

May 27, 1969

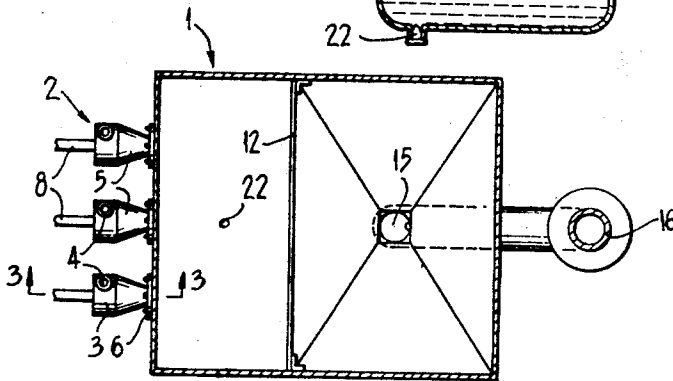
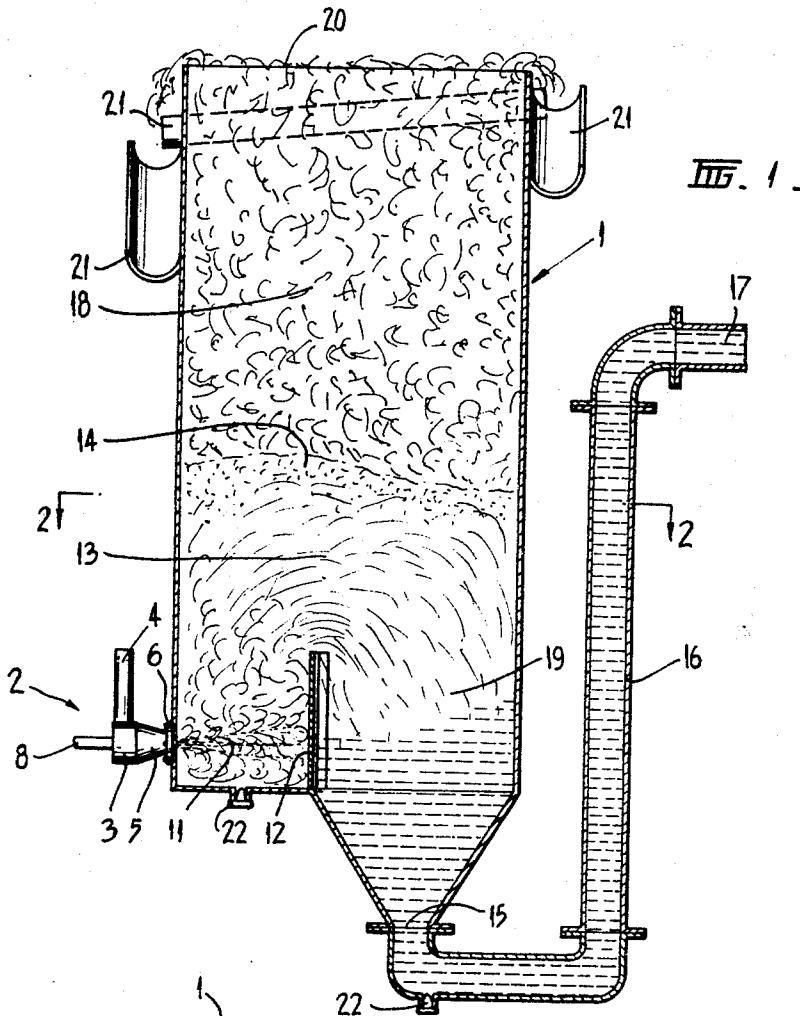
W. J. N. DAVIS

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METHOD AND APPARATUS FOR FROTH FLOTATION

Filed April 25, 1966

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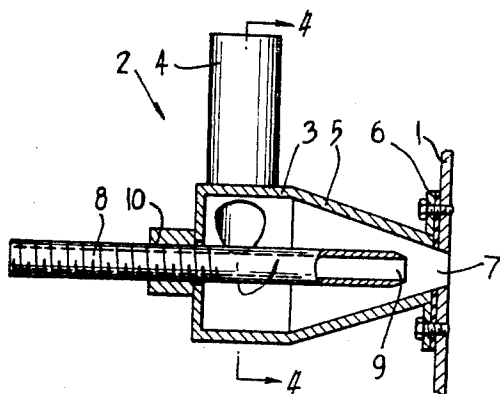


FIG. 3.

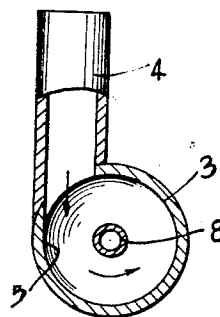


FIG. 4.

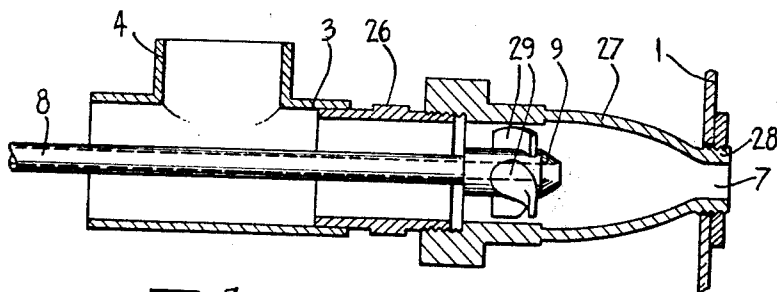


FIG. 5.

