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IDAHO BUREAU OF MINES AND GEOLOGY
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SOME PHYSICAL FACTORS
AFFECTING
FLOTATION MACHINE PERFORMANCE

By

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INTRODUCTORY -

Flotation machines may be classified as follows:

1. Machines employing pneumatic means of effecting agitation and aeration.
   A. Air-lift cells employing pipes
   B. Porous-media cells

2. Machines employing mechanical means (impellers) of effecting agitation and aeration.
   A. Gravity-flow machines
      a. employing supercharging accessories
      b. self-aerating
   B. Suction-flow machines
      a. employing air-making accessories -- blowers
      b. self-aerating
   C. So-called Hog Trough type
      a. Self-aerating
      b. employing air-making accessories

Generally speaking, it is true that:

1. Impeller-type machines are much more popular, and they are more widely used than pneumatic-type machines.

2. Of the pneumatic-type machine, the "air-lift" type is the more popular and is almost exclusively used in modern flotation practice. Porous media cells are obsolete.

3. Of the impeller-type, all classes above listed are found widely in use. There are, perhaps, more gravity-flow machines in use today throughout the world, than any other type. They have outstanding merit on difficult, coarse-sand feeds.

Some impeller-type machines are self-aerating, while others depend wholly, or in part, upon "blowers" and accessory pipes to provide air for the impeller.

The various commercial machines, as falling into the above classes, will not be further discussed. For details of design, etc., the literature of companies manufacturing this equipment should be consulted.

EXPERIMENTAL -

It is the purpose of this paper to present data derived from experiments designed to investigate some of the physical factors affecting flotation.
machine performance, particularly of the gravity-flow type. The factors investigated are:

1. Mechanism of the gravity-flow principle
2. Impeller speed
3. Impellers, depth and number of blades
4. Cell depth, power and aeration
5. Pulp-density, power and aeration
6. Frothers, effect upon power, aeration and bubble size

EQUIPMENT

For carrying out the experimental study, stated above, items of equipment were available as follows:

1. One 1-cu.ft. gravity-flow flotation machine
2. One 7-cu.ft. gravity-flow flotation machine
3. A single-phase, 1000-watt wattmeter
4. A 1/3 HP ball-bearing motor
5. A 1/2 HP ball-bearing motor
6. V-pulleys of varying diameters and V-belts
7. Graduated flasks for aeration measurements
8. Other accessory equipment, etc.

The 1-cu.ft. cell is shown in Fig. I. The 7-cu.ft. cell is shown in Fig. II. Both machines, as may be noted, are cylindrical in form.

Spindle bearings of both machines were of the self-aligning ball-type.

Both machines were of the gravity-flow type, i.e., the pulp to be agitated and aerated flows upon the top surface of the impeller.

Provision was made in the design of the machines so that the performance of the cells, as affected by the manner of the gravity flow, could be studied.

The standpipe machine, now so widely in use, often is criticized on the count of not providing sufficient aeration, and one purpose of this study was to discover, if possible, how this might be corrected without resorting to use of blowers.

THE STANDPIPE MACHINE

In the original standpipe machine, as covered in my early patent, U. S. 1,417,696, and in a later one, U. S. 1,994,066, the design essentially comprised: 1) an impeller consisting of a disc with radially-positioned blades as shown in Fig. III; 2) a vertical impeller shaft; 3) a standpipe surrounding the shaft, extending above the pulp level and terminating at its bottom and just above the impeller, in a disc-like flange to substantially cover the impeller.

Pulp to be treated is fed to the impeller via the standpipe at a point just above the cover plate. The standpipe has the double purpose of feeding
Fig. I
1-Cubic Foot Flotation Machine

Fig. II
7-Cubic Foot Flotation Machine

Fig. III
Standpipe-Machine Type of Impeller
both air and pulp to the impeller. The combination of impeller, standpipe, and cover, is substantially the equivalent of the sand-pump of the Wilfley type.

Now it is obvious that, if the standpipe is continuously to deliver air to the impeller, it must be open to the impeller at all times. Moreover, the volume of air delivered to the impeller is determined by the area of the air intake opening.

It is also obvious that if the impeller is to function as a pump — which it must since one of its duties is to pump large volumes of pulp into the pulp-body in the cell — a pulp-head on the impeller at and around the hub is required. At the same time, if the impeller is to receive air, the standpipe, at this critical position, must be open.

