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TESTING FLOTATION FROTHERS

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In practice, fothers are selected following general guidelines and verification by laboratory and/or plant tests. The terms "powerful" or "selective," which are commonly used to characterize frothers, have intuitive rather than scientific meaning.

A research program has been set out to study fundamental properties of the flotation frothers and to identify the tests which can provide information needed to characterize and classify such flotation agents. Since flotation frothers are used to reduce bubble size and increase froth stability, in the procedures adopted in this paper they were characterized by their ability to reduce bubble size in a flotation cell and to increase foam stability. It has been shown that the developed frother classification system based on these two measurements is able to correctly distinguish the frothers known as being selective from those which are known to be powerful.

Key words: flotation frothers, dynamic foamability index, cristal coalescence concentration

INTRODUCTION

Froth flotation process commonly requires quite a large variety of flotation agents. Although it is believed that the most important are collectors, which are used to render valuable minerals hydrophobic, as the term froth flotation implies the process is inseparable from the froth. Froth generation requires the use of frothers which are utilized to facilitate air dispersion into fine bubbles, and to stabilize the froth. According to Leja-Schulman's penetration theory (Leja & Schulman, 1954; Leja, 1956/57), frothers accumulate preferentially at the water/gas interface and interact with collector molecules adsorbed onto solid particles in the particle-to-bubble collision and attachment.

The difficulties inherent in giving a comprehensive scientific analysis of flotation frothers were in depth analyzed by Wrobel 50 years ago (Wrobel, 1953). The situation

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50 years later is not that different and the terms "powerful" and "selective" are still commonly used to describe the properties of these flotation agents. The frothers that are purchased for commercial use usually come along with the information exemplified by Table 1.

Table I. Flotation Forther Characteristics as Provided by Manufacturers

Property	Frother 1	Frother 2	Frother 3
Molecular weight	200	250	400
Viscosity, cP	7	12	27
Density, g/cm^3	0.970	0.980	0.988
Freez point, ^oC	below –50	below –50	below –50
Flashpoint, ^oF	250	285	325

^oF stands for Fahrenheit degrees.

While the information provided in Table I is important for handling these products it does not say anything about their flotation properties. Some manufacturers, therefore, provide some additional qaulitative information in which these products may be further characterized as "selective" or "powerful". So, what we - who have to use these products - do? Well, we develop a research program and screen the acquired products following some general guidelines which may vary depending on the school.

In the fundamental studies on flotation fothers there are many unknowns, and one known fact. It is well accepted that pure liquids do not foam. For a liquid to foam, it must be able to form a membrane around the gas bubble that opposes the thinning of the lamellae. Foaming does not occur in pure liquids because there exists no such mechanism for the retardation of lamellae drainage (Kitchener & Cooper, 1959). When surface active molecules are present, however, their adsorption at the gas/liquid interface serves to retard the loss of liquid from the lamellae and to produce a more mechanically stable system. This directly leads to a simple conclusion that relates frother activity to its surface tension. However, in the concentration ranges in which frothers affect foaming and bubble size the water surface tension is affected very little (Sweet et al., 1997). Recent results prove without any doubt that frothers control the size of bubbles by decreasing bubble coalescence (Cho & Laskowski, 2002a; Cho & Laskowski, 2002b), and that the bubble coalescence can be entirely prevented at frother concentrations exceeding the critical coalescence concentration (CCC).

The testing procedure described in this paper is based on the fundamental and well recognized fact that flotation frothers reduce the bubble size. Likewise, they are known to increase foam stability. These two measurements should then be employed to characterize fundamental flotation related properties of these agents.

EXPERIMENTAL PROCEDURES

MATERIALS

Since MIBC is the most common fother, the first series of tests included various n-hexanol isomers/derivatives (Cho and Laskowski, 2002a; Cho and Laskowski, 2002b). In the second series, the mono-alkyl ethers of propylene oxide, which include three important commercial frothers (DF-200, DF-250 and DF-1012) have been tested (Laskowski et al., 2003). The studied frothers are listed in Table II.

