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DISPERSED OIL IMPACT ON FROTH STABILITY IN FLOTATION

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Foam stability in flotation has been studied for more than half of the last century, however, the mechanisms responsible for the defoaming action of many presently used reagents are not completely understood. This research presents oil flotation data, which may be used in the evaluation of aqueous methods for oily soil treatment. MIBC (isobutylcarbinol, 4-methyl-2-pentanol) and $C_{12}E_{10}$ (polyoxyethylene 10 lauryl ether) were used as surfactants. Dynamic and static froth stability in the presence of emulsified paraffin oil was determined as a function of the surfactant concentration. The froth stability was examined for the O/W emulsion only and combined with silica particles (-38μm) suspension. The entry, spreading and bridging coefficients were determined to elucidate the mechanism of oil interaction in the froth phase.

Key words: froth control, foam control, oil flotation, polyoxyethylene 10 lauryl ether ($C_{12}E_{10}$), isobutylcarbinol (MIBC)

INTRODUCTION

Froth stability is an important matter, which determines the performance of flotation machines, particularly when an oil dispersion is being separated. This is especially true for the flotation column and the air sparged hydrocyclone. The principles of operation of both units can be found elsewhere (Pondstabodee et al. 1998, Schultz et al. 1991, Luttrell et al. 1991, Falutsu 1994, Miller et al. 1982, Miller and Hupka 1983, Miller and Kinneberg 1985, Miller and Das 1995, 1996). Soil cleaning systems involve both dispersed oil and solid particles. Solid particles can exhibit various degrees of hydrophobicity/hydrophilicity depending on the presence of a stable film and surfactant adsorption. Hydrophobic particles in a mixture with non-polar liquids typically constitute effective defoaming agents (Denkov et al. 1999,

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Denkov 1999). Thus froth control may be a difficult task in oil flotation systems such as are encountered in many soil cleaning applications.

In the present paper, dispersed oil and hydrophobic particles were considered separately and in combination.

FROTH STABILITY FUNDAMENTALS

INFLUENCE OF DISPERSED OIL

Dispersed oil can stabilize or destabilize the froth phase, depending on the relative significance of three interfacial phenomena 1) aqueous film thinning rate during oil droplet entry to the gas phase, 2) oil spreading on the water surface, and 3) thin water film bridging. It has been indicated in the literature that the destabilizing effect was observed only when oil droplets were able to enter the surface of the aqueous phase (Garret 1993, Denkov et al. 1999, Basheva et al. 2000, Bergeron et al. 1997). In order to describe conditions controlling oil droplet entry to the aqueous surface, Harkins (1941) defined the entering (or the rupture) coefficient $E_{o/w}$:

$$E_{o/w} = \gamma_{wg} + \gamma_{ow} - \gamma_{og} \tag{1}$$

where γ corresponds to the surface or interfacial tension, and the subscripts w, g, o pertain to water, gas and oil. Positive values of the entering coefficient mean that oil droplet enters the water/gas interface. For negative values the oil droplet remains in the aqueous phase without contact with the gas phase. The interfacial and surface tensions are not only dependent on the surfactant concentration but also on mutual saturation of all phases. The original entering coefficient accommodates three partial values, the initial $E_{o/w}$, the semi-initial $E'_{o/w}$ and the final or equilibrium $E''_{o/w}$ (Ross 1950). The initial coefficient describes the system, when an oil droplet is newly added to the aqueous solution and both phases are not yet saturated with each other. The semi-initial coefficient defines a system when one of the phases is already saturated and the final coefficient describes a system with all phases saturated.

It turns out that this classical approach does not predict the real behavior of dispersed oil very well. The entering coefficient is calculated considering each of the involved phases separately. It does not take into account surface interaction forces in the system during approach of the oil droplet to the surface of the aqueous solution. In this regard a generalized entering coefficient for an oil droplet in an aqueous environment was discussed (Kruglyakov and Vilkova 1999, Bergeron et al. 1997, Aronson et al. 1994, Bergeron et al. 1993). In the modified equation the oil/gas surface tension is replaced with the tension of the aqueous film, which includes interfacial forces and is regarded as the disjoining pressure, Π:

$$E_{g,o/w} = -\int_{\Pi(h=\infty)=0}^{\Pi(h)} h_w \, d\Pi_{g/w/o} \tag{2}$$

where $E_{g,o/w}$ determines the generalized entry coefficient, Π denotes disjoining pressure and h the film thickness. The integration is performed from disjoining pressure of an infinitely thick film h=∞, for which Π = 0, to the disjoining pressure of an actual film of thickness h, Π(h). The subscripts w and g/w/o mean respectively water film and water film between gas and oil phases.

