

Turbine Mixer Fundamentals and Scale-up Method at the Port Nickel Refinery

P. B. QUENEAU, R. J. JAN, R. S. RICKARD, AND D. F. LOWE

The Port Nickel Refinery at Braithwaite, Louisiana is being rehabilitated and expanded to achieve a capacity of 80 million pounds per year of nickel. The atmospheric leaching of granulated and ground matte with recirculated and aerated electrolyte from the copper tankhouse is one of the first steps in the Port Nickel flowsheet. An investigation was undertaken to develop the design parameters necessary for the commercial scale-up of this leach circuit. Mechanical factors to be specified include tank geometry, impeller type, and froth handling capability. Also needed for scale-up was quantitative data showing the effect of mixer power and gas input rate on the rate of oxygen transfer. During the leaching period, the rate mechanism changed from oxygen diffusion control to chemical rate control which necessitated careful correlation of the kinetic data with mixer scale-up parameters. The scaled up system calls for a co-current five stage leaching train. Use of a single turbine impeller on a vertical central shaft provides sufficient power for off-bottom solids suspension while providing the required oxygen mass transfer rate. Radial impellers are provided for the first three tanks in which oxygen transfer is rate controlling, and axial impellers for the last two tanks where hydrolysis of basic copper sulfate is the rate controlling factor.

AMERICAN Metal Climax, Inc., is in the process of renovating the Port Nickel refinery in Braithwaite, Louisiana, to produce nickel, copper and cobalt from nickel-copper mattes. The plant is expected to eventually reach a capacity of 80 million pounds of nickel per year. This paper describes a program undertaken to define the design parameters necessary for scale-up of the atmospheric leach circuit at the Port Nickel Refinery.

Atmospheric leaching of granulated and ground matte with recirculated and aerated electrolyte from the copper tankhouse is the first hydrometallurgical step in the Port Nickel flowsheet (see Fig. 1).

The leach performs several functions: it solubilizes nickel; rejects iron and copper; and consumes the acid generated during copper electrowinning. Separation of copper and iron from nickel is achieved by the atmospheric leach so it is essential that this unit operation be operated at peak efficiency. To obtain such efficiency, detailed information was needed about the effects of gas flow rate and oxygen content; impeller location, diameter, type, speed and number; matte particle size; slurry depth; and whether or not a defoamer should be used.

Leaching of nickel-copper matte with acidic copper sulfate solution has been in practice at Outokumpu Oy for over ten years and has been described by Toivanen¹ and Saarinen.² The process to be utilized at Port Nickel is quite similar, the major differences being use of a one-step co-current operation and use of feed material which is higher in sulfur content.

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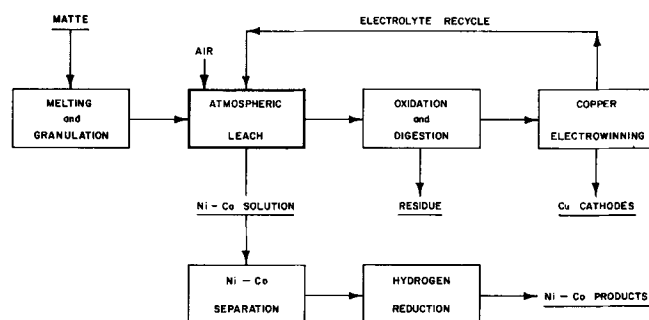
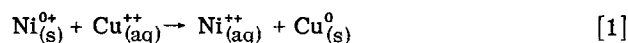


Fig. 1—Block diagram showing the relationship between atmospheric leaching and other unit operations at the Port Nickel refinery.

LEACHING CHEMISTRY

A substantial body of data on the chemistry related to atmospheric leaching is available in technical literature.¹⁻²⁰ The reaction system involves the contacting of a hot aerated acidic solution of copper sulfate with granulated copper-nickel matte containing the phases Ni_3S_2 , Cu_7S_4 and $\text{Ni}(\text{Cu}^0)$ alloy (α -nickel alloy assays 66 pct Ni and 34 pct Cu). Contact of the matte with the lixiviant causes an initial rapid rise of nickel concentration in solution (see Fig. 2) due to the cementation reaction [1]:



Much of the elemental copper so formed is oxidized by aqueous oxygen to form Cu_2O , which forms a rim around the α -nickel alloy.³ The Cu_2O is then dissolved by the aerated acid solution and is again available for nickel cementation.

The nickel cementation- Cu_2O dissolution cycle continues until the pH of the lixiviant reaches about 2, at which point the rate of Cu_2O dissolution decreases rapidly. The atmospheric leach then goes into a new re-

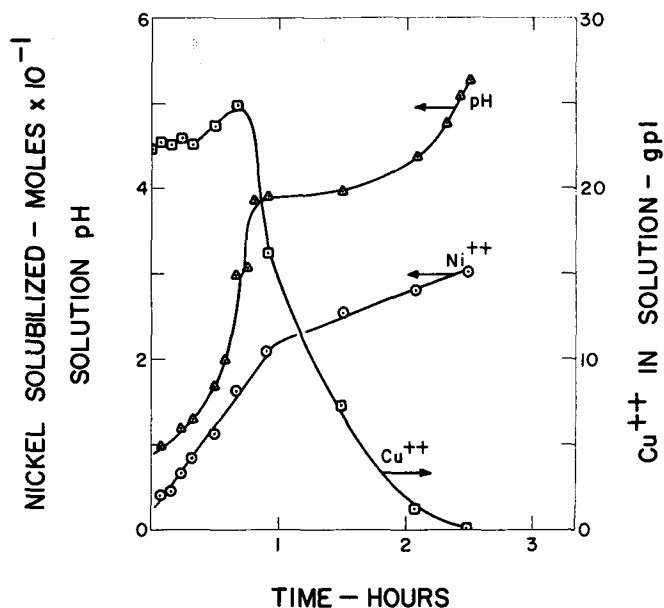
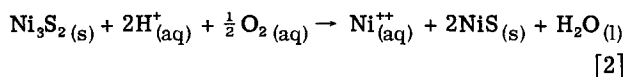