It was conceived that the first corrective step to take, to enable the standpipe to deliver a sufficient and continuous draft of air to the impeller, would be to employ the standpipe as an air conduit only, and to admit pulp to the impeller elsewhere. A second logical condition to provide should be to free the axis-ward ends of the impeller blades of pulp so that they may "bite" into and receive air. These two conditions can be fulfilled only by feeding pulp to the impeller, in form of streams or cylindrical sheet, outwardly of and independently of the air pipe.

A further and fundamental condition required is that the area of the feed ports and the peripheral speed of the impeller shall be so related and proportioned that the impeller will act more like a "fan" than a pump-impeller, and that the capacity of the rotating impeller, to eject pulp, shall considerably exceed the volume of pulp flowing through the ports onto the impeller.

**THE EXPERIMENTAL FLOTATION MACHINES**

The experimental machines, above mentioned, were designed to permit testing of the above theories and, at the same time, to make parallel tests of the original standpipe-flow principle.

The two experimental machines had the following specifications:
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Impeller:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter</td>
<td>10&quot;</td>
<td>6&quot;</td>
</tr>
<tr>
<td>Blades, number</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Blades, depth</td>
<td>1-1/4&quot;</td>
<td>1/2&quot;</td>
</tr>
<tr>
<td>Blades, thickness</td>
<td>1/4&quot;</td>
<td>3/16&quot;</td>
</tr>
<tr>
<td>Shaft</td>
<td>1-5/16&quot;</td>
<td>1&quot;</td>
</tr>
<tr>
<td>Standpipe, diameter</td>
<td>3-1/2&quot;</td>
<td>2&quot;</td>
</tr>
<tr>
<td>Holes, number</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Holes, diameter</td>
<td>1&quot;</td>
<td>1/2&quot;</td>
</tr>
<tr>
<td>Holes, volume</td>
<td>.7864 sq. in.</td>
<td>.1863 sq. in.</td>
</tr>
<tr>
<td>Holes, place</td>
<td>Just above cover plate</td>
<td>Just above cover plate</td>
</tr>
<tr>
<td>Constriction plate, diameter</td>
<td>11&quot;</td>
<td>6-1/2&quot;</td>
</tr>
<tr>
<td>Holes, number</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Holes, diameter</td>
<td>1&quot;</td>
<td>1/2&quot;</td>
</tr>
<tr>
<td>Holes, place</td>
<td>On 7&quot; circle</td>
<td>On 3-3/8&quot; circle</td>
</tr>
<tr>
<td>Power Required Empty</td>
<td>165 watts</td>
<td>160 Watts</td>
</tr>
</tbody>
</table>

In these machines, provision was made so pulp, in identical and variable volumes, could be fed to the impeller either via the standpipe or outwardly of and independently of the standpipe.

By this provision, tests could be made for many conditions, including:

1. Pulp flow upon the impeller, either via standpipe or via ports, outwardly of the standpipe;
2. Variable pulp volume to the impeller.

In the experiments to follow, power in watts and rate of aeration were taken for each condition tested.

**EFFECT OF LOCATION OF FEED PORTS ON POWER AND AERATION**

In the immediate tests, the pulp was "water."
With the 12 ports in the constriction plate closed, power and aeration data were taken for variable rates of pulp flow via the standpipe. The 12 standpipe ports were opened by two's. With the standpipe ports closed, similar data were taken for pulp flow via the constriction plate ports.

In these experiments, both the seven- and the one-cu.ft. cells were used — for the 7-cu.ft. machine, at two impeller speeds, and for the 1-cu.ft. machine, at one speed. The data are compiled in Tables I, II, and III.

### TABLE I.

Pulp Flow
Power-Aeration Relationships,
Standpipe vs. New Flow

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>New Flow</td>
<td>Standpipe</td>
</tr>
<tr>
<td>29</td>
<td>1000</td>
<td>1000+++</td>
</tr>
<tr>
<td>24</td>
<td>690</td>
<td>1000+</td>
</tr>
<tr>
<td>19.2</td>
<td>830</td>
<td>1000+</td>
</tr>
<tr>
<td>14.4</td>
<td>740</td>
<td>920</td>
</tr>
<tr>
<td>9.6</td>
<td>710</td>
<td>850</td>
</tr>
<tr>
<td>4.8</td>
<td>710</td>
<td>785</td>
</tr>
<tr>
<td>0.0</td>
<td>680</td>
<td>680</td>
</tr>
</tbody>
</table>

Notes: Machine: 7-cu.ft. size
Peripheral speed of impeller: 1330 ft. min.
Fig. 1a. Pulp Flow, Power & Aeration Relationships--Standpipe vs. New Flow.
7 Cu. Ft. Cell--From Table I.
TABLE II.