An oil droplet entering a gas bubble, shown in Fig. 1, is separated by a thin aqueous film, also called a pseudoemulsion film. Measurements of the disjoining pressure are difficult and elaborate, and may be found from the dependence of capillary pressure on the film thickness function. The situation becomes complicated when the pseudoemulsion film is curved. However, when the interfaces are assumed flat the system simplifies, and the capillary pressure, P_c, can be found as a difference between the pressure in the meniscus and in the gas bubble:

$$P_c = P_g - P_w \tag{3}$$

The film reaches equilibrium thickness when the capillary pressure P_c is equal to the disjoining pressure of the film, which ensures that water is not flowing between the meniscus and the pseudoemulsion film. The important aspect is that the capillary pressure can control pseudoemulsion film stability, which is graphically presented in Figure 2. When the capillary pressure is small, as presented in Figure 2a, a thicker film reaches equilibrium. According to terminology proposed by Bergeron (Bergeron 1993) such a film can be called the common film (CF). Further film thinning is prevented by the energy barrier. Increasing the capillary pressure above maximum, as shown in Figure 2b, the thinning phenomenon continues until a new thickness, h_0, behind the energy barrier is reached. This new thickness is on the order of several nanometers, and referred to as the Newton film (NF) (Bergeron 1993). The generalized entering coefficient is represented by the shaded area. In Figure 2a the shaded area corresponds to positive pressure values, therefore yields negative E_g (in equation 2). At an elevated capillary pressure, see Figure 2b, the overall entering coefficient depends on the ratio of areas A to the area B. When B exceeds the sum of A areas, the entering coefficient is positive.

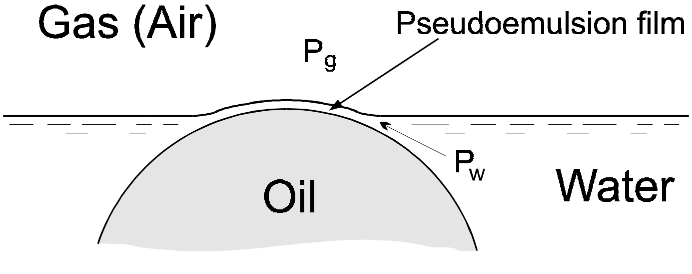

Fig. 1. Oil/water/gas system, oil droplet entering aqueous solution surface, modified from (Bergeron et al. 1993)

Besides the capillary pressure, the kinetic energy - when able to overcome the energy barrier - is another determining factor for the film thickness. The kinetic energy level allows for the entering or non-entering behavior of oil droplets to be understood, but still there are other phenomena, which must be answered. One of the recent research directions has been the study film thinning. Stratified foam film thinning was observed very early in the beginning of the 20th century. Nikolov and Wasan (1989) investigated this phenomenon using an anionic surfactant as the foaming agent. They found that micelles had an ordered structure in the thinning film. The stratification in the thinning process corresponded very well to the Debye atmosphere diameters of the micelles. The ionic strength of the solution could influence the stratification thickness by decreasing the Debye atmosphere and by lowering the electrostatic repulsion. Ordered surfactant micelles hinder film drainage. Bergeron and Radke (1992) measured the disjoining pressure isotherm for a single, isolated foam film. They found oscillations for films 50 nm thick. Step-wise thinning creates an additional energy barrier to the oil drop entry.

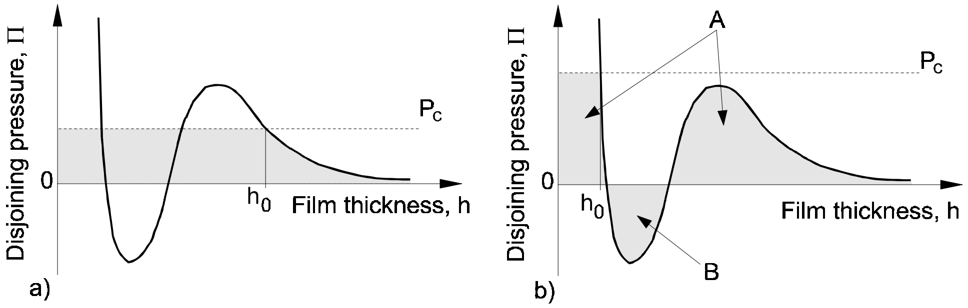

Figure 2. Disjoining and capillary pressures. a) equilibrium film thickness at common black film b) equilibrium film thickness at Newton black film

Similarly to the entry coefficient, the classical spreading coefficient $S_{o/w}$ was defined (Harkins 1941, Ross 1950):

$$S_{o/w} = \gamma_{wg} - \gamma_{ow} - \gamma_{og} \tag{4}$$

The initial, semi-initial and final coefficients were also proposed.