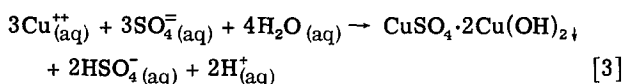
Fig. 2—A typical graph showing nickel extraction, solution pH and copper concentration as a function of time for atmospheric leaching of nickel-copper matte.

gime of rate control, one that is dictated by the rate of oxidation of Ni_3S_2 :



Data presented later in this paper will show that the rate of reaction [2] depends on the rate of oxygen transfer across the air-liquid interface. Reaction [2] is rate-controlling up to pH 4 and results in a linear rate of nickel dissolution (Fig. 2).

Above pH 4 a third zone of rate control occurs. In this region the aqueous copper hydrolyzes by:



The acid generated by this hydrolysis results in a pH rest at pH 4 (Fig. 2). This acid must be consumed by reaction [2]. Atmospheric leaching is complete when a pH of 5.3 is reached, at which point aqueous copper and iron have been lowered to less than 5 ppm (iron hydrolyzes in a manner analogous to copper). Nickel extraction varies from 10 to 90 pct depending upon matte composition and leaching conditions.³

EXPERIMENTAL PROCEDURE

Preliminary data on the effect of impeller type, diameter and speed, pct solids, and air input on power consumption and mixing patterns were obtained by suspending matte in an inert solution. This solution, 20 pct KNO_3 by weight, simulated at 35°C the density (1.12 g/cu cm) and viscosity (0.8 cp) of the Port Nickel spent electrolyte at 75°C. All other experiments were performed at 75°C using solution from the spent electrolyte stream at the AMAX matte pilot plant with a composition of 25.5 g/l Ni, 17.6 g/l Cu, 104 g/l $\text{SO}_4^{=}$ and 0.57 g/l Fe. The analyses and size distributions of the two samples of matte used in this study are shown in Table I:

Table I. Analyses and Size Distribution of Granulated Mattes

Analyses, Wt Pct	Matte, Sample A	Matte, Sample B
Ni	39.8	39.5
Cu	38.2	38.5
S	19.6	19.0
Fe	0.5	0.5
Co	0.4	0.4
Slag	1.0	1.0
Size, Tyler Mesh		
+100	0.01	0.14
100 X 150	2.5	1.6
150 X 200	10.1	8.5
200 X 270	13.0	9.3
270 X 400	20.8	48.4
-400	53.6	32.0

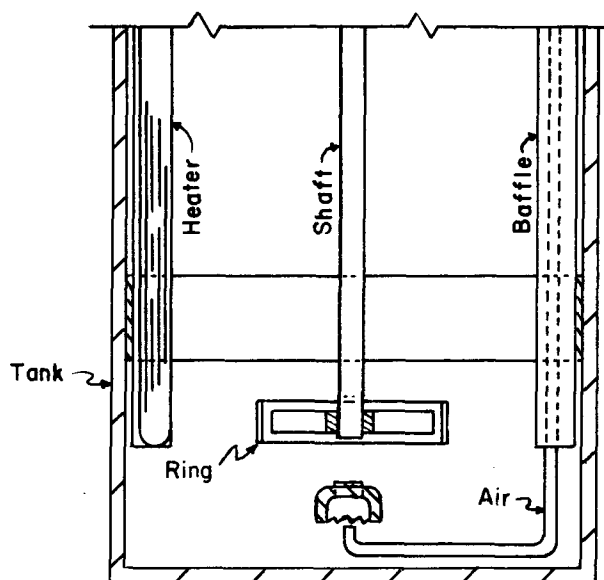


Fig. 3—Apparatus used for Port Nickel atmospheric leaching mixing studies.

An 11-in. cylindrical glass mixing tank was filled to either an 11-in. or 15-in. depth for each test. Mixing was achieved with a 1/4 hp agitator that was continuously variable in speed from 0 to 1200 rpm. Power imparted to the slurry was transferred from the ball-bearing-mounted agitator to a resistance dynamometer which was calibrated by dead weight suspension each day. Impellers tested were either 3 or 4 in. in diameter and constructed of 316 stainless steel. Impeller configurations included a straight blade turbine (*i.e.*, radial flow turbine), a pitched blade turbine (*i.e.*, 45 deg pitch axial flow turbine) and a marine propeller (square pitch). The blade widths of the 3- and 4-in. turbines were 3/8 and 1/2 in. respectively. Four 1-in. baffles displaced 0.2 in. from the wall and extending down to 3.5 in. from the tank bottom eliminated vortexing (refer to Fig. 3). Resistance heaters were placed behind three of the baffles. Behind the fourth baffle a tube was set which transferred air to a 2-in. diam bubble cap situated near the tank bottom and centered below the impeller. To maximize bubble shear, a ring 1 in. high was suspended around the periphery of the impeller as shown in Fig. 3.

