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Froth flotation of coal fines: The influence of turbulence on cell performance

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SYNOPSIS

The paper identifies two zones in a Leeds flotation cell. The ratio (β) of the dissipative forces and the interfacial tension force acting on a bubble and a solid particle are shown mathematically to be proportional to the square of the particle diameter for the quiescent zone and inversely proportional to the particle diameter for the turbulent zone.

To locate the range of operation, correlations were established for the bubble diameter through photography and bubble counts. β was found to be fairly constant in the particle size range 38 to 150 μm, and the level of turbulence unlikely to affect the bubble-particle attachment and hence the beneficiation efficiency. This was verified in a series of flotation runs with a standard Leeds cell and a modified cell of twice the height to increase the capacity of the quiescent zone.

A series of tests on the size range 300 to 600 μm showed that the turbulence level had a marked effect on the cell performance through a relative improvement in the beneficiation efficiency due to the increased height of the cell.

To identify the significant variables in the size range 38 to 150 μm, a factorial design was carried out. Promoter dosage and particle size were found to be significant, aeration rate and impeller speed being insignificant at the 95 per cent confidence level. Multiple regression correlations were established for the recovery of organic material, mineral rejection, and beneficiation efficiency.

SAMEVATTING

Twee sones is teenwoordig in 'n Leeds vlotasiesel. Die verhouding (β) van die verstrooiingskragte en die tussenvlakspanningkrag wat op 'n borrel en 'n vaste partikel inwerk word wiskundig bewys om proporsioneel met die kwadraat van die deursnee van die partikel te wees vir die stilsone en omgekeerd proporsioneel tot die deursnee van die partikel te wees vir die turbulente sone.

Om die gebied te bepaal waarin hierdie toetse van toepassing is, is die borrel deursnee met fotografie en borreltellings gedoen. β is redelik konstant vir die partikelgrootte tussen 38 tot 150 μm en die mate van turbulensie sal onwaarskynlik 'n effek op die borrel-partikel aanhegting en dus op die voordeligheidseffektiwiteit hê. Bogenoemde is bevestig deur 'n reeks vlotasie eksperimente in 'n standaard Leeds sel en in 'n veranderde sel waar die hoogte verdubbel is om die kapasiteit van die stilsone te vermeerder.

'n Reeks toetse in die grootte gebied 300 tot 600 μm toon 'n duidelike effek van die turbulensievlak op die selverrigting deur 'n relatiewe verbetering in die voordeligheidseffektiwiteit met die vermeerde hoogte van die sel.

Ter identifisering van die beduidende veranderlikes in die grootte gebied 38 tot 150 μm is 'n faktoriaal ontwerp uitgevoer.

Bevorderings toedienings en partikel grootte is beduidend, maar met belugting tempo en dryfrat spoed is dit onbeduidend op 'n 95 persent betroubaarheidsvlak. Veelvoudige regressie korrelasies is bepaal vir organiese herwinning, minerale verwerping en voordeligheidseffektiwiteit.

Introduction

South Africa has large reserves of low-grade coal, which has a high ash content. Coal smaller than 0,5 mm is regarded as fines, which, as a result of increased mechanization and handling, amount to between 5 and 20 per cent of the run-of-mine production. This increase in the production of fines, coupled with increases in coal prices and mining costs, has made the beneficiation of such fines economically attractive.

The objective in coal beneficiation is to get rid of the ash-forming mineral matter. Much work has been done on the optimization of flotation-cell performance through the adjustment of operating variables such as reagent addition, aeration rate, pulp density, and degree of agitation[1-3]. An investigation by Panopoulos and King[3] on a range of particle sizes from $-500 + 425$ μm to reground coal smaller than 50 μm indicated that, for Witbank No. 2 seam coal, only the ultra-fine size (smaller than 50 μm) showed any potential for the cleaning of coal by flotation as an industrial process. Panopoulos *et al.*[4] investigated the effect of particle-size distribution on the flotation of two South African coals and concluded that flotation recoveries are greatest for particle sizes between 100 and 200 μm but fall off rapidly as the size increases above 200 μm.

Since a large portion of the fines produced lies in the range 200 to 500 μm, it is important to understand why the flotation recoveries fall off with increasing size and to adapt the process accordingly to extend the range of fines amenable to flotation.

