PNEUMATIC FLOTATION OF SOME SOUTH AFRICAN COALS

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ABSTRAK

Pneumatiese flottasie is in Wes-Duitsland tot so 'n mate ontwikkel dat volskaalse aanlegte in die bedryf as betroubaar beskou word.
Die behoefte aan nuwe tegnologie word vanuit die Suid-Afrikaanse perspektief beskou en die pneumatiese flottasietegniek word kortliks beskryf.

Ten einde vas te stel of hierdie metode met sukses vir Suid-Afrikaanse steenkool, wat moeilik flotteer, gebruik kan word, is eksperimentele ondersoeke met steenkool van die Waterberg, die Soutpansberg en enkele Natalse steenkoolvelde uitgevoer.

Pneumatiese flottasie word vergelyk met standaard laboratoriumflottasie en met volskaalse konvensionele flottasie.

Die resultate toon duidelik die potensiaal wat hierdie tegniek inhou as 'n aanvulling of gedeeltelike vervanging van konvensionele flottasie.

SUMMARY

The process of pneumatic flotation has been developed in the Federal Republic of Germany to such an extent that full-scale plants are considered operationally reliable.
The need for new technologies is reviewed from the South African perspective and the technique of pneumatic flotation is described briefly.
In order to determine whether this technique can be applied successfully to South African coal fines, which are difficult to float, pilot scale testing was done on coals from the Waterberg, Soutpansberg and some of the Natal coalfields.
Pneumatic flotation is compared with standard laboratory flotation as well as with full-scale conventional flotation.
The results obtained clearly show the potential of this technique to complement or to replace conventional flotation to some extent.

THE NEED FOR NEW TECHNOLOGIES

During the early eighties, it was standard practice in South Africa to beneficiate the nominal -1,0 mm fraction of a coking coal or blend coking coal by means of conventional flotation, i.e. agitation flotation.
Although it was realized that the metallurgical efficiency deteriorates towards the top end as well as the bottom end of the screen size band, not much could be done at that time. Moreover, owing to low market prices it was economically not

attractive to make great efforts to beneficiate coal fines. Pilot-scale attempts to upgrade coal fines, i.e. the -1,0 mm fraction, by means of heavy medium cyclones were promising. However, not many plants are in operation yet. In the past five years, newly developed coal spirals have been successfully introduced at many coal mines, upgrading for instance the +0,3 mm -1,0 mm fraction. Low capital costs as well as low operational costs make spirals attractive, even at somewhat lower metallurgical efficiencies, when compared with froth flotation.

For ultrafines, however, spirals cannot be applied successfully. In this context, ultrafines refers to the -0,1 mm fraction.

The flotation of ultrafines by means of agitation flotation caused problems in many cases. Either poor metallurgical results were accepted, or desliming and discarding the ultrafines was applied.

Depending on the mineralogical properties of the coal and the type of crushing plant, ultrafines may account for a substantial percentage of the plant feed and, owing to the increase in continuous mining methods, this percentage will even increase in future.

Therefore, improving the overall performance of a beneficiation plant by upgrading ultrafines more efficiently is an attractive challenge. It is also obvious that, percentagewise, greater improvements can be obtained than in the case of coarse particles, where high efficiencies are already achieved.

Fig. 1 demonstrates the present and envisaged trend for the beneficiation of coal fines in South Africa.

The abscissa represents the particle size range from zero to 3 mm and the ordinate the efficiency, which could be either metallurgical or economic efficiency. No scales are given because of the qualitative nature of this graph.

For small sizes, conventional flotation is obviously superior to spirals. As the particle size increases, the efficiency for both processes overlaps, i.e. the processes are equally efficient; and when they increase further, spirals become more efficient than conventional flotation.

In order to beneficiate the ultrafines more efficiently, several attempts were made:

Split flotation, i.e. treating size fractions separately, and stage reagent addition proved to be not very successful, mainly because of the long retention times for ultrafines (Botha, 1980).

Although it is expected that conventional flotation treatment of ultrafines can be improved to some extent by tailor-made reagents, or by reagent combinations, inadequate hydrodynamics set a limit to these improvements.
In the seventies extensive research was carried out under the leadership of Professor Bahr at Clausthal University, Federal Republic of Germany, which led to the development of a new

flotation technique which today is referred to as "pneumatic flotation".

Several full-scale plants are in operation world-wide.

Another technique, known as "column flotation", also is receiving attention by various research groups, locally and abroad.

Because excellent results are being obtained with full-scale pneumatic flotation plants in treating particle size distributions similar to some ISCOR coals, it was decided to acquire a pilot-scale pneumatic flotation cell.
The aim was to establish whether this technique could be successfully applied to more-difficult-to-float South African coals in order to achieve the envisaged trend qualitatively given in fig. 1.

PRINCIPLES OF PNEUMATIC FLOTATION AND COMPARISON WITH OTHER FLOTATION TECHNIQUES

The most effective technique to date for cleaning coal fines below certain sizes is froth flotation.

In a conventional flotation process the pulp is fed by gravity to the flotation cell and agitated by means of an impeller. Air is introduced into the pulp through the shaft of the impeller and dispersed by means of a rotor-stator system. The agitation and separation zones are not clearly distinguished. Owing to the cross flow, where the loaded bubbles move at right angles to the main flow of the pulp, and the turbulent flow conditions, the finest hydrophilic particles, which are more or less homogeneously suspended in the pulp, cannot be prevented from passing into the froth proportionally to the liquid quantity (Schubert, 1988). These misplaced particles can only be removed by re-floating the concentrate, thus increasing capital and operating costs. Additionally, the finest hydrophobic particles are less likely to collide with relatively coarse air bubbles and are lost in the discard.

Based on theoretical considerations (Bahr, 1971) and experimental results (Luedke, 1973; Stich, 1977), especially concerning the formation of gas bubbles and their adhesion to solids particles, a novel pneumatic flotation plant was developed jointly by Bergbau Forschung GmbH, the institute for mineral beneficiation of the Technical University of Clausthal and the company Westerholt of Ruhr Kohle AG.

In order to attach solid particles to air bubbles effectively, certain relative velocities are necessary. Because of the absence of an impeller, high fluid velocities are required to disperse the air into fine bubbles and to maintain the suspension. It was realized that bubble/particle attachment, and the separation of the phases, could be considerably improved when carried out in separate units.
Aerators situated outside the separating vessel were developed where bubble/particle attachment is achieved in a few milliseconds.
The bubbles are either produced by sized pores or by an annular

clearance followed by a mixing zone.

The characteristics of pneumatic flotation can be summarized as follows:

- no moving parts
- production of fine air bubbles
- particle adhesion to air bubbles occurs in an aerator ("forced bubble adhesion")
- aerator and separating vessel are physically separated.

Although a variety of aerators, pulp feed arrangements and separating vessel designs exist, the applied principles remain unchanged.

During the past few years other flotation devices were further developed, having the first two features in common with pneumatic flotation, i.e. no moving parts and production of fine bubbles.

These flotation devices are known as column flotation.

The major differences compared with pneumatic flotation are:

- air-bubble/particle adhesion takes place within the separating column
- countercurrent flow of air bubbles and solid particles
- application of wash water to obtain secondary enrichment in the froth and to support downstream movement.

In general, the height/diameter ratio of column flotation cells is larger than for pneumatic flotation.

For column flotation, ratios of 2,2 - 10 are reported (Schubert,

1988), but ratios of >30 can be achieved in test units.
For pneumatic flotation plants, ratios of 1,5 - 3 are common, for test units ratios of up to 6.

TEST SET-UP AND METHOD

The test set up is shown in fig. 2.
The material is fed to a 200 l conditioner. Reagent is added by means of a positive displacement pump. By adding clean water to the conditioner, the solids concentration can be decreased.
By means of a mono pump, the pulp is fed to the aerator and brought into contact with pressurized air. Basically, the aerator consists of a 12 mm stainless steel pipe , feeding the pulp to the separating vessel at a speed of approximately 11 m/s.

Air is introduced through a narrow annular slot and , in consequence of the high pulp velocity, dispersed into fine bubbles.
Bubble/solids adhesion occurs within the aerator. The aerated pulp is ejected into the cylindrical separation container in the form of a free jet.
While low ash coal particles, attached to air bubbles, enter the froth layer at the top of the flotation cell, the discard particles move downwards and are discarded at the bottom.
The coal-laden froth flows freely into the concentrate launder.
The volume flow rates of pulp and air are measured by means of a magnetic induction flowmeter and a float position measuring device respectively.