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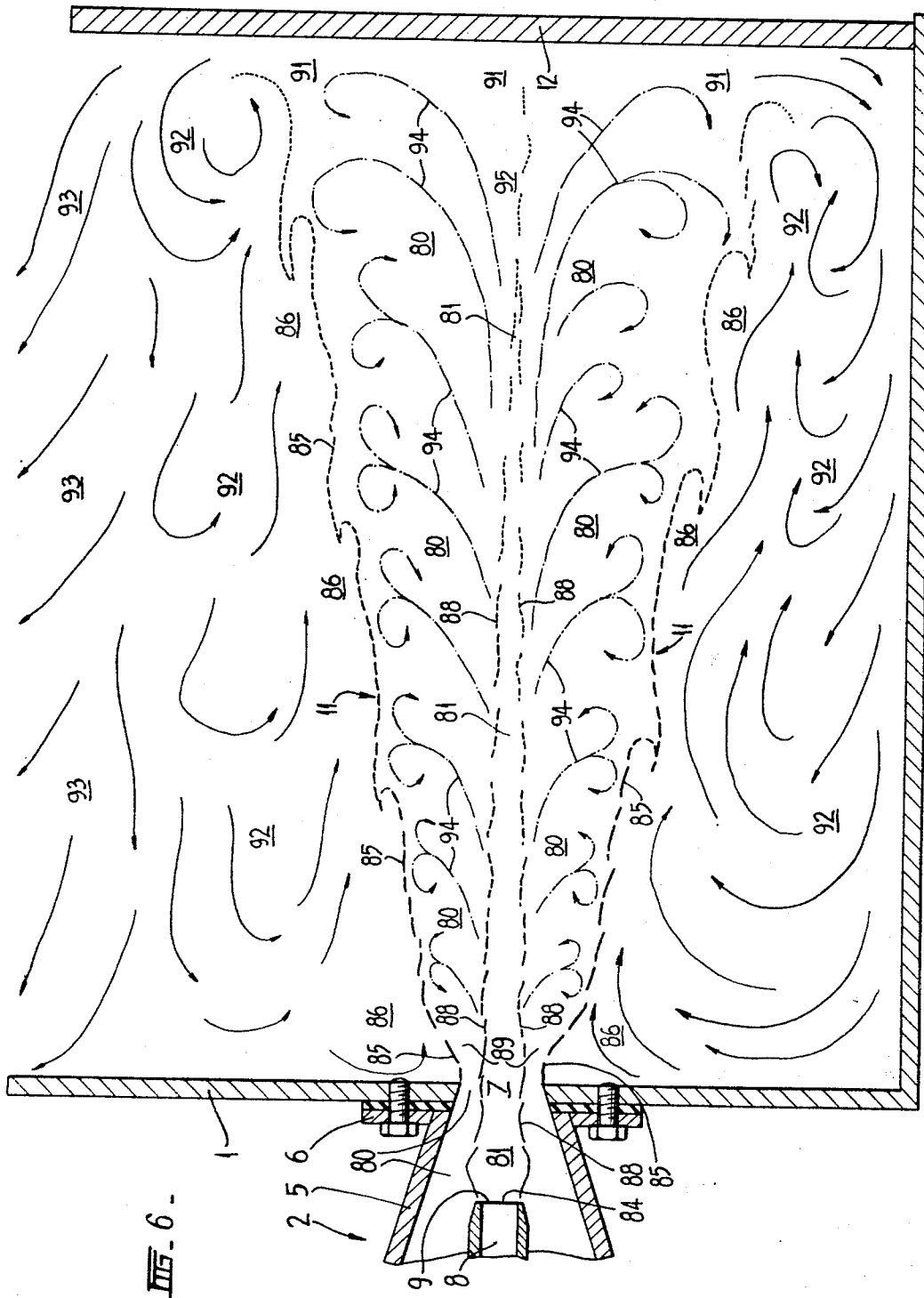
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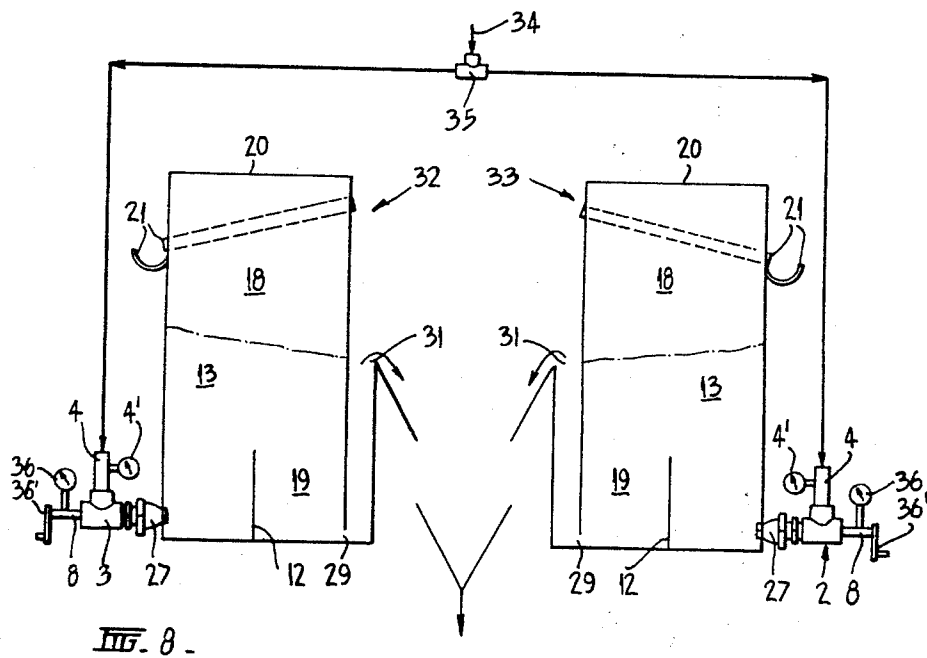
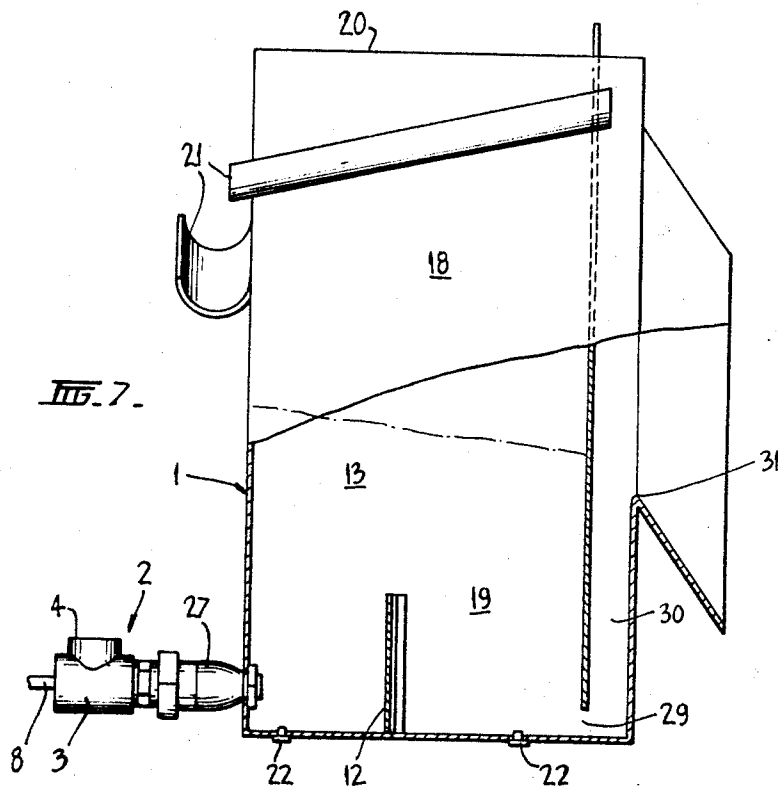
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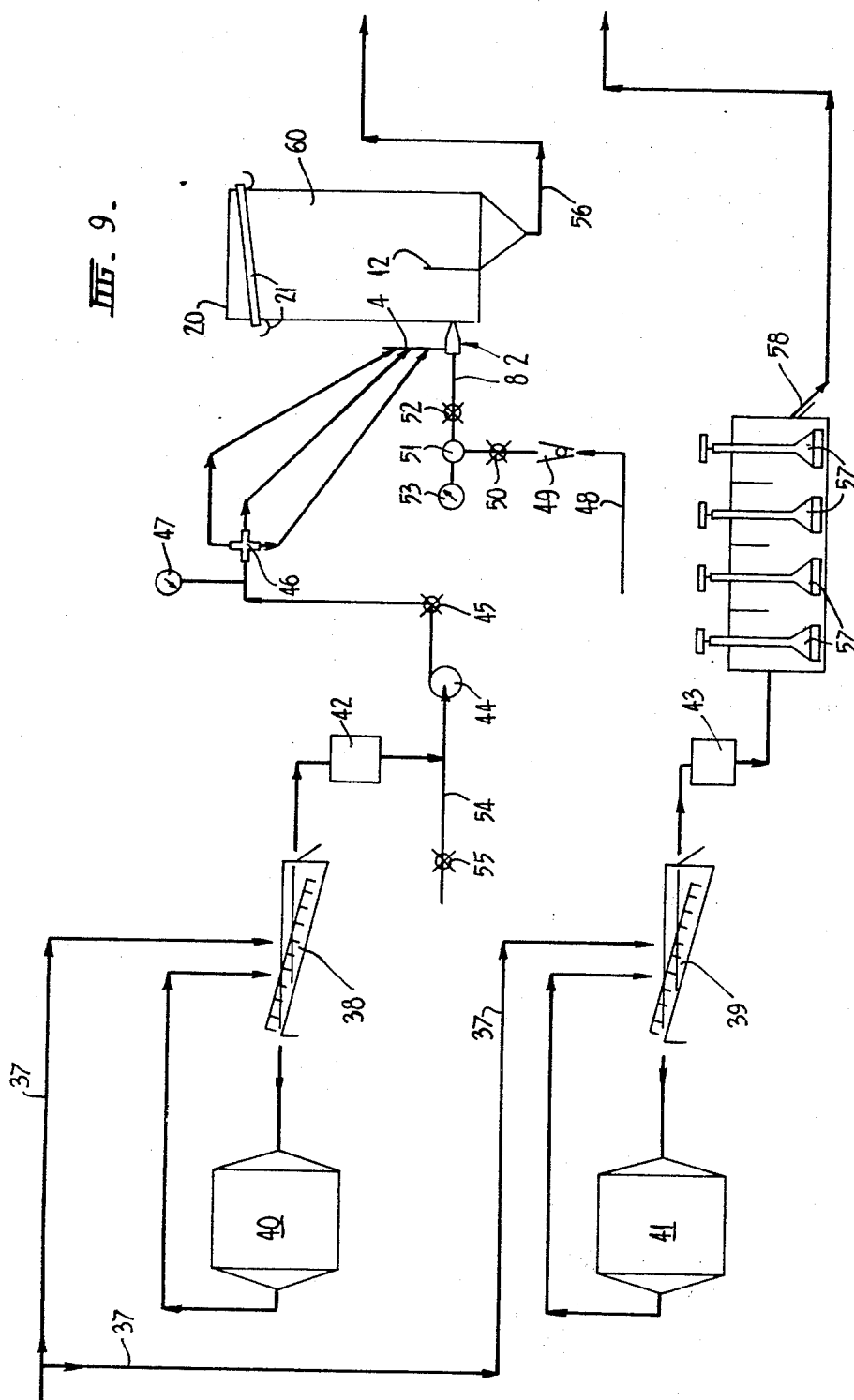
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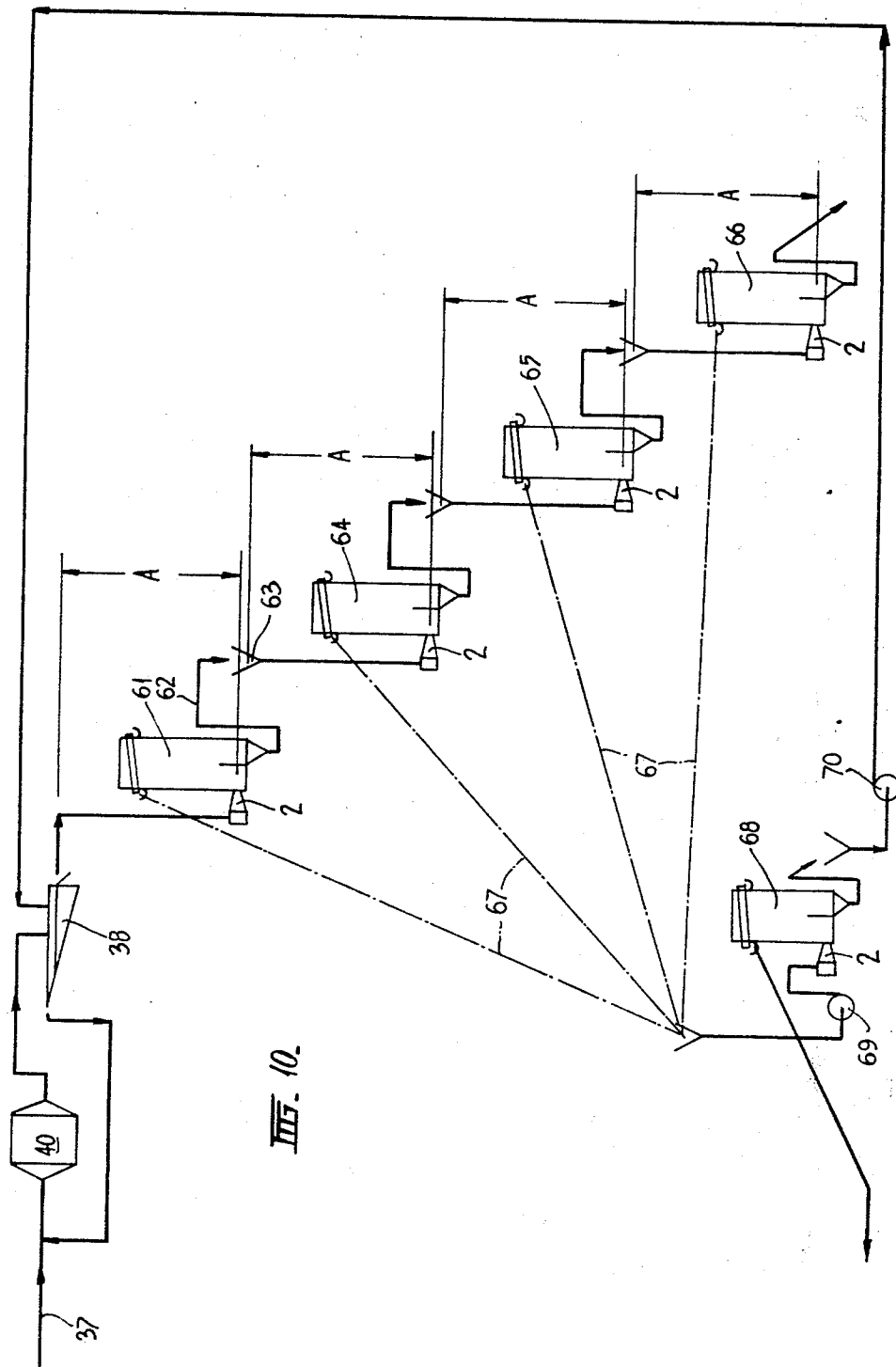
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METHOD AND APPARATUS FOR FROTH FLOTATION

William John Nankivell Davis, Broken Hill South, New South Wales, Australia, assignor to The Zinc Corporation Limited, Melbourne, Victoria, Australia
Filed Apr. 25, 1966, Ser. No. 544,876
Int. Cl. B03d 1/02, 1/22

U.S. Cl. 209—164

11 Claims

ABSTRACT OF THE DISCLOSURE

A froth flotation procedure which comprises injecting into a body of pulp in a flotation vessel a pulp-air jet consisting of a jet of pulp under pressure and a jet of air under pressure, the pulp jet and air jet being in contact as they enter the pulp body, forming air bubbles at the interface between the pulp jet and the air jet, dispersing the air bubbles through the pulp jet to form a pulp-air mixture, and forming bubble-particle aggregates within the pulp-air mixture.