The mathematical analysis in this paper suggests that particle sizes above 150 μm are affected by the turbulence level in a flotation cell, which prevents the attachment of bubble and solid or causes a degree of separation of the bubble–solid aggregates. The notation used is listed at the end of the paper.

The purpose of the investigation described here was to examine the effect of turbulence level in the cell on the beneficiation efficiency over a particle size range 36 to 600 μm through an increase in the depth of the standard Leeds cell. In so doing, the volume of the quiescent zone is increased, and the forces tending to separate bubble and particle are accordingly decreased.

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Review of Previous Work

The Dependance of Flotation on Process Variables

Early work by Brown and Smith[1] showed that flotation rate depends on particle size, aeration rate, and reagent concentration. In a series of factorial experiments[2] on the beneficiation of oil shale by froth flotation, Yates analyses indicated that collector, frother dosage, and particle size are also significant factors affecting flotation performance.

Emerging clearly from those two investigations[2,3] is a very strong correlation between frother dosage and recovery, which is explained by a decrease in bubble size and rise velocity and hence an increase in the specific interfacial area of the bubbles.

In a review on flotation, Jameson *et al.*[5], basing their findings on the data of Collins[6], Reay and Ratcliff[7,8], and Anfruns and Kitchener[9], considered the batch flotation process to be first order with rate constants

$$k \; \alpha \; [d_p^{1,5}/d_b^3]$$

for $4\,\mu m < d_p < 30\,\mu m$ and $d_b < 100\,\mu m$,

and

$$k \; \alpha \; [d_p^2/d_b^{2,67}]$$

for $10\,\mu m < d_p < 50\,\mu m$ and $600\,\mu m < d_b < 1000\,\mu m$.

The significance of particle size and bubble size is clearly evident from the above.

Criteria for Separation and Maximum Floatable Size

Several attempts[10–14] have been made to analyse the particle–bubble aggregate stability under static or dynamic conditions.

Considering smooth spherical particles and quiescent conditions in which only gravity opposes the surface tension forces, Scheludko *et al.*[12] derived the following expression for the maximum supportable size:

$$d_{p\,max} = 2[3\tau_{LG}/2(\rho_S - \rho_L)g]^{0,5}\,\sin(\theta/2).$$

A somewhat similar expression was derived by Tsai and Lumpkin[2]:

$$d_{p\,max} < [4\tau_{LG}/(\rho_S - \rho_L)g]^{0,5}.$$

Gaudin[10] and Nutt[15] considered a centrifugal force in place of gravity. Schulze[13,16] presented a comprehensive analysis of turbulence in which the turbulence is modelled by a relative bubble–particle aggregate-to-water velocity. Scheludko[12] considered the kinetic energy in a particle–bubble collision. Each of these models shows an order of magnitude decrease in the value of $d_{p\,max}$ as compared with the 'gravity' model.

Finch and Smith[17] point out that the models based on turbulence and the kinetic energy of collisions appear to give better agreement with plant observations than the models proposed by Huh and Mason[11] and by Scheludko *et al.*[12], but little convincing work has been done to determine the upper size limit in present flotation practice.

This tends to suggest that the conditions obtaining in a full-scale plant are turbulent, and that the range of particle size amenable to flotation could be extended through redesign of the cell or control of its turbulence level.

Forces Acting on Particles and Bubbles

The Quiescent Zone

The force associated with the adhesion of a particle and a bubble is

$$F_A = \tau_{LG}\,(\sin\theta)\,\pi D. \quad (1)$$

The net force acting on a bubble F_B is the sum of the buoyancy force, the external (gravitational) force, and the drag force, namely

$$\pi g d_b^3\rho_L/6 - \pi g d_b^3\rho_b/6 - C_{Db}\,V_x^2\rho_L S_b/2 \quad (2)$$

Similarly, before attachment to the bubble, the net force acting on a particle F_p is

$$\pi g\, d_p^3\rho_L/6 - \pi g\, d_p^3\rho_p/6 - C_{Db}\,V_x^2\rho_L S_p/2. \quad (3)$$

For attachment to occur,

$$F_A > F_B - F_p. \quad (4)$$

Equations (1) to (3) can be simplified since

$$d_p^3\rho_L \ll d_b^3\rho_L,\; C_{Db}\,S_b \gg C_{Dp}\,S_p,\; \rho_L \gg \rho_b \text{ and } S_b = (\pi/4)d_b^2. \quad (5)$$