Separating vessel, measuring equipment and feed pump were supplied by the company Allmineral, Federal Republic of Germany, together with their South African agency IMS (Industrial Machinery Suppliers).

Owing to some instabilities within the flotation cell, at the interface pulp-froth, the height of the separating vessel had to be extended from 1,3 m to 1,8 m.

The retention times in the conditioner and in the separation vessel are approximately 3 minutes and 1,5 minutes respectively.

The diameter of the separation vessel is 0,3 m.

During the test work, a constant pulp flow rate of 4,2 m^3/h was maintained. At a solids concentration of 3%, the solids throughput per unit area amounts to 1,8 t/m^2h.

The pneumatic flotation cell was tested under laboratory as well as under plant conditions.
This necessitated three different feeding arrangements to the conditioner of the test cell, viz.,

- dry feeding by means of a vibratory feeder
- tapping off a representative plant-stream pulp
- feeding from a 6 m^3 mixing vessel

Obviously, the last two feeding arrangements have certain disadvantages which will be discussed later.

For a given test material the following variables were altered:

- Chemical variables:
  - collectors
  - frothers
- Operational variables:
  - pulp density
  - air flow rate
  - froth height
  - reagent dosage

RESULTS

Waterberg coalfield

Flotation feed material was air-dried and dry screened at 0,3 mm. The -0,3 mm fraction served as test material. The air-dried sample was fed to the conditioner of the pneumatic flotation cell by means of a vibratory feeder.

The screen and sink-float analyses are given in table 1 and table 2 respectively. Table 3 lists the results of laboratory flotation tests.

Particle size/microns	Fractional mass/%	Fractional ash/%
-300 +212	31,4	31,6
-212 +150	17,4	31,8
-150 + 75	14,8	35,8
- 75 + 45	9,8	33,7
- 45	26,6	45,8

Table 1 : Screen-ash analysis of flotation feed material

Density/g/cm^3	Cumulative mass/%	Cumulative ash/%
1.45 Float	30,7	8,3
1.55 Float	45,7	12,9
1.70 Float	60,4	17,3
Total	100,0	35,5

Table 2 : Sink-float analysis of flotation feed material

Reagent* dosage/l/t	Rougher concentrate		Cleaner concentrate	
	Mass/%	Ash/%	Mass/%	Ash/%
1,0	25,2	15,2	-	-
1,5	44,6	17,1	23,1	11,1
2,0	52,1	17,8	36,3	13,0
2,5	60,4	19,0	46,0	14,6
3,0	64,3	19,6	52,3	15,3
3,5	63,8	19,2	52,9	14,7
4,0	63,9	19,5	53,0	14,6

* Paraffin used as collector. Frother dosage 3 g/m^3.

Table 3 : Laboratory standard flotation tests on flotation feed material

In order to ascertain when steady conditions were achieved in the pneumatic flotation cell, samples of the feed, concentrate and tailings were taken at intervals of 2 minutes. The results are summarized in table 4.

Reagent	Reagent dosage l/t	Air/pulp ratio	Froth height/ cm	Solids concen-tration/%	Feed Ash/%
Paraffin and 4% Flotanol	1.7	0.8	35	3,7	35,7
CCI and 4% Flotanol	2.0	0.8	28	3,7	35,4

Reagent	Paraffin and 4% Flotanol			CCI and 4% Flotanol		
Time from start/min	Concentrate ash/%	Tailings ash/%	Yield/ %	Concentrate ash/%	Tailings ash/%	Yield/ %
2	17,2	50,4	44,2	15,5	52,1	45,8
4	17,1	53,3	48,4	13,8	51,3	42,5
6	16,3	50,7	43,4	12,7	49,2	38,4
8	15,4	49,9	41,1	12,4	49,5	37,6
10	14,7	46,8	34,5	12,4	50,1	39,1
12	14,3	46,4	33,1	12,5	49,6	38,4

Table 4 : Unsteady conditions during the startup of pneumatic flotation

In fig. 3 the results given in table 2 to table 4 are plotted. The results obtained for washability, single-stage and two-stage laboratory flotation were curve fitted, and only the fitted curves are shown.

Each dot represents the concentrate ash and the corresponding yield at a certain time from the start of pneumatic flotation.

With increasing time, the yield as well as ash content diminish, thus indicating that steady conditions are achieved only after approximately 12 minutes. It can also be seen from fig. 3 that with increasing time the results of pneumatic flotation become more favourable when compared with laboratory flotation. Based on these results, sampling was started after 20 minutes during further test work when operational variables were altered. Samples were taken every 5 minutes for 40 minutes and combined to give a composite sample.

Fig. 4 shows the results obtained. Owing to the limited number of tests, no clear relationships could be established. Therefore, the conditions for the individual tests are not specified.
However, it is obvious that pneumatic flotation gives better results in a single stage than laboratory flotation standard tests and can approach, or even exceed, those obtained in a laboratory cleaning stage.

Another sample with a nominal top size of 0,3 mm was obtained from the underflow of a sieve bend.
The material had a feed ash content of 40% and was floated under the previously determined, apparently favourable, conditions.
A concentrate ash of 14,2% was obtained at a yield of 40%, thus confirming the potential of pneumatic flotation.

Kliprivier coalfield, Natal - flotation feed

A sample of the feed to conventional flotation, with a nominal top size of 0,3 mm, was obtained from the underflow of sieve bends.

The test procedures were similar to those applied for Waterberg coal.

The results of single-stage laboratory flotation tests are given in table 5, and the results obtained by means of pneumatic flotation in table 6 and fig. 5 respectively.

Reagent * dosage/l/t	Rougher concentrate	
	Mass/%	Ash/%
0,1	35,9	16,2
0,2	44,6	15,2
0,4	50,9	15,4
0,8	59,6	15,3

* Paraffin used as collector. Frother dosage $3 g/m^3$

Table 5 : Laboratory standard flotation tests on flotation feed material

Fig. 5 clearly shows the superior results obtained by means of pneumatic flotation when compared with laboratory flotation.

Test	Reagent	Reagent dosage/ l/t	Air/pulp ratio	Froth height/ cm	Solids concen-tration/%	Feed ash/%
1	Paraf-fin and 4% Flo-tanol	3,4	1,5	25	3	28,5
2		1,8	1,5	35	3	28,6
3	NSR	3,9	1,5	30	3	29,0
4		4,0	1,5	50	9	29,0

Time*/ min	Test 1			Test 2			Test 3			Test 4		
	Conc ash%	Tail ash%	Yield %	Conc ash%	Tail ash%	Yield %	Conc ash%	Tail ash%	Yield %	Cash ash%	Tail. ash%	Yield %
2	13,4	49,2	57,9	12,2	36,4	32,3	13,2	40,3	41,7	15.4	56,6	67,0
4	13,2	49,0	57,6	12,2	38,1	36,9	13,5	41,5	40,6	17.0	50,6	64,3
6	13,2	50,1	57,2	12,3	36,2	33,4	13,7	43,9	49,3	20.0	42,0	59,1
8	13,4	54,5	63,3	11,8	36,7	32,6	13,6	42,2	46,2	20.5	41,3	59,1
10	13,1	48,2	56,2	12,3	38,1	37,0	13,7	43,0	47,8	20.4	45,4	65,6
12	13,3	48,7	57,1	12,4	38,8	38,9	13,8	44,6	50,6	20.2	46,8	66,9
14	13,7	52,1	61,5	12,4	36,8	33,9	13,9	45,8	52,7	18.9	59,3	75,0
16	13,8	52,4	62,1	-	-	-	-	-	-	14.9	51,1	61,0
18	13,3	49,9	58,5	-	-	-	-	-	-	-	-	-
Mean	13,4	50,5		12,2	37,3		13,6	43,0		18,4	49.1	
s	0,23	2,10		0,21	1,01		0.23	1,89		2,32	6.51	

s = standard deviation

* Starting 20 minutes after startup

<u>Table 6</u>: Pneumatic flotation of flotation feed material

In this case, power paraffin was obviously a more efficient reagent than NSR (a coke oven by-product).

