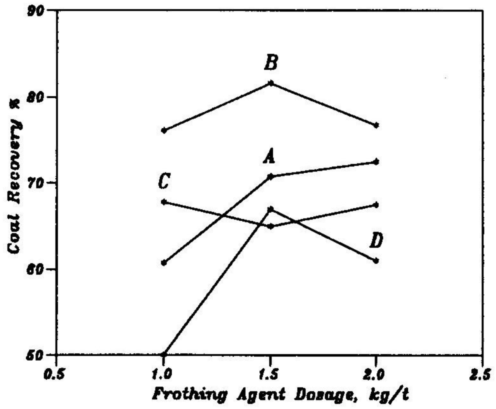

Fig.3. Effect of frother dosage on coal recovery.
2.93 kg/t diesel oil dosage,
flotation time 4 min.
A – PG400, B – PG600,
C – PG1000 and D – PG1500

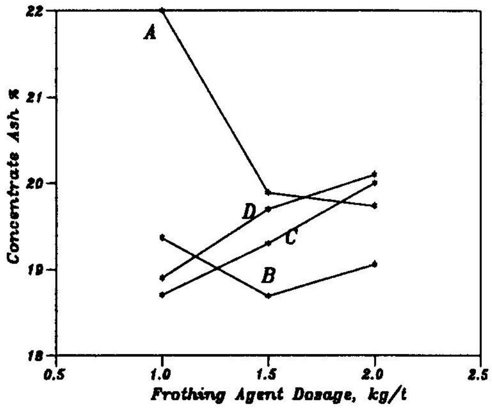

Fig. 4. Effect of frother dosage on concentrate ash content. 2.93 kg/t diesel oil dosage,
flotation time 4 min.
A – PG400, B – PG600,
C – PG1000 and D – PG1500

a harmful effect. Such harmful effect is sometimes reflected in coal recovery or in concentrate grade or in both. A low dosage of PG400 is the most harmful with regard to concentrate ash content. Also, as observed above, performance of PG1000 is better than that of PG1500. Over the range of frother dosage under investigation (1–2 kg/t), PG600 showed the best performance. PG1000 and PG1500 were characterized by increasing concentrate ash content as frother dosage increased. On the other hand, this tendency is not observed for other investigated frothers. These frothers, i.e, PG400 and PG600 produce decreasing and decreasing, followed by increasing, ash content in the concentrate, respectively as frother dosage increases.

Figure 5 illustrates recovery–time profiles of the considered frothing agents. Constant diesel oil (2.93 kg/t) and constant frother dosage (1.5 kg/t) were applied. This procedure was carried out to illustrate the effect of frother type (as a function of its molecular weight) on the flotation kinetics. The modified two-parameter first-order model (Eq. 1) was selected to estimate equilibrium recovery (R) and flotation rate constant (k). In this model,

$$r = R\left(1-\frac{1}{kt}\right)\left[1-\exp(-kt)\right] \qquad (1)$$

r is cumulative recovery and t is flotation time. The application of this model was justified and was found to be more appropriate than the simple classical first order model (Klimpel 1980; Dowling et al. 1985). It is clear that the highest ultimate recovery is obtained with PG600. The ultimate recovery follows the order: PG600 > PG400 > PG1000 > PG1500. There is no apparent difference in the flotation rate between investigated frothers.

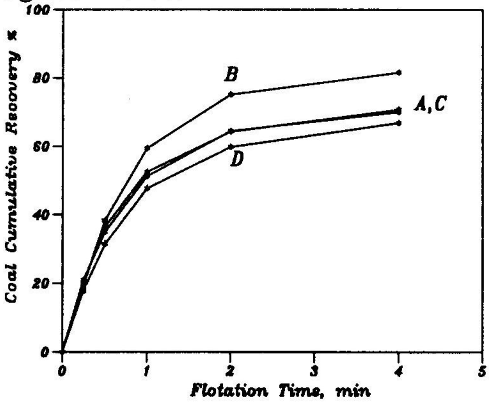

Fig. 5. Recovery–time profiles of considered frothing agents. 2.93 kg/t diesel oil dosage and 1.5 kg/t frother dosage. A – PG400, B – PG600, C – PG1000 and D – PG1500

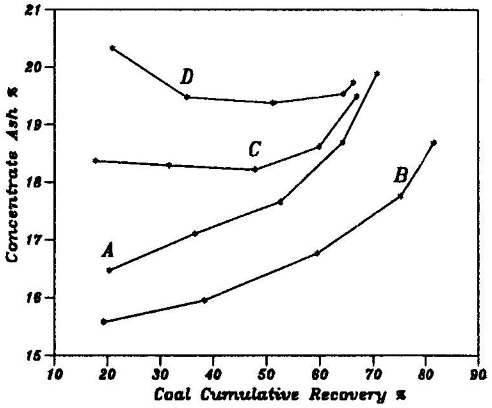

Fig. 6. Grade–recovery profiles of considered frothing agents. 2.93 kg/t diesel oil dosage and 1.5 kg/t frother dosage. A – PG400, B – PG600, C – PG1000 and D – PG1500

Figure 6 shows grade–recovery profiles of the investigated frothing agents. It is clear that PG600 is the most selective frother. The frother selectivity follows the order: PG600 > PG400 > PG1000 > PG1500. It is obvious that increasing molecular weight of the polyethylene glycol frother to at least 1000 has a harmful effect on selectivity.