$C_{Db}\,V_x^2$ can be evaluated through the consideration of a similar force balance on a bubble rising at its terminal rise velocity, at which $dV_x/dt = 0$ and whence

$$C_{Db}\,V_x^2 = (4/3)g\,d_b(1 - \rho_b/\rho_L) \approx (4/3)g\,d_b. \quad (6)$$

When equations (1) to (3) are substituted in equation (4), the simplifications in equation (5) are introduced, and $(4/3)gd_b$ is substituted for $C_{Db}\,V_x^2$, the criterion for attachment to occur is

$$\tau_{LG}\,(\sin\theta)\,\pi D > \pi d_p^3\,\rho_p\,g/6, \quad (7)$$

from which the ratio of the separating force to the interfacial tension force

$$\beta = d_p^2\rho_p g/[\tau_{LG}(\sin\theta)] \quad (8)$$

if the reasonable approximation is made that $D = d_p$. Schulze[18] defines β as a modified Bond number that equals 1 at the maximum floatable particle size $d_{p\,max}$.

The Turbulent Zone

The dissipative forces exerted on a bubble in a turbulent liquid at bubble Reynold's number

$$Re \gg 1 \text{ is } 6\pi\mu d_b U. \quad (9)$$

The drag exerted on the particle is given by the Stokes equation

$$F = 3\pi\mu d_p U. \quad (10)$$

Therefore the net force acting on the particle and the bubble attached would be of the order of

$$6\pi\mu U(d_b - d_p/2), \quad (11)$$

but, since $d_b \gg d_p$, this reduces to

$$6\pi\mu d_b U. \quad (11a)$$

The ratio of the detachment to attachment forces in the turbulent zone

$$\beta' = 6\,\mu d_b U/[\tau_{LG}(\sin\theta)d_p] \quad (12)$$

again on the assumption that $D = d_p$.

At $\beta' = 1$, separation would occur and $d_p = d_{p\,min}$. This can be viewed as the particle size below which attachment to the bubbles would not occur but the particle would merely follow the turbulent pulsations.

Equations (8) and (12) can be rewritten as

$\beta = k\, d_p^2$ for the quiescent zone .... (13)

and

$\beta' = k'/d_p$ for the turbulent zone. .... (14)

From these relationships, it is possible to postulate a graph of the form shown in Fig. 1.

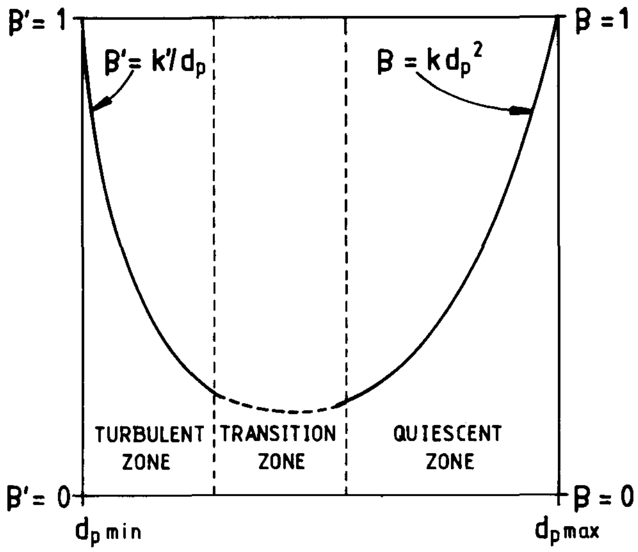

Fig. 1—Graph postulated on the basis of equations (13) and (14)

Determination of β

Bubble size is related to interfacial tension according to

$\tau_{LG1}/\tau_{LG2} = d_{b1}/d_{b2}$. .... (15)

For the air-water system, τ_{LG2} is taken as constant and equation (8) can be rewritten as

$\beta = [d_p^2 \rho_p\, d_{b2}\, g/6]/[\tau_{LG2}\, d_{b1} \sin\theta]$. .... (16)

Two multiple regression correlations for d_{b1} and d_{b2} were established through the experimentation described later. These are

$d_{b1} = e^{2,6497}\, N^{-0,1914}\, G^{0,2045}\, P^{-0,3838}$ .... (17)

$d_{b2} = e^{1,1792}\, N^{-0,0543}\, G^{0,0844}$, ... (18)

where d_{b1} is the Sauter mean diameter of the bubble in the presence of promoter, and d_{b2} the bubble diameter in pure water. The parameter settings used here for the determination of β were N = 1150 r/min, G = 4 l/min, P = 0,3 μl/g coal.

