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THE INFLUENCE OF GANGUE PARTICLE SIZE IN MINERAL FLOTATION

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ABSTRACT: The strength of adhesion of individual and mixed aggregates of galena and quartz particles to an air-xanthate solution interface was determined using a centrifuge technique. The magnitude of the critical centrifugal force necessary to detach and sink the galena and quartz aggregates were compared with theoretical estimates single spherical particle. The experimental results from attachment force measurements of aggregates containing galena/quartz artificial mixtures (in xanthate collector solution) and flotation tests indicated that the ration of galena/quartz particle size had an important influence over the magnitude of the attachment force of galena particles and respectively over flotation selectivity. It was found that the selectivity for galena/quartz system flotation can be directly correlated with strength of adhesion of the galena particles in the galena/quartz mixtured aggregates to the interface.

1. INTRODUCTION

Theoretical studies by Nutt (1960) and Schehidko et al. (1968) have expressed the mechanics of the attachment of hydrophobic spherical particle to a flat liquid/gas (L/G) interface or to a gas bubble. To detach the particle, a force must be applied which must exceed a certain critical value. The magnitude of this critical force , i.e. the maximum attachment force of a single spherical particle on the L/G interface (F_{At}) can be expressed as an approximation by the equation (Nutt, 1960; Schehidko et al., 1968/69):

$$F_{At} = \pi\sigma R_p(1-\cos\theta) \quad (1)$$

where R_P is the particle radius, *c* is the surface tension at the L/G interface and 6 is the equilibrium wetting angle.

Varbanov et al. (1988) have experimentally established that ensembles of monodispersed glass spheres of radius smaller 100 *\xm* do not obey equation (1) and detach at greater force than predicted by the theoretical model.

In the case of large aggregates of irregularly shaped particles initial studies have indicated that the' adhesive force deviates considerably from that of monodispersed smooth particles (Alexandrova et al., 1984). Nishkov and Pugh (1988; 1989) have investigated experimentally the adhesion of aggregates of rough and angular shaped galena particles to an air/solution interface by measuring the critical centrifugal force necessary to detach and sink the aggregates. It was found that the flotation efficiency for the galena/xanthate system can be directly correlated with the strength of attachment of the particles to the air/solution interface. From the studies of Nishkov and Pugh (1988; 1989) it appears that direct experimental determintion of the critical adhesion by centrifugal technique could be useful for studying selectivity of different types of minerals in the froth flotation process.

The present investigation is concerned with studying the selectivity of the galena/quartz system in the presence of xanthate collector. The main objectives may be summarized as follows:

- To determine the "selective detachment forces" using the pre-established centrifuge technique (Nishkov and Pugh, 1988; 1989) on aggregates containing galena and quartz particles of well defined size distributions.
- To study the effects of galena and quartz particle size on the magnitude of the attachment forces *of* two types of mineral particles at the liquid/gas

interface and the selectivity of galena/quartz system flotation.

2. EXPERIMENTAL

2 1. Characteristics of Mineral Systems

Two samples of hand-picked Swedish natural galena and quartz were supplied by Boliden Mineral AB. The samples were crushed in an agate mortar and separated by sieving and beaker decontation technique into narrow particle size fractions for experimental studies.

The particle size distribution and the average particle size were determined using a Particle Size Counter manufactured by Elzon Particle Data, USA.

Table 1.

Particle size fraction (urn)	Average particle size (tun)	
	Galena	Quartz
0-2	1	1
5-12	9	8
40-63	48	50
63-90	72	76
90-125	102	104

Three types of mineral systems were chosen in this work.
(a) A sulfide mineral - galena
(b) An oxide system - quartz
(c) Artificial mixtures containing 50 wt% galena and 50 wt% quartz of well defined particle sizes (wt ratio galena/quartz was 1:1).

The solid content of the suspensions for both attachment force measurements and flotation experiments was maintained to 6 g/1.

2.2. Reagents

Analar grade potassium ethylxanthate (KEtX) was used as collector The xanthate collector was supplied by Hoechst, Frankfurt. Sodium hydroxide (reagent grade) was used for pH adjustment. The experimental studies were carried out in a slightly alkaline solution (pH 8 5) corresponding to maximum flotability of galena.

2.3. Attachment Force Measurements

A Beckman ultracentrifuge L5-50B (rotation up to 50.000 rpm) was used with a rotor SW 50-1, equipped with six buckets that swing out to a horizontal position as the rotor is accelerated The radial distance (R ^) of the meniscus was constant (8 cm) for all experiments.

The suspension, containing 0.6 g of mineral (in case of the mixtures - 0.3 g of each) in 100 ml of collector solution at a preadjusted pH, was stirred for 10 min in a beaker using a magnetic stirrer in an attempt to simulate the shear field experienced in the microflotation cell.