Pulp Flow
Power-Aeration Relationships
Standpipe vs. New Flow

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>New Flow</td>
<td>Standpipe</td>
</tr>
<tr>
<td>29</td>
<td>670</td>
<td>730</td>
</tr>
<tr>
<td>24</td>
<td>585</td>
<td>650</td>
</tr>
<tr>
<td>19.2</td>
<td>510</td>
<td>580</td>
</tr>
<tr>
<td>14.4</td>
<td>460</td>
<td>530</td>
</tr>
<tr>
<td>9.6</td>
<td>440</td>
<td>490</td>
</tr>
<tr>
<td>4.0</td>
<td>420</td>
<td>460</td>
</tr>
<tr>
<td>0.0</td>
<td>415</td>
<td>415</td>
</tr>
</tbody>
</table>

Notes: Machine: 7-cu.f.t. size
Peripheral speed of impeller: 1080 ft. min.
Fig. 11a. Pulp Flow, Power & Aeration Relationships--Standpipe vs. New Flow.
7 Cu. Ft. Cell--From Table II.
TABLE III.

Pulp Flow
Power-Aeration Relationships

Standpipe vs. New Flow

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>New Flow</td>
<td>Standpipe</td>
</tr>
<tr>
<td>5.10</td>
<td>332</td>
<td>450</td>
</tr>
<tr>
<td>4.25</td>
<td>322</td>
<td>420</td>
</tr>
<tr>
<td>3.40</td>
<td>312</td>
<td>385</td>
</tr>
<tr>
<td>2.65</td>
<td>300</td>
<td>340</td>
</tr>
<tr>
<td>1.70</td>
<td>285</td>
<td>310</td>
</tr>
<tr>
<td>.85</td>
<td>275</td>
<td>265</td>
</tr>
<tr>
<td>.00</td>
<td>265</td>
<td>265</td>
</tr>
</tbody>
</table>

Note: Machine: 1-cu.ft. size
Peripheral speed of impeller: 1360 ft. min.
Fig. IIIa. Rate of Pulp Flow, Power & Aeration Relationships
Standpipe vs. New Flow.
1 Cu. Ft. Cell--From Table III.
The data of Tables I, II, and III are depicted graphically, respectively in Figures 1a, 1b, and 1c. Aeration (in c.c. per minute per sq. in. of cell area) and power (watts) are plotted vertically vs. volume of pulp flow (in cu. ft. per minute) on the horizontal axis.

The new principle of feeding pulp outwardly and independently of the standpipe is referred to in the above tables and graphs as the "New Flow."

The pulp volume data were calculated by use of the formula:

\[ q = 0.625 \times b \times a \]

where \( b \) = pulp head on the portholes in inches
\( a \) = area of portholes in sq. in.
0.625 = a const. to correct for friction
and \( q \) = vol. in cu. ft./min.

The reader may obtain an idea of the rate of flow upon the impeller in pounds, or in tons, of ore by assuming a pulp containing 20 lbs. per cu. ft. In present practice, the flow of original feed per cubic foot of cell volume might reach as much as two cu. ft. per minute. Hence, it is seen that the range covered in the above experiments greatly exceeds any that would be encountered in present practice.

The above data make clear these facts:

1. When pulp is fed to the impeller via the standpipe, aeration is deficient and power consumption excessive — aeration falling off and power increasing sharply with increasing pulp flow upon the impeller.

2. When pulp is fed outwardly, and independently, of the air pipe, onto the impeller, aeration is intense and the power required is low, with both aeration and power increasing with increasing pulp flow upon the impeller.

3. Aeration over the entire cell area is much more uniform when the pulp is fed to the impeller outwardly of the standpipe — the cell is "quieter" and there is less "boiling."

In the light of these data, some further analysis of the situation is justified.

Consider the case of the 7-cu.ft. machine with 10" impeller operating at a peripheral speed of 1350. The impeller shaft is 1-5/16" in diameter, and the stand-column 2-1/2" I.D. The impeller has 12, 1-1/4" by 1/4" blades. The radius of the feed-ports circle is 7".

The area of the annular opening between the pipe and the impeller shaft is \( (9.621 - 1.353) \times 8.338 \text{ sq. in.} \)

The area of one 1" feed port is \( 0.7854 \text{ sq. in.} \) and the total area of 12 1" feed ports is 9.42 sq. in.