Figure 7 summarizes the effect of molecular weight of the polyethylene glycol frother on its performance. Coal recovery and concentrate ash content were considered as evaluation parameters. The results presented in this figure were obtained at 2.93 kg/t diesel oil dosage, 1.5 kg/t frother dosage and after 4 min flotation time. It is clear that while a little effect of molecular weight was observed with regard to concentrate ash content, a remarkable decrease in coal recovery is observed when the molecular weight of polyethylene glycol goes beyond 600. This figure illustrates the best performance of PG600 over other investigated frothers. It is worth mentioning that the range of molecular weights between 600 and 1000 was not investigated throughout this work. Hence, investigating the effect in this range is highly recommended to determine the molecular weight of the polyethylene glycol frother that gives the best performance, i.e, PG600 or other in the range of 600–1000.

Figure 8 shows the effect of frother concentration on the surface tension of its aqueous solution. It is clear that the surface activity of the investigated frothers follows the order: PG600 > PG400 > PG1000 > PG1500. Thus, one can conclude that the observed best performance of PG600 over other frothing agents may result from

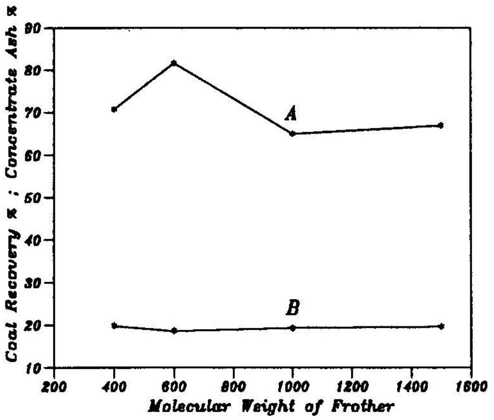

Fig. 7. Effect of molecular weight of polyethylene glycol frother on coal recovery (A) and on concentrate ash content (B). 2.93 kg/t diesel oil, 1.5 kg/t frother and flotation time 4 min

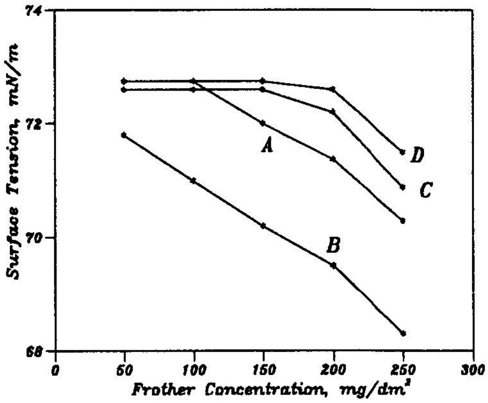

Fig. 8. Effect of frother concentration on surface tension of its aqueous solution. A – PG400, B – PG600, C – PG1000 and D – PG1500

its higher surface activity. This result may be justified by the fact that the stability of froth is governed by surface tension. With regard to this phenomenon, the obtained flotation results agree well with the surface tension results. Also one can see that as the molecular weight of polyethylene glycol frother increases its surface activity also increases to some limit, and then begins to decrease. This phenomenon is very clear, in particular, if one notices that PG1000 and PG1500 on one side and PG400 on the other have lower surface activity than PG600.

CONCLUSIONS

This study presents the effect of the molecular weight of a polyethylene glycol frother in low rank coal flotation. Four chemical frothers characterized by molecular weights equal to 400, 600, 1000 and 1500 were considered. These reagents were referred to, throughout the text, as PG400, PG600, PG1000 and PG1500. The experimental results showed that increasing molecular weight of a polyethylene glycol frother to 1000 or higher leads to a worse performance. At a specific diesel oil dosage (3 kg/t), the coal recovery as well as frother selectivity followed the order: PG600 > PG400 > PG1000 > PG1500. Also, PG600 showed the highest flotation rate. Hence, it seems that the best performance with regard to all considered flotation parameters, i.e, flotation recovery, rate and selectivity, is obtained with PG600. The best performance of PG600 was attributed to its higher surface activity. It was found also that a high frother dosage as well as a low one has a harmful effect on flotation results. This harmful effect was reflected in coal recovery for some frothers and in concentrate ash content for others. Therefore, one can conclude that the performance of the polyethylene glycol frother improves as its molecular weight increases until it reaches a maximum (600 in this study). With further increase in molecular weight, the performance of polyethylene glycol frother becomes worse. Investigating the performance of polyethylene glycol frothers with molecular weights in the range of 600–1000 is highly recommended.

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Badano wpływ masy cząsteczkowej spieniaczy polietylenowo-glikolowych na wyniki flotacji węgla nisko uwęglonego. Zbadano cztery spieniacze o różnych masach cząsteczkowych: 400, 600, 1000 i 1500. W tekście oznaczono je jako PG400, PG600, PG1000 i PG1500. Otrzymane wyniki badań wskazują, że spieniacze o masie cząsteczkowej 1000 i wyższej dają gorsze wyniki flotacji węgla niż spieniacze o mniejszych masach cząsteczkowych. Najlepsze wyniki flotacji, czyli wysoki uzysk, selektywność rozdziału oraz dobrą kinetykę procesu otrzymuje się dla spieniacza PG600, ustępuje mu nieco aktywnością spieniacz PG400. Tak dobre działanie w procesie flotacji węgla spieniacza PG600 można tłumaczyć tym, że z badanych spieniaczy wykazywał największą aktywność powierzchniowo czynną.