This invention relates to an improved method and apparatus for froth flotation, particularly for the recovery of minerals from ores.

Froth flotation is the principal technique in use today for the separation and concentration of specific minerals from ores.

In this specification, the efficiency of the froth flotation process is defined by the following two criteria:

The "Recovery (the quantity criterion) which is the weight of desired mineral or particular element recovered from the process expressed as a percentage of the total weight of desired mineral or particular element in the original pulp fed to the process.

The "Concentrate Grade" (the quality criterion) which is the weight of desired mineral or particular element recovered in the froth expressed as a percentage of the total weight of solids recovered in the froth.

The process is now normally carried out in mechanical flotation machines, the general form of which is a tank, containing an impeller, through which the pulp flows. The impeller maintains the solids in suspension in the pulp, induces air into the pulp and causes the air to be broken up into bubbles and dispersed throughout the pulp to make the necessary contacts with the mineral particles. The froth which is formed on the surface of the pulp flows over the side of the tank into launders and is removed.

Providing the desired mineral particles are capable of being separated from the undesired mineral particles by the flotation process, two types of effects determine the magnitude of the recovery of desired mineral in a given time. One type of effect is due to the chemicals added or already present in the pulp. The other type of effect, which is of principal concern in this invention, is due to the flotation machine and, in particular, to the method of dispersing and mixing air throughout the pulp.

The recovery of the desired mineral by a single mechanical machine decreases as the flow rate of pulp through the machine increases. Generally the pulp must be retreated many times to achieve the maximum recovery of desired mineral. For example, at The Zinc Corporation, Limited's mine at Broken Hill, New South Wales, it is possible to recover at least 97% of the desired lead sulphide mineral, galena, from the ore by the froth flotation process. Ideally, each of The Zinc Corporation, Limited, mechanical flotation machines should recover approximately 20% of the desired mineral in

the feed to the machine when fed at a pulp flowrate of 100 tons per hour. The number of retreatment stages required to recover 97% of the desired mineral is considerable, as is illustrated below:

The first machine recovers 20% leaving 80% to pass to the next machine. This second machine recovers 20% of the desired mineral fed to it, but this is only 20% of 80%, or 16% of the original feed content. Thus, two machines recover 36%, leaving 64% to pass to the third machine which recovers 20% of this, or 12.8% of the desired mineral of the original feed. Thus, three machines recover 48.8% of the desired mineral in the original feed. If this calculation is continued it would be found that nine retreatments are required to recover approximately 89% of the valuable mineral in the original feed and at least another ten retreatments would be required to recover a further 8% to yield a total recovery of 97%. Thus, ideally, a total of 19 flotation machines should be required to recover 97% of the desired mineral. If, for the same feed rate of 100 tons of pulp per hour, the performance of the air dispersion and air-pulp mixing device of the individual flotation machine used in the above example could be improved so that at least 73% of the desired mineral is recovered from the feed (instead of 20%), only three machines would be required to recover slightly more than 97% compared with 19 machines before. The use of a substantially smaller number of machines results in the following advantages:

(1) Providing the electric power requirement per machine is unchanged, substantially less power per ton of pulp treated is required.

(2) Capital cost per ton of pulp treated is lower because of the fewer number of machines and the smaller floor area or building space required.

(3) Maintenance cost per ton of pulp treated is lower because of the fewer number of machines.

(4) The grade of the froth concentrate from a machine is largely dependent on the desired mineral content (as a proportion) in the feed to that machine. With the large number of machines normally required at present, the grade of the froth concentrate progressively decreases as the amount of desired mineral in the pulp is depleted. Often the grade of concentrate from the final machine is less than the grade of the original feed to the first machine. As a result, other machines must be used to retreat the low-grade concentrates to make a useful product. Often this low-grade concentrate is recirculated and mixed with the original feed and retreated in this manner rather than in separate machines. Sufficient machine capacity must be provided for this purpose. With a small number of machines the last one operates on a higher-grade feed and produces a higher-grade concentrate. As a result, fewer retreatment machines to improve the concentrate quality are required. Alternatively, the need to circulate this low-grade concentrate and to mix it with the new feed may be obviated.

(5) With a large number of machines, the amount by weight of mineral recovered in the final stages is very low and produces unstable froths. Such froths tend to collapse and drop their mineral load back into the pulp. As a result, machine recovery is often very much lower than the ideal and still more machines are required. In the example above, ideally 19 machines each recovering 20%, would recover a total of 97% of desired mineral. At The Zinc Corporation, Limited mine, 28 machines are actually required due to the drop-off in machine recovery in the latter stages. Furthermore, a significant concentrate upgrading mechanism normally occurs in froths. If a froth took a considerable time to overflow the walls of the machine, unwanted mineral would have time to drain back into the pulp. This results in upgrading of the desired mineral concentrate. This effect cannot be achieved

in the present final stage machines where the froths are unstable and collapse due to the low mineral content. With a small number of high-recovery machines, froth mineral concentrations, and therefore froth stability, are substantially higher. The decrease in recoveries and concentrate grades obtained with conventional machines do not occur to the same extent.

(6) The problem of plant control is simpler with a smaller number of machines.

This invention involves the injection of pulp and air into a body of pulp in a tank or vessel by means of a pulp-air injecting device, whereby more efficient air dispersion, pulp-air mixing and particle-bubble contacts are achieved in the apparatus.

In one form, the invention involves the injection of jets of pulp and air under pressure into a body of pulp in a tank or vessel to form optimum size air bubbles and to mix intensely the pulp and air in the issuing jet. This intense mixing distributes the air bubbles throughout the jet and promotes contact between such bubbles and mineral particles. The pulp-air jet is de-energised, allowing bubble-particle aggregates to rise to the surface of the body of pulp to form a froth.

The interaction of the air and pulp within the pulp-air jets, according to this invention, produces such air dispersion and such mixing of air bubbles and pulp that an extremely high metallurgical efficiency is achieved, substantially independently of the residence time of the pulp in the tank.

The apparatus of this invention operates without any moving parts and with a low power requirement per ton of pulp treated. As a result, considerably fewer machines employing injecting devices of the type described by this invention are required to achieve a maximum recovery of desired mineral compared with present and past practices, thus permitting the advantage explained above to be substantially achieved.

Other details of the invention will become apparent from the following description of the preferred forms of the invention shown in the accompanying drawings, in which:

FIGURE 1 is a sectional elevation of flotation apparatus constructed according to the invention.

FIGURE 2 is a plan view taken on line 2—2 of FIGURE 1.

FIGURE 3 is a sectional elevation of one of the pulp-air injecting devices shown in FIGURE 2, taken on the line 3—3 of FIGURE 2.

FIGURE 4 is a view in sectional elevation taken on the line 4—4 of FIGURE 3.

FIGURE 5 is a sectional elevation of an alternative form of pulp-air injecting device.

FIGURE 6 is a diagrammatic representation of the pulp-air jet, based on photographic evidence.

FIGURE 7 is a sectional elevation of another form of a flotation apparatus incorporating the pulp-air injecting device shown in FIGURE 5.

FIGURE 8 is a diagrammatic view of an arrangement for carrying out comparative tests of two sets of flotation apparatus constructed in accordance with FIGURE 7.

FIGURE 9 is a diagrammatic view of an arrangement for carrying out comparative tests of flotation apparatus constructed according to the invention and of conventional flotation machines employing mechanical devices or impellers to obtain air dispersion and pulp-air mixing, the said tests being described below in Examples 1, 2, 3 and 4.

FIGURE 10 is a view of a modified arrangement in which the pulp pressure is obtained by elevation of one flotation stage relative to the next, as described below in Example 5.

In the drawings, the same reference numerals are used to indicate like or corresponding parts or features.

The flotation apparatus shown in FIGURES 1 and 2 is provided with a tank 1 and with a series of pulp-air

injection devices 2 mounted in horizontal alignment near the lower end of the tank 1, three only of the injection devices 2 being shown in FIGURES 1 and 2. The said flotation apparatus is described in more detail hereunder.

Referring to FIGURES 3 and 4, each pulp-air injection device 2 comprises a cylindrical body 3, a pulp connection 4 entering the cylindrical body 3 tangentially, a convergent nozzle 5 secured to or formed integrally with the forward end of the cylindrical body 3, an orifice 7 at the forward end of the nozzle 5 which is in register with an aperture in tank 1, a flange 6 on the forward end of the nozzle 5 which is bolted to the tank 1, and an air pipe or connection 8 mounted axially in the body 3 with its forward end 9 extending towards the forward end of the nozzle 5 to just behind the orifice 7.

The pulp connections 4 are connected to a source of pulp under pressure which is to be subjected to flotation treatment and air connections 8 are connected to a source of air under pressure. Each air connection 8 is screwed within an internally-threaded boss 10 on the rear end of the body 3, so that by rotating the connection 8 the position of its forward end 9 relative to the orifice 7 can be adjusted.

Pulp under pressure passes into the connection 4 of each injection device 2 and enters the cylindrical body 3 tangentially to the walls which causes the pulp to swirl around the walls of the nozzle 5 before issuing in the form of a pulp annulus through the orifice 7 of the said nozzle into the body of pulp in the tank 1. Air under pressure is passed into the connection 8 and issues from the forward end 9 of said connection 8 just behind the orifice 7 of the nozzle 5, and then is injected in the form of an air core into the body of pulp in the tank 1.

An alternative form of the injection device is shown in FIGURE 5. This device comprises a cylindrical body 3, a pulp connection 4 entering the cylindrical body 3 radially, a sleeve 26 connected to the forward end of the body 3, a convergent nozzle 27 containing an orifice 7 and screwed to the threaded forward end of the sleeve 26, the forward end 28 of the nozzle 27 being arranged to pass through an aperture in the tank 1 and being secured in position therein, an air pipe or connection 8 mounted axially in the body 3, and a series of swirl-inducing vanes 29 mounted on the forward end 9 of the air connection 8.

The pulp connection 4 is connected to a source of pulp under pressure which is to be subjected to flotation treatment and the air connection 8 is connected to a source of air under pressure.

Pulp under pressure passes into the connection 4 of the injection device, enters the cylindrical body 3 radially and is forced between the swirl-inducing vanes 29 which cause the pulp to swirl around the walls of the nozzle 27 before issuing as a pulp annulus through the orifice 7 of said nozzle into the body of pulp in the tank 1. Air under pressure is passed into the connection 8 and issues from the forward end 9 of said connection 8.

Reference will now be made to FIGURE 6. The injecting device 2 may be of the type shown in FIGURES 3 and 4 or of the type shown in FIGURE 5. Air issues from the forward end 9 of connection 8 of the injecting device 2 and is maintained as a central core 81 as it is injected into the body of pulp in tank 1 due to the particular flow conditions of the surrounding, swirling annulus of pulp 80. Substantially no mixing of pulp and air occurs within the injecting devices 2, the air core 81 being maintained through the orifice and as the pulp-air jet enters the pulp body in tank 1.