The intake area of the impeller between the impeller disc and the constriction disc — on a diameter equal to that of the air pipe, which is 3-1/2" — is the area of a cylinder of diameter 3-1/2" by length equal to the depth of
the impeller blades plus a clearance of 1/16" and is (5.1416 x 3.5 x 1-5/16" =) 14.43 sq. in. Since this latter figure (14.43) is greater than the area of the annular area between the shaft and air pipe (9.42 sq. in.), the effective area through which the pulp must flow is to be considered as 9.42 sq. in.

The linear velocity of the impeller on a radius of 4" — which is the radius of the inside end of the impeller blades — is 532 ft. per minute.

The linear velocity of the impeller on the 7" diameter (which is the diameter of the ports in the constriction feed-plate), is 951 ft. per min., and the intake area of the impeller on a 7" radius is (3.1416 x 7 x 1.3125 =) 28.5 sq. in.

Each impeller blade passes under each port (in the constriction plate) 512 times per minute. Since there are 12 blades, each stream is hit over 6000 times a minute. Hence, each stream of pulp is cut up into 6000 small volumes per minute, and thrown, as by fan action, outwardly, tangentially into the pulp. It should be again made clear that now the hydraulic head is not on the impeller, but rather it is on the portholes in the constriction plate. The space between the impeller disc and the constriction plate is, due to the high pulp-ejecting capacity of the impeller under these conditions, largely empty and there is space between the blades to "bite" and pull in the air.

These elementary considerations of the two principles of admitting pulp to the impeller make it easier to understand the efficaciousness of the new method of feeding the pulp outwardly, and independently, of the air pipe. The need for this "outside" feeding becomes outstandingly more important as we get into the larger machines using larger, slower-running impellers. Since peripheral speed varies as the diameter, and further, since impeller peripheral speed is constant for all sizes of impeller, larger impellers are inherently slower near the impeller axis than are the smaller-diameter impellers. This accounts for the fact that smaller machines of the early standpipe type, in many instances, do better work than the larger ones; they have greater pumping capacity at the impeller intake.

Feeding pulp to the impeller outwardly of the air intake pipe, where the impeller intake area is much larger, makes possible the use of 12 impeller blades. This provision essentially doubles the impeller capacity. The 12-bladed impeller ejects 12 streams of pulp into the cell, as against six for the original impeller — resulting in smoother cell performance and longer life of parts.

**IMPELLER SPEED, POWER AND ABRADION**

Little or no study of the important factor of impeller speed is on record in the literature. Manufacturers, as well as operators, seem to have given this question little or no scientific study. The results of experiments in which impeller speed was the principal variable are recorded in Tables IV, V, and VI (shown graphically in Figs. IVa, IV, and V).
The relationships of impeller speed, power, and aeration are not, for the various conditions tested, precisely linear. The curves, however, within the speed-range tested (1000-1600 ft. per min.) are sufficiently close to straight lines that little error results from so considering them.

Let us examine the data of Table IV (See Fig. IV).

At 1565 the impeller took 435 more watts than at 1152 ft. per min. The increase in impeller speed is \((1565 - 1152 \times 100 = 38.5\) per cent. The increase in watts required is \((430 - 405 + 405 \times 100 = 107\) per cent. Thus, the percent increase in power required for each percent increase of peripheral speed is \((107 + 38.5 =)\) about 2.6 per cent.

The mathematical relationship between impeller speed and power is:

\[
P_{sx} = P_s(1.00 + K_sS_s)
\]

where \(P_{sx}\) = the power required at \(x\) speed  
\(P_s\) = measured power at known speed  
\(S_s\) = increase in impeller speed, in per cent  
and \(K_s\) = a const. = 2.6 = percent increase in power for each one per cent increase in linear speed.

If this formula be tested by applying the data of Tables V and VI, it will be found that the constant 2.6 fits closely in all cases.

The operator, by use of this constant, may now determine with reasonable accuracy what it will cost him to increase his impeller speed or what he may expect to save by reducing it. For example, if his existing impeller speed is, say, 1000 ft. min., and the horsepower being consumed is 5 --- to increase the speed to 1100 (a 10 per cent increase), the power required will be:

\[
P_{sx} = 5(1.00 + 2.6 \times 10) = 6.4\text{ HP.}
\]

It is probable that the constant 2.8 applies to all impeller-type machines.