At the beginning of an experiment, the test solution

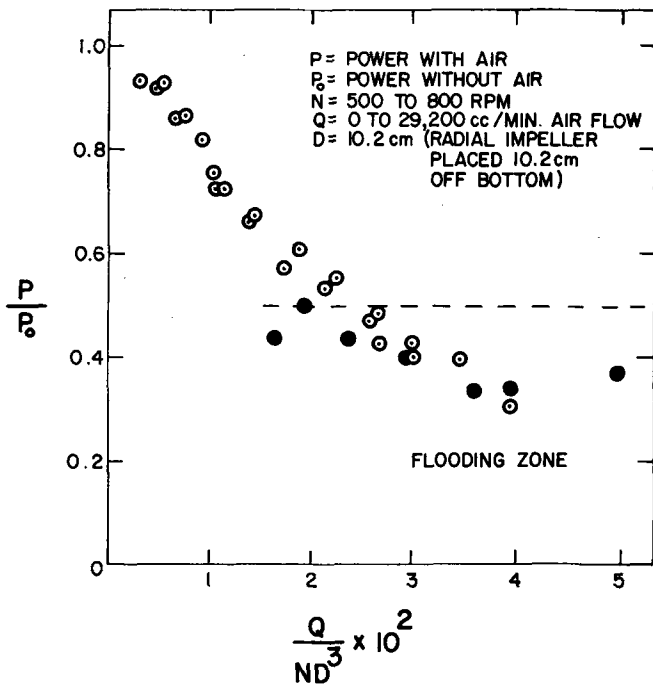


Fig. 4—Correlation of the power ratio with the flow number when utilizing a single radial impeller to agitate a 16 pct solids slurry of Sample B. The dark points indicate the settling out of solids.

Table II. Froth Level and Oxygen Content of the Slurry Using Sample B (9.4 HP/1000 Gal Mixer Power; 0.37 Ft/Min Superficial Air Velocity)

Time (Min)	pH	Froth Level, (Pct of Slurry Height)	O ₂ , (ppm)
0	0.8	0.0	4.3
30	1.6	3.3	<0.1
45	1.8	6.7	<0.1
50	2.0	10.0	<0.1
60	2.3	13.0	<0.1
70	2.8	33.0	<0.1
75	4.0	20.0	<0.1
80	4.2	10.0	0.1
90	4.3	1.0	1.3
115	5.1	1.0	1.6

was equilibrated to the desired temperature, agitation and air flow rate. A weighed quantity of solid was then added at time zero to give a 16 pct solids slurry. Because the reaction was exothermic, a damp cloth was wrapped around the tank and wetted as necessary to absorb the heat evolved. Samples of the 75°C slurry were taken periodically, filtered and assayed for nickel, copper and iron. Total sample volume never exceeded two pct of the total test volume, and the samples were sufficiently representative of the matte-electrolyte mixture so that change in pct solids due to sampling was negligible. An IBC Model 170 oxygen meter measured the dissolved oxygen. Solution pH and Eh were recorded, as was power consumption. In all tests, mixing configuration and degree of uniformity were observed visually.

EXPERIMENTAL RESULTS

Experimental data were obtained with respect to solids suspension, changing rate control, copper and iron

rejection, oxygen mass transfer, effect of mixer geometry and effect of antifoamers.

Solid Suspension

To effectively transfer matte through a series of stirred tanks, off-bottom suspension of the solids in the liquid phase is essential. Particular attention was paid to the effects of power, air input and impeller position on suspension.

The combined effect of air flow rate (Q), impeller speed (N) and impeller diam (D), expressed as the flow number Q/ND^3 on matte suspension is plotted in Fig. 4 as a function of power input with air (P) divided by power input without air (P_0). Loss of suspension occurred at high air input, at low impeller speed or small diam and at low mixer power input. Impeller type and height off the bottom are also important factors in suspension. A 4-in. axial turbine positioned 4 in. from the bottom provided off-bottom suspension at 6 hp/1000 gal whereas an otherwise identical radial turbine required 10 hp/1000 gal. Lowering the radial turbine to 3 in. from the bottom reduced the minimum power requirement to 5 hp/1000 gal. No air was supplied during these latter comparison tests using matte Sample B.

Changing Rate Control

The three experimental results described below indicate a change in the rate-controlling step at about pH 2 and again at pH 4.

1) The leach liquor was oxygen deficient throughout the leach cycle, but especially so below pH 4.2 (refer to Table II). The use of oxygen rather than air increased the rate of nickel extraction between pH 1 and 4 by 90 pct, but had little effect on the extraction rate above pH 4.

2) Matte Samples A and B, differing only in particle size, gave identical rates of nickel extraction between pH 2 and 4. The finer ground sample showed increased nickel extraction below pH 2.

3) Between pH 4.0 and 5.3, leaching rate was directly related to slurry turbulence (*i.e.*, to Reynolds Number) and almost completely independent of air input rate. The proportionality between time needed to go from pH 4.0 to 5.3 and Reynolds Number is illustrated in Fig. 5. Attempts to make a similar correlation in other pH ranges were not successful. Reynolds Number was based on impeller diameter and speed.

Copper and Iron Rejection

Efficient rejection of copper and iron from the leach liquor is one of the primary process objectives. The changes in solution copper concentration, nickel extraction and pH as a function of time are shown in Fig. 1. Copper concentration increased slightly at the start of many of the leach tests. A decrease in the rate of copper rejection was always observed above pH 1.5, and the subsequent rapid acceleration in copper rejection was accompanied by a pH plateau at about pH 4. When copper had been almost completely rejected from solution, the rate of nickel extraction declined sharply.