Due to the frictional forces acting at the interface 88 between the swirling pulp annulus 80 and the air core 81, the air core 81 is also caused to rotate which assists in maintaining the air core 81 in a substantially co-axial position.

The swirling pulp annulus 80 has a fluid flow condition which causes the formation of a region 84 along the axis of the swirl near the forward end 9 of connection 8 in

which the static pressure is substantially below that of the surrounding, swirling pulp annulus 80. As a result, the air pressure required at connection 8 is substantially below the pulp pressure required at connection 4 under normal operating conditions.

As an example, an injecting device 2 substantially similar to that shown in FIGURES 3 and 4 with a one-inch diameter orifice 7, a cylindrical body 3 having an internal diameter of 3 inches and length of 2 inches, a nozzle section 5 of length 3 inches, an air connection 8 of internal diameter of 1/2 inch and extending to 3/4 inch from the orifice 7 and a pulp connection 4 with an internal diameter of 1 3/4 inches, required a pulp pressure of 13.5 pounds per square inch gauge at connection 4 to pass 5.25 cubic feet per minute of pulp comprising 49.4% by weight of ground lead-zinc mineral ore of average specific gravity of 3.7 and 50.6% by weight of water through the device. The air pressure required at connection 8 to pass 5.4 standard cubic feet per minute of air through the device was only 4.0 pounds per square inch gauge. Without swirl in the pulp, the air pressure required for the same pulp and air flow conditions stated above would be of substantially similar magnitude to the pulp pressure at connection 4.

Referring in particular to FIGURES 1 and 6, the pulp-air jet 11 issues from the orifice 7 of the pulp-air injection device 2 into the tank 1 containing a body of pulp. Upon leaving the orifice 7, the jet 11 consists of the swirling pulp annulus 80 around the internal air core 81 which is also swirling. Immediately the outer surface of the pulp annulus 80 contacts the body of pulp in tank 1, frictional forces occurring at this pulp annulus—pulp body interface 85 cause pulp 86 already in tank 1 in the immediate vicinity of the pulp-air jet to be accelerated with and entrained by the jet and become part of the jet. This loss of energy at the outer surface of the pulp annulus 80 due to the frictional interaction with the main body of pulp tends to decrease the swirl and forward velocity of the pulp annulus 80. As the pulp-air jet penetrates further into the body of the pulp in the tank 1, more pulp 86 in the vicinity of the jet becomes entrained in the pulp annulus 80 so that the external circumference of the pulp annulus 80 increases. The resulting increase in external area of the pulp annulus 80 causes the entrainment of pulp 86 from the main body at an increasing rate and also causes retardation of the pulp annulus 80 at an increasing rate.

Due to the high viscosity of pulp compared with air, the retardation of the swirling pulp annulus 80 occurs from the interface 85 between pulp annulus 80 and main body of pulp to the interface 88 between the pulp annulus 80 and the air core 81. At the interface 88 frictional forces cause the shearing of air from the air core 81 resulting in the formation of air bubbles in the inner region of the pulp annulus 80. This effect first becomes visible in the region 89, a short distance from the orifice 7, and is more pronounced as the jet moves away from said orifice towards the baffle 12. As shown in FIG. 6 this shearing away of air from the air core is progressive and hence the air core progressively converges. The velocity of the air core 81 is not retarded to the same degree as that of the pulp annulus 80 due to the low viscosity of air, so that a relatively high difference in velocities of the air core 81 and pulp annulus 80 is maintained over a substantial length of the pulp-air jet, which enhances the formation of air bubbles.

As the pulp-air jet penetrates further into the main body of pulp in tank 1, air bubbles continue to form at the pulp-air interface 88 and the bubbles formed disperse outwardly from the interface 88 through the pulp annulus 80 as indicated generally by the flow lines 94, and form a pulp-air bubble mixture within the pulp annulus 80. The air bubbles so formed and dispersed remain substantially within the pulp-air jet. As the air bubbles form and disperse within the pulp-air jet, they repeatedly collide with

mineral particles. The majority of collisions with hydrophobic mineral particles result in the formation of mineral particle-bubble aggregates, which are substantially retained within the pulp-air jet. The swirling of the air core 81 and of the pulp annulus 80 promote stability of the jet as a whole so that the dispersion, mixing and collision mechanism described above is maintained until the air core 81 is completely dispersed.

Substantially all of the pulp to be treated by the flotation process in tank 1 is injection into tank 1 through the injection devices 2 and is therefore subjected to the above described air dispersion, pulp-air bubble mixing and particle-bubble collision process which has been found to produce a very efficient air bubble size range and optimum conditions for mineral particle-bubble contacts to occur. The combination of these features results in a flotation process with a very high metallurgical efficiency.

When the air core is substantially dispersed as in the region 95 the pulp-air jet usually still possesses sufficient velocity to keep most of the air bubble-mineral particle aggregates in suspension. It is therefore desirable to further de-energise the pulp-air jet to allow these aggregates to separate from this pulp stream to form a froth before the pulp leaves the tank 1. Moreover, some particles may fail to adhere to air bubbles due to the turbulent flow conditions in the jet. De-energising the jet assists such particles to adhere to air bubbles.

There are several methods by which the pulp-air jet can be further de-energised. In the apparatus shown in FIGURES 1, 2 and 6, the jets are caused to impinge on a plain baffle 12 which is at a sufficient distance from the orifices 7 into the tank 1 to ensure substantially complete dispersion of the air cores 81 of the jets. This baffle 12 causes substantial turbulence in the jets in the zone 91 of impingement resulting in energy dissipation, and creates secondary flows of pulp-air mixture as shown by the flow lines 92 counter-current to the original jets back towards the orifices 7 causing further energy dissipation. As the pulp-air jets 11 and the secondary flows 92 are bounded by the bottom and three sides of tank 1 and by the baffle 12, the pulp-air mixture leaves this region flowing substantially upwards as shown by the flow lines 93, towards the surface 14 of the main body of pulp through the secondary mixing zone 13. The upward flow in the secondary mixing zone 13 is of relatively lower intensity compared with that of the original jets 11 and promotes adherence between unattached particles and bubbles leaving the region of the jets 11.

The flotation apparatus shown in FIGURES 1 and 2 is also provided with a pulp discharge opening 15, a pulp discharge pipe 16 and a final pulp discharge opening 17.

The pulp-air mixture, on reaching the surface 14 of the main body of pulp above the secondary mixing zone 13 passes along beneath this surface 14 away from the wall of tank 1 containing the injection devices 2, over the baffle 12, and downwards towards the pulp discharge opening 15.

As the pulp-air mixture passes across the tank 1, beneath the pulp surface 14, the particle-bubble aggregates separate from the pulp-air mixture and form a froth 18 on the pulp surface 14. The close proximity of the flow of pulp-air mixture to the pulp surface 14 caused by the relative positions of the injection devices 2, the baffle 12 and the pulp discharge opening 15, results in a relatively small depth of pulp through which the particle-bubble aggregates must travel to reach the pulp surface 14. These flow conditions considerably enhance both degree and rate of separation of particle-bubble aggregate from the pulp.

When the pulp stream leaves the pulp surface 14 and flows down towards the pulp discharge opening 15, it may retain some particle-bubble aggregates. A region of low pulp flow rate is formed above the pulp discharge opening 15 which is termed the de-aeration zone 19. The

low downward pulp velocity in this zone 19 lowers the fluid drag on the remaining particle-bubble aggregates and permits them to rise to the pulp surface 14. Substantially de-aerated pulp passes through the pulp discharge opening 15, up the pulp discharge pipe 16 and out through the final pulp discharge opening 17. The height of the pulp surface 14 can be adjusted by altering the height of the final pulp discharge opening 17.

The froth 18 formed by the particle-bubble aggregates leaving the pulp stream builds up, forming a froth column which overflows from the upper end 20 of the tank 1 into froth overflow launders 21.

Drainage is effected through the drainage holes 22 in the bottom of the tank which are normally closed.

Although a baffle 12 is used in the form of the invention shown in FIGURES 1, 2 and 6 to deenergise the jets and to form the flow pattern described above, other techniques may be used to achieve a substantially similar result.

The jets can be made up to impinge on another surface such as the wall of the tank containing the main body of pulp opposite the orifices 7 of the injection devices 2. Under such circumstances, the pulp, after passing beneath the surface 14 of the main body of pulp may then be caused to pass into a second tank (not shown) where the de-aerating and final pulp discharge functions may be performed. This second tank may be integral with or separate from the main tank 1.

Alternatively, opposing pulp-air jets (not shown) can be located in the opposite walls of the tank containing the main body of pulp so that de-energisation is obtained by the interaction of each pair of opposing jets impinging on one another. De-aeration and final pulp discharge functions may be performed in a second tank as described above.

Alternatively, the injection devices 2 can be mounted on the bottom of a tank containing the main body of pulp and directed upwardly towards the pulp surface 14. Sufficient depth of pulp in the tank is provided to de-energise the jets before they reach the pulp surface 14. De-aeration and final pulp discharge functions may be performed in a second tank as described above.

Alternatively, the injection devices 2 can be mounted in the tank containing the main body of pulp in such a manner that the jets impinge on the bottom of the tank. De-aeration and final pulp discharge functions may be performed in a second tank as described above.

The volume flowrate of pulp through the machine substantially depends upon the pulp pressure at the pulp connections 4 and on the number and size of the pulp-air injection devices 2. The larger the injection devices 2, or the greater the number of injection devices used, the lower is the pulp pressure required at connections 4, and therefore the lower the power required to treat a given tonnage per hour of pulp. The injection devices have been found to operate satisfactorily at pulp pressures, at connections 4, between 5 and 50 lbs. per square inch gauge, the lower pressure being favoured because of the lower power requirement for a given pulp flowrate.

The air pressure required at air connections 8 depends upon the volume of air per minute to be mixed into the pulp. Pressures between 0.5 and 12 lbs. per square inch gauge have proved to be satisfactory for the present devices, with the preferred range being between 1.0 and 5.0 lbs. per square gauge, depending upon the pulp pressure at connections 4 and the degree of wear of the parts of the pulp-air injection device 2.

The effects of some of the various design parameters on the metallurgical performance criteria of one of the preferred forms of the invention are given below. These effects were determined from tests conducted on two substantially similar forms of the invention as shown in FIGURE 7. The apparatus shown in FIGURE 7 differs from that shown in FIGURES 1 and 2 in that the pulp discharges from the tank 1 through the pulp discharge

slot 29, up the pulp discharge box 30 and finally over the pulp discharge weir 31, and in that the pulp-air injection device 2 is similar to that shown in FIGURE 5 and had an orifice diameter of one inch. The apparatus for carrying out the tests is shown in FIGURE 8 and consisted of two similar forms of apparatuses 32 and 33, each constructed as shown in FIGURE 7.