Now the relationship between impeller speed and aeration likewise may be expressed by a similar formula. Thus:

\[
A_{sx} = A_s(1.00 + K_{sa}S_s)
\]

where \(A_{sx}\) = aeration at \(x\) speed  
\(A_s\) = aeration at known speed  
\(S_s\) = per cent increase in impeller speed  
and \(K_{sa}\) = 7.7 = percent increase in aeration for each one per cent increase in linear speed.

Thus, in a machine employing the new gravity-flow principle, above described, the operator --- for any constant pulp feed volume and density --- may increase or decrease his rate of aeration 77 per cent by increasing his

* These are "gross-watt" figures. When "net-watt" figures are used --- obtained by subtracting 165 --- the constant becomes 4.65.
impeller peripheral speed by 10 per cent.

**TABLE IV.**  
Impeller Speed, Power and Aeration Relationships

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1152</td>
<td>6</td>
<td>14</td>
<td>405</td>
<td>125</td>
</tr>
<tr>
<td>1402</td>
<td>6</td>
<td>14</td>
<td>620</td>
<td>295</td>
</tr>
<tr>
<td>1595</td>
<td>6</td>
<td>14</td>
<td>840</td>
<td>495</td>
</tr>
</tbody>
</table>

Note: Cell: 7-cu.ft.
## TABLE V.

**Impeller-Speed, Power and Aeration Relationships At Variable Impeller Loads**

<table>
<thead>
<tr>
<th>Peripheral Speed, Ft./Min.</th>
<th>Watts</th>
<th>23</th>
<th>24</th>
<th>25.2</th>
<th>24.4</th>
<th>25.5</th>
<th>25.8</th>
<th>26.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1080</td>
<td></td>
<td>670</td>
<td>586</td>
<td>610</td>
<td>460</td>
<td>440</td>
<td>415</td>
<td>410</td>
</tr>
<tr>
<td>1330</td>
<td></td>
<td>1000</td>
<td>890</td>
<td>830</td>
<td>740</td>
<td>710</td>
<td>700</td>
<td>680</td>
</tr>
</tbody>
</table>

Notes: Cell Vol.: 7-cu.ft.; Pulp depth: 26"; Pulp Density: 1.00
### TABLE VI.

Power-Speed Relationships

<table>
<thead>
<tr>
<th>Peripheral Speed Ft./ Min.</th>
<th>Watts</th>
</tr>
</thead>
<tbody>
<tr>
<td>930</td>
<td>205</td>
</tr>
<tr>
<td>1100</td>
<td>275</td>
</tr>
<tr>
<td>1265</td>
<td>365</td>
</tr>
<tr>
<td>1360</td>
<td>390</td>
</tr>
</tbody>
</table>

Note: Cell Vol.: 1-cu.ft.
      Pulp Density: 1.235
Fig. IVa. Impeller Speed, Power and Aeration Relationships—1 Cu. Ft. Cell
Fig. IV. Impeller Speed, Power and Aeration Relationships—7 Cu. Ft. Cell
Fig. V. Impeller Speed, Power & Pulp Flow Relationships—7 Cu. Ft. Cell—From Table V.
IMPELLER-BLADE DEPTH FACTOR

In the design of an impeller of the gravity-flow type, there are no data available to enable one to arrive at the proper depth of blades. The impeller has two important functions: 1) to pump, or eject, feed-pulp into the cell, and 2) to effect aeration. In the new constriction plate method of feeding pulp onto the impeller, the impeller should, under all reasonable conditions of feed, eject pulp at a rate greater than the volume of pulp flowing through the constriction plate. Under this condition, the inward ends of the impeller blades are free to "bite" into the air. Aeration is the result of two actions: 1) the "blower" action of the blades, and 2) the "ejector" action of the pulp being "swished" into the pulp-body in the cell.

Table VII presents data obtained from experiments in which impeller-blade depth and volume of feed to the impeller were the variables.

**TABLE VII.**

Effect of Impeller Blade Depth On Power and Aeration

<table>
<thead>
<tr>
<th>Peripheral Speed of Impeller, Fts./Min.</th>
<th>Ports Open</th>
<th>Vol. Pulp Flowing Upon Impeller, Cu.Ft./Min.</th>
<th>Impeller Blades Depth</th>
<th>Watts</th>
<th>Aeration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1/4&quot; 1&quot;</td>
<td>12</td>
<td>29</td>
<td>1000++</td>
<td>950</td>
<td>475</td>
</tr>
<tr>
<td>1320 1398</td>
<td>8</td>
<td>19</td>
<td>1000+</td>
<td>705</td>
<td>452</td>
</tr>
<tr>
<td>1350 1402</td>
<td>6</td>
<td>14</td>
<td>920</td>
<td>620</td>
<td>370</td>
</tr>
<tr>
<td>1400 1405</td>
<td>0</td>
<td>0</td>
<td>680</td>
<td>530</td>
<td>311</td>
</tr>
</tbody>
</table>

* Data taken from Fig. 1.