After conditioning, the mineral particles were allowed to sediment and then, tilting repeatedly the glass beaker, brought to the L/G interface. In order to establish an equilibrium contact angle the mineral particles were then left for 30 min attached for the interface before transferring them with a spatula onto the surface of the initial solution in the centrifuged tubes. The aggregates were then subjected to the detaching action of centrifugal forces at a range of centrifuge speeds. For each experiment the centrifuge speed was increased gradually to a pre-set value and maintained at this speed for one minute. The critical speeds where the galena or quartz particles were thrown from the interface into the body of the solution were noted.

2.4. Flotation Experiments

In these experiments, a cylindrical glass cell (volume 100 cm) with porous glass frit bottom and an external gas source was used. Bubbles were generated by flowing nitrogen through a glass frit at a controlled flow rate of 50 cm^3 per minute. The flotation procedure was as follows: A standardized amount of studied artificial galena/quartz mixtures was placed in the microflotation cell and the collector solution added. The pulp was conditioned by magnetic stirring for 10 min before the nitrogen was introduced. Flotation was carried out for 5 minutes. The selectivity of separation in the froth flotation can be expressed by the formula below.

$$g \quad \frac{\text{Recovery ofvaluable mineral (galena) in the froth}}{\text{Recovery of gangue mineral (quartz) in the froth}} \qquad (2)$$

3. RESULTS AND DISCUSSION

3.1. Study of the Effect of Particle Size on Adhesion Force and Selectivity of Galena/Quartz System Flotation

The critical centrifugal force required to detach and submerge the aggregates containing respectively galena, quartz or artificial mixture galena/quartz particles from L/G interface was determined for the ^various particle size fractions in the presence of 10"^{3} M potassium ethyl xanthate. The experimentally aetermined attachment forces of mineral particles were compared with the mnrimum attachment forces according to Nutt's theory. Since the contact angle cannot be quantified for the purpose of the present investigation values of 0 = 60° for 10'^{3} M KEtX on « galena surface and 6 = 6° on a quartz surface were accepted according to the data of Varbanov (1985).

Table 2.

Partide aze fraction (Mm)	GALENA			QUARTZ		
	Attachment force (*M)		Fexp «h	Attachment force (dyne)		Fexp Fth
	theory	exper		meory	exper	
0-2	5 5X10"^{3}	Not de-tached		6 0x10-'	UxlO"^{4}	22
5-13	4.9xl0-^{3}	043	8.8	4«xKr^4	J7xl<H	18
40-63	2.6x10-!	212	8.2	3 0x10-3	JJxlO-^{3}	18
63-90	4.0x10-1	34	8.5	4.6xl0-^{3}	16x10-3	19
90-125	SCxlO-^{1}	51	91	63«10-^{3}	llxlO"^{2}	18

From the data presented in Table 2 it can seen that the experimental attachment forces for the aggregated real mineral particles appear *to* be greater than theoretical values predicated for the idealized model This may be explained by the differences in degrees of wetting of the irregularly shaped edges and corners of the aggregated galena and quartz particles. It is important to consider interparticular interactions and collective effects due to aggregation of particles at the interface. The collective effects arising from capillary forces binding the particles together would also be expected to play a role within the balance of attachment forces.

The critical centrifugal forces (Le. maximum attachment forces) required to detach the galena and quartz particles from the aggregates of artificial mixtures containing equal size galena and quartz particles were determined for the following fractions (0-2; 5-12; 40-63; 63-90 urn) in the presence of 10"^{3} M KEtX.

Let introduce a relative attachment ration N_{Fat}

$$N_{F_{at}} = \frac{F_{at}^{max}}{F_{at}^{mix}} \qquad (3)$$

where FJ™ is the attachment force for an aggregate consisting of the same type of particles (ie. for quartz *F%* and for galena *F°*) and *F?* is the attachment force for one of the two minerals constituting a mixed aggregate (Le. for quartz *F^G+e>* and for galena *F?™»*). In Fig. 1. the ratios Np* for equal size galena and quartz particles in

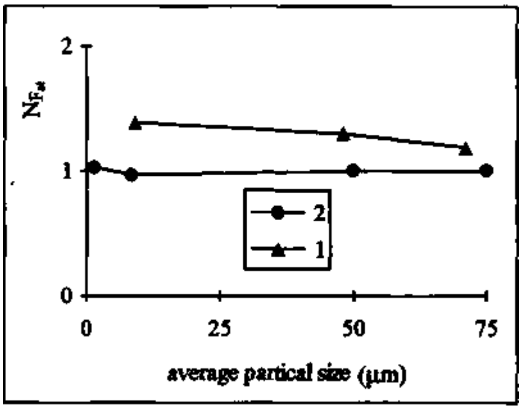

Fig. 1. The ratio N_{Fat} for ▲ equal size galena and for ● quartz particles versus the average particle size of the various fractions.