For power paraffin, the common trend - lower reagent dosage results in less ash in the concentrate as well as in lower yields - can be observed.

The results obtained at 9% solids concentration show considerable scatter. It is not known, however, whether this behaviour is due to the high solids concentration or some other undetected, unstable feeding condition.

The reagent consumption, expressed in l/t, was similar for tests 3 and 4 which were run at 3% solids and 9% solids respectively. This indicates that the reagent consumption for the production of a specified ash content will depend on the solids concentration of the feed.

<u>Kliprivier coalfield, Natal - Settling tower overflow</u>

Some 10 years ago, it was established that ultrafines were detrimental to the flotation process.

By means of a settling tower, the fines are removed from the flotation feed. The size distribution of the removed material, the settling tower overflow, is given in table 7.

By removing these ultrafines from the flotation feed the flotation yield improved and dramatically increased the produced tonnages. Floating the ultrafines separately by means of conventional flotation was not successful as the yield remained below 5% at a concentrate ash content of 12%. Therefore, this material was discarded to the slimes dams.

Particle size/microns	Cumulative volume/% undersize
300	100
150	93,0
75	81,2
38	62,3
19	46,1
9.4	29,4
4.7	15,7
2.4	3,4

Table 7 : Particle size distribution of the settling tower overflow as determined by means of the "Microtrac" (diffraction pattern analysis)

Pneumatic flotation was applied on these ultrafines.

A part of these ultrafines was tapped off and fed directly to the conditioner of the pneumatic flotation test unit.

The solids concentration varied between 9% and 12% by mass.

The results obtained are plotted in fig. 6. At solids contents above 9%, the variation of froth height and reagent dosage did not lead to concentrate ashes below 16% at reasonable yields.

Altering the air flow rate was not successful either.

By reducing the solids content to about 3% a dramatic improvement was obtained.

Using NSR as the flotation reagent, the results were further improved.

In a next step, using power paraffin as a reagent, the solids concentration was increased to 6%. No great differences could be observed when comparing the results obtained in these tests with those obtained in the tests with 3% solids concentration, and paraffin.

In fig. 6, the maximum yield achievable is plotted. It is assumed that the particles are completely liberated and that tailings ashes of 100% are possible. In this case yield is calculated from:

$$Y = \frac{100 - a_o}{100 - a_1}$$

a_o = ash content of the feed

a_1 = ash content of the concentrate

The comparison of this idealized yield with the results obtained at solids concentrations of between 3% and 6% shows that pneumatic flotation is very efficient when concentrate ashes of 12% to 16% are produced.

For concentrate ashes below 12%, the efficiency is reduced considerably, thus following the common trend of South African coals, viz.,

high concentrate ashes - high efficiencies

low concentrate ashes - low efficiencies

Fig. 6 shows clearly that solids concentrations above 9% lead to poor results.

At low solids concentrations, however, high yields at acceptable concentrate ashes are obtained.

Considering that approximately 50% of the feed is smaller than 20 microns, the results are surprising indeed.

Kliprivier coalfield, Natal - slimes dams

In order to investigate the possible recovery of coal from the existing slimes dams, extensive laboratory test work was carried out. Washability tests, as well as two-stage laboratory flotation tests, revealed a possible yield of below 30% at ash contents of 10%.

Concentrate ashes of below 16% could not be achieved by means of single-stage laboratory flotation tests.

Test work on coking properties, performed at a later stage, revealed that higher concentrate ashes than 10% could well be tolerated.

Samples from selected exploration holes were fed to a $6m^3$ mixing tank and from there to the conditioner of the pneumatic flotation unit. Draining the mixing tank allowed test work of approximately 45 minutes with the pneumatic test unit.

The particle size distributions are given in table 8.

Particle size/microns		Fractional mass/% Sample 1	Sample 2
+500		8,8	4,6
-500	+212	8,7	8,0
-212	+150	3,9	3,9
-150	+75	13,7	11,8
-75		64,9	71,7

Table 8 : Particle size distribution of selected slimes dam samples

The results obtained by means of pneumatic flotation are plotted in fig. 7. High yields were achieved for ash contents between 12,5% and 15%. Again it is obvious that it is difficult to achieve ash contents below 12% in a single stage and at reasonable yields.

In a one-off test, NSR was used as a reagent and this collector performed similarly to power paraffin.

The considerably increased yield obtained by single-stage pneumatic flotation, at acceptable concentrate properties, could justify the economical recovery of the slimes dam material. It is noteworthy that all flotation test work done on Kliprivier coal, pneumatic flotation as well as laboratory flotation, gave considerably higher yields than indicated by washability tests. Different particle characteristics, relating to surface properties or densities, are likely to be responsible for this trend.

Vryheid coalfield, Natal - thickener underflow

The ultrafines of the tailings of a conventional flotation process are fed to a thickener. Flocculant is added and the thickener underflow is discarded.

For practical reasons, a sufficient amount of thickener feed could not be obtained and the underflow had to serve as test material. The possibly detrimental effect of the presence of flocculant had to be accepted. Approximately 3 tons of the material was received in drums, in a wet condition, and fed to a mixing tank as described before.

The results of laboratory single-stage and two-stage flotation tests, using power paraffin and NSR respectively as reagents, are given in table 9.

Reagent dosage/ l/t	Rougher concentrate				Cleaner concentrate			
	Paraffin*		NSR		Paraffin*		NSR	
	Mass/%	Ash/%	Mass/%	Ash/%	Mass/%	Ash/%	Mass/%	Ash/%
1,0	44,1	16,4	-	-	31,0	12,2	-	-
1,5	46,8	16,3	-	-	33,4	12,1	-	-
2,0	47,2	16,6	44,2	14,7	39,0	13,2	38,6	11,6
2,5	49,6	17,1	45,9	15,4	43,3	13,7	41,8	12,4
3,0	50,4	17,2	48,1	15,5	44,4	13,9	45,0	13,0

* Frother dosage 3g/m^3

<u>Table 9</u> : Results of standard laboratory flotation tests of the thickener underflow

During pneumatic flotation the reagent dosage, air/pulp ratio and solids concentrations were altered. The major variable was the reagent dosage and the froth height was kept constant.

The results obtained are plotted in fig. 8.

Unfortunately, the results scatter considerably. This is due to different ash contents of the feed material received as well as to segregation in the mixing tank during draining off. The ash content of the individual drums varied from 36% to 45%, while segregation caused an average standard deviation of 2% per batch, as the evaluation of individual sample increments revealed. Selected results are given in table 10.

Feed ash/ %	Concentrate ash/ %	Tailings ash/ %	Yield/ %
51,1	19,6	80,6	48,4
35,2	12,1	65,3	56,6

Table 10 : Selected results for pneumatic flotation of thickener underflow

Therefore, only a limited number of tests could be used to indicate trends.
Tests with a similar feed ash and small standard deviation were selected for this purpose.
Fig. 9 shows the influence of reagent dosage on the concentrate ash. With decreasing reagent dosage, the concentrate ash decreases more than the results of the laboratory tests indicated. It is interesting to note that, with increasing solids concentration, the reagent consumption drops considerably.

Although NSR proved to be more efficient than power paraffin during laboratory tests, no difference could be detected for pneumatic flotation, as can be seen from fig. 8.

In table 11 the screen ash analysis of the feed, concentrate and tailings are given. The results are plotted in fig. 10.

Particle size/microns		Mass/%	Feed Ash/%	Concentrate Mass/%	Ash/%	Tailings Mass/%	Ash/%
+150		21,5	18,0	32,1	14,6	5,0	52,4
-150	+75	15,4	25,2	21,2	17,5	6,4	64,8
-75	+45	7,4	43,5	6,6	21,4	8,6	69,7
-45	+20	10,9	49,1	8,0	20,3	15,4	72,5
-20		44,8	42,5	32,1	13,8	64,6	64,8

Table 11 : Screen-ash analysis of the feed , concentrate and tailings of pneumatic flotation of thickener underflow

It is obvious that pneumatic flotation is very efficient for particle sizes below 20 microns, where low concentrate ashes and high tailings ashes are produced from high feed ash contents.

However, the trend observed for the concentrate, low ashes at both ends of the size distribution and a maximum in between, is somewhat surprising and can at present be explained only by an overdosage of reagent.