Including the disjoining pressure into the definition, a generalized spreading coefficient $S_{g,o/w}$ was obtained (Kruglyakow et al. 1999, Bergeron et al. 1997, Jha et al. 2000):

$$S_{g,o/w} = \int_{\Pi(h=\infty)=0}^{\Pi(h)} h_{oil} \, d\Pi_{g/o/w} \tag{5}$$

where Π determines the disjoining pressure, h - the film thickness, and subscripts g/o/w mean oil films between the gas and water phases, respectively. The integral in equation (5) is very similar to that describing the generalized entry coefficient in equation (2) but the water film is replaced by the oil film. As entry of an oil droplet is crucial for foam destabilization, spreading of oil was reported as an unnecessary phenomenon (Garret 1993, Denkov et al. 1999, Jha 2000). Mechanisms of foam destruction either include or do not include oil spreading.

Bridging of aqueous foam films by oil was investigated theoretically by Garret (Garret 1980). Assuming that the liquid bridge obeys the Neumann's triangle rule of three phase contact, and that the thin water film is planar, he determined conditions for an oil bridge stability. Figure 3 presents two states for oil bridges. As indicated by Garret, a mathematical proof exists that bridges for which the oil-water contact angle $\Theta_{ow} \leq \pi/2$ cannot be stable. For the contact angle $\Theta_{ow} > \pi/2$, a stable bridge can exist with equilibrium film thickness h_{eq}. On the basis of these findings, the bridging coefficient (B) was defined (Garret 1980, Aveyard et al. 1993, Bonfillon-Collin and Langevin 1997, Denkov 1999):

$$B = \gamma_{wg}^2 + \gamma_{ow}^2 - \gamma_{og}^2 \tag{6}$$

Positive and zero values of B mean an unstable film, while negative values of B allow for an equilibrium film thickness, h_{eq} at which the film is mechanically stable. The system presented in Figure 3 refers to a planar water film. Other shapes were investigated in detail by Denkov (1999). He found that in some cases small droplets can yield a stable bridge even if the bridging coefficient is positive. This observation was explained by the existence of the so-called perturbed zone of the water film in the vicinity of an oil bridge. Minimal water flow from the vicinity of the bridge, which could be practically neglected, still yields stable bridge for positive B. Large oil droplet bridges were found to be always unstable for positive B.

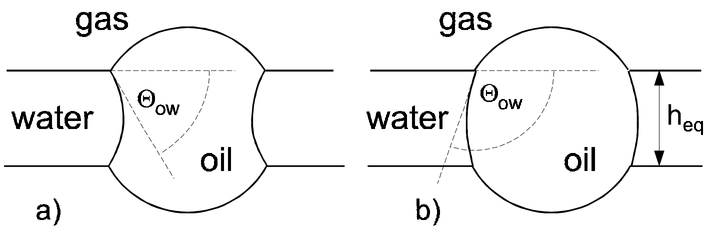

Figure 3. Oil bridging. a) unstable bridge, $\Theta_{ow} \leq \pi/2$, b) stable bridge, $\Theta_{ow} > \pi/2$, adopted from (Denkov 1999)

Three main mechanisms of foam film collapse due to the dispersed oil presence were proposed (Basheva et al. 2000, Denkov et al. 1999, Aveyard et al. 1994),see Figure 4. All of them require oil droplet entry. In spreading - fluid entrainment oil causes Marangoni-driven flow of liquid in the foam film (fluid entrainment), which results in local film thinning and rupture. The other two mechanisms require formation of an oil bridge between the gas phases. Lack of oil wetting by water in the first case or stretching of the oil film in the latter case leads to the rupture.

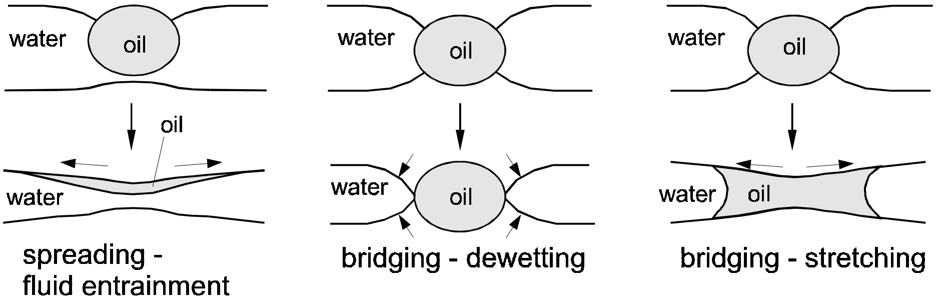

Figure 4. Three possible mechanisms of foam film destruction by an oil droplet, adopted from (Denkov et al. 1999)