Table II. List of the tested frothers

Common name	Purity	Chemical formula	Molecular weight	HLB
MIBC	Technical	$CH_3CHCH_3CH(OH)CH_3$	102.2	6.1
HEX	Reagent	$C_6H_{13}OH$	102.2	6.0
DEMPH	Technical	$C_6H_{13}OH(EO)_2(PO)$	248.4	6.6
DEH	Technical	$C_6H_{13}OH(EO)_2$	190.3	6.7
MPDEH	Technical	$C_6H_{13}OH(PO)EO)_2$	248.4	6.6
(PO)1	Reagent	$CH_3(PO)OH$	90.12	8.3
(PO)2	Reagent	$CH_3(PO)_2OH$	148.12	8.15
DF-200	Technical	$CH_3(PO)_3OH$	206.29	8.0
DF-250	Technical	$CH_3(PO)_4OH$	264.37	7.8
DF-1012	Technical	$CH_3(PO)_{6.3}OH$	397.95	7.5

EO and PO are abbreviations for $–OC_2H_4$- and $–OC_3H_6$-, respectively.

BUBBLE SIZE

Quite a large variety of experimental methods have been introduced to measure the size of bubbles (Chen et al, 2001; Grau and Heiskanen, 2002). The bubble sizer developed at the University of Cape Town (O'Connor et al., 1990, Tucker et al., 1994), referred to as UCT bubble sizer, has been used in our measurements (Cho and Laskowski, 2002a; Cho and Laskowski, 2002b). Bubbles were generated in an Open Top Leeds Flotation Cell set at 1000 rpm and at air flow rate of about 5 dm^3/min. The sampler of the UCT bubble sizer was positioned 50 mm above the stator. Distilled water was used to prepare solutions of the tested frothers.

DYNAMIC FOAMABILITY INDEX

The procedure that has been used follows the methodology developed by Malysa and his colleagues (Malysa et al., 1978; Czarnecki et al., 1982). This method requires determination of the retention time (rt) from the slope of the linear portion of the dependence of the total gas volume (V) contained in the system (solution and foam) plotted versus gas flow rate (Q).

$$rt = \frac{\Delta V}{\Delta Q} \tag{1}$$

The obtained rt values are then used to determine the DFI which is defined as the limiting slope of the rt-concentration plot for c $\rightarrow$ 0:

$$DFI = \left(\frac{\partial rt}{\partial c}\right)_{c=0} \tag{2}$$

SURFACE TENSION

Du Noy Ring Tensiometer was used to measure the surface tension of aqueous solutions at varying frother concentrations.

RESULTS

Figs. 1 and 2 show the bubble size versus concentration curves plotted for polyglycol frothers and MIBC. The figures also indicate the critical coalescence concentration (CCC) determined graphically from the plots. At concentrations c > CCC, the bubbles cease to coalesce, the size of bubbles becomes constant and is not affected by frother concentration any more. The CCC values for the studied polyglycols are given in Table III. By normalizing frother concentration with regard to the CCC values for each frother it can easily be shown that all the curves converge on one single curve (Fig. 3).