Nevertheless, in spite of an unfavourable feed material in many respects, the test results indicate the superiority of pneumatic flotation when compared with standard flotation tests.

Soutpansberg coalfield

In order to determine whether pneumatic flotation can be also successfully applied to coarse coal, tests were carried out with Soutpansberg flotation feed. The size distribution is given in table 12 and the results of pneumatic flotation in table 13.

Particle size/microns	Fractional mass/%
+850	15,3
-850 +600	17,7
-600 +300	27,3
-300 +150	18,5
-150 +75	11,2
-75	10,0

<u>Table 12</u> : Particle size distribution of Soutpansberg flotation feed

Solids concentration/%	Feed ash/%	Concentrate ash/%	Tailings ash/%	Yield/%
6	22,0	13,8	62,1	83,0
12	18,6	12,9	57,0	87,1
15	21,3	12,8	50,3	77,3

<u>Table 13</u> : Results of pneumatic flotation of Soutpansberg coal

The results indicate, according to the decreasing tailings ash, a decreasing efficiency with increasing solids concentration. It must be borne in mind, however, that the flotation of South African coals becomes more inefficient with decreasing concentrate ashes. The results are similar to those achieved at the existing conventional flotation plant.
However, the mass throughput per unit area amounts to 8,8 t/m^2h at 15% solids concentration, compared with approximately 2 t/m^2h for conventional flotation.

Even at 6% solids, the throughput is 3,6 t/m^2h, which still compares favourably.
Although the metallurgical results obtainable with coarse coal seem fairly similar to those of conventional flotation in this case, capital outlay and operational costs may be in favour of pneumatic flotation.

Other results

Results for overseas coals, obtained at pilot scale as well as at full scale, (Mehrhoff, 1981; Breuer and Jungmann, 1985; Bahr, Legner, Luedke and Mehrhoff, 1987; Imhof, 1988) and on other minerals as for instance iron ore, lead-zinc, (Bahr, Imhof and Luedke, 1985), kaolin, (Jungmann and Reilard, 1988) are reported in the literature.

EVALUATION OF RESULTS

The experimental circumstances were difficult. Test work under defined conditions was hampered by the availability and handling of large quantities of representative test material. While sufficient quantities were treated, less defined conditions, especially variations of the feed composition, had to be accepted.

For these reasons it was not possible to determine the influence of the various variables, or their interaction, in a satisfactory manner.

From the test work performed, however, some trends for pneumatic flotation can be suggested:

- with decreasing particle sizes the solids concentration should be decreased
- the lower the solids concentration the higher the specific reagent consumption
- the reagent consumption is similar to that for conventional flotation at similar solids concentrations
- air/pulp ratios should be low for low concentrate ashes
- the froth height should not be less than 20 cm

While the above statements are somewhat subjective, the comparison of pneumatic flotation with laboratory flotation and full-scale flotation clearly shows the advantages of pneumatic flotation for the coals tested, viz.,

- better performance than single-stage laboratory flotation for fine material
- equal performance for the flotation of fairly coarse material
- high solids throughputs per unit area due to low retention times
- ultrafines can be successfully recovered in cases where full scale conventional flotation has failed

The results show, beyond any doubt, the potential of pneumatic flotation for the beneficiation of South African coal fines. Therefore, pneumatic flotation could well be an alternative to conventional flotation techniques.

THE FUTURE OF FINES FLOTATION

The present trend to replace flotation by gravity methods for particle sizes above, for instance , 0,3 mm is expected to continue. Extending gravity methods to even finer sizes, especially for coals high in sulphur, seems attractive as gravity methods seem to remove the inorganic portion of sulphur more effectively than flotation.

Below certain particle sizes, no alternative to flotation exists today, and possibly will not appear for the coming decade.

In order to optimize the flotation yield, not only will better reagents be necessary but also more efficient flotation techniques.

More emphasis than in the past will have to be put on automation and process control. In consequence of increased quantities of ultrafines, increased attention will have to be paid to effective dewatering methods.

The presented results show, on a pilot scale, that pneumatic flotation is a technique with great potential.

Therefore, it is necessary to prove that scale-up can be done successfully.

At this stage, no results comparing pneumatic flotation with column flotation are available.

It is interesting to note that new concepts and designs in full-scale column flotation aim at shorter and wider columns, where bubble formation and bubble/particle collision are realized

outside the column in a mixing chamber (Schubert, 1988), and attempts are made to avoid porous media for air dispersion.
Should this trend materialize, there would then no longer be any major differences between the techniques of pneumatic flotation and column flotation.

CONCLUSION

Pilot scale pneumatic flotation was applied successfully to South African coals from different coal fields.
The results obtained, especially with ultrafines, indicate a superiority of pneumatic flotation compared with conventional flotation. It follows that this technique has the potential to complement or to replace conventional flotation.
Obviously, the promising results obtained would have to be proved by full-scale plant operation.
Therefore ISCOR decided to erect a full-scale plant at Durnacol mine capable of treating 10 tons per hour of the settling tower overflow which is discarded at present.

As this production plant is also regarded as a test plant, its performance will certainly influence the future of this process in South Africa.