Over the range in ash content considered here, ρ_L varies by approximately 10 per cent and was assumed to be constant in the calculation of β. This is acceptable when viewed against the three hundred times increase in the value of d_p^2 over the range in particle size.

For the purpose of these experiments with a single coal type and at a constant level of promoter dosage, a constant value of θ = 50° was taken from the range 39 to 63° observed by Brown and Smith[1], Whelan and Brown[19], and Busnowska[20]. Any variation in the value of θ will similarly be negligible when compared with the change in magnitude of d_p^2.

When these values are substituted in equations (17), (18), and (16),

$\beta = 1,008 \times 10^{-7}\, d_p^2$. .... (19)

At β = 1, the maximum particle size $d_{p\,max}$ = 3150 μm.

Fig. 2 is a graph of β versus d_p for the range of variables in these experiments and appropriate to the quiescent zone.

Experimental

Equipment

The standard Leeds cell (height 150 mm) was used for certain of the experiments and has a capacity of 3 litres. It was improved by the addition of a mechanical froth scraper, a pH probe, and a reagent injection port. In other experiments the cell was modified further by a doubling of the height to 300 mm and, in so doing, allow-

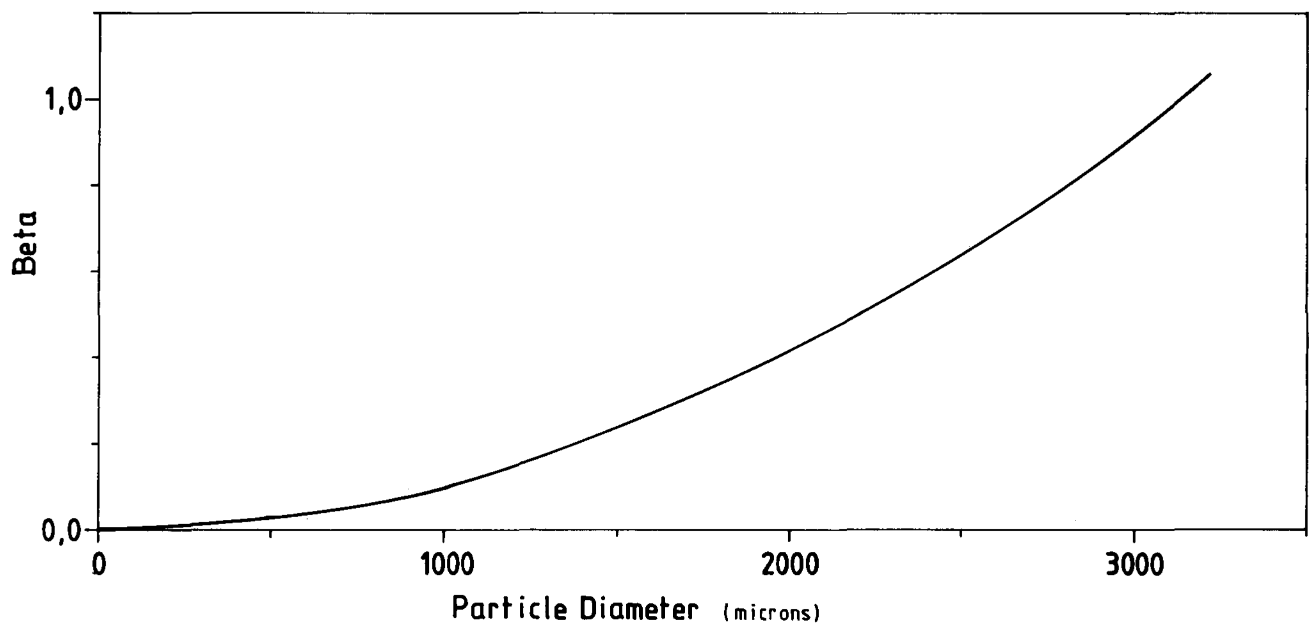

Fig. 2—β versus particle diameter (μm)

ing for a larger 'quiescent' zone.

Parameter Settings

Scanlon *et al.*[21] thoroughly researched the flotation performance of ACCOAL 4433 and optimized the ratio of frother:collector:surfactant for a wide variety of coal substrates. Celik and Somasundaran[22] showed that optimum flotation occurs at a neutral pH. In their investigation of the effects of slurry residence time, Panopoulos and King[3] concluded that recovery is negligible after about 200 seconds.