Regarding the initiation of breakage of the foam film, the most probable hypothesis states that Gibbs-Plateau borders play a role. The Gibbs-Plateau borders are aqueous solution regions where three or four thin films meet. As indicated by Schramm and Novosad, emulsified oil cannot flow through foam lamellae when the droplet diameter is too large (Schramm and Novosad 1990). Koczo et al. observed that foam collapse occurs in the Gibbs-Plateau borders (Koczo et al 1994). The hydrophobic particles resided in lamellae 1 - 2 seconds to return to the Gibbs-Plateau borders immediately afterwards. It can be expected, based on observations of Shramm and Novosad, that oil droplets behave in the same way. According to Koczo, thin foam films forced oil droplets to move from lamellae to the Plateau borders, where they were able to bridge the aqueous films. Foam can collapse in the dynamic conditions for sufficiently thick lamellae allowing oil droplet holdup and entry. The Plateau-border mechanism was confirmed by an investigation of the antifoam effective droplet size. Bergeron et al. had shown that oil droplets smaller than 6 μm were not able to destabilize the froth regardless the solution chemistry. This size is relatively large and suggests that these oil droplets were hidden in the Plateau-borders, where they were not able to bridge the foam films (Bergeron et al. 1997).

There are also reports of foam stabilization by the dispersed oil (Koczo et al. 1992, 1994). This phenomenon was found for the non-entering oil droplets when the emulsion accumulated in Plateau-borders and inhibited foam drainage.

HYDROPHOBIC PARTICLES

Dippenaar (1982) investigated the mechanism of froth destabilization by fine solids. Hydrophobic particles destabilized the aqueous film when its thickness was smaller than the particle diameter. Single hydrophobic particles ruptured the film, while with multiple particles the film was stabilized. Johansson and Pugh (1992) found that the froth stability was uneffected by hydrophilic particles (contact angles less than 40°). When the hydrophobicity increased (contact angle 65°), froth stability reached a maximum and then decreased for particles with contact angle more than 80°.

The bridging-dewetting mechanism is responsible for the film rupture here (Garret 1993, Aveyard et al. 1994, Frye and Berg 1989, Aronson 1986). Another mechanism was also indicated by Garret (1993). He proposed that the solid particle can cause film thinning by the Marangoni effect when it is in contact with one air/water surface. Solid particles are regarded as better defoamers than dispersed liquids, which is believed to be related to roughness.

SYNERGISM OF OIL AND HYDROPHOBIC PARTICLES

A synergistic effect of hydrophobic particles and non-polar oils was discovered and patented in early 1950s. A list of twenty six patents was given by Garret (Garret 1993). However, studies on the controlling mechanisms were reported twenty years later (Povich 1975, Kulkarni et al. 1977). Particle size of effective liquid-solid defoamers range from 1 nm to 1 μm, and the particle concentration from 1 % to 30 % by weight. The pseudoemulsion film rupture and enhancement of the oil droplet entry is today the accepted antifoaming mechanism (Aveyard et al. 1993, 1994, Koczo et al. 1994, Frye and Berg 1989). Active are hydrophobic solid particles protruding from the oil droplets, and facilitating the pseudoemulsion film rupture.