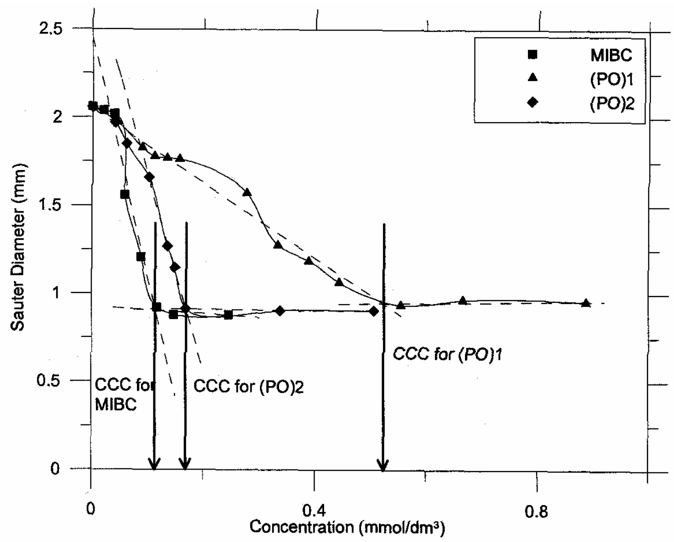

Fig. 1. Graphical evaluation on the CCC values for MIBC, (PO)1 and (PO)2

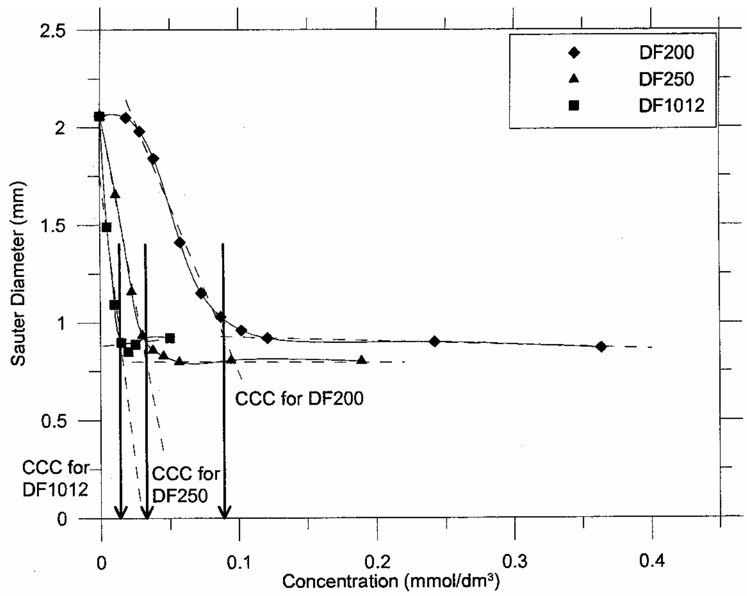

Fig. 2. Graphical evaluation on the CCC values for Dowfroths

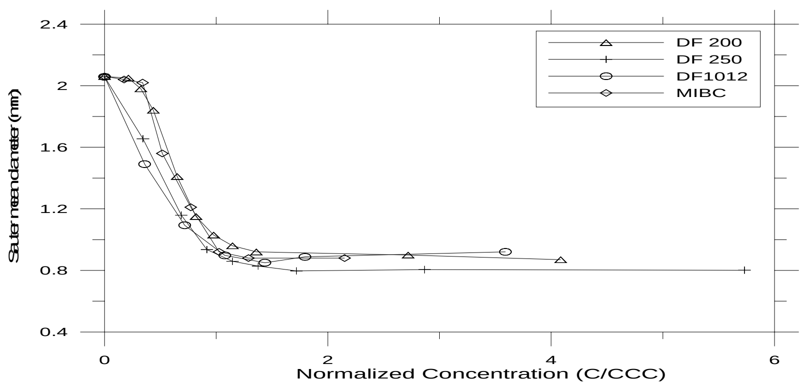

Fig. 3. Effect of the normalized concentration on bubble size

The obtained results indicate that with the increasing number of propylene oxide groups per molecule in the homologous series of polyglycol frothers, the ability of these compounds to reduce the bubble size improves (Laskowski et al. 2003). The frothers that produce finer bubbles also produce more stable dynamic foams as the correlation between DFI and CCC values suggest (Fig. 4.). This figure confirms that the frothers that are more efficient in reducing bubble size also produce more stable foam. Larger DFI values indicate more stable foam, the foam in which bubbles do not easily coalesce.

As already discussed (Laskowski, 2003), the DFI-CCC diagram (Fig. 4) can be used to classify frothers. Those situated in the left-upper corner of this diagram are very powerful fothers, while the ones situated in the right-bottom corner are weaker and more selective.

