Air-sparged hydrocyclone (ASH) technology for cyanide recovery

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Abstract
An air-sparged hydrocyclone (ASH) mobile system was evaluated for continuous stripping and recovery of cyanide (the AVR process) from process water at a gold plant site. The ASH unit performed exceptionally well as an absorber. HCN was absorbed from the gas phase in a single pass with an efficiency exceeding 99%. HCN concentration in the discharged gas phase was lower than 10 ppm, which provided for a safe working environment. The stripping efficiency, controlled by the Henry's Law constant, exceeded 40% in one pass.

Key words: Cyanide recovery, Air-sparged hydrocyclone, Gold processing, Process water

The AVR process

A number of plants for the recovery of cyanide from precious metal processing solutions have been built and operated over the past years using the acidification-volatilization-regeneration (AVR) technologies (Mudder et al., 2001). In the AVR process, a barren cyanide solution is usually acidified with sulfuric acid to lower the pH and convert the NaCN to HCN gas. During air stripping, the cyanide-laden air is discharged into a sodium hydroxide (NaOH) solution to capture the HCN. The disadvantage of the cyanide recovery process is the large capital cost associated with the recovery plant.

The high efficiencies demonstrated by the air-sparged hydrocyclone (ASH) in gas stripping (Lelinski and Miller, 1996) appears to make it ideally suited for the stripping of HCN gas for recycle. Therefore, the ASH may provide an economical alternative to stripping towers. Conventional HCN stripping towers are not only expensive, but they are high-maintenance items, requiring frequent descaling to maintain operating efficiency.

The decision to recover or destroy cyanide is based on the economics of a specific treatment plant. Cyanide recovery is highly economical from an operating point of view, but it requires a major upfront capital investment. By reducing this capital cost by a large factor, the number of cyanidation plants for which recovery would be economically viable would increase significantly. Additionally, the key part of a cyanide recovery system has been the conventional stripping tower, a large structure that requires a large, permanent foundation. Work on the ASH as a gas-stripping unit in VOC removal has indicated that small, semiportable units may be highly practical, and this could potentially permit the construction of modular cyanide recovery plants that could be used.

Cyanide is a major contributor to operating costs in a variety of chemical and metallurgical industries. Due to the toxicity of cyanide-containing effluents, predisposal treatment is often a necessary step in these industries. A new technology using the air-sparged hydrocyclone (ASH) as a reactor for HCN stripping and absorption, particularly as applied to the cyanidation processing of gold and silver ores, is proposed here.

The ASH technology

The ASH was originally developed for fast flotation in a centrifugal field (Miller and van Camp, 1982), and the technology is now being used industrially for many applications for wastewater treatment (Jovine et al., 2001). The ASH technology was also used in air stripping for environmental applications, such as the removal of volatile organic compounds (VOC) from contaminated water (Lelinski and Miller, 1996). For VOC removal, contaminated water is fed tangentially to the cyclone. The water then comes into contact with small air bubbles generated at the cyclone wall and the VOC is stripped from the water into the vapor phase. It was established that the capacity of a standard ASH is about 27.0 to 53.9 m^3/min per cubic meter of cell volume (200 to 400 gpm per cubic foot of cell volume) compared to 0.14 to 0.68 m^3/min per cubic meter of cell volume (1 to 5 gpm per cubic foot of cell volume)

Figure 1 — Mobile ASH system installed at Midas.

Table 1 — Modes of operation of the ASH Mobile System with a 50.8-mm (2-in.) size stripping ASH unit.

Number of stripping stages	Size of adsorbing ASH unit, in. (mm)	Number of passes of the gas phase
1	6 (152.4)	1
1	2 (50.8)	1
1	2 (50.8)	R*
	*R = recirculated	

for a typical stripping tower. ASH technology was tested at the Tooele Army Depot in Utah and at an industrial site for removal of VOC from the groundwater. Initial results revealed that ASH technology is able to perform with an efficiency comparable to a conventional stripping tower, with much lower total equipment and operating space requirements.

One of the advantages initially identified for the ASH/CN system was that the system is small and readily moveable, particularly in comparison with the Cyanisorb technology that requires the use of large packed tower and the resultant large concrete foundations and footprint. It was felt that, given equal capital and operating costs, the fact that an ASH/CN unit could be fabricated and assembled completely off-site, then transported and made operational in