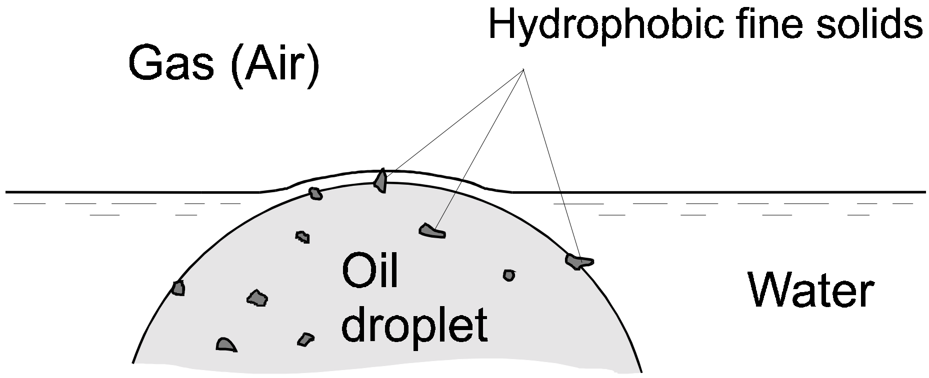

Figure 5. The pin-effect of fine protruding hydrophobic particles

EXPERIMENTAL PROCEDURE

MATERIALS

Two surface active compounds from Sigma and Aldrich were used, Polyoxyethylene 10 lauryl ether ($C_{12}E_{10}$), and 4-methyl-2-pentanol (isobutylcarbinol, MIBC), 99% purity. $C_{12}E_{10}$ is known as a good detergent, exhibiting strong foaming action (Porter, 1991), which can be effective in oily soil clean-up. Paraffin white, light oil was obtained from Mallinckrodt. Experiments with solid particles were performed using fine (minus 38 μm) silica sand from US Silica. In all experiments deionized water was used.

TECHNIQUES

The froth stability was evaluated using 60 cm long and 3 cm diameter glass tube with a porous glass frit (medium size) at the bottom. Oil-in-water emulsion was prepared using a homogenizer. The dispersion stability was evaluated based on determination of coalescence in a cylinder at 1 cm height from the bottom. The estimated rate of oil content decrease ranged from 8.5×10^{-3} s^{-1} at $C_{12}E_{10}$ concentration of 1×10^{-5} M to 1×10^{-4} s^{-1} at a $C_{12}E_{10}$ concentration 5×10^{-4} M. Oil droplet size distribution indicated presence of both numerous oil droplets below 1 μm in diameter and droplets as large as 20 to 60 μm depending on the $C_{12}E_{10}$ or MIBC concentration. 40 cm^3 of surfactant solution were poured into the tube and simultaneously air was blown at a rate of 0.54 dm^3/min. Considering the very stable froth created from $C_{12}E_{10}$ solutions, the dynamic froth stability was evaluated from the ratio of the froth volume to the air volume introduced to the tube:

$$\text{Dynamic Froth Stability} = \frac{\text{Volume of froth created in a unit time}}{\text{Volume of air introduced in a unit time}} \cdot 100\% \qquad (7)$$

Static froth stability was evaluated as the collapse rate of the froth given in centimeters per second. The dynamic surface and interfacial tension measurements were performed by the pendant bubble method using a Rame-Hart goniometer.

RESULTS AND DISCUSSION

The dynamic froth stability and the collapse rate of $C_{12}E_{10}$ aqueous solutions without oil and with 1% by weight of paraffin oil-in-water emulsion are presented in Figure 6. Almost no froth was generated below 1×10^{-5} M concentration, in the dynamic conditions. The froth reached 100 % dynamic stability at concentration 5×10^{-5} M, and the collapse rate dropped significantly to 0.017 cm/s. Both very high dynamic stability and very low collapse rate were observed for the same concentration. The dispersed oil shifted the dynamic stability 100 % point beyond 1 × 10^{-4} M. The collapse rate turned out to be relatively high even at this concentration, and was equal to 0.33 cm/s. A low collapse rate of 0.025 cm/s was observed at 5 × 10^{-4} M. It is evident that in the presence of paraffin oil there is a 1 × 10^{-4} to 5 × 10^{-4} M concentration range which yields a stable dynamic froth but still a weak static froth.

The presented froth stabilities can be related to the classical entry, spreading and bridging coefficients, see data in Figure 7, which were calculated for 30 seconds contact and equilibrated system. The dynamic surface and interfacial tension measurements indicate that surfactant adsorption attained equilibrium only after 10 minutes, see Figure 8. Therefore the flotation system did not reach chemical equilibrium. Hence a 30 seconds time of contact was arbitrarily chosen to represent the interfacial conditions during the dynamic stability tests. The difference between coefficient values for 30 seconds and for an equilibrated system results from the progressive adsorption of surfactant at the interfaces. The entry coefficient after 30 seconds is much larger than for an equilibrated system, therefore it has a positive value, and according to the theory, represents non-entering oil droplets.

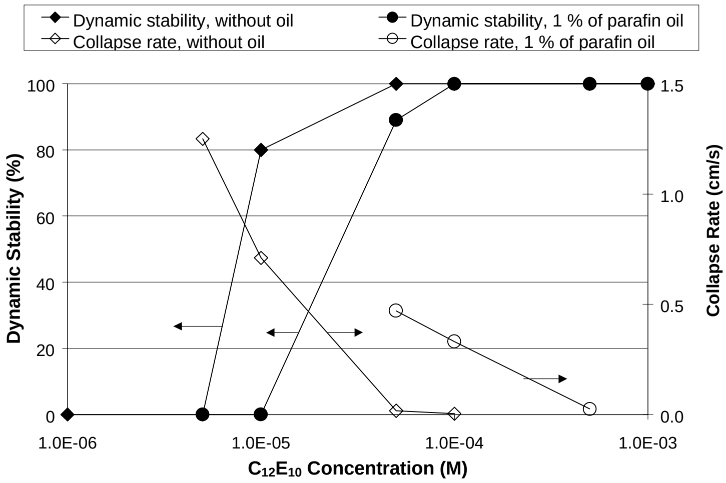

Figure 6. Dynamic froth stability and collapse rate for $C_{12}E_{10}$ aqueous solutions