ACKNOWLEDGEMENT

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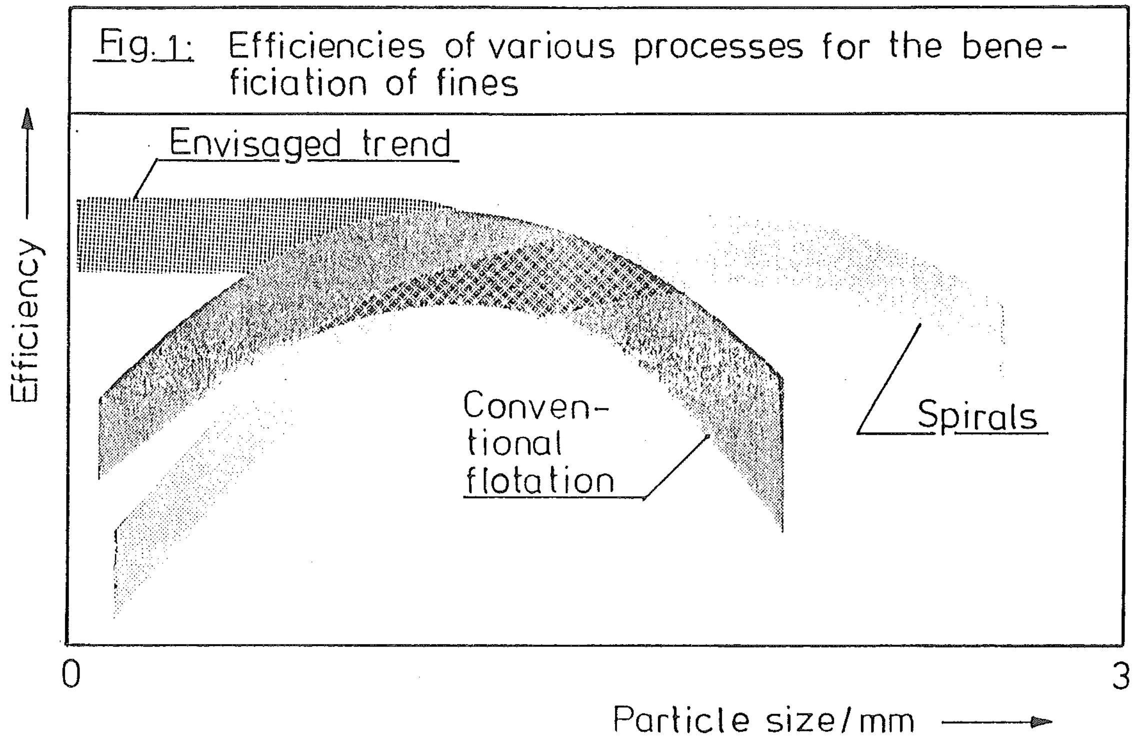
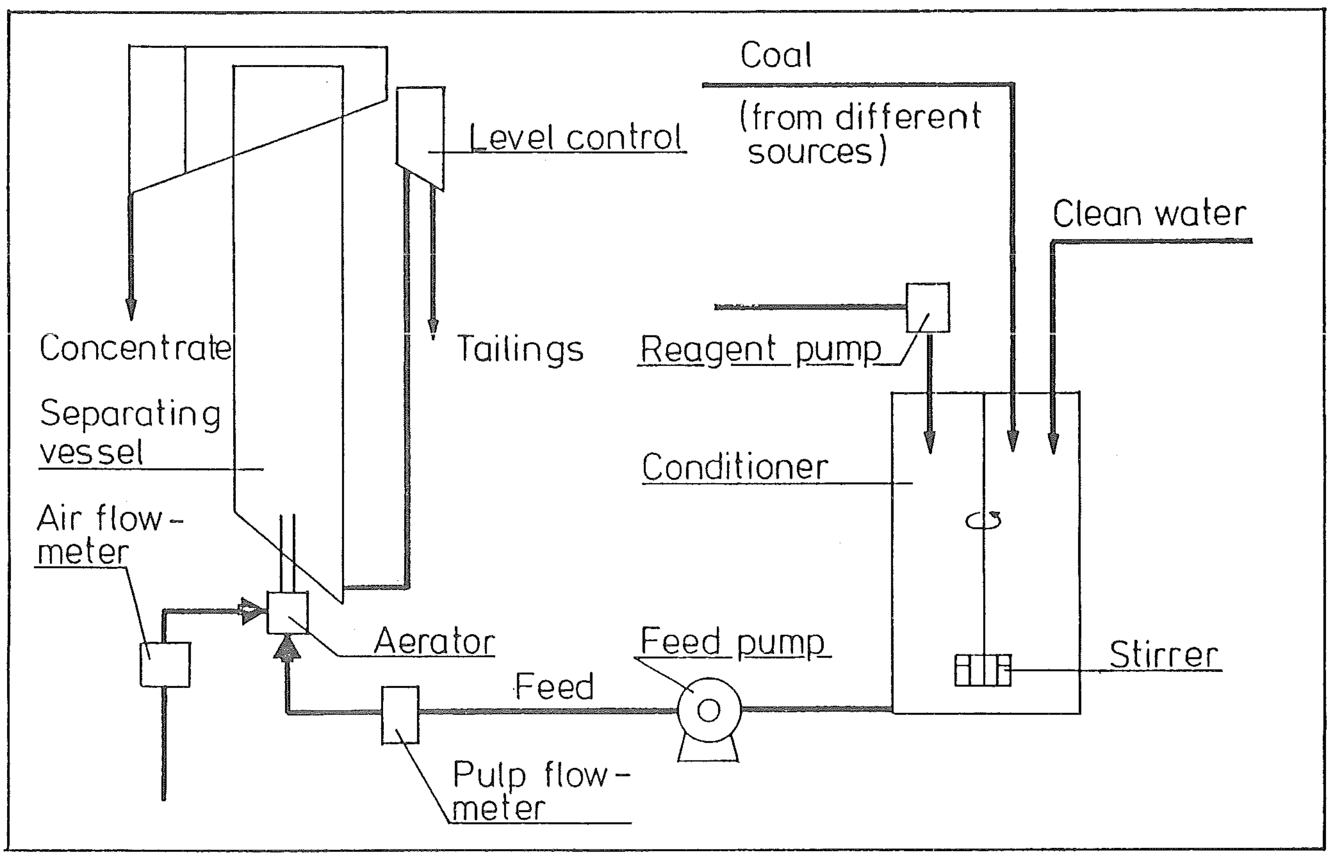


Fig. 2: Test set up of pneumatic pilot scale flotation



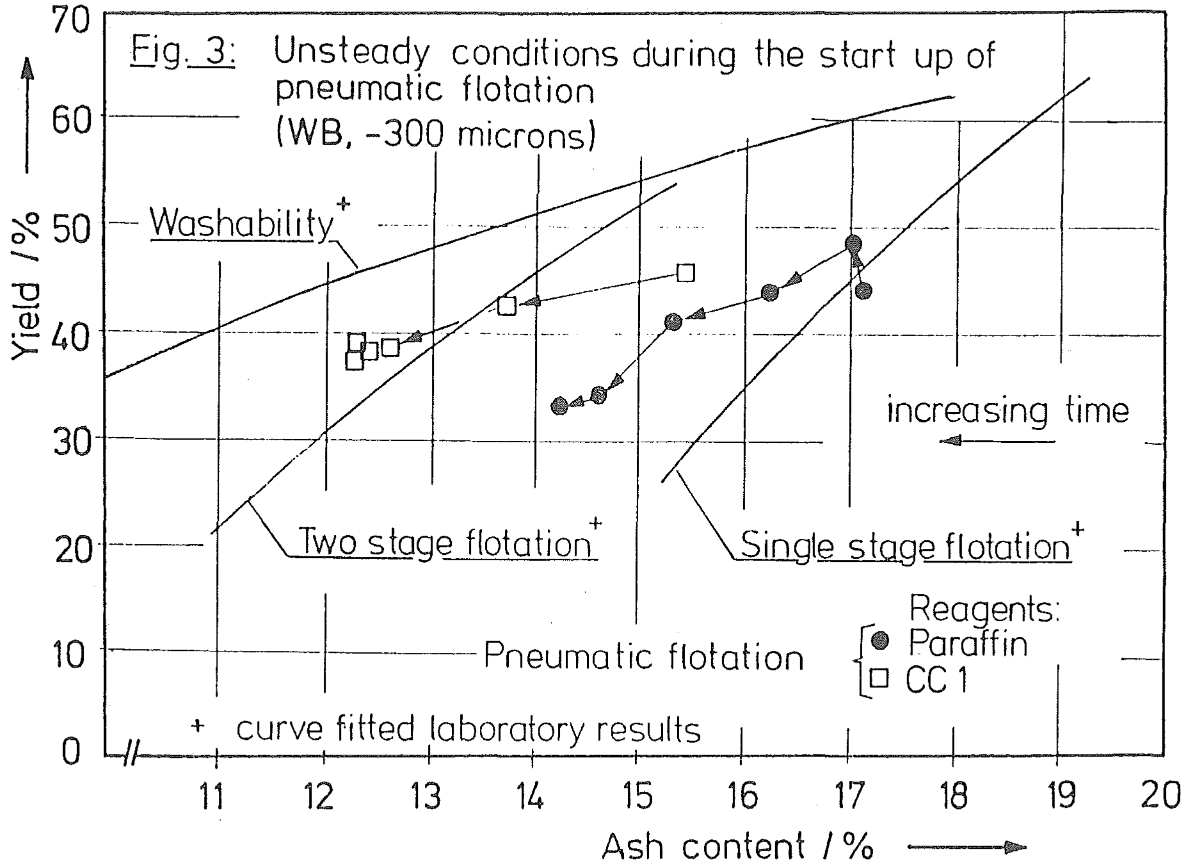


Fig. 3: Unsteady conditions during the start up of pneumatic flotation (WB, -300 microns)
Washability+
Two stage flotation+
Single stage flotation+
increasing time
Pneumatic flotation
Reagents:
Paraffin
CC 1
+ curve fitted laboratory results
Yield / %
Ash content / %
0
10
20
30
40
50
60
70
11
12
13
14
15
16
17
18
19
20