Referring to FIGURE 8, ground lead mineral ore pulp 34 was passed into distributor 35 which split it into two even flows, one of which passed to the pulp connection 4 of the pulp-air injection device 2 of apparatus 32 and the other passed to the pulp connection 4 of the pulp-air injection device 2 of apparatus 33. Each pulp connection 4 was fitted with a pressure gauge 4'.

Air was passed into the injection device 2 at connections 8. Each air connection 8 was fitted with a pressure gauge 36 and each air supply with a means 36' of measuring the air flowrate.

The air and pulp were injected into each tank 1 in which the processes already described took place resulting in the overflow of froth at the upper end 20 of each tank 1 and the discharge of pulp over each of the pulp discharge weirs 31.

The apparatus 32 was operated in a standard manner during all tests and was therefore taken as the reference standard. The parameters studied were varied on apparatus 33, one at a time, and the effects of these variations were measured in terms of the metallurgical criteria (lead recovery and lead concentrate grade) of the apparatus 33 standardised in a regular manner by comparison with those obtained from apparatus 32 at the same time. The lead recoveries and concentrate grades were calculated from lead assays of samples of pulp feed, pulp discharge and froth concentrate taken substantially at the same time from each apparatus using a standard procedure.

The effects of changes in some of the major parameters of the apparatus on the metallurgical results are given in Tables 1 to 6. In such case, other variables were substantially constant. Where the variation of a parameter had no effect, no results are quoted.

(1) EFFECT OF AIR FLOWRATE

The recovery of lead minerals in the concentrate increased as the air flowrate increased up to a maximum value which should preferably not be exceeded. Typical data are shown in Table 1.

TABLE I

Air flowrate to apparatus 33, standard cubic feet per minute	Lead recovery, percent, apparatus 33
Nil	Nil
1.4	76.5
2.5	79.8
3.0	81.8
5.4	84.0
6.6	85.3

Air flowrate above a certain maximum figure causes the production of large air bubbles of undispersed air which pass up through the froth column, bursting at the surface, giving the condition known to those skilled in the art as "breakthrough." When "breakthrough" occurs, the froth column is disrupted and tends to collapse. Lead recovery decreases.

The maximum amount of air which can be dispersed and mixed in the pulp depends on a number of factors, the more important being:

(a) Percentage solids by volume in the pulp

The lower the percentage solids by volume in the pulp the greater the maximum amount of air which can be dispersed and mixed in the jet, and the greater the lead recoveries at the respective maxima.

The practical limits of pulp solids content for the operating conditions of the tests were from 27.0% to 5.2% solids by volume. The corresponding maximum air

inputs and lead recoveries through this range are given in Table 2.

TABLE 2

Pulp percentage solids by volume to apparatus 33	Maximum air flowrate to apparatus 33, standard cubic feet per minute	Lead recovery, percent, apparatus 33
27.0	2.2	75.0
22.6	3.8	79.0
16.8	5.7	85.7
10.5	7.9	88.6
5.2	>8.2	90.5

(b) Length of pulp-air jet

The maximum air flowrate increased as the length of the pulp-air jet was increased. This length was taken as the distance from the forward edge of the pulp-air injection device 2 to the baffle 12 of apparatus 33. The maximum air input to the apparatus was substantially a linear function of this distance within the limits of the tests carried out. Data are given in Table 3.

TABLE 3

Distance pulp air injection device to baffle 12 of apparatus 33	Maximum air flowrate to apparatus 33, standard cubic feet per minute	Lead recovery, percent, apparatus 33
12	3.0	74.0
24	6.0	81.0
36	>8.2	84.0

Photographic evidence has shown that the higher the air flowrate, the further does the air core persist within the pulp annulus. If the air core is substantially undispersed when the pulp-air jet impinges on the baffle 12, undispersed air rises to the froth surface tending to give the "breakthrough" condition. However, within the limits indicated, the greater the distance from the pulp-air injection device 2 to the baffle 12, the longer the pulp-air jet and the greater the maximum amount of air which can be dispersed, and the greater the resulting mineral recovery.

(2) EFFECT OF SWIRLING THE PULP-AIR JET

A test was conducted in which the swirl-inducing vanes 29 were removed from the pulp-air injection device 2 of apparatus 33. In the absence of these swirl-inducing vanes 29, the pulp-air jet did not swirl. The effect of the absence of swirl from the pulp-air jet on the lead recovery is shown in Table 4.

TABLE 4

Type of pulp air injection device	Lead recovery percent, apparatus 33
Device with swirl inducing vanes 29 fitted.....	70.0
Device with swirl inducing vanes 29 removed.....	64.5

The pulp-air injection device 2 shown in FIGURES 3 and 4 generates swirl in the pulp-air jet by the injection of pulp tangentially into the body 3 of the device. The advantages of the use of the tangential input injection device (FIGURES 3 and 4) compared with the swirl-inducing vane injection device (FIGURE 5) are that the number of wearing parts is reduced, fabrication is simpler and the pulp pressure required, other things being equal, is lower.

For example, a pulp-air injection device of the type shown in FIGURES 3 and 4 with a body 3 having a diameter of three inches and an orifice 7 having a diameter of one inch required a pulp pressure of 13.5 lbs. per square inch gauge at connection 4 to pass 5.26 cubic feet per minute of pulp comprising 49.4% by weight of ground lead-zinc mineral ore of average specific gravity of 3.7 and 50.6% by weight of water through the device. However, a pulp-air injection device of the type shown in FIGURE 5 with a body 3 having a diameter of three inches, an orifice 7 having a diameter of one inch and fitted with three swirl-inducing vanes 29, required, a

pulp pressure of approximately 35 lbs. per square inch gauge to pass pulp of substantially similar composition and at a substantially similar flow-rate to that described above through the device.

(3) EFFECT OF CROSS-SECTIONAL AREA OF DE-AERATION ZONE 19

Tests were conducted in which the cross-sectional area of the de-aeration zone 19 of apparatus 33 was increased from 24 to 144 square inches and to 250 square inches. Other variables were held substantially constant. The decrease in pulp velocity through the de-aeration zone 19 resulting from the increase in cross-sectional area caused the fluid drag on particle bubble aggregates still remaining in the pulp to be reduced so that fewer aggregates passed out through the pulp discharge. As a result lead recovery increased as the cross-sectional area of the de-aeration zone increased. This effect is shown in Table 5.

TABLE 5

Cross sectional area of de-aeration zone of apparatus 33, square inches	Lead recovery, percent, apparatus 33
24	67.2
144	71.0
250	76.5

(4) EFFECT OF THE DEPTH OF MAIN BODY OF PULP

The depth of the main body of pulp in the tank 1 above the orifice 7 of the pulp-air injection device 2 of apparatus 33 shown in FIGURE 8 should preferably be adequate to maintain full submergence of the pulp-air jet and to permit the formation of the secondary mixing zone 13 and de-aeration zone 19 as previously described. A pulp depth of 30 inches above the one-inch diameter orifice of the pulp air injection device 2 was found to be satisfactory.

(5.) EFFECT OF THE HEIGHT OF THE FROTH COLUMN 18, FIGURE 7

Concentrate grade was found to be substantially a function of the amount of drainage of undesirable material, mechanically entrapped in the froth column 18, which occurred before the froth discharge over the upper end 20 of the apparatus 33, FIGURE 8. The amount of drainage of such undesirable material from the froth column 18 was substantially a function of the time the froth took to pass up the column 18 and therefore substantially a function of the height of the column 18, other things being equal. The height of the froth column 18 of apparatus 33, FIGURE 8 was varied from four inches to 85 inches in a series of tests and the effect of these changes on the grade of concentrate in the froth overflowing the upper end 20 of apparatus 33 was noted. The relevant data are given in Table 6.

TABLE 6

Height of the froth column of apparatus 33, inches	Lead concentrate grade, apparatus 33, percent lead
4	68.8
23	71.1
44	73.0
56	73.9
85	75.5

The advantages of methods of froth flotation employing the invention, compared with conventional methods, are shown in the following Examples 1 to 5.

Examples 1 to 4 refer to the apparatus shown in FIGURE 9, and Example 5 to the apparatus shown in FIGURE 10.

In Examples 1 and 2 the flotation apparatus 60 of FIGURE 9 was similar to that shown in FIGURES 1 to 4, and in Examples 3 and 4 the flotation apparatus 60 of

FIGURE 9 was similar to that shown in FIGURES 5 and 7.

Examples 1 and 3 refer to the recovery of lead mineral from a pulp feed containing a high lead mineral content, and Examples 2 and 4 refer to the recovery of lead mineral from a pulp feed containing a low mineral content.

EXAMPLE 1.—Ore at The Zinc Corporation, Limited mine, Broken Hill, New South Wales, is prepared for the recovery of the desired lead mineral, galena, by the conventional flotation process, by grinding in water in ball mills. The sizing of the particles in the pulp to the flotation process is controlled by a rake classifier. The ore is so prepared in five grinding sections, each of which receives between 30 tons and 40 tons of dry ore per hour. For the purpose of this example, the discharge of one group of grinding sections was fed to the flotation apparatus 60 substantially similar to that shown in FIGURES 1 to 4 while the discharge of another group of grinding sections was fed to a series of conventional mechanical flotation machines. As depicted in FIGURE 9, the new unground ore and water 37 passed to the grinding sections consisting of two groups of rake classifiers 38, 39 and two groups of ball grinding mills 40, 41. Provision was made to divert the discharge of the group of classifiers 38 into sump 42. Sump 42 was connected to a pump 44 which was in turn connected through a pulp pressure and flow regulating valve 45 to a simple pulp distributing device 46 with ten outlets. Each outlet was connected to the pulp inlet connections 4 of the ten pulp-air injection devices 2 of the apparatus 60 by 1½-inch diameter rubber hose. A pressure gauge 47 was mounted on the pump delivery pipe at the distributor 46 to indicate the pulp pressure. Compressed air 48 at a normal pressure of 90 lbs. per square inch was passed through a flowrate metering device 49 and pressure and flow regulating valve 50 to a distributor 51 with ten outlets. Each outlet was connected through an isolating valve 52 to the air inlet connections 8 of the ten pulp-air injection device 2 of the apparatus. A pressure gauge 53 to indicate the air supply pressure to the pulp-air injection devices 2 was mounted on the distributor 51. Pump 44 could also receive flushing water through connection 54 and isolating valve 55.

Sump 43 of the second group of grinding mills 41 and classifiers 39 remained connected directly to the feed connection of the first machine of a series of seven identical conventional flotation machines 57 each containing an impeller driven by an electric motor, for the purpose of inducing air into the machine, mixing air with the pulp, recirculating pulp and maintaining the mineral particles in suspension in the pulp. These machines were arranged to treat the pulp in succession to obtain the required recovery of desired mineral. The discharge 56 of the apparatus 60 and the discharge 58 of the last conventional machine 57 were returned to the conventional process.