Nevertheless, a defoaming action of the oil was observed. It can be concluded that the effective entry coefficient is in fact smaller due to the disjoining pressure, which was not taken into account in the above calculations. Most probably at 1 × 10^{-4} M the effective entry coefficient is already negative, therefore very stable (dynamically) froth is observed, as shown in Figure 6. The classical spreading coefficient reaches values close to zero beginning at concentrations 5 × 10^{-5} M in the case of an equilibrated system and 1 × 10^{-4} M in the case of the system after 30 seconds contact time. Nevertheless the role of spreading is not clear. Negative values for concentrations lower than 5 × 10^{-5} M may indicate that it is not a satisfactory condition for froth destabilization. Similarly, as in the case of the entry coefficient, the intermolecular forces are not considered in the classical approach and calculated small negative values of the spreading coefficient can be in fact positive.

The bridging coefficient is positive over the entire range of concentrations investigated, which indicates unstable bridges. Paraffin oil caused a decrease in the dynamic stability for the concentration range from 5×10^{-6} to 1×10^{-4} M. Relatively large positive values of the entry and bridging coefficients suggest that formation of unstable bridges (bridging-dewetting or bridging-stretching) is the most probable mechanism of froth colapse and spreading appears to play a minor role. Low static stability in the concentration range from 5×10^{-5} to 5×10^{-4} M can be explained by both mechanisms, bridging-dewetting and spreading-fluid entrainment, since the spreading coefficient approaches zero in this concentration range.

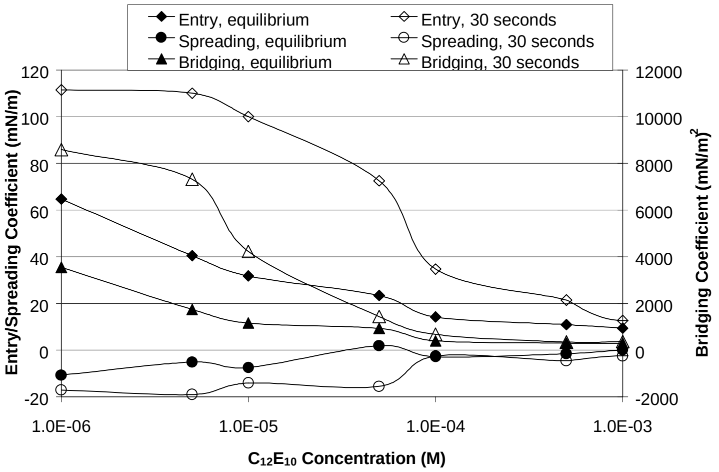

Figure 7. Entry, spreading and bridging coefficients of the system: $C_{12}E_{10}$ aqueous solution and dispersed paraffin oil

The difference between dynamic and static stabilities in the presence of paraffin oil is unclear. According to Manlowe and Radke (1990) froth can be metastable under some dynamic conditions. They explained such a behavior by short contact times between the gas and oil phases under dynamic conditions. It can be assumed that dynamic conditions inhibit foam destabilization. This supposition, however, requires further investigation.

The dynamic froth stability and the collapse rate of MIBC aqueous solutions without oil and with 1% of paraffin oil are presented in Figure 9. The dynamic stability of MIBC shows that the impact of paraffin oil is similar to that of $C_{12}E_{10}$. An order of magnitude greater frother concentration was required for achieving 100% dynamic froth stability. However, the static stability was practically not influenced by the presence of oil.

The influence of fine solid particles (- 38 μm) is presented in Table 1. Silica particles were added as hydrophilic particles and as hydrophobilized by exposure to oil for 24 hours prior to the experiment. The dynamic stability in 1 × 10^{-4} M $C_{12}E_{10}$ solution was not affected. The collapse rate, however, increased when oil exposed silica particles (24 hours) were used, the static froth stability turned out to be much lower, and the collapse rate increased from 0.33 to 0.44 cm/min.