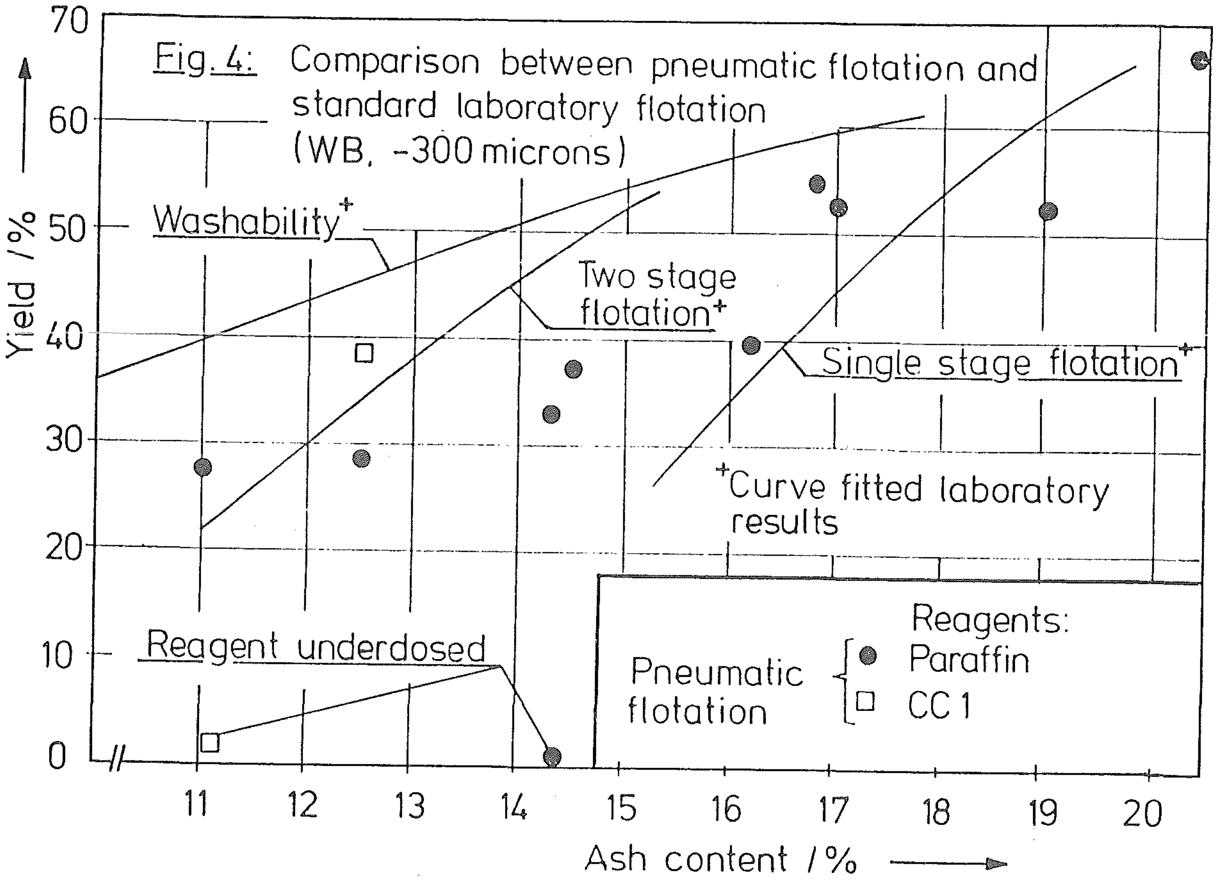
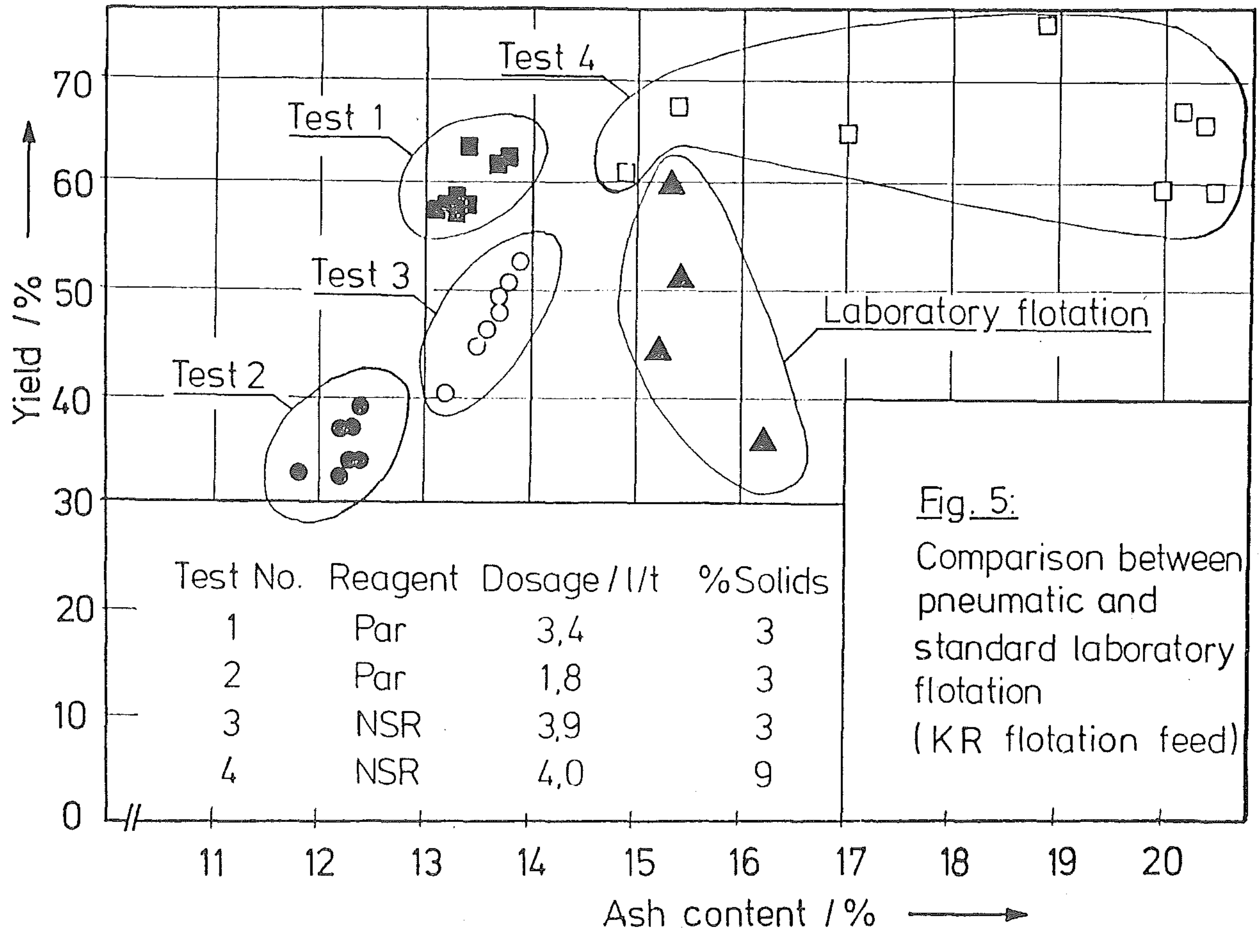


Fig. 4: Comparison between pneumatic flotation and standard laboratory flotation (WB, -300 microns)
Washability+
Two stage flotation+
Single stage flotation+
+Curve fitted laboratory results
Reagent underdosed
Pneumatic flotation
Reagents:
Paraffin
CC 1
Yield / %
Ash content / %
0
10
20
30
40
50
60
70
11
12
13
14
15
16
17
18
19
20



Test No.	Reagent	Dosage / l/t	% Solids
1	Par	3,4	3
2	Par	1,8	3
3	NSR	3,9	3
4	NSR	4,0	9

Fig. 5: Comparison between pneumatic and standard laboratory flotation (KR flotation feed)