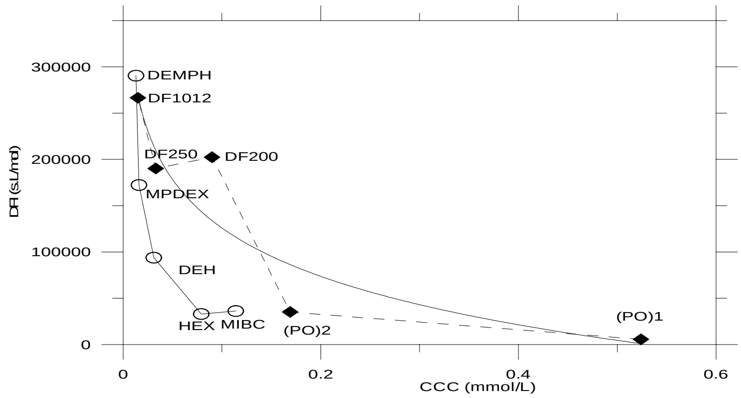

Fig. 4. Relationship between DFI and CCC values for the tested frothers

The results so far discussed have been obtained while working with two-phase systems (foams). It is still not clear how all this is related to the flotation performance of the frothers. To analyse it further, in my paper presented at the 22nd Int. Mineral Processing Congress (Laskowski, 2003) I compared Fig. 4 with Fig. 5.

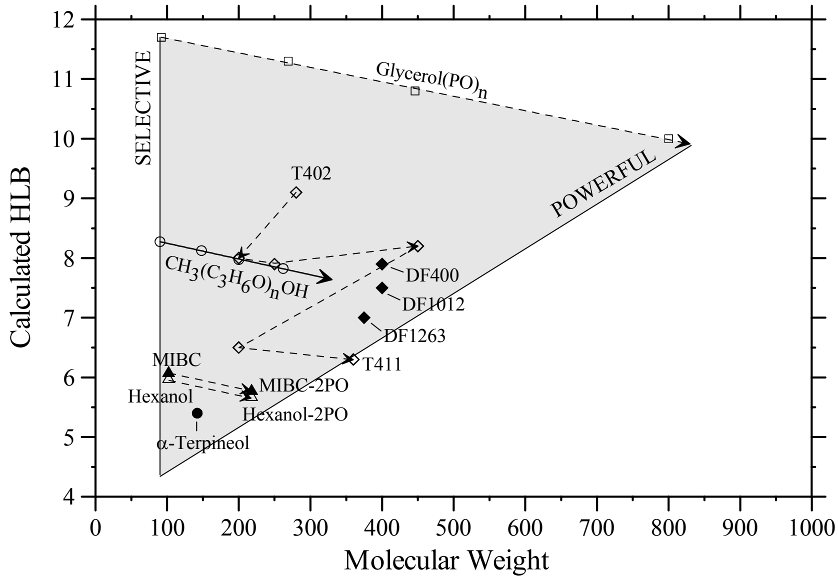

Fig. 5. The HLB-Molecular Weight diagram for flotation frothers

In the latter diagram, various frothers are positioned on the HLB – Molecular Weight plot (HLB stands for Hydrophile Lipophile Balance). As seen the frothers which fall on the left side of this diagram are known to be selective in flotation, while the ones which are situated far to the right from this line are known to exhibit properties of the strong flotation frothers. The former can be used in flotation of very fine particles, whereas the latter will provide higher recoveries and better performance in floating of coarser particles. Comparison with Fig. 4 explains that those which are selective are characterized by small DFI and large CCC values, while the powerful frothers are characterized by large DFI and small CCC values.

DISCUSSION

The results shown in this paper demonstrate that flotation frothers can be well characterized by the CCC and DFI values. These indices are easy to determine experimentally and they should be provided by frother manufacturers along with other characteristics of such agents. It has also been demonstrated that CCC values can be used in preparing frother blends (Laskowski et al., 2003).

Table III. CCC values for the investigated frothers

Frother	CCC	
	mmol/dm^3	ppm
MIBC	0.11	11.2
(PO)1	0.52	46.8
(PO)2	0.17	25.1
DF-200	0.089	18.4
DF-250	0.033	8.7
DF-1012	0.015	6.0

While there is no doubt that the CCC and DFI numbers are very valuable in characterization of flotation frothers, our understanding of these values is still not complete. This is quite obvious when comparison is made with the common surface tension measurements. Fig. 6 shows the surface tension isotherms (room temperature) for three Dowfrothers.