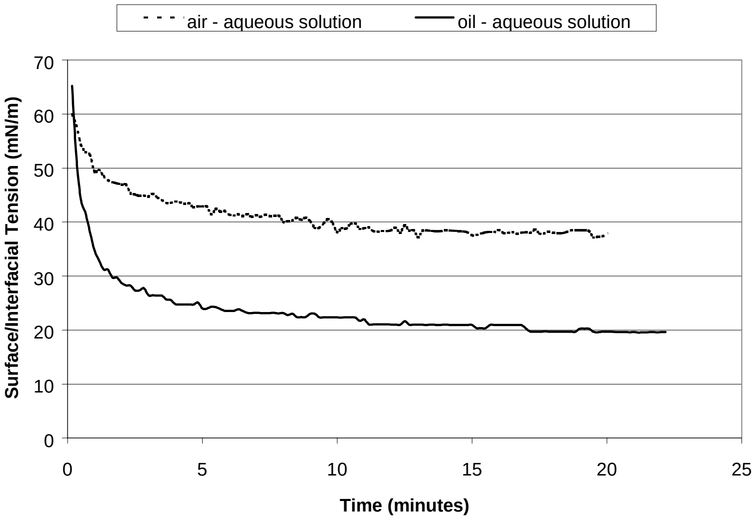

Figure 8. Surface/interface tension of 1 × 10^{-5} M $C_{12}E_{10}$ as a function of time

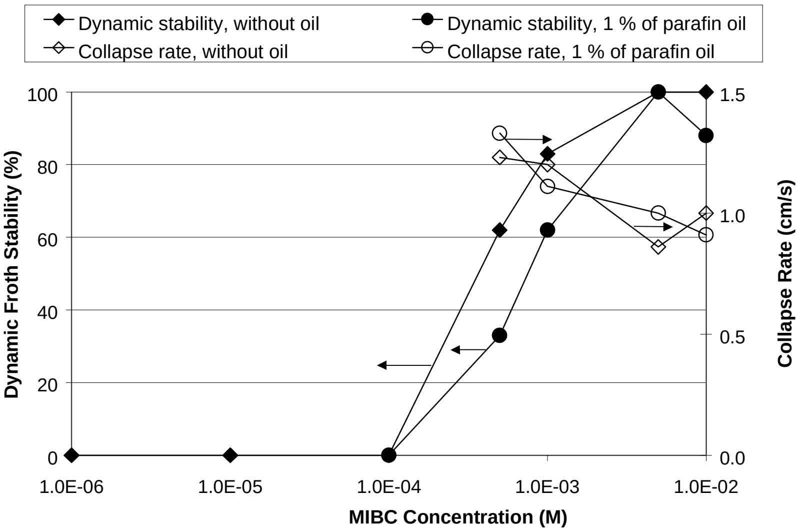

Figure 9. Dynamic stability and collapse rate of MIBC aqueous solutions

Table 1. The influence of solid particles on the froth stability. 1×10^{-4} M $C_{12}E_{10}$ aqueous solution containing 1 % by weight of emulsified oil

Presence of Solid Particles	Dynamic Stability (%)	Collapse Rate (cm/sec.)
None	100	0.33
Hydrophilic silica, 1 wt. %	100	0.32
Silica particles wetted by oil for 24 hours prior to the experiment	100	0.44

CONCLUSIONS

1. The frothing ability of aqueous solutions of polyoxyethylene 10 lauryl ether ($C_{12}E_{10}$) was determined. Experimental results indicated excellent frothing properties of this compound.
2. The presence of paraffin oil deteriorated the froth dynamic stability for $C_{12}E_{10}$ only slightly. For 1 wt. % oil in the concentration range of $C_{12}E_{10}$ from 1×10^{-5} to 5×10^{-4} M it was possible to obtain a dynamically stable froth, which simultaneously had low static stability. It appears that dynamic conditions inhibit defoaming action.
3. The equilibrium interfacial and surface tensions were achieved after 10 minutes, while the dynamic froth stability was evaluated during the initial 30 seconds. Therefore a non-equilibrated system was considered for calculation of the oil-controlled foam stability coefficients.
4. The entry, spreading and bridging coefficients calculated based on classical assumptions did not correlate with the experiments, which is confirmed by previous reports in the literature.
5. Comparison of the dynamic and static froth stability obtained with $C_{12}E_{10}$ and MIBC showed that ethoxylated compound provided for better froth stability at lower concentrations.
6. Hydrophobic silica particles, conditioned for 24 hours in paraffin oil decreased the static froth stability to some extent without deterioration the dynamic stability.
7. The froth behavior results are usefull in the analysis of flotation, particularly air-sparged hydrocyclone flotation, because a stable dynamic froth is essential for high recovery. On the other hand an unstable static froth facilitates natural transport after the separation process. Small soil particles which are expected to be entrained in the flotation concentrate during oil flotation from soil should not influence the dynamic stability and may help destabilize the froth after flotation.