In the present investigation, the response variable expressing the efficiency of flotation was measured in terms of beneficiation efficiency as defined by Tsai and Lumpkin[2]:

$$\text{Beneficiation efficiency} = [\text{Mass \% organic recovery}] \times [\text{Mass \% mineral rejection}]/100,$$

where

$$\text{Mass \% of organic recovery} = \frac{\text{Mass \% organics in overflow}}{\text{Mass \% organics in feed}} \times \text{yield \% of overflow}$$

$$\text{Mass \% mineral rejection} = 100 - \frac{\text{Mass \% minerals in overflow}}{\text{Mass \% of minerals in feed}} \times \text{yield \% of overflow.}$$

Flotation Procedure

All the flotation tests were conducted on samples of fines from the desliming screens at the Welgedacht Colliery in northern Natal. The coal sample as a 5 per cent slurry by mass was conditioned in the flotation cell by the running of the impeller at 1000 r/min for 3 minutes. The required amount of promoter was then introduced by syringe into the slurry via the injection port and, while the pH of the slurry was carefully controlled, the mixture was conditioned for 3 minutes. The impeller speed was then adjusted to its desired setting, and air was introduced into the cell at the desired flowrate for 3 minutes.

Both the concentrate and the tailings were collected quantitatively for analysis.

Bubble Sizing

A photographic technique was used to establish a mean bubble size for the entire range of experimental conditions. The slurry was conditioned as above, promoter was added, and, after the 3-minute conditioning period, the slurry was filtered and the clear filtrate returned to the cell.

Bubble swarms were photographed for different air rates, impeller speeds, and promoter quantities, and the size distribution of the bubbles for each set of conditions was determined visually. The bubble sizing was repeated without the use of promoter, and two multiple non-linear correlations were established for the Sauter mean diameter.

The ranges of variables were as follows:

Aeration rate, G = 2,5 to 5,5 l/min
Impeller speed, N = 700 to 1500 r/min
Promoter dosage = 25 to 75 μl.

The correlations established are given in equations (17) and (18), with correlation coefficients of 0,840 and 0,957 respectively.

Results

Effect of Turbulence Level

Fourteen runs were carried out, 7 with the standard Leeds cell and 7 with the double-height cell. Particle size was the only variable, there being 7 size cuts over the range +38 μm to −600 μm. The results are reported in Table I, and the beneficiation efficiency for the two cells is plotted against particle size in Fig. 3.

TABLE I
BENEFICIATION EFFICIENCY

Conditions
Solids content = 5% (m/m)
ACCOAL dosage = 0,3 ul/g solid
Impeller speed = 1150 r/min
Aeration rate = 4 l/min

Particle size range µm	Overflow % (by mass)	Ash in overflow %	Ash in feed %	Organics recovered %	Minerals rejected %	Efficiency %
Standard Leeds Cell						
− 53 + 38	38,59	22,30	52,10	62,59	83,48	52,25
− 63 + 53	43,56	20,50	47,10	65,46	81,04	53,05
− 75 + 63	61,67	18,60	35,00	77,23	67,23	51,92
−106 + 75	69,03	15,90	29,10	81,88	62,28	51,00
−150 +106	71,29	15,60	27,60	83,10	59,71	49,62
−425 +300	17,96	11,70	35,50	24,59	94,08	23,13
−600 +500	13,33	9,00	31,90	17,81	96,24	17,14
Modified Leeds Cell of Double Height						
− 53 + 38	39,32	23,20	52,10	63,04	82,49	52,00
− 63 + 53	44,79	20,10	47,10	67,65	80,89	54,72
− 75 + 63	63,25	17,90	35,00	79,89	67,65	54,05
−106 + 75	71,86	17,80	29,10	83,31	56,04	46,69
−150 +106	73,77	15,60	27,60	85,99	58,31	50,14
−425 +300	42,82	13,10	35,50	57,69	84,20	48,57
−600 +500	26,51	14,70	31,10	32,82	87,47	28,71

From the graph of β versus particle diameter (Fig. 2), it is clear that the detachment forces increase considerably in the range 150 to 600 μm as evidenced by the steepening of the slope of the curve. It is reasonable therefore to expect the beneficiation efficiency to decrease with increasing particle size since not all the particles that impact with bubbles will attach themselves owing to the increasing detachment forces in the larger particle size range.