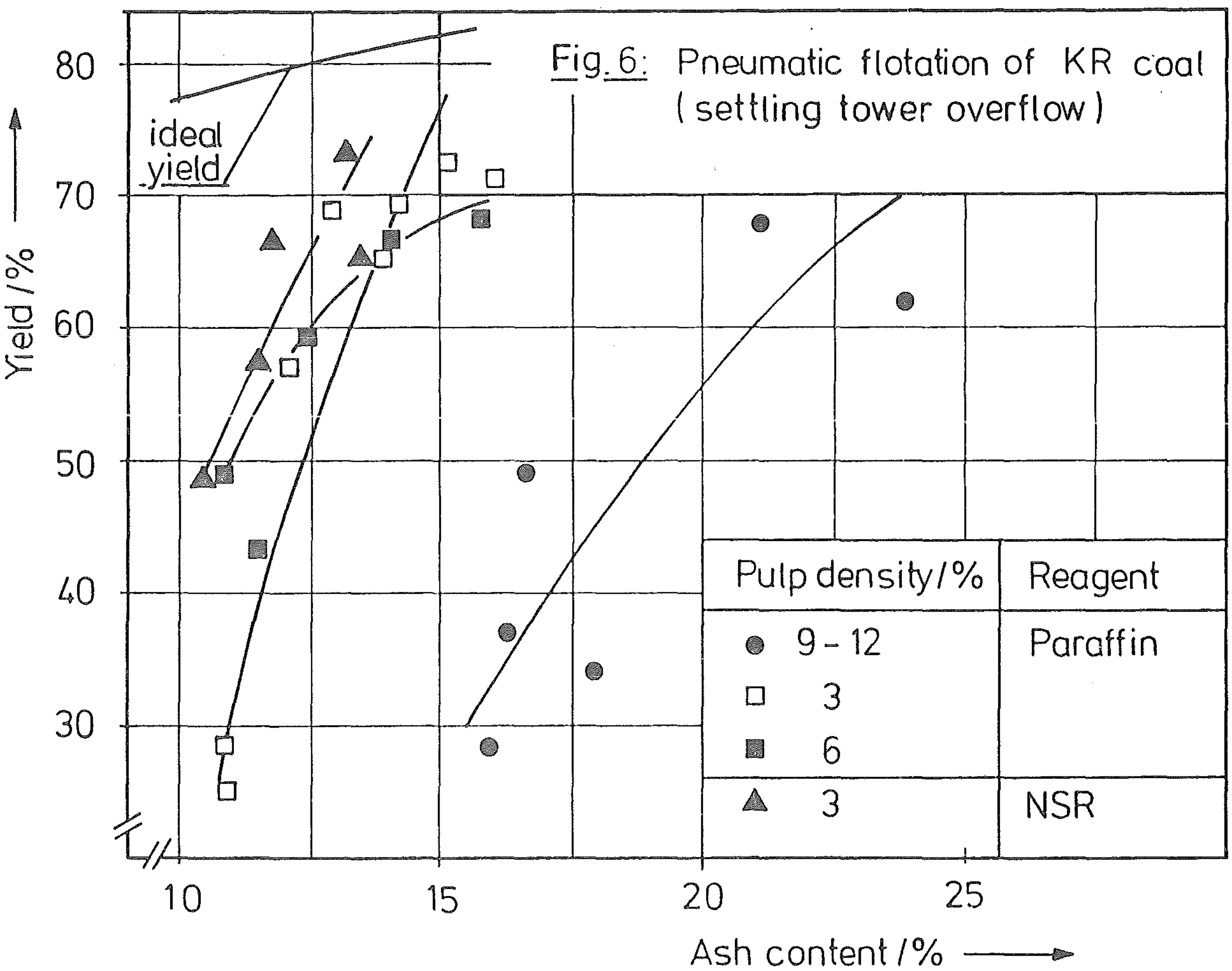


Fig. 6: Pneumatic flotation of KR coal (settling tower overflow)

Pulp density / %	Reagent
● 9 - 12	Paraffin
□ 3	
■ 6	
▲ 3	NSR

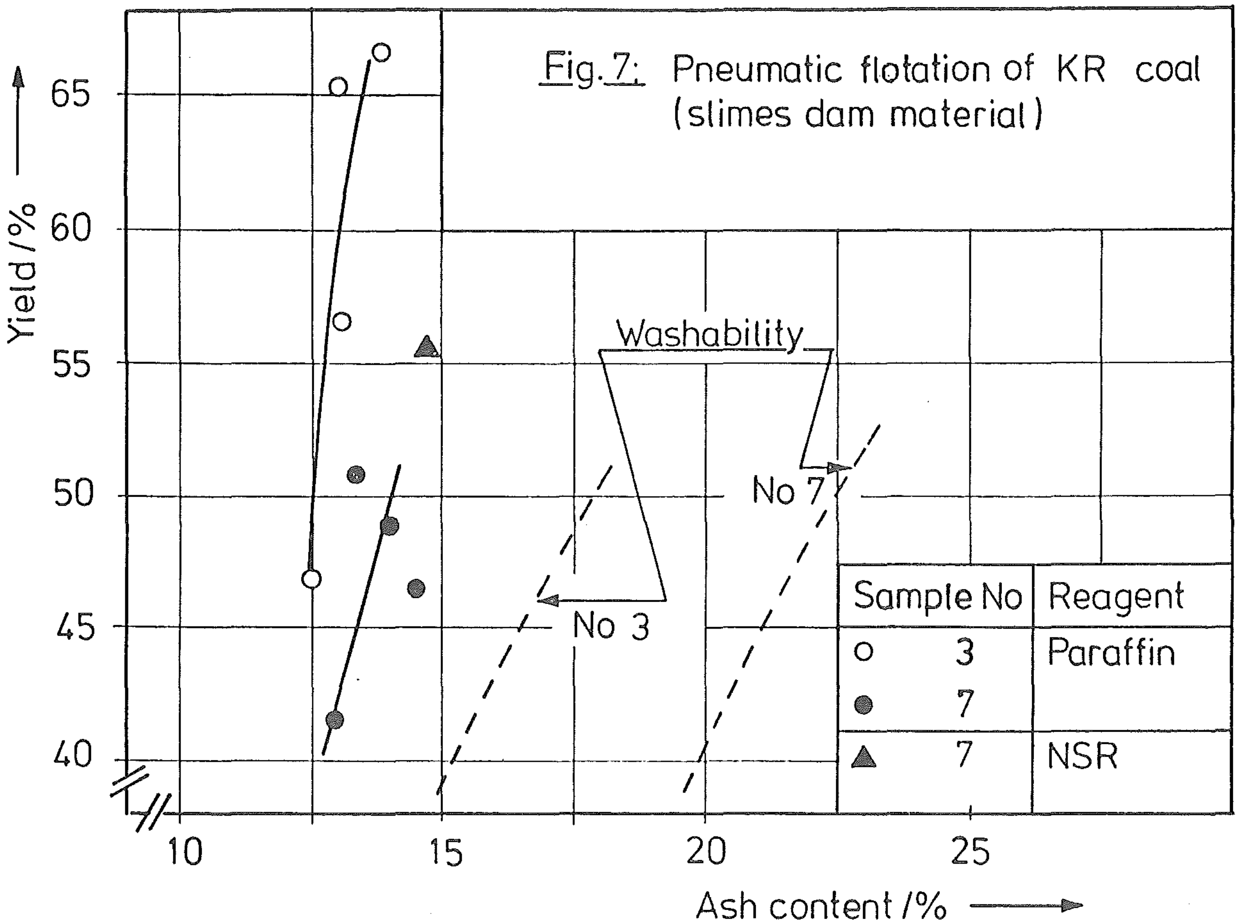


Fig. 7: Pneumatic flotation of KR coal
(slimes dam material)
Yield /%
65
60
55
50
45
40
10
15
20
25
Ash content /%
Washability
No 7
No 3
Sample No
Reagent
3
Paraffin
7
7
NSR