Iron rejection was parallel to copper rejection; at pH 5.3 both had been almost completely removed from solution.

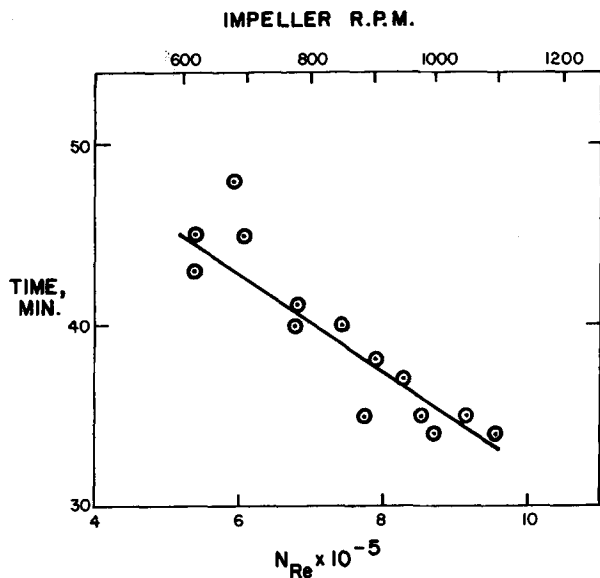


Fig. 5—Correlation of time needed to go from pH 4.0 to 5.3 with impeller rpm and Reynolds Number (N_{Re}).

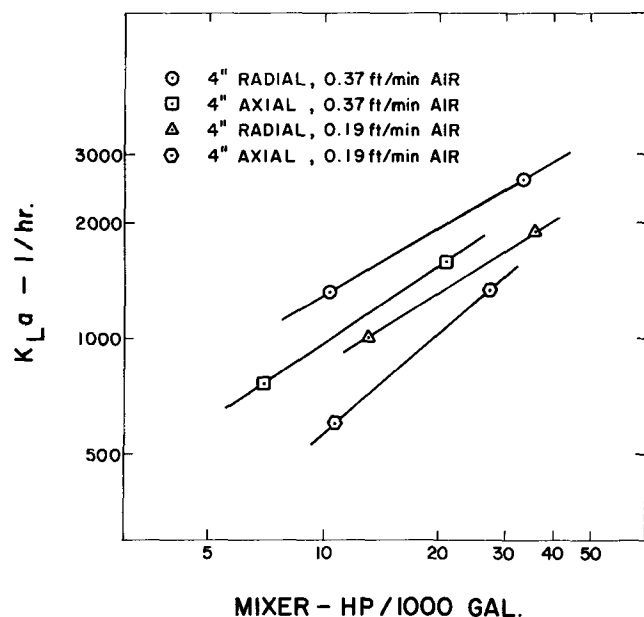


Fig. 6—Mass transfer coefficient K_La , as a function of mixer power input, impeller type and superficial air velocity (no defoamer).

Oxygen Mass Transfer

Oxygen mass transfer across the gas-liquid interface is the rate-controlling step during atmospheric leaching between pH 2 and 4. The mass transfer coefficient, K_La , is often used to indicate the effectiveness of a given system in utilizing oxygen.

$$\text{Oxygen Transfer Rate} = K_La(C^* - C)_{lm}$$

where C^* is the oxygen concentration (ppm) in the liquid at equilibrium with the oxygen in the gas phase, C is the oxygen content (ppm) in the solution during leaching, and lm symbolizes the log-mean driving force between the $(C^* - C)$ at the bottom of the tank and the $(C^* - C)$ at the top of the tank. The units of K_La are 1/h, resulting in oxygen transfer rate units of ppm O_2 /h. Calculation of K_La was based on the slope of the linear portion of the

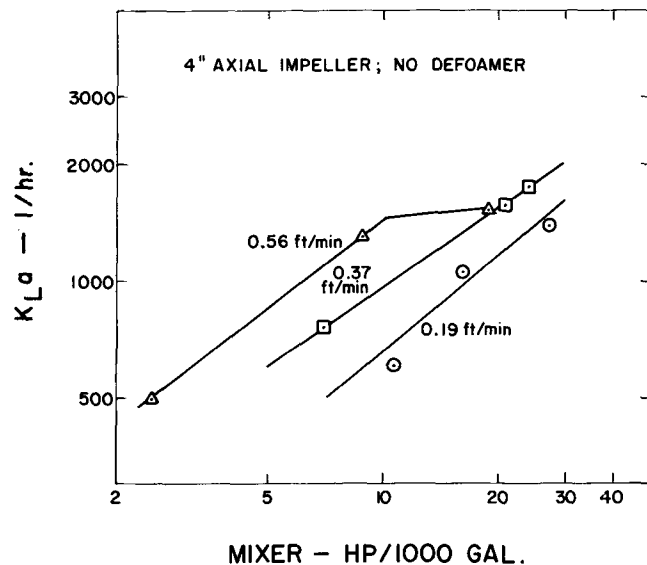


Fig. 7—Mass transfer coefficient, K_La , as a function of mixer power input and superficial air velocity using a 4-in. axial impeller (no defoamer).