Note: In these experiments, a 1/2 HP motor was used and the lack of constancy in speed is due to overloads on the motor.

From this experiment, it is obvious that blade-depth over-and-above that required to move a volume of pulp outwardly and off the impeller disc somewhat faster than the feed volume, results in useless power expenditure. It is obvious, too, from these data, that speed may be substituted for impeller-blade depth and vice versa. A substitution of speed for impeller-blade depth may not result in equivalent operating cost and quality of metallurgy. Speed is an ally of abrasion, and speed and bubble size also are related factors. For this
new principle, the happy medium seems to be a speed of about 1400 ft. per
minute and a blade depth of about 1/2" for each 6" of impeller diameter.

One thing becomes perfectly obvious; it is — for highest impeller effi-
ciency the rate of feed to the impeller should be pretty accurately known,
provided for, and maintained.

Potential great savings in the power required in flotation is a possibil-
ity in the light of the high constants relating power and cell-depth and power
and impeller-speed.

PULP DENSITY, POWER AND AERATION RELATIONSHIPS

The data of Table VIII, Fig. VII show that power increases linearly and
aeration decreases linearly with increase in pulp density. The total increase
in power required as the pulp density was raised from 1.00 to 1.235 is
(265 - 190 =) 75 watts. The increase in power for each 0.01 increase in pulp
density is (75 + 23.5 =) 3.13 watts. In terms of per cent, the increase is
(3.13 + 190 x 100 =) 1.64 per cent for each 0.01 unit increase in pulp density.

Thus, if the power to operate an impeller of the type herein used is known
for water (sp.gr. 1), the power required for a pulp of any specific gravity
may be approximated by use of the formula:

\[ P_{dx} = P_d(1.00 + K_d D_d) \]

where \( P_{dx} \) = Power required at x pulp density
\( P_d \) = Power at known pulp density
\( D_d \) = Per cent increase in pulp density in hundredths of a unit
\( K_d \) = Constant = 1.69 = per cent increase of power for each
0.01 unit increase in pulp density.

The formula relating pulp-density and aeration is:

\[ A_{dx} = A_d(1.00 - K_A D_d) \]

where \( A_{dx} \) = Aeration at x pulp density
\( A_d \) = Aeration of water
\( D_d \) = Per cent increase in pulp density in hundredths
of a unit
\( K_A \) = Constant = 0.35 = per cent decrease in aeration for each
0.01 increase in pulp density

The results of the above experiments, on the effect of pulp density on
aeration, suggest that in the case of high-density pulps, cell depth (depth of
impeller submergence) should be held to a minimum for highest economy of
operation. Practice gives no thought to this relationship.
### Table VIII.

Pulp Density, Power and Aeration Relationships

<table>
<thead>
<tr>
<th>Pulp Density</th>
<th>Watts</th>
<th>Aeration, CC./Min./Sq. In.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gross</td>
<td>Net</td>
</tr>
<tr>
<td>1.000</td>
<td>340</td>
<td>190</td>
</tr>
<tr>
<td>1.047</td>
<td>350</td>
<td>200</td>
</tr>
<tr>
<td>1.094</td>
<td>365</td>
<td>215</td>
</tr>
<tr>
<td>1.141</td>
<td>382</td>
<td>232</td>
</tr>
<tr>
<td>1.188</td>
<td>396</td>
<td>245</td>
</tr>
<tr>
<td>1.235</td>
<td>415</td>
<td>265</td>
</tr>
</tbody>
</table>

Notes: Cell: 1-cu.ft.
Impeller speed: 1360
Solids: -60 mesh magnesite

**Cell Depth, Power and Aeration**

Cell depth has been for many years a controversial factor in the question of flotation design and performance. Metallurgically, the factor has not been scientifically studied. Operators either are or are not prejudiced on the subject. Certainly, two important factors in flotation machine performance, as affected by cell depth, are power and aeration.

Using the 1-cu.ft. cell, the effect of cell depth on these two factors was studied. The data are presented in Table IX, Fig. VIII.