ACKNOWLEDGEMENTS

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LIST OF SYMBOLS

B - Bridging coefficient
$E_{g,o/w}$ - Entry coefficient, generalized, for an oil droplet entering an aqueous solution surface
$E_{o/w}$ - Entry coefficient, classical, for an oil droplet entering an aqueous solution surface
h - Film thickness
h_0 - Equilibrium film thickness under the condition of the capillary pressure equal to the disjoining pressure
h_{eq} - Equilibrium film thickness of an oil bridged aqueous film
h_{oil} - Oil film thickness
h_w - Water film thickness
P_c - Capillary pressure
P_g - Gas pressure
P_w - Water or aqueous phase pressure
$S_{g,o/w}$ - Spreading coefficient, generalized, for an oil phase spreading on an aqueous phase
$S_{o/w}$ - Spreading coefficient, classical, for the oil phase spreading on an aqueous phase
γ_{og} - Interfacial tension, oil - gas
γ_{ow} - Interfacial tension, oil - aqueous solution
γ_{wg} - Surface tension of an aqueous solution
Π - Disjoining pressure
$\Pi_{g/o/w}$ - Disjoining pressure of a gas/oil/water film
$\Pi_{g/w/o}$ - Disjoining pressure of a gas/water/oil film
$\Pi(h)$ - Disjoining pressure of a film of thickness h
$\Pi(h=\infty)=0$ - Disjoining pressure of an infinitely thick film, which is essentially zero
$\Theta_{o/w}$ - Contact angle of an oil droplet on water

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Stabilność piany była badana od pierwszej połowy zeszłego wieku, jednak mechanism jej destabilizacji przez środki przeciwpianowe nie został dotychczas całkowicie poznany. W przedstawionej publikacji określono stabilność piany wodnych roztworów surfaktantów w obecności emulsji oleju parafinowego, jako modelowego układu spotykanego podczas oczyszczania zaolejonej ziemi przez flotację pianową. Zastosowano dwa powierzchniowo czynne związki: $C_{12}E_{10}$ oraz MIBC. Określono również wpływ obecnosci piasku o wielkości ziaren poniżej 38 μm.

Pierwszy zastosowany związek, $C_{12}E_{10}$ wykazał znacznie silniejsze działanie pianotwórcze niż MIBC. Powstawanie stabilnej piany zaobserwowano przy stężeniach powyżej 5×10^{-6} mol/dm^3, przy czym 100 % stabilności piany otrzymano powyżej stężenia 5×10^{-5} mol/dm^3. Obecność emulsji olejowej spowodowała, że porównywalną stabilność dynamiczną obserwowano przy stężeniach kilkakrotnie większych. MIBC pozwalił na osiągnięcie stabilnej piany przy stężeniach powyżej 1×10^{-4} mol/dm^3, przy czym 100 % stabilności piany otrzymano dla stężenia MIBC 5×10^{-3} mol/dm^3 jedynie w początkowym etapie jej tworzenia. Po początkowych kilku sekundach od rozpoczęcia doświadczenia szybkość gaśnięcia piany zwiekszła się i dorównywała szybkości tworzenia, co prowadziło do osiągnięcia równowagowej wysokości piany w warunkach dynamicznych. Obecność oleju parafinowego podobnie jak w prypadku $C_{12}E_{10}$ spowodowała, że kilkakrotnie większe steżenia surfaktanta były wymagane do osiągnięcia podobnych stabilności dynamicznych.

Stabilność statyczna piany przy zastosowaniu $C_{12}E_{10}$ korelowała ze stabilnością dynamiczną w układzie bez emulsji olejowej. Przy zastosowaniu oleju parafinowego zaobserwowano brak korelacji pomiędzy dynamiczną i statyczną stabilnością w zakresie stężeń od 1×10^{-4} mol/dm^3 do 5×10^{-4} mol/dm^3. Stabilność statyczna roztworów MIBC była bardzo niska w całym badanym zakresie stężeń.

Hydrofilowe ziarna krzemionki w roztworrze $C_{12}E_{10}$ o stężeniu 1×10^{-4} mol/dm^3 nie wykazały wyraźnego wpływu na stabilność piany, w przeciwieństwie do ziaren krzemionki hydrofobizowanej przez zaadsorbowanie oleju parafinowego, które znacząco obniżyły statyczną stabilność piany. Stabilność dynamiczna, która wynosiła 100 %, pozostała nie zmieniona.