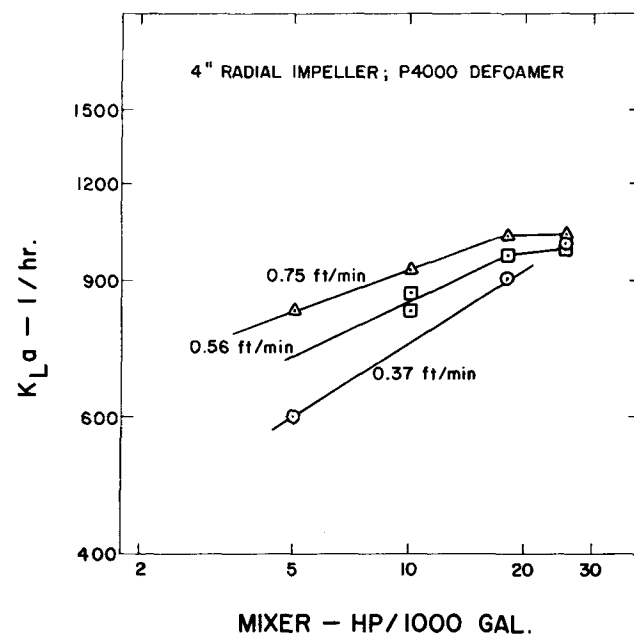


Fig. 8—Mass transfer coefficient, K_La , as a function of mixer power input and superficial air velocity using a 4-in. radial impeller and defoamer.

nickel extraction curves and utilizes the stoichiometry shown in reaction [2]. The K_La values generated by 4-in. axial and radial impellers between pH 2 and 4 at various power and air input levels are shown in Figs. 6, 7 and 8. Supplementary data are tabulated in Table III.

Effect of Mixer Geometry

Multiple impellers are sometimes placed on one shaft if the tank is tall or if high power input is needed at reasonable tip speed. The rate of nickel extraction attained with two impellers was lower than that achieved with one impeller at similar power input as shown in Table IV. The combination of axial (A) over radial (R) was more effective than radial over radial or axial

Table III. Comparison of Total Mixer and Air Power Requirements Using One Radial Impeller with P4000 Defoamer

Mixer Power, HP/1000 gal	Air Rate, cc/min X 10 ⁻³	Superficial Air Velocity, ft/min	$K_L a$ 1/h	Air Power,* HP/1000 gal	Mixer + Air Power Input HP/1000 gal	Total Energy HP-H/1000 gal†	Air Utilization, pct
5.0	7.0	0.37	600	1.5	6.5	25	33
5.0	10.5	0.56	720	2.2	7.2	22	28
5.0	14.0	0.75	820	3.0	8.0	21	24
5.0	14.0	0.75	820	3.0	8.0	21	24
9.0	10.5	0.56	820	2.2	11.0	29	33
14.0	7.0	0.37	820	1.5	16.0	44	45
5.0	7.0	0.37	600	1.5	6.5	25	33
10.0	7.0	0.37	740	1.5	11.5	38	39
20.0	7.0	0.37	930	1.5	21.5	57	45
5.0	14.0	0.75	820	3.0	8.0	21	24
10.0	14.0	0.75	930	3.0	13.0	31	27
20.0	14.0	0.75	1030	3.0	23.0	52	29

* Air horsepower is based on 1.5 times the isothermal horsepower to deliver the volume of air at 5 psig; ambient pressure was 12.0 psia.

† Based on the time required to achieve 40 pct nickel extraction.

Table IV. Nickel Extraction Rate for Single and Double 4-in. Impeller Systems at 9.4 HP/1000 Gal Mixer Power and 0.37 Ft/Min Superficial Air Velocity

Impeller Type	Efficiency of Air Utilization, pct	Mass Transfer Coef., 1/H	Extraction Rate, Pct Ni/Min
A	46	930	0.24
R	56	1235	0.29
A + 4 in. + A*	36	680	0.19
R + 4 in. + R	31	560	0.16
A + 4 in. + R	40	780	0.21

* 4 in. spacing between two axial (A) impellers.

time to complete the reaction was not significantly changed (*i.e.*, reaction time was 6 pct longer when using the disc). A second test was run to see if the ring surrounding the circumference of the impeller was really necessary. Removal of the ring had no effect on reaction time.

Effect of Anti-foamer

Failure to control frothing is a major operating hazard in three-phase mixing systems if sulfides are present. Frothing refers to the foam on top of the air-expanded slurry. It was observed with Sample A and occurred primarily between pH 2 and 4 (refer to Table II). With Sample B, frothing was so extreme between pH 2 and 4 at high air input rates that an anti-foaming agent became essential. Addition of 0.4 pounds of Dow p4000 anti-foamer per ton of matte processed decreased the rate of leaching by 30 pct (refer to Fig. 9).

Expansion of the slurry due to entrained air rather than frothing varied from 0 to 21 pct and was a function of both air flow rate and mixer power. Slurry expansion data is tabulated in Table V.