As in the case of pulp-density, power increases and aeration decreases with cell depth. The relationships, roughly, are linear in the pulp-density range tested.

At a pulp depth of 7.5", the power required was 220 watts; at a cell depth of 13", the power taken was 271 watts. This is an increase in power of \((121 - 70 = 51)\) 51 watts, or 73 per cent, for an increase in cell depth of \((13 - 7.5 = 5.5)\), or 73 per cent. The power increase, for each per cent increase in cell depth is \(\frac{75}{73} = 1.00\).
Fig. VII. Pulp Density, Power and Aeration Relationships
1 Cu. Pt. Cell--From Table VIII
The formula expressing the relation of cell depth and power is:

\[ P_{hx} = P_h (1.00 + K_p d_h) \]

where \( P_{hx} \) = Power at x cell depth
\( P_h \) = Power at known cell depth
\( d_h \) = Per cent increase in cell depth
and \( K_p \) = Const. = 1.00 = per cent increase in power for each per cent increase in pulp depth.

The aeration at a cell depth of 7.5" is 830, and at 13" is 685. The decrease is 245 or \( \frac{245}{830} = \frac{29.5}{75} \) per cent. The decrease in aeration as the cell depth is increased is \( \frac{29.5}{75} \times 400 \) per cent for each per cent increase in pulp depth.

The formula expressing aeration in relation to cell depth is:

\[ A_{hx} = A_h (1.00 - K_a d_h) \]

where \( A_{hx} \) = Aeration at x pulp depth
\( A_h \) = measured aeration at known cell depth
\( d_h \) = Per cent increase in cell depth
and \( K_a \) = Const. = 0.40 = per cent decrease in aeration per each per cent increase in cell depth.

These data make it very clear that to ignore the importance of cell depth is to disregard power costs. There is no better place for the operator to look for a place to materially reduce his operating costs.

**TABLE IX.**

**Cell-Depth, Power, Aeration Relationships**

<table>
<thead>
<tr>
<th>Pulp Depth, Inches</th>
<th>Watts</th>
<th>Aeration CC/Min./Sq.In. Cell Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>271</td>
<td>585</td>
</tr>
<tr>
<td>11-1/4</td>
<td>257</td>
<td>650</td>
</tr>
<tr>
<td>10-1/2</td>
<td>250</td>
<td>680</td>
</tr>
<tr>
<td>9-1/2</td>
<td>237</td>
<td>710</td>
</tr>
<tr>
<td>7-1/2</td>
<td>220</td>
<td>830</td>
</tr>
</tbody>
</table>
Fig. VIII. Cell Depth, Power & Aeration Relationships—1 Cu. Ft. Cell—From Table IX.
TABLE X.

Pine Oil,
Its Effect On
Power and Aeration

<table>
<thead>
<tr>
<th>Pine Oil GM.³</th>
<th>Lb./Ton Watts</th>
<th>Aeration CC./Min./Sq.In.</th>
<th>Density of Aerated Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
<td>---</td>
<td>280</td>
<td>590</td>
</tr>
<tr>
<td>87</td>
<td>.0062</td>
<td>270</td>
<td>585</td>
</tr>
<tr>
<td>174</td>
<td>.0124</td>
<td>269</td>
<td>580</td>
</tr>
<tr>
<td>261</td>
<td>.0186</td>
<td>263</td>
<td>570</td>
</tr>
<tr>
<td>346</td>
<td>.0246</td>
<td>262</td>
<td>570</td>
</tr>
<tr>
<td>435</td>
<td>.0310</td>
<td>260</td>
<td>570</td>
</tr>
</tbody>
</table>

FROTHERS, POWER AND AERATION -

Reagents such as pine oil and cresylic acid are used in flotation to effect mineral-flotation. They accomplish this result owing to their ability to lower the surface tension of water. Because they are surface tension-lowering substances, it is of interest to ascertain if their presence in flotation pulps, in the minute quantities employed in practice, has any effect on power and aeration.

The data presented in Figure IX explore this factor.

It is seen that pine oil, in amounts approximately that used in practice, depresses somewhat both the power required and the aeration. It is noted, too, that the specific gravity of the aerated pulp decreases from 0.90 for aerated pure water to 0.825 for water containing 435 mg. pine oil per ton of water. It was also observed that the bubbles became progressively smaller with each addition of pine oil and that, naturally also, the velocity of rise of the bubbles decreased. It was also observed that the bubbles, as they became smaller and smaller, became more uniform in size.