Before the test was conducted, the tonnage of dry ore fed to each group of grinding sections 40, 41, which was automatically and continuously metered and controlled, was regulated so that 69 tons per hour would pass to the apparatus 60 and 69 tons per hour would pass to the conventional machines 57. Each group then operated for one hour to permit equilibrium conditions to be attained. Towards the end of this hour, the isolating air valves 52 of the apparatus were opened and the air supply to the pulp-air injection devices 2 was regulated by valve 50 to approximately 60 standard cubic feet per minute. As no liquid was present, no air pressure reading on gauge 53 was obtained. Pump 44 was started and valve 55 opened, permitting flushing water to be pumped into the

apparatus. Meanwhile, the conventional machines 57, being part of the normal plant, continued to operate.

After an hour had passed from the time the new ore fed to the groups of grinding mills 40, 41 was adjusted, the discharge of the group of classifiers 38 was changed from the conventional process to sump 42, and the flushing water valve 55 closed. At the same time the necessary flotation chemical reagent additions to sump 43 were adjusted so that the equivalent of 0.071 lb. of sodium ethyl xanthate per ton of dry ore contained in the pulp as a 10% solution in water, and 0.003 lb. of methyl isobutyl carbinol per ton of dry ore contained in the pulp, as a full strength liquid, were continuously added. Similarly, at the same time, identical chemical reagents were added to sump 42 at the equivalent rates of 0.078 lb. of sodium ethyl xanthate and 0.001 lb. of methyl isobutyl carbinol per ton of dry ore contained in the pulp.

The pulp with reagents was then pumped by the pump 44 from sump 42 to the pulp-air injection devices 2 and injected into tank 1 of apparatus 60 whereby the process described previously then took place in the tank 1. the froth 18 generated containing the concentrate gradually built up forming a column and finally overflowed the walls 20 of the tank 1 into the concentrate collection launders 21. These launders 21 delivered the froth and concentrate to the concentrate disposal circuit of the conventional plant. Once the froth overflowed the tank walls 20, the air supply 48 was regulated to just prevent bubble rupture at the froth surface.

The pulp flowed from tank 1 at 56 and was permitted to operate in this manner for 15 minutes. After this time a sample of the pulp feed was taken at sump 42, a sample of the pulp issuing from the apparatus 60 was taken at discharge 56, and a sample of the froth concentrate overflowing the walls 20 of the apparatus 60, was taken along each wall. As these samples were taken, the specific gravity of the pulp was measured at sump 42, the pulp pressure was read on the pressure gauge 47, the air pressure was read on the pressure gauge 53 and the flowrate of air was read on the flowmeter 49. The chemical analyses of the three samples for the economically-important elements lead, silver and zinc, the particle size distribution of the pulp feed sample, and percentage solid content of the feed, were determined. The "Recovery" was determined for each of the elements lead, silver and zinc in the froth concentrate. The volume flowrate of pulp to the apparatus was calculated from the dry tonnage rate of new unground ore fed to the classifier 38 and the percentage solids content of the pulp as calculated above from the pulp specific gravity. The time required to pass the pulp through the flotation machine was calculated from the volume of the mixing zones of tank 1 and the volume flowrate of pulp through the tank 1. Operating data of economic importance were also calculated in terms of each ton of solids contained in the pulp.

The seven conventional mechanical flotation machines which were already operating were sampled at the same time as the sampling of the apparatus 60 described above.

A sample of the pulp feed to the first conventional machine was taken at sump 43, a sample of the pulp issuing from the seventh conventional machine was taken at discharge 58 and samples of the froth concentrates overflowing the front wall of each machine were also taken.

As these samples were taken, the specific gravity of the pulp was measured at sump 43. The chemical analyses of the nine samples for the economically-important elements lead, silver and zinc, the particle size distribution and the percentage solid content of the pulp feed sample, were determined. The seven froth concentrate sample analyses were combined in a standard manner to yield a lead, a silver and a zinc analysis which was representative of the respective metal contents of the combined froth concentrates from the seven machines.

The "Recovery" was determined for each of the elements lead, silver and zinc in these combined froth concentrates. The volume flowrate to pulp to the first conventional machine was calculated from the dry tonnage rate of new unground ore fed to the classifier 39. The time required to pass the pulp through the seven machines was calculated. Operating data of economic importance were also calculated in terms of each ton of solids contained in the pulp.

All the above information is recorded in Table 7.

TABLE 7

[Data obtained from the operation of a flotation apparatus employing one preferred form of the invention compared with seven conventional mechanical flotation machines, for lead flotation of high lead content ore]

Description	Specific value for—	
	Apparatus of invention	Seven conventional machines
1. Number of flotation machines.....	1	7
2. Volume per machine (cubic feet).....	72	25.1
3. Total volume (cubic feet).....	72	175.7
4. Floor area per machine (square feet).....	38.5	19.6
5. Total floor area (square feet).....	38.5	147.2
6. Tons of solids in pulp feed per hour.....	67.5	69.5
7. Average specific gravity of solids.....	3.7	3.7
8. Specific gravity of pulp feed.....	1.57	1.56
9. Percentage solids in pulp feed by weight.....	49.4	49.5
10. Volume flowrate of pulp feed (cu. ft. per minute).....	52.6	53.5
11. Times for pulp to pass through machine mixing zones (seconds).....	41.0	196.8
12. Pressure of pulp feed (lbs. per sq. in. gauge).....	13.5	Nil
13. Volume flowrate of air to machine (cu. ft. per minute s.t.p.).....	54	Not metered
14. Pressure of air to machine (lbs. per sq. in. gauge).....	4.0	Not metered
15. Power required per machine at 13.5 lbs. per sq. in. gauge pulp pressure (kw.).....	7.82	1.77
16. Total power required at 13.5 lbs. per sq. in. gauge pulp pressure (kw.).....	7.82	12.4
17. Reagents added per ton of solids in feed pulp:		
Methyl isobutyl carbinol (lbs.).....	0.001	0.003
Sodium ethyl xanthate (lbs.).....	0.078	0.071
18. Particle sizing of solids in pulp feed—percent we ght finer than:		
300 micron.....	97.4	95.6
211 micron.....	92.1	87.5
152 micron.....	84.0	76.8
105 micron.....	71.4	63.1
65 micron.....	55.7	48.3
19. Chemical analyses of solids in pulp feed:		
Lead (percent).....	18.3	17.3
Silver (ounces per ton).....	4.9	4.4
Zinc (percent).....	12.8	12.0
20. Chemical analyses of solids in froth (concentrate grade):		
Lead (percent).....	73.2	73.0
Silver (ounces per ton).....	16.1	16.3
Zinc (percent).....	4.5	4.4
21. Chemical analyses of solids in pulp discharge:		
Lead (percent).....	4.45	4.85
Silver (ounces per ton).....	1.9	1.5
Zinc (percent).....	14.4	13.6
22. Recoveries of metals in froth concentrate:		
Lead (percent).....	80.6	77.1
Silver (percent).....	66.2	67.7
Zinc (percent).....	7.1	6.7
23. Other economic data:		
Number of stages required to achieve 80.6% and 77.1% recoveries respectively of lead in the concentrates.....	1	7
Power required per ton of new ore treated to achieve 80.6% and 77.1% recoveries respectively of lead in the concentrates (kw. h.) per ton).....	0.12	0.18
Floor space required per ton of new ore treated per hour to achieve 80.6% and 77.1% recoveries respectively of lead in the concentrates (square feet).....	0.57	2.1
Flotation machine volume per ton of new ore treated per hour to achieve 80.6% and 77.1% recoveries respectively of lead in the concentrates (cubic feet).....	1.1	2.5

Comparison of the operation of the apparatus 60 employing the invention with conventional flotation machines illustrates some advantages of the apparatus. Under the conditions of the comparison, the apparatus 60 yielded a 3.5% higher recovery of lead in the froth concentrate for a substantially similar pulp feed rate, and with

a 0.2% higher lead concentrate grade relative to the conventional machines. These results were achieved in one stage compared with seven stages in conventional flotation and required only 26% of the floor area, 41% of the volume and 63% of the power required by the conventional machines.

Example 2.—In this example, the operation of the apparatus 60 which was substantially similar to that depicted in FIGURES 1 to 4 and was employed for the recovery of lead mineral from a pulp feed of low desired mineral content, is described and compared with the operation of conventional mechanical machines performing the same duty, and with reference to FIGURE 9.

In the flotation process at The Zinc Corporation Limited mine at Broken Hill, New South Wales, approximately 97% of the lead mineral contained in the ore in the pulp fed to the process is recovered in the froth concentrate. Twenty-eight stages of conventional machines are required to achieve this recovery, of which the first twelve stages of flotation are conducted in three parallel series comprising twelve small (22 cubic feet nominal volume) machines, and each of the three series receives one-third of the total plant feed. In Example 1, the apparatus 60 was compared with the first seven such machines of one series.

The pulp which discharges from the twelfth machine of each series usually contains a lead content of approximately 2%. This pulp is treated by one series of sixteen large 83 cubic foot machines. For the purpose of the test, the apparatus 60 was operated to recover lead mineral from the pulp discharging from the twelfth stage and the results compared with the first six conventional machines which normally treat this material in the plant. Since it was impracticable to reduce the flowrate of the conventional machines to the flowrate of the apparatus 60, the comparison of economic data was made on a "per ton of solids" basis.

The apparatus arrangement used was the same in every respect to that described for Example 1 and depicted in FIGURE 8 from sump 42 to discharge 56. The conventional machine arrangement, fed from sump 43, consisted of six machines, and not four as shown in FIGURE 8. For the purpose of Example 2, sump 43 continuously received the total discharges of the three machines comprising the twelfth stage and provision was made to divert a portion of this discharge to sump 42.

As before, the isolating air valves 52 of the apparatus were opened and the air supply to the pulp-air injection devices 2 was regulated by valve 50 to approximately 60 standard cubic feet per minute. As no liquid was present, no air pressure reading on gauge 53 was obtained. Pump 44 was started and valve 55 opened permitting flushing water to be pumped into the apparatus. When flushing water discharged at 56, portion of the discharge from the twelfth stage of the conventional process was passed to sump 42 and the flushing water valve 55 closed. At the same time the necessary flotation chemical reagent addition to sump 42 was adjusted so that the equivalent of 0.002 lb. of sodium ethyl xanthate per ton of dry ore contained in the pulp, as a 10% solution in water, was continuously added.