DISCUSSION

Suspension of Solids

An impeller imparts both liquid flow and shear stress to a slurry. Flow lifts the solids off the tank bottom and disperses injected or induced gas throughout the tank. Flow is proportional to ND^3 (N = impeller speed and D = impeller diam). Shear stress, which is proportional to N^2D^2 , breaks up large gas bubbles and creates sufficient turbulence to continually distort the bubbles and to prevent a static interface from forming. As D increases at a given level of power per unit volume, maximum shear stress increases but total shear per unit volume decreases. This loss of shear energy during scale-up must be compensated by increased flow. The technology of solids suspension in agitated tanks has been extensively researched by both Zwietering²¹ and Narayanan.²²

As the air flow (Q) fed to a rotating impeller is increased, the power drawn by the impeller and the ability of the impeller to suspend solids decrease. The re-

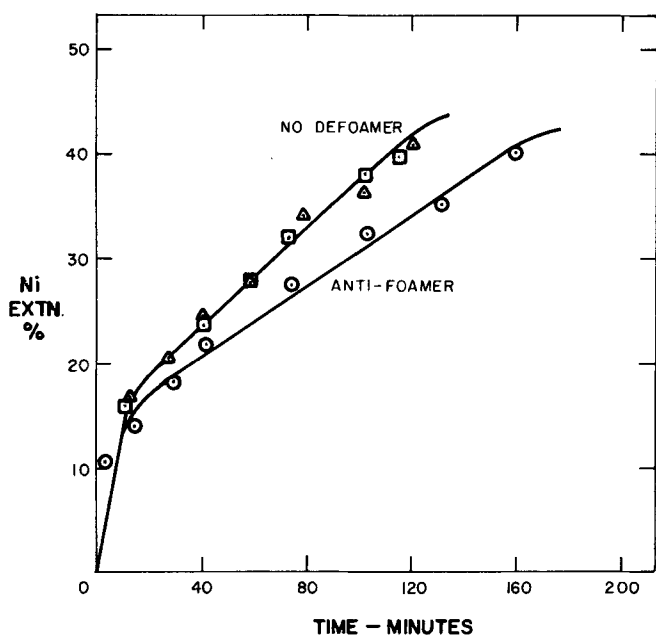


Fig. 9—Effect of defoamer and impeller spacing on nickel extraction for the axial (A) over radial (R) impeller design at 9.4 hp/1000 gal mixer power., 0.37 ft/min air rate, 15-in. slurry height and either 4 or 6 in. between impellers.

over axial. Spacing the impellers either 1.0 or 1.5 impeller diam apart had little effect on leaching rates (see Fig. 9).

One test was performed to determine the effect of using a disc between the blades of the radial impeller;

sulting loss in solids suspension is illustrated in Fig. 4. Points located below the dotted line are in a region where mixer power was lowered by more than 50 pct due to the high rate of air injection. Dark points indicate where solids settled to the tank bottom. At the open points below the dotted line in Fig. 4, solids suspension was attained; however, large bubbles escaped from the impeller region. This appearance of undispersed air is called "impeller flooding".²³

The type of impeller used dictates the proportion of flow to shear energy imparted to the slurry and thus plays a significant role in solids suspension.²⁴ A radial turbine impeller maximizes shear and can be designed to handle a wide range of gas throughputs; air input rates of 5000 cu ft/min have been fed to such turbines.¹⁶ A marine impeller maximizes flow and can be designed for 370 cu ft/min of gas at most.²⁵ An axial turbine gives a response intermediate between the radial turbine and the propeller. Because turbine impellers can be most effectively scaled up for high air input applications, most of our work has been limited to this impeller type.

The radial turbine, which maximizes shear, can generate enough flow for solids suspension if it is used properly.^{21,22} The distance the radial turbine is placed off the bottom is particularly important.^{26,27} Solids suspension was not obtained at low power levels and high air flow rates using the 4-in. radial turbine unless the turbine was positioned less than one impeller diam from the tank bottom. Tests using the 4-in. radial impeller at 5 hp/1000 gal were performed with the impeller 3 in. off-bottom. All other tests used the 4-in. off-bottom position. The off-bottom position appears to have little effect on the magnitude of the oxygen mass transfer coefficient, ($K_L a$), but a large effect on the ease of solids suspension.

The mixing tank shown in Fig. 3 was successful in achieving effective solids suspension when using a radial impeller and was patterned after that used at Nicaro, Cuba.²⁸ The design utilizes baffles which extend only part way to the bottom of the tank, thereby allowing some rotary motion to develop at the tank bottom. Rushton²⁹ has since shown that this rotary motion can result in heavy solids settling out. Thus, full baffling was specified for scale-up.

Rate-controlling Steps

The primary rate-controlling factor during atmospheric leaching proved to be the transfer of oxygen from the gas to the liquid phase. The most direct evidence to support this conclusion is the record of aqueous oxygen analyses shown in Table II. The leach liquor was starved for oxygen throughout the leaching period, and especially so between pH 2 and 4. The principle mode of oxygen consumption is believed to be the oxidation of Ni_3S_2 as shown in reaction [2]. Using oxygen rather than air doubled the reaction rate rather than giving the five-fold increase one might expect by considering only the additional oxygen partial pressure in the gas phase. Oxygen concentration in the liquid phase was not measured during the pure oxygen test, but presumably its magnitude increased sufficiently to give only a two-fold increase in the $(C^* - C)_{lm}$ term of the oxygen transfer rate expression.

A second factor important in establishing leaching completion time was a cementation reaction, effective during the first quarter hour of leaching and occurring simultaneously with Ni_3S_2 oxidation discussed above. The cementation described by reaction [1] was a displacement reaction between Cu^{++} and Ni^0 . Its rate was particle-size dependent. Thus, leach tests using matte Sample A showed a slower initial leaching rate than did tests using matte Sample B. After the metallic nickel content of the feed was consumed or coated with Cu_2O , the nickel extraction rate became linear and was dominated by reaction [2].