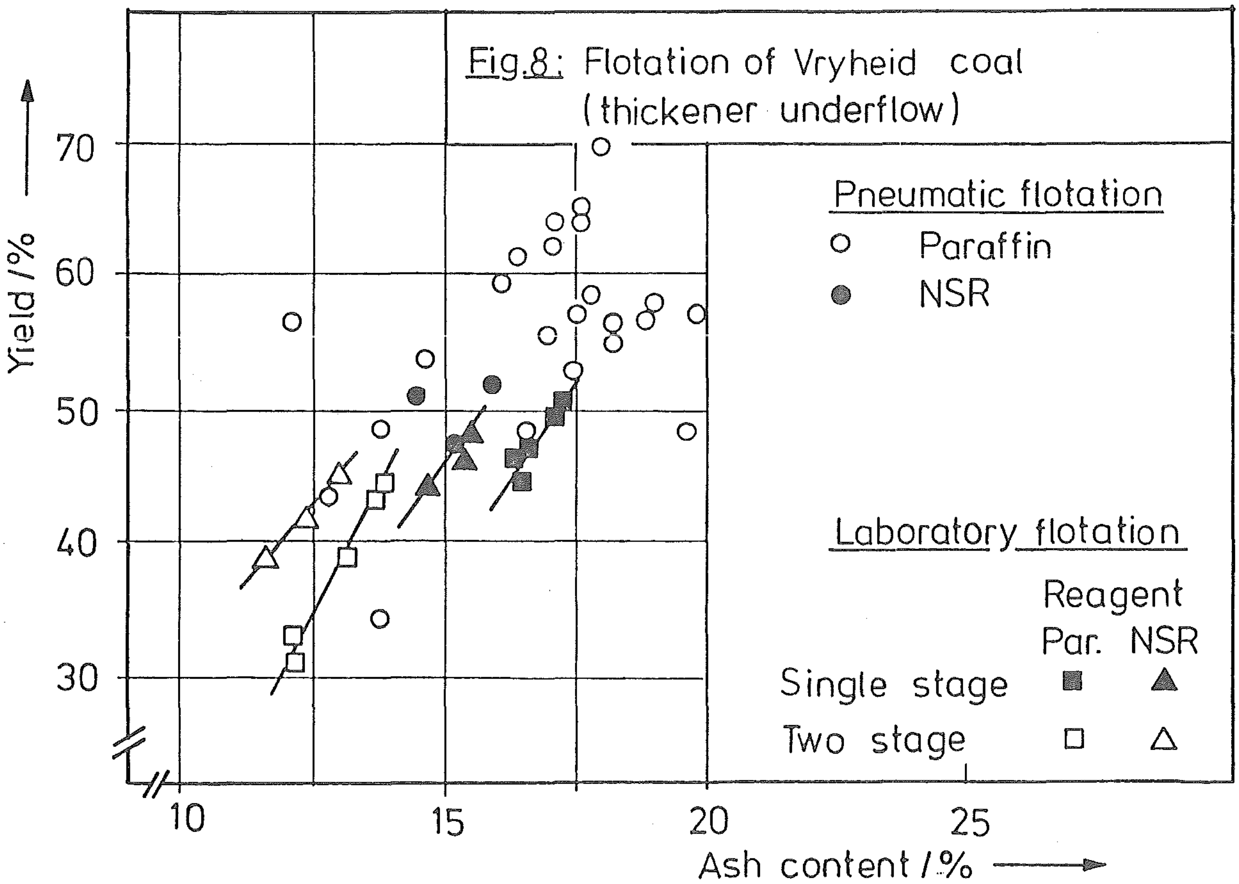


Fig. 8: Flotation of Vryheid coal
(thickener underflow)
Yield /%
70
60
50
40
30
10
15
20
25
Ash content /%
Pneumatic flotation
Paraffin
NSR
Laboratory flotation
Reagent
Par.
NSR
Single stage
Two stage

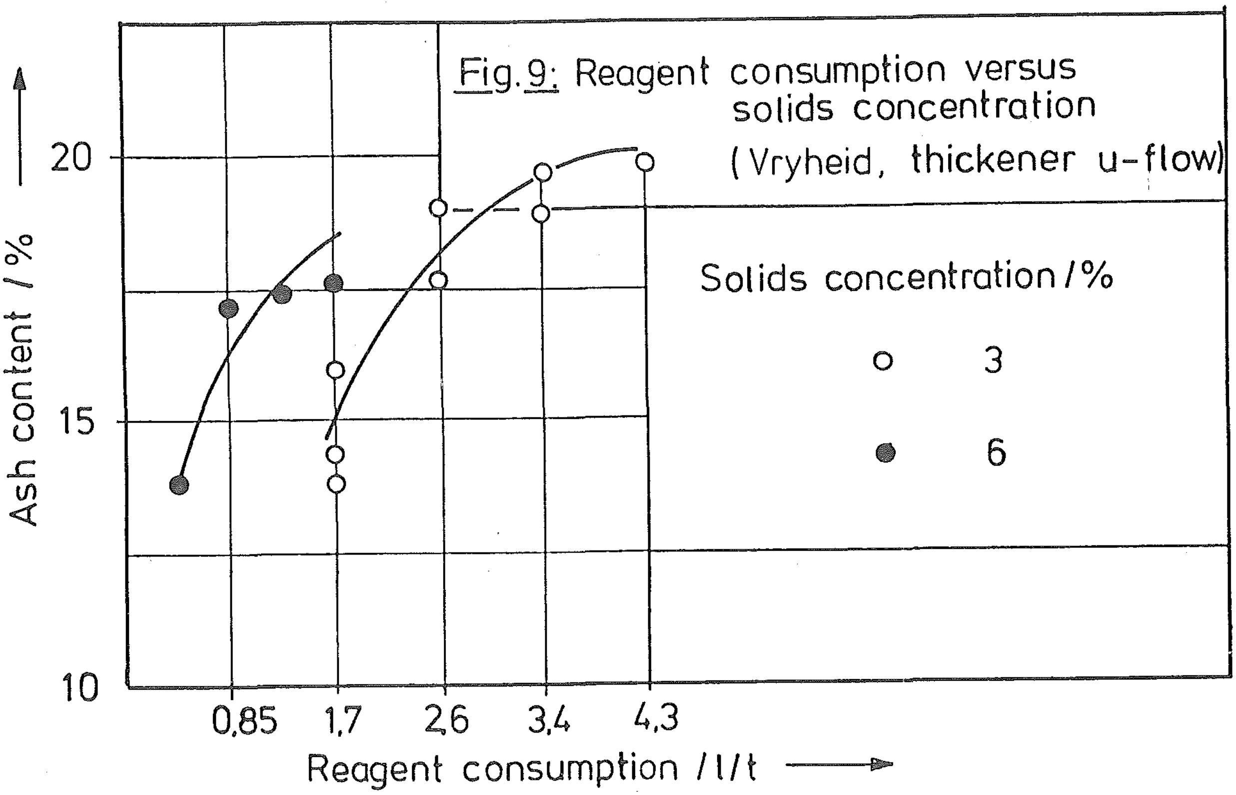


Fig. 9: Reagent consumption versus solids concentration
(Vryheid, thickener u-flow)
Solids concentration / %
3
6
Ash content / %
20
15
10
0,85
1,7
2,6
3,4
4,3
Reagent consumption / l/t

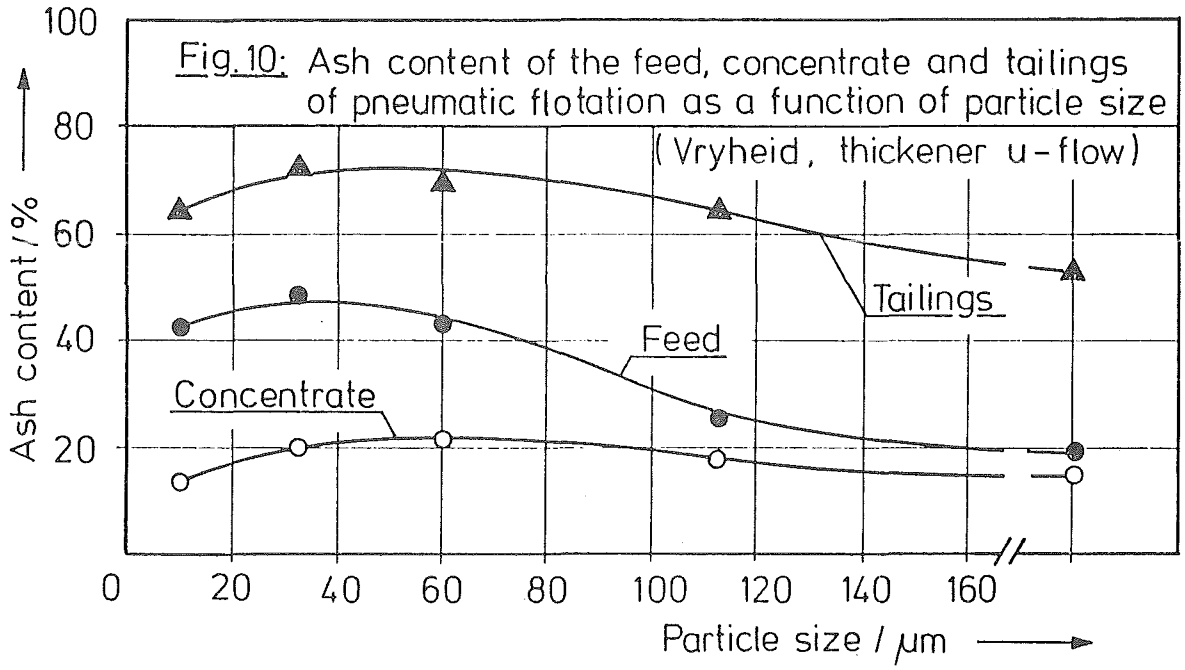


Fig. 10: Ash content of the feed, concentrate and tailings of pneumatic flotation as a function of particle size
(Vryheid, thickener u-flow)
Tailings
Feed
Concentrate
Ash content / %
100
80
60
40
20
0
20
40
60
80
100
120
140
160
Particle size / µm