The pulp with reagents was then pumped by pump 44 from sump 42 to the pulp-air injection devices 2 and injected into the tank 1 of apparatus 60. The processes described previously took place in the tank 1. The froth generated containing the concentrate gradually built up forming a column and finally overflowed the walls 20 of the tank 1 into the concentrate collection launders 21. These launders delivered the froth and concentrate to the concentrate disposal circuit of the conventional plant. Once the froth overflowed the tank walls 20, the air supply 40 was regulated to just prevent bubble rupture at the froth surface. The pulp flowed from tank 1 at 56 and was returned to the conventional circuit. The apparatus was permitted to operate in this manner for

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fifteen minutes. After this time the samples and other data as already described in Example 1 were collected and processed in a similar manner. In addition, the flow-rate of pulp was metered and solids content of this pulp calculated in a standard manner. The final information is recorded in Table 8 as shown below.

The six conventional flotation machines which were continuously operating, being part of the normal plant, were sampled at the same time as the sampling of the apparatus described above. All pertinent data were recorded and samples and data processed in a manner similar to that already described in Example 1. The final information is recorded in Table 8.

TABLE 8

[Data obtained from the operation of a flotation apparatus employing one preferred form of the invention compared with six conventional mechanical flotation machines, for lead flotation of low lead content ore]

Description	Specific value for—	
	Apparatus of invention	Six conventional machines
1. Number of flotation machines.....	1	6
2. Volume per machine (cubic feet).....	72	83
3. Total volume (cubic feet).....	72	498
4. Floor area per machine (square feet).....	38.5	25
5. Total floor area (square feet).....	38.5	156
6. Tons of solids in pulp feed per hour.....	67	101
7. Average specific gravity of solids.....	3.3	3.3
8. Specific gravity of pulp feed.....	1.46	1.46
9. Percentage solids in pulp feed by weight.....	45.5	45.5
10. Volume flowrate of pulp feed (cu. ft. per minute).....	60.5	90.8
11. Time for pulp to pass through machine mixing zone, seconds.....	36	329
12. Pressure of pulp feed (lbs. per square inch gauge).....	14.5	Nil
13. Volume flowrate of air to machine (cubic feet per minute s.t.p.).....	55	Not metered
14. Pressure of air to machine (lbs. per sq. in. gauge).....	3	Not metered
15. Power required per machine at 14.5 pounds per sq. in. gauge pulp pressure (kw.).....	9.82	3.6
16. Total power required at 14.5 pounds per sq. in. gauge pulp pressure (kw.).....	9.82	21.5
17. Reagents added per ton of solids in feed pulp:		
Methyl isobutyl carbinol.....	Nil	Nil
Sodium ethyl xanthate (lbs.).....	0.002	Nil
18. Particle sizing of solids in pulp feed—percent weight finer than:		
300 micron.....	96.5	96.1
211 micron.....	89.1	87.5
152 micron.....	77.5	74.5
105 micron.....	61.6	58.2
65 micron.....	44.9	42.3
19. Chemical analyses of solids in pulp feed:		
Lead (percent).....	1.95	1.90
Silver (ounces per ton).....	0.8	0.8
Zinc (percent).....	13.7	13.8
20. Chemical analyses of solids in froth (concentrate grade):		
Lead (percent).....	47.4	23.3
Silver (ounces per ton).....	10.4	7.5
Zinc (percent).....	17.9	26.7
21. Chemical analyses of solids in pulp discharge:		
Lead (percent).....	0.76	0.78
Silver (ounces per ton).....	0.6	0.5
Zinc (percent).....	13.2	13.1
22. Recoveries of metals in froth concentrate:		
Lead (percent).....	62.0	61.0
Silver (percent).....	33.2	46.6
Zinc (percent).....	3.3	9.6
23. Other economic data:		
Number of stages required to achieve 62.0% and 61.0% recoveries respectively of lead in the concentrates.....	1	6
Power required per ton of dry solids treated to achieve 62.0% and 61.0% recoveries respectively of lead in the concentrates (kw.h. per ton).....	0.15	0.21
Floor space required per ton of dry solids treated per hour to achieve 62.0% and 61.0% recoveries respectively of lead in the concentrates (square feet).....	0.57	1.54
Flotation machine volumes per ton of dry solids treated per hour to achieve 62.0% and 61.0% recoveries respectively of lead in the concentrates (cubic feet).....	1.07	4.93

Comparison of the operation of the apparatus 60 of Example 2 on pulp with a low desired mineral content with conventional flotation machines illustrates some ad-

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vantages of the apparatus. Under the conditions of the comparison, the apparatus yielded a 1.0% higher recovery of lead in the froth concentrate in one stage compared with six stages for the conventional machines. The concentrate grade of 47.4% lead was 24.1% lead higher and this in itself will be recognised as a considerable metallurgical advantage by those skilled in the art. Further, these metallurgical results were achieved with only 37% of the floor space, 21.7% of the volume and 71.4% of the power per ton of ore treated.

Example 3.—In this example, the operation of an alternative form of the apparatus, which was substantially similar in detail to that depicted in FIGURES 5 and 7 and was employed for the recovery of lead mineral from a pulp feed of high desired lead mineral content, is described and compared with the operation of conventional mechanical machines performing the same duty, and with reference to FIGURE 9.

The apparatus arrangement used was the same as that described for Example 1 and depicted in FIGURE 8 except that the apparatus 60 was substantially similar to that shown in FIGURES 5 and 7, the apparatus 60 was fitted with three pulp-air injection devices 2 substantially similar to that shown in FIGURE 5, the pulp distributor 46 and air distributor 51 were three-way, and the conventional machine arrangement fed from sump 43 consisted of four machines.

The test was conducted in a substantially similar manner to that already described in Example 1 and substantially similar data were collected and calculated.

This information is recorded in Table 9.

TABLE 9

[Data obtained from the operation of one preferred form of the invention substantially similar to that shown in Figures 5 and 6, compared with four conventional mechanical flotation machines, for lead flotation of high lead content ore]

Description	Specific value for—	
	Apparatus of invention	Four conventional machines
1. Number of flotation machines.....	1	4
2. Volume per machine (cubic feet).....	15.25	22.6
3. Total volume (cubic feet).....	15.25	90.4
4. Floor area per machine (square feet).....	5.4	11.3
5. Total floor area (square feet).....	5.4	45.2
6. Tons of solids in pulp feed per hour.....	35	36
7. Average specific gravity of solids.....	3.5	3.6
8. Specific gravity of pulp feed.....	1.52	1.55
9. Percentage solids in pulp feed by weight.....	48.0	49.5
10. Volume flowrate of pulp feed (cu. ft. per minute).....	25.6	25.0
11. Time for pulp to pass through machine(s) (seconds).....	36	217
12. Pressure of pulp feed (lbs. per sq. in. gauge).....	25	Nil
13. Volume flowrate of air to machine (cu. ft. per minute s.t.p.).....	30	Not metered
14. Pressure of air to machine (lbs. per sq. in. gauge).....	3.0	Not metered
15. Power required per machine at:		
25 lbs. per sq. in. gauge pressure (kw.).....	6.34	1.27
10 lbs. per sq. in. gauge pulp pressure (kw.).....	2.24	
16. Total power required at:		
25 lbs. per sq. in. gauge pulp pressure (kw.).....	6.34	5.07
10 lbs. per sq. in. gauge pulp pressure (kw.).....	2.24	
17. Reagents added per ton of solids in feed pulp:		
Methyl isobutyl carbinol (lbs.).....	0.002	0.002
Sodium ethyl xanthate (lbs.).....	0.09	0.06
18. Particle sizing of solids in pulp feed—percent weight finer than:		
300 micron.....	94.4	96.0
211 micron.....	86.3	88.1
152 micron.....	74.3	76.1
105 micron.....	59.90	62.0
65 micron.....	44.50	46.8
19. Chemical analyses of solids in pulp feed:		
Lead (percent).....	13.8	15.2
Silver (ounces per ton).....	3.9	3.8
Zinc (percent).....	10.2	12.5
20. Chemical analyses of solids in froth (concentrate grade):		
Lead (percent).....	70.8	77.0
Silver (ounces per ton).....	16.9	18.6
Zinc (percent).....	4.2	3.1
21. Chemical analyses of solids in pulp discharge:		
Lead (percent).....	4.9	6.0
Silver (ounces per ton).....	1.8	1.7
Zinc (percent).....	10.9	13.6

TABLE 9—Continued

Description	Specific value for—	
	Apparatus of invention	Four conventional machines
22. Recoveries of metals in froth concentrate:		
Lead (percent).....	69.3	65.6
Silver (percent).....	58.5	63.4
Zinc (percent).....	5.6	3.2
23. Other economic data:		
Number of stages required to achieve 69.3% and 65.6% recoveries respectively of lead in the concentrates.....	1	4
Power required per ton of new ore treated to achieve 69.3% and 65.6% recoveries respectively of lead in the concentrates (kw-h. per ton):		
At 25 lbs. per sq. in. gauge pulp pressure.....	0.18	0.14
At 10 lbs. per sq. in. gauge pulp pressure.....	0.06	
Floor space required per ton of new ore treated per hour to achieve 69.3% and 65.6% recoveries respectively of lead in the concentrates (square feet).....	0.15	1.26
Flotation machine volume per ton of new ore treated per hour to achieve 69.3% and 65.6% recoveries respectively of lead in the concentrate (cubic feet).....	0.44	2.51

Comparison of the operation of the apparatus 60 of Example 3 with conventional flotation machines illustrates some advantages of the apparatus. Under the conditions of the comparison, the apparatus 60 yielded a 3.7% higher recovery of lead in the froth concentrate for a substantially similar pulp feed rate, but with a 6.2% lower lead concentrate grade than the conventional machines. This lower concentrate grade was due in part to the lower percent lead in the feed to the apparatus, 13.8%, compared with 15.2% to the conventional machines. However, the apparatus achieved this result in one stage compared with four stages in conventional flotation and required only 11.9% of the floor area and 16.9% of the volume required by the conventional machines.

Power consumption is very important from the economic viewpoint. The apparatus for this test was operated with three pulp-air injection devices 2 at a pulp pressure of 25 lbs. per square inch gauge although for the feed rate of 35 tons per hour, five pulp-air injection devices can be used at a pulp pressure of 10 lbs. per square inch gauge. Using five pulp-air injection devices, the power requirement is only 44.7% of the conventional machines requirement.

Example 4.—In this example, the operation of an alternative form of the apparatus, which was substantially similar in detail to that depicted in FIGURES 5 and 7 and was employed for the recovery of lead mineral from a pulp feed of low desired lead mineral content, is described and compared with the operation of conventional mechanical machines performing the same duty, and with reference to FIGURE 9.

The apparatus arrangement used is the same as that described for Example 2 and depicted in Figure 9 except that the apparatus 60 was substantially similar to that shown in FIGURES 5 and 6, the apparatus was fitted with three pulp-air injection devices 2 substantially similar to that shown in FIGURE 5, the pulp distributor 46 and air distributor 51 were three-way, and the conventional machine arrangement fed from sump 43 consisted of three machines.