This is evidenced in Fig. 3 for both cells, but it is more significant in the case of the standard Leeds cell. It is therefore proposed that the better performance of the double-height cell as against that of the standard cell is due to the extension of the quiescent zone remote from the turbulence of the impeller.

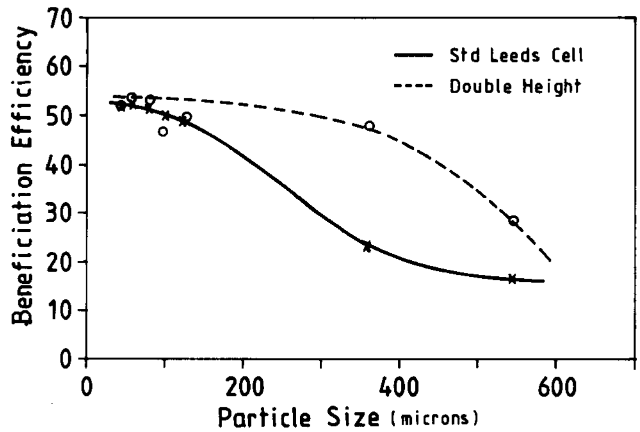

Fig. 3—Beneficiation efficiency (%) versus particle size (μm)

It could be argued that the improvement in performance is due to an increase in bubble residence time, and hence an increase in the probability of impaction. Were that so, a marked improvement in beneficiation efficiency would also be evident in the lower particle-size range, that is smaller than 150 μm. This is not apparent to any significant extent. In essence, the doubling of the height of the standard Leeds cell extended the range of efficient operation from a maximum particle size of 150 to 350 μm without a significant decrease in the beneficiation efficiency.

Cell Performance in Lower Size Range

No conclusion could be drawn from the results in the experiments to establish which parameters determine the cell performance in the range 38 to 150 μm. It is clear, however, that cell type is of little significance.

To identify variables affecting the beneficiation efficiency in that size range, a 2^4 factorial experiment was carried out with the standard Leeds cell. Particle size, promoter dosage, impeller speed, and aeration rate were the variables chosen (Table II).

TABLE II
VARIABLES AFFECTING BENEFICIATION EFFICIENCY

Variable	Level: High	Level: Low
Particle size (μm)	$-150 + 106$	$-53 + 38$
Aeration rate (l/min)	5,0	2,5
Impeller speed (r/min)	1400	900
Promoter dosage (μl)	60	30

The combinations are identified in Table III, together with the results. A standard Yates analysis was used to identify the significant variables, and the experimental error was estimated by the grouping of third- and higher-order interactions.

Table IV summarizes the significant variables and the appropriate confidence level for each.

TABLE III
ANALYSIS OF VARIABLES

Feed coal
Ash %: $-150 + 106\ \mu$m = 25,90%
$-53 + 38\ \mu$m = 49,70%

Exp. no.	High settings	Overflow % (by mass)	Ash in in overflow %	Organics recovered %	Minerals rejected %	Efficiency %
1	d_pGNP	83,17	16,30	93,94	47,66	44,77
2	d_pGN	41,43	13,10	48,58	79,05	38,40
3	d_pGP	73,87	15,60	84,13	55,51	46,70
4	d_pG	49,23	13,20	57,66	74,91	43,20
5	d_pNP	81,83	14,60	94,30	53,87	50,81
6	d_pN	27,41	12,00	32,55	87,30	28,41
7	d_pP	78,57	14,60	90,55	55,71	50,45
8	d_p	42,21	13,20	49,44	78,49	38,81
9	GNP	52,82	24,30	82,50	73,20	60,39
10	GN	21,95	16,00	36,65	92,93	34,06
11	GP	50,17	24,80	75,00	74,97	56,23
12	G	19,21	18,60	31,08	92,81	28,85
13	NP	49,31	22,30	76,17	77,88	59,32
14	N	22,39	17,50	36,73	92,12	33,83
15	P	45,87	25,10	68,30	76,84	52,48
16	–	20,32	18,40	32,96	92,48	30,48

d_p Particle size, P Promoter dosage, G Aeration rate, N Impeller speed

TABLE IV
SIGNIFICANT VARIABLES

Variable	Confidence level 95%	99%
Organics recovered		d_pP
Minerals rejected	d_pP	d_pP
Beneficiation efficiency	d_pP	P