10'^{3} M KEtX solution are shown as a function of the average particle size of the various fractions. The curve 1 presents the ratio of the attachment force of galena particles constituting the galena aggregates to the attachment force of galena particles constituting the aggregates of.equal size galena and quartz particles $F_{at}^{G}/F_{at}^{G(G+Q)}$ as a function of the average particle size. The curve 2 presents the ratio of the attachment force of quartz particles constituting the quartz aggregates to the attachment force of quartz particles constituting the aggregates of equal size galena and quartz particles $(F_{at}^{Q}/F_{at}^{Q(G+Q)})$ as a function of the average particle size. For both galena and quartz the ratio N_{Fat} appears to be constant with increasing of the average particle size (for quartz Npg =1 and for galena N_{Fat} =1.3). Therefore the adhesion force of galena particles appears to decrease slightly in the case of detachment of these particles from aggregates containing equal size galena and quartz particles for all studied fractions.

- The flotation tests of artificial mixtures containing equal size galena and quartz particles were carried out under the same conditions as the attachment force measurements. In Fig.2. the flotation selectivities of different particle size fractions in 10~3 M KEtX solution are shown as a function of the average particle size after 5 min flotation. For all particle size fractions the selectivity appears to be constant (high values) with the increase in particle size. However, it is important to note that the fine fractions have a lower rate of flotation recovery than the large fractions.

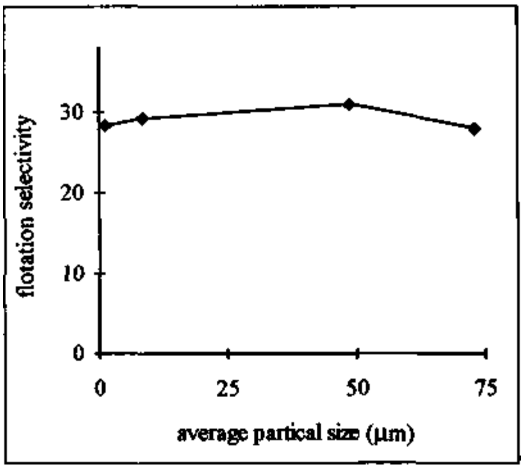

Fig.2. The flotation selectivity after 5 min flotation (10"3 M KEtX) versus the average particle size of the various size fractions consisting of galena and quartz equal size particles.

From the experiments with artificial mixtures containing equal size galena and quartz particles it can be concluded that the ratio N_{Fat} and the selectivity of flotation keep constants with the increase in particle size for all size fractions. The slight decrease of adhesion force of galena particles corresponds to the high values of the flotation selectivity.

The critical centrifugal forces required to detach the galena and quartz particles from aggregates of artificial mixtures containing different size galena and quartz particles were determined for the various particle size fractions in the presence of 10*3 M KEtX (Table 3).

In Fig. 3. the ratios N_{Fat} for galena and quartz particles in 10^{-3} M KEtX solution are shown as a function of the ratio of galena/quartz particle size (N_s). The curve 1 presents the ratio of the attachment force of galena particles constituting the galena aggregates to the attachment force of galena particles constituting the aggregates of galena and quartz particles *(F^/F^0^)* as a function of the galena/quartz particle size ratio. The curve 2 presents the ratio of attachment force of quartz particles constituting the quartz aggregates to the attachment force of quartz particles constituting the galena/quartz aggregates *(Ff/F®10*®*) as a function of the galena/quartz size ratio. For quartz the ratio

Table 3.

galena size fraction (|im)	quartz size fraction (|im)	N_s*
40-63	40-63	0.96
90-125	40-63	2.04
90-125	5-12	12.75
90-125	0-2	102.00

* N_s is the ratio of the average galena particle size to the average quartz particle size.

N_{Fal} appears to be constant (N_{Fat}=l) with the increase in particle size ratio of the fractions constituting the aggregates. Therefore the critical centrifugal force required to detach and submerge the quartz particles from galena/quartz aggregate is equal to the centrifugal force required to detach and submerge the aggregate of quartz particles. For galena the ratio N_{Fat} appears to increase with the increase in particle size ratio of the fractions

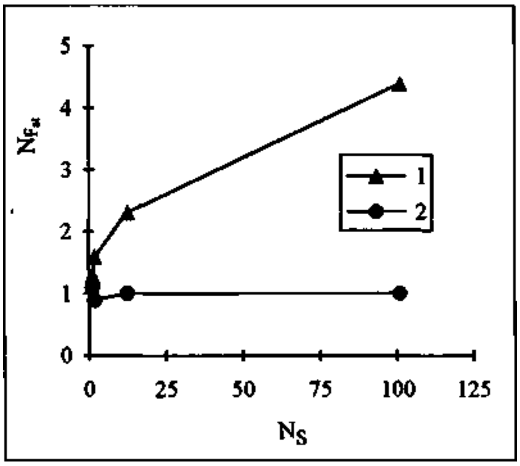

Fig. 3. The ratio N_{Fat} versus the ratio of galena to quartz particle size for the various size fractions, • galena and • quartz particles.

constituting the aggregates. These experimental results clearly demonstrate that the adhesion force of galena particles constituting the galena/quartz aggregates depends of the particle size ratio.