The test was conducted in a substantially similar manner to that already described in Example 2 except that the necessary flotation chemical reagent addition to sump 43 was adjusted so that the equivalent of 0.01 lb. of sodium ethyl xanthate per ton of dry ore contained in the pulp, as a 10% solution in water, was continuously added and, at the same time, the equivalent of 0.011 lb. of sodium ethyl xanthate per ton of dry ore contained in the pulp was added to sump 42.

Substantially similar data to that of Example 2 was collected and calculated.

This information is recorded in Table 10.

TABLE 10

(Data obtained from the operation of one preferred form of the invention and three conventional mechanical flotation machines for lead flotation with low lead content ore)

Description	Specific value for—	
	Apparatus of invention	Three conventional machine
1. Number of flotation machines.....	1	3
2. Volume per machine (cubic feet).....	15.25	83
3. Total volume (cubic feet).....	15.25	249
4. Floor area per machine (square feet).....	5.4	25
5. Total floor area (square feet).....	5.4	75
6. Tons of solids in pulp feed per hour.....	35	162
7. Average specific gravity of solids.....	3.3	3.3
8. Specific gravity of pulp feed.....	1.61	1.51
9. Percentage solids in pulp feed by weight.....	48.5	48.5
10. Volume flowrate of pulp feed (cu. ft. per minute).....	159	736
11. Time for pulp to pass through machine(s) (seconds).....	36	127
12. Pressure of pulp feed (lbs. per sq. in. gauge).....	40	Nil
13. Volume flowrate of air to machine (cu. ft. per minute s.t.p.).....	30	Not metered
14. Pressure of air to machine (lbs. per sq. in. gauge).....	5.0	Not metered
15. Power required per machine at:		
10 lbs. per sq. in. gauge pulp pressure (kw.).....	2.24	3.51
40 lbs. per sq. in. gauge pulp pressure (kw.).....	12.68	
16. Total power required at:		
10 lbs. per sq. in. gauge pulp pressure (kw.).....	2.24	10.52
40 lbs. per sq. in. gauge pulp pressure (kw.).....	2.68	
17. Reagents added per ton of solids in feed pulp:		
Methyl isobutyl carbinol.....	Nil	Nil
Sodium ethyl xanthate (lbs.).....	0.011	0.010
18. Particle sizing of solids in pulp feed. Percent weight finer than:		
300 micron.....	91.6	91.6
211 micron.....	80.4	80.4
152 micron.....	65.4	65.4
105 micron.....	48.4	48.4
65 micron.....	33.7	33.7
19. Chemical analyses of solids in pulp feed:		
Lead (percent).....	2.28	2.10
Silver (ounces per ton).....	0.8	0.7
Zinc (percent).....	14.1	14.0
20. Chemical analyses of solids in froth (concentrate grade):		
Lead (percent).....	38.0	30.9
Silver (ounces per ton).....	8.5	7.6
Zinc (percent).....	20.6	23.3
21. Chemical analyses of solids in pulp discharge:		
Lead (percent).....	1.43	1.40
Silver (ounces per ton).....	0.5	0.6
Zinc (percent).....	13.7	13.8
22. Recoveries of metals in froth concentrate:		
Lead (percent).....	38.7	34.9
Silver (percent).....	24.7	24.4
Zinc (percent).....	3.4	3.9
23. Other economic data:		
Number of stages required to achieve 38.7% and 34.9% recoveries respectively of lead in the concentrate.....	1	3
Power required per ton of dry solids treated to achieve 38.7% and 34.9% recoveries respectively of lead in the concentrates (kw-h. per ton):		
At 40 lbs. per sq. in. gauge pulp pressure.....	0.37	0.06
At 10 lbs. per sq. in. gauge pulp pressure.....	0.06	
Floor space required per ton of dry solids treated per hour to achieve 38.7% and 34.9% recoveries respectively of lead in the concentrates (square feet).....	0.15	0.46
Flotation machine volumes per ton of dry solids treated per hour to achieve 38.7% and 34.9% recoveries respectively of lead in the concentrate (cubic feet).....	0.44	1.52

The apparatus for the test of Example 4 was operated with three pulp-air injection devices 2 at a pulp pressure of 40 lbs. per square inch gauge, although for the feed rate of 35 tons per hour, five pulp-air injection devices at a pulp pressure of 10 lbs. per square inch gauge can be used.

Comparison of the operation of the apparatus of Example 4 on pulp with a low desired mineral content with

conventional floatation machines illustrates some advantages of the apparatus. Under the conditions of the comparison, the apparatus yielded 3.8% higher recovery of lead in the froth concentrate in one stage compared with three stages for the conventional machines. The concentrate grade of 38.0% lead was 7.1% lead higher and this in itself will be recognised as a considerable metallurgical advantage by those skilled in the art. Further, these metallurgical results were achieved with only 33% of the floor space and 29% of the volume per ton of ore treated.

Power consumption per ton of ore treated for the test was substantially higher. However, if a sufficiently large number of pulp-air injection devices 2 is employed to permit the use of a 10 lbs. per square inch gauge pulp pressure, the total power consumption is substantially similar to that of conventional machines.

Example 5.—An example of another form of the apparatus employing the invention which is illustrated in FIGURE 10 will now be described.

In its operation, this form of the invention requires low pressure compressed air and the pulp supplied at low pressure. A major advantage of this form of the invention is that it does not require the use of electric power. Conventional machines on the other hand generally require low pressure air plus electrica power to drive the impellers. Floatation stages incorporating either the form of the invention shown in FIGURES 1 to 4 or the form of the invention shown in FIGURES 5 and 7 can be so arranged that the pulp pressure is obtained by the elevation of one machine with respect to the machine of the next stage, as shown in FIGURE 10. Under such circumstances the power requirement is only for the supply of low-pressure air. Maintenance requirements are low due to the absence of moving parts.

In FIGURE 10 the new ore feed is prepared for floatation by the grinding mill 40 and particle sizing device 38 and then flows under gravity to the apparatus 61 comprising the first stage of floatation employing the invention, the height A being arranged to provide the necessary pulp pressure at the pulp-air injection devices 2. Although the apparatus and pulp-air injection device depicted in FIGURE 10 is similar to that shown in FIGURES 1 to 4, the example applies also to the apparatus shown in FIGURE 7 and the pulp-air injection device 2 shown in FIGURE 5. The pulp discharges from the apparatus 61 at 62 into a sump 63 and thence flows to the pulp-air injection devices 2 of apparatus 64 comprising the second stage of floatation. The height between the sump 63 and pulp-air injection devices 2 of apparatus 64 is again so arranged as to provide the necessary pulp pressure at the pulp-air injection devices 2. In a similar manner, successive stages of floatation are accomplished; e.g. in apparatus 65 and apparatus 66, until the required recovery of desired mineral in the froth concentrate 67 is achieved. In all stages the necessary pulp pressures are generated by the elevation of one stage with respect to the next. Due to the high recovery performance of the preferred forms of the invention, the number of stages required compared with conventional floatation machines is small, so that the total height required for all stages is not excessive.

Should retreatment of the froth concentrates 67 be required, these are gravitated to an upgrading floatation stage 68. If necessary, this stage is supplied with a feed pump 69 and a pulp discharge pump 70 to return the pulp to the grinding and classifying section 40, 38.

I claim:

1. A method of froth floatation which comprises: injecting into a body of pulp, in a flotation vessel, a two-part pulp-air jet consisting of (a) an enongated convergent central core of air under presure surrounded by (b) a rotating concentric slightly divergent concurrently flowing, annulus of pulp under pressure,

the rotational velocity of the air core being substantially lower than that of the pulp annulus and the forward velocity of the air core being substantially greater than that of the pulp annulus;

maintaining the air core and pulp annulus as substantially separate parts of the pulp-air jet for a substantial distance into the pulp body,

the friction forces at the interface between the air core and the rotating pulp annulus causing shearing of air from the air core at said interface to form air bubbles which disperse throughout the pulp annulus;

forming particle-bubble aggregates within the pulp annulus by contacts between mineral particles and the newly formed air bubbles; and

retaining the said particle-bubble aggregates substantially within the said pulp annulus until the air core is dispersed, the air core being substantially conical in shape and its diameter progressively decreasing as the pulp-air jet proceeds into the pulp body.

2. A method according to claim 1, wherein substantially all of the pulp in the flotation vessel is initially injected into the vessel by means of at least one of the said pulp-air jets.

3. A method according to claim 1, in which after dispersal of the pulp-air jet the resulting pulp-air mixture containing bubble-particle aggregates flows upwardly through a secondary mixing zone towards a pulp-froth interface and then to a de-aeration zone in which the pulp flowrate is reduced thereby promoting separation of remaining bubble-particle aggregates from the pulp, and wherein pulp is discharged from the de-aeration zone.

4. A method according to claim 1, in which the pulp pressure at input is between 0.35 and 3.5 kg./cm.² gauge.

5. A method according to claim 1, in which the air core of said combined jet is injected with a substantially higher velocity than the surrounding pulp annulus and with an input pressure between 0.035 and 0.84 kg./cm.² gauge.

6. A method according to claim 5, in which the air pressure at input is between 0.07 and 0.35 kg./cm.² gauge.

7. Froth floatation apparatus comprising:

a flotation vessel;

a body of pulp in the flotation vessel; and

at least one pulp-air injecting device for injecting into the body of pulp in the vessel a two-part pulp-air jet consisting of an elongated central core of air under pressure surrounded by a rotating concentric, concurrently flowing, annulus of pulp under pressure, the rotational velocity of the air core being substantially lower than that of the pulp annulus, and the forward velocity of the air core being substantially greater than that of the pulp annulus, and

wherein each pulp-air injecting device comprises an air inlet pipe to which air under pressure is admitted; an annular chamber surrounding said air inlet pipe; a tapering or converging nozzle connected to the annular chamber and communicating with the flotation vessel;

means for admitting pulp under pressure to the annular chamber; and

means in the annular chamber or nozzle for imparting swirling motion to the pulp annulus of the pulp-air jet,

the air inlet pipe terminating within the nozzle at a short distance from the outlet orifice of said nozzle.

8. Apparatus according to claim 7, wherein the annular chamber has a connection for admitting fresh pulp tangentially thereinto.

9. Apparatus according to claim 7, wherein inclined vanes are arranged in the annular chamber or nozzle, which inclined vanes impart swirling motion to the fresh pulp as it passes between said vanes.

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10. Apparatus according to claim 7, wherein said flotation vessel is provided with a baffle-plate arranged perpendicularly, and at a distance, to the nozzle orifice of said injecting devices.

11. Apparatus according to claim 10, characterized in that the baffle-plate terminates below the upper surface of the pulp body, and a de-aeration zone is formed in the flotation vessel on the side of the baffle-plate remote from the pulp-air injecting device.

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10 HARRY B. THORNTON, *Primary Examiner*.
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U.S. Cl. X.R.

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