Also important in establishing leaching completion time was the system's sensitivity near the end of the leach to solution turbulence. This sensitivity became apparent at about pH 4, the point at which the nickel dissolution rate slowed (see Fig. 2) and the oxygen concentration began to climb (see Table II). The correlation between turbulence, as defined by Reynolds Number, and time spent between pH 4.0 and 5.3 is shown in Fig. 4. The greater the solution turbulence (*i.e.*, the higher the Reynolds Number) the shorter was the time period after pH 4. Apparently rate control formerly dominated by oxygen diffusing through a gas-liquid interface was giving way to some other step occurring within the liquid phase. This liquid phase reaction is probably the hydrolysis of copper as in reaction [3] with the rate-limiting step perhaps being the nucleation-growth of the basic copper sulfate phase.

Oxygen Transfer Rate

Mixer power, impeller type and air input rate had a substantial effect on the rate of oxygen transfer to the lixiviant. Fig. 6 shows a log-to-log plot of $K_L a$ as a function of mixer power, air flow (superficial velocity) and impeller type. The radial turbine (*i.e.*, a high shear impeller) generated higher $K_L a$ values than did the axial turbine. As the rate of air addition increased, so did the oxygen transfer rate and thus the value of $K_L a$.

Fig. 7 graphs $K_L a$ values generated by 4-in. axial impeller without defoamer. Fig. 8 applies to a 4-in. radial impeller with defoamer. Most mixing literature shows the families of curves resulting from different rates to be linear and parallel; an exception thereto occurs in a paper by Oldshue, which shows the $K_L a$ curves as non-linear.²⁷ In both Figs. 7 and 8, the $K_L a$ value does not show an increase corresponding to the increase in mixer power at high air superficial velocity. Once sufficient power has been supplied to thoroughly disperse the air, additional power is wasted.³⁰ A similar effect was not found at the lower air superficial velocities. For economic plant design, $K_L a$ values are required which have been generated at several levels of mixer power air input using the appropriate tank geometry.³¹⁻³⁶

Effect of Mixer Geometry

The ratio of tank height to tank diam commonly used for solid suspension in turbine systems varies from 1:1 to 1:2; for gas dispersion, ratios of 4:1 to 1:1 are recommended.²⁸ To simultaneously achieve efficient solids suspension and gas dispersion at 1:1 ratio was selected.

The optimum impeller diam to tank diam ratio (*i.e.*, impeller ratio) for gas-liquid mass transfer depends on both the level of mixer horsepower and the gas flow rate.³³ Small-diam impellers impart maximum shear. Solids suspension demands solution flow rather than shear, and dictates a large-diam impeller.³⁷ The impeller-to-tank diam ratio used in this study (*i.e.*, 0.36) was a compromise which permitted both solids suspension and gas dispersion. For scale-up, this impeller ratio was decreased to compensate for the resulting increase in the ratio of flow to shear.²⁷ A ring was used around the impeller periphery in the laboratory-scale system, as was done at Nicaro, Cuba,²⁸ in hopes of maximizing bubble shear. The ring proved to have no effect on gas dispersion, indicating that most of the fluid shear forces were concentrated at the impeller blade edges and not at the ring.

Scale-up of mixers is complicated by the increase of impeller tip speed as impeller size increases at constant power input per unit volume. Above a tip speed of 1200 ft/min, impeller wear is excessive. Increase in tank size at the 1200 ft/min maximum tip speed further decreases the power input per unit volume. A partial solution to this problem is the addition of an extra impeller to the stirrer shaft.

Considerable data has been published on the relative merits of single vs multiple turbines.^{26, 31, 33, 35, 38} It has been shown that multiple turbines can generate better or poorer oxygen mass transfer coefficients depending on mixer power, air input and geometry. One study concluded that multiple turbines are best utilized at high air flows or at high power levels and that two turbines were always less efficient than one (see Table IV).³⁸ However, testing with multiple turbines was limited, and did not preclude the possibility that multiple turbines could be used with high efficiency.

The radial impeller used in our study had no center disc. Use of a center disc with the radial turbine is not needed at small impeller diam, but is essential for radial turbines more than 18 in. in diam being used in gas dispersion applications.²⁵ The disc prevents gas from passing through the low velocity zone at the impeller's hub, thus escaping the circulation pattern. It also forces the gas to flow out to the high-shear zone at the impeller blade tips.³⁹

Effects of Anti-foamers

The adverse effect of surface-active agents on oxygen transfer in aqueous systems is well established in

Table V. Slurry Expansion Due to Mixing and Air Entrainment for a 4-In. Radial Impeller With Disc at Complete Off-Bottom Suspension

Air Rate (cc/Min) × 10 ⁻³	Superficial Air Velocity ft/Min	Mixer HP/1000 gal	RPM	Slurry Height (Pct Increase)
7.0	0.37	5.0	520	9.1
7.0	0.37	11.8	650	11.4
7.0	0.37	16.6	750	13.6
7.0	0.37	23.9	850	18.2
10.5	0.56	10.8	650	13.6
10.5	0.56	14.7	750	15.9
10.5	0.56	22.6	850	20.5
14.0	0.75	9.9	650	15.9
14.0	0.75	13.9	750	18.2
14.0	0.75	21.4	850	21.2

literature.⁴⁰⁻⁴³ This negative effect might at first seem surprising in that surface-active agents inhibit bubble coalescence and result in a much higher gas-liquid interfacial area. Unfortunately, this increase in area is more than offset by the barrier to oxygen diffusion created by the surface-active substance collecting at the liquid-air interface. Oxygen transfer sharply decreases at small concentrations of the surface-active material, then increases as more reagent is added. This increase is due to the surface area effect overwhelming the barrier effect.