Observation placed the size of bubble at about 2-1/2 mm. for pure water, and at about 1 mm. for water containing .0310 lb. pine oil per ton of water.

BUBBLE VOLUME, SIZE AND VELOCITY OF RISE -

Knowledge of bubble size in flotation is of considerable interest. The problem of determining the size of bubbles formed in a flotation pulp by
Fig. IX. Effect of Frother (Pine Oil) on Power & Aeration.
1 Cu. Ft. Cell.
rotating impellers is not an easy one. To my knowledge, it has never been
done.

A set-up for conducting experiments to this end is shown in Fig. X. It com-
promises: 1) the 1-n.u.f.t. Flotation machine already described, 2) a 250-co. dis-
pensing burette positioned, as shown in Fig. X, with its valved end upward and
its open end downward immersed into and below the surface of the pulp, and 3) a
source of vacuum.

In many experiments, a convenient source of vacuum is the air intake pipe of
the flotation cell itself. Another convenient source is the air intake pipe of
a second small laboratory cell of the self-aerating type. With this apparatus,
a bubble column of any height may be "lifted out" of the flotation cell into
the burette for observation and study. When the air intake pipe of the cell
under study is used as the source of vacuum, the column may be automatically
held constant at any desired height.

With this outfit, the following data may be acquired:

1. The rate of aeration of the pulp in terms of cc. per min. per sq. in.
of cell area;
2. The specific gravity of the aerated pulp or degree of aeration;
3. The approximate size of bubbles comprising the aeration;
4. The velocity of rise of bubbles;
5. The rate of flotation.

THE DEGREE OR RATE OF AERATION

The inverted dispensing burette set-up is a more convenient and more accurate
 technique for measuring rate of aeration than the hand-operated inverted gradu-
ate flask. The pulp is drawn up into the burette with a rubber tube and the
mouth, to a level above the zero mark. Then, with a stop watch, the time of
pulp displacement between the zero mark and the 100 or 150 cc. mark, is taken.
Knowing the time for displacement, the volume of pulp displaced, and the area of
the burette tube, rate of aeration is readily calculated.

THE SPECIFIC GRAVITY OF THE AERATED PULP

Using the inverted burette set-up, the specific gravity of the pulp or
"degree of aeration" is measured as follows: With the mouth, or with some other
convenient source of vacuum, draw the aerated pulp into the burette tube to a
level above the zero mark, and close the burette valve. Now, watching the re-
ceding pulp level as the air bubbles displace the pulp, with a sponge rubber
disc, close the open end of the burette at the instant the pulp level reaches
the zero mark. The bubbles drain upward out of the column of pulp. Now, know-
ing the height of the aerated column and of the de-aerated column, the specific
gravity or degree of aeration is arrived at by simple calculation.

Bubbles, bubble size, and other characteristics of the bubble in flotation,
as are further taken up in another paper now in preparation.

* Rahmenwald, A. W., "How Efficient is a Flotation Machine?"; Engr. and
Fig. X

A Set-Up for Observing Characteristics of Bubbles Formed in an Impeller-Type Cell.
ERRATA

Page 8-Table I, column 2, second line from bottom, change number 710 to 695; in column 4, third line from bottom, change number 364 to 367.

Figure I-Relocate points in accordance with corrections on Page 5, as stated above.

Page 6-Table II, column 4, second line from bottom, change 144 to 155; in same column, third line from bottom, change 144 to 175; in column 5, third line from bottom, change 190 to 155.

Figure II-Relocate points in accordance with corrections on Page 6, as stated above. Also on the uppermost curve write "Watts" instead of "Aeration" and on the curve marked "Watts, New Flow" write "Aeration, New Flow".

Page 7-Table III, column 4, third line from bottom, change 250 to 350.

Page 9-First paragraph, change the figure 4" to 2".

Page 10-The constant 2.8, relating power and peripheral speed, holds only for a more or less specific condition with respect to pulp flow and impeller speed. The constant may be as low as 2.3. The constant 7.7, relating peripheral speed and aeration, does not hold for all conditions. It may vary from 5 to 8.

Page 11-Table IV, column 4, change 520 to 620.

Page 14-Table VII, column 4, from top to bottom read: 1000++, 830, 710 and 680.

Page 17-Table IX, column 3, from top to bottom read: 420, 450, 480, 525 and 580.

Figure VIII-Correct curve marked "Aeration", using new values given above.