Comparison of the surface tension results with the CCC values given in Table III indicates that while for the DF-200 the surface tension at the CCC concentration for this forther (8.9×10^{-5} M) is almost that of pure water, the surface tension for DF-250 at its CCC value ($3.3. \times 10^{-5}$M) is about 66 mN/m and for the DF-1012 (CCC=1.5×10^{-5} M) it is about 61 mN/m. Since surface tension values are interrelated with adsorption via Gibbs adsorption isotherm this means that the adsorption of DF-1012 at its CCC is much larger than the adsorption of DF-250 at the corresponding CCC values for DF--250; in turn the adsorption of DF-250 is much higher than the adsorption of DF-200 at their respective CCC values. Since the DF-1012 molecules are much larger than the molecules of DF-250 (which in turn are larger than DF-200 molecules) this indicates that the adsorption for larger molecules of polyglycols must be much higher to prevent bubbles from coalescence.

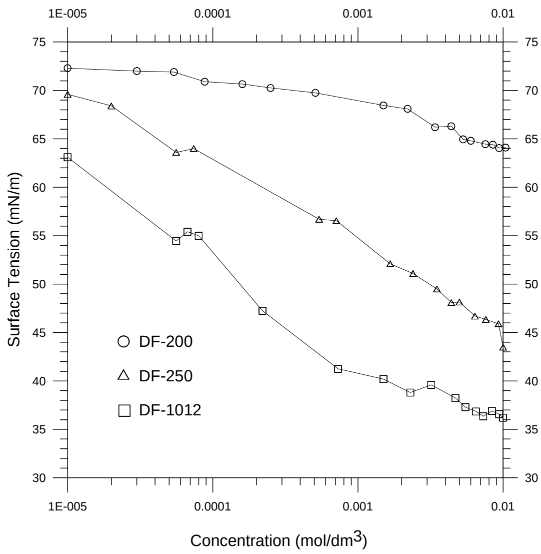

Fig. 6. Surface tension isotherms for DF-200, DF-250 and DF-1012 frothers

This is a very surprising result. It may as well indicate that the "static" surface tension measurements cannot be directly utilized in the analysis of the properties of dynamic systems, such as foams. These foams are very unstable, exist only during bubbling gas and collapse when the foam formation process is stopped. It is likely that the stability of such systems is determined by elasticity forces (Malysa, 1992). Under dynamic conditions the coalescence must then be related not so much to the frother adsorption as to the rate with which it can adsorb (Comley et al, 2002).

CONCLUSIONS

1. Flotation frothers can be characterized by the DFI and CCC values.
2. The diagram in which the DFI values are plotted versus CCC values can be used to classify frothers. The frothers which are situated in the upper-left corner of the diagram are very powerful, while those situated in the bottom-right corner are selective.
3. The CCC and DFI values should be provided for all commercial frothers by frother manufacturers.

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W praktyce odczynniki pianotwórcze (spieniacze) dobierane są zgodnie z ogólnymi zasadami i sprawdzone w testach laboratoryjnych oraz przemysłowych. Określenia takie jak: „mocne lub „selektywny" są powszechnie stosowane dla scharakteryzowania spieniacza. Mają one znaczenie raczej intuicyjne niż naukowe. Został przyjęty program badawczy dla zbadania podstawowych właściwości odczynników pianotwórczych stosowanych w flotacji, oraz dla ustalenia testów, które dostarczą koniecznych informacji potrzebnych dla scharakteryzowania i klasyfikacji odczynników pianotwórczych. Odczynniki pianotwórcze stosowane są w celu redukcji rozmiarów pęcherzyków i wzrostu stabilności. Procedury, jakie użyto w tej pracy, były weryfikowane przez ich zdolność do charakteryzowania redukcji wielkości pęcherzyków w komorze flotacyjnej i wzrostu stabilności piany. Zostało pokazane, że system klasyfikacji spieniaczy, bazujący na dwóch zaprojektowanych parametrach, jest w stanie poprawnie rozróżniać spieniacze zwane jako „selektywne" od tych, które znane są jako „mocne".