The effect of Dow P4000 anti-foamer (polypropylene glycol) on the rate of nickel extraction is shown in Fig. 9. Use of 0.4 lb of anti-foamer per ton of matte reduced the $K_L a$ by 30 pct. However, foaming was reduced to nil.

MIXING SYSTEM SCALE-UP

The industrial mixing system scale-up design for the atmospheric leach train at Port Nickel is instructive, and is presented below.⁴⁴

The full-scale leaching system calls for a co-current five-stage stirred tank reactor system to handle 21,000 lb/h of matte at 16 pct solids. Table VI gives the system specifications. The mixing configuration utilizes cylindrical leach tanks with slurry height equal to slurry diam. A single-turbine impeller on a central vertical shaft provides sufficient power for off-bottom solids suspension while providing the required oxygen mass transfer rate. Radial impellers are provided for the first three tanks, in which oxygen demand is the highest, and axial impellers are provided for the last two tanks. If the first stage is out of service, each subsequent stage is capable of handling the mixing and gas dispersion requirements of its preceding stage. In this case the gas distribution would be revised from the conditions given in Table VI as follows:

- Stage 2—1350 SCFM
- Stage 3— 650 SCFM
- Stage 4— 100 SCFM
- Stage 5— 100 SCFM

The general scale-up procedure was to plot the reac-

Table VI. Scale-Up Mixing Parameters for Atmospheric Leaching at Port Nickel

	Tank				
	1	2	3	4	5
Tank Diam, ft	14.2	14.2	14.5	14.5	14.5
Tank Height, ft	18.5	18.5	17.0	17.0	17.0
Outlet Height, ft	14.2	14.2	14.5	14.5	14.5
Turbine Type	Radial	Radial	Radial	Axial	Axial
Number of Turbines	1	1	1	1	1
Impeller Off-bottom, In.	36	36	36	36	36
Agitator Motor H.P.	75	75	60	25	25
Number of Baffles	4	4	4	4	4
Width of Baffles, in.	15	15	15	15	15
Baffle Off-bottom, in.	12	12	12	12	12
Baffle Off-wall, in.	3	3	3	3	3
Defoamer Use	No	No	No	No	No
Air Input Rate, SCFM	1350	650	100	100	100
Superficial Velocity, ft/min	8.2	3.9	0.6	0.6	0.6
Air Utilization, pct	40	32	28	28	28
Required Mass Transfer Rate, ppm O ₂ /h	5200	2000	270	270	270
Required Mass Transfer Coefficient, 1/h	910	330	55	55	55

tion rate vs nickel concentration for the entire process range.⁴⁴ Then the pounds of oxygen required as a function of nickel concentration was calculated by using the stoichiometry in Reaction [2]. The first part of the reaction was mass transfer-controlled so that the required mass transfer coefficient $K_L a$ could be calculated. Different combinations of impeller speed and diam were chosen, the degree of solids suspension and physical gas dispersion were calculated for the full-scale system and cost comparisons were made. The final mixer selected gave the proper combination to satisfy all of these processes with minimum total cost, both operating and capital.

In addition, the retention time distribution of particles passing through the leaching system when operating either 4 or 5 stages was determined. The results were as follows:

- 5 stages—98 pct retained longer than 1.5 h.
- 99 pct retained 1.0 h or longer.
- 4 stages—93 pct retained 1.5 h or longer.
- 97 pct retained 1.0 h or longer.

In order to provide the maximum operational flexibility of the system, the agitation equipment was designed so that it could be operated at a full range of gas rates down to 0 SCFM. No special provisions were necessary for stages 4 and 5. However, in order to design for a full range from 0 to 650 SCFM for stage 3, it was necessary to use a 60 hp drive assembly with a constant speed motor. For stages 1 and 2, the range of power response over the full range of gas rate from 0 to 1350 SCFM was such that economics favored the use of 2 speed motors having high and low speeds of 1200 and 900 rpm respectively. All other motors were specified 1750 rpm single speed. A sparge disc located 3-in. beneath the impeller and concentric with the agitator shaft provided air distribution.

Oxygen transfer in the first stage of the leach train gives about 65 pct of the total requirement for Cu^0 and Ni_3S_2 oxidation. A pH of 4 should be attained in this first stage. Because the gas volume will expand the slurry and thus reduce the effective retention time, the first stage was sized for one h retention time without gas. The mixing pilot plant data shows that from pH 4 to completion, a maximum of 0.8 h is required. Because this second part of the process is mostly controlled by the rate of copper hydrolysis, rather than by oxygen transfer, a different analysis was used for scale-up. A two-stage system with about 2.3 h retention time was specified initially. However, additional tank capacity was subsequently required in anticipation of receiving some plant feed of a more refractory nature that would require longer retention time during atmospheric leaching.

The mixing system designed for the leaching is believed conservative. It is expected that the full-scale installation will provide higher oxygen transfer efficiencies than were obtained in the pilot plant, so that the gas input rates may be reduced below minimum design rates.⁴⁴ This reduction can be done without affecting the agitators. Also, should plant capacity requirements ever be increased, the as-designed system should be able to handle some additional load. Use of anti-foaming agents will be avoided if at all possible because they can create problems during processing of the pregnant leach liquor.

Scale-up of gas-liquid-solid mixing systems from pilot plant data tends to be an art rather than a science. Thus, both gross overdesign and underdesign are not uncommon. Much design data has been accumulated by mixing equipment suppliers which has not appeared in the technical literature. We are in debt to Oldshue and Rushton for their published contributions to the theory and practice of mixing, and hope that this paper will stimulate further published work in the field.

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