The flotation selectrvnies of artificial mixtures containing different particle size fractions in 10^{-3} M KEtX solution are plotted in Fig.4. as a function of particle size ratio after S min flotation. It can be seen that the selectivity decreases with the increase in the particle size ratio of the various artificial mixtures.

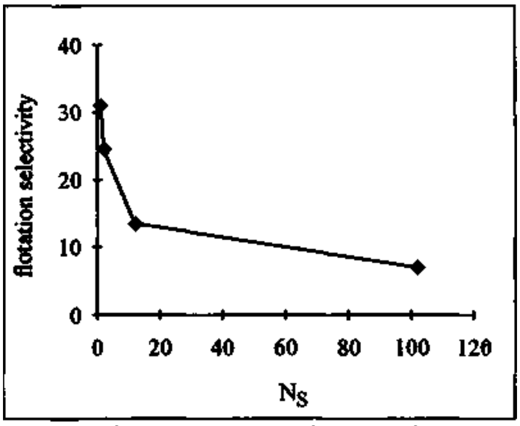

Fig.4. The flotation selectivity after S min flotation in 10~[3] M KEtX versus the galena/quartz particle size ration.

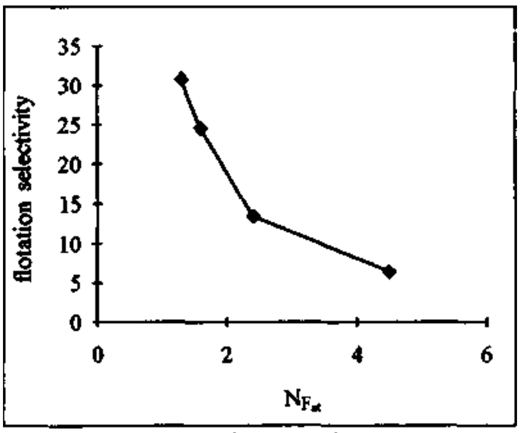

Fig. 5. The selectivity after 5 min flotation versus the ratio N_{Fat} of galena particles. The points represent the particle size ratio of the various artificial mixtures.

This experimental result shows reasonable agreement with the theoretical predictions of Varbanov (1985; 1989) for the dependence of selectivity on radii for the two minerals in flotation system.

Fig. 5. illustrates the relationship between selectivity after S min flotation and the ratio N_{Fa} for galena particles at various ratios of galena/quartz particle size. From this results it may be clearly seen that the selectivity of flotation decreases with the decrease of the attachment force of galena particles in galena/quartz aggregates. The experimental results from attachment force measurements of aggregates containing galena/quartz artificial mixtures and flotation tests indicate that the ratio of galena/quartz particle size has an important influence over the magnitude of the adhesion force of galena particles and respectively over flotation selectivity.

4. CONCLUSIONS

The attachment forces of aggregates containing rough and angular shaped galena, quartz or artificial mixture galena/quartz particles at L/G interface can be determined using a centrifuge technique.

The magnitude of the detachment forces for the aggregates consisting of one type of mineral were compared with theoretical estimates from Nutt (1960ySchetudko (1968) theory for single spherical particles. The quantitative theoretical predictions appear to be nine times for galena and two times for quartz of magnitude less than the experimental values.

From this study it appears that the flotation selectivity for galena/quartz system can be directly correlated with strength *of* adhesion of galena particles to L/G interface.

The experimental results from attachment force measurements of aggregates containing galena/quartz artificial mixtures and flotation test indicate that the ratio of galena/quartz particle size has an important influence over the magnitude of the adhesion force of galena particles and respectively over flotation selectivity. The weak decrease of the attachment force of galena particles constituting the aggregates of equal size galena and quartz particles corresponds to the high values of the flotation selectivity for various size fractions. The increase in the size ratio leads to the steep decrease in the adhesion force of galena particles constituting the galena/quartz aggregates, which corresponds to the low values of the flotations selectivity.

These experimental results suggest the possibility of improvement of the flotation selectivity by:

(a) Preliminary classification of the initial material or the bulk concentrates, and separate flotation of different particle size fractions.

(b) Removing the fine fraction of nonfloatable mineral before flotation.

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