Multiple regression analysis gave the following correlations:

$$\% \text{ Organics recovered} = e^{-1,1361} d_p^{0,2327} G^{0,1062} N^{0,0110} P^{1,0576} \quad [r = 0,958]$$

$$\% \text{ Minerals rejected} = e^{-7,1645} d_p^{-0,2435} G^{-0,0624} N^{-0,0113} P^{-0,4400} \quad [r = 0,952]$$

$$\% \text{ Beneficiation efficiency} = e^{-1,4188} d_p^{-0,0104} G^{0,0440} P^{0,6178} \quad [r = 0,869]$$

It is clear from these results that, in the lower size range of 38 to 150 μm, particle size is of less significance than promoter dosage. In the correlation for beneficiation efficiency, the exponent on d_p is $-0,01$ compared with an approximate value of $-0,69$ in the size range larger than 150 μm for the standard Leeds cell and larger than 350 μm for the double-height cell.

The significance of promoter dosage in the lower size range, which has been demonstrated elsewhere[2,3], is clearly indicated in the three correlations.

Apart from the strong dependence of bubble size on promoter dosage (equation 18), which has been explained in the literature[2,3], recovery depends upon supply of collector and demand of the solid. Under-dosage results in poor beneficiation since potential high-grade material is starved of reagent, whereas over-dosage results in the carry-over of particles of high mineral content. Hence, an increase in promoter dosage increases the recovery of organic material and decreases the mineral rejection.

Conclusions

It is proposed here that, in the feed larger than 150 μm, the beneficiation efficiency is severely affected by turbulence in the cell. When the cell was redesigned to extend the depth of the zone remote from the impeller, the range of efficient operation could be extended to particle sizes of 350 μm without any decrease in beneficiation efficiency. Beyond that level and up to 600 μm, acceptable levels were still attainable.

In the particle sizes smaller than 150 μm, the turbulence level in the cell was of almost no significance, and the cell design is accordingly unimportant.

Notation

Symbol	*Description*	*Unit*
C_{Db}, C_{Dp}	Drag coefficient of bubble or particle	–
D	Diameter of circle of contact between particle and bubble	m
$d_b d_p$	Diameter of bubble or particle	m
F_A	Interfacial tension force between particle and bubble	N/m
F_B	Net force acting on bubble	N/m
F_p	Net force acting on particle	N/m
G	Aeration rate	l/min
g	Gravitational acceleration	m/s^2
N	Impeller speed	r/min
P	Promoter dosage	μl
S_b, S_p	Projected area of bubble or particle normal to direction of flow	m
t	Time	s
U	Relative velocity between particle and liquid	m/s
V_x	Terminal rise velocity of bubble	m/s
β	Ratio of detachment forces to attachment forces between particle and bubble	–
ρ	Density	kg/m^3
μ	Viscosity of the slurry	Ns/m^2
τ_{LG}	Air-liquid interfacial tension	N/m
θ	Contact angle	°

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Agglomeration

The 5th International Symposium on Agglomeration is to be held in Brighton, UK, from 25th to 27th September, 1989. The Symposium is being co-sponsored by The Institution of Chemical Engineers and the Institute of Metals. This is the fifth in a series of symposia on agglomeration. Previous meetings took place in Toronto (1985), Nurnberg (1981), Atlanta (1977), and Philadelphia (1961).

Brighton is an attractive and historic seaside town within easy reach of London. London's Gatwick Airport is only 30 minutes away by rail or road, and offers direct flights from over 126 cities worldwide. From the Continent, Brighton is easily accessible by car via the Sealink car ferry from Dieppe to Newhaven (15 km from Brighton Town Centre).

The topics of this meeting will include

Metals and mineral processing
Speciality and effect chemicals processing
Adhesion science and technology
Multi-phase aggregation behaviour
Novel powder production
Characterization and measurement
Agglomeration and the environment
Particles and chemistry.

Papers are invited on the above topics, and an extended abstract (less than 1000 words) should be sent to the address below by 25th November, 1988. It is intended that accepted papers will be published in a volume that will be distributed at the Symposium itself.

The Social Programme will include a Welcoming Reception and a Conference Dinner for all participants. In addition, there will be an accompanying persons' programme, which may include a sightseeing tour of Brighton, and visits to stately homes such as Arundel Castle and Goodwood House, and to the beautiful surrounding countryside of Sussex and nearby Kent.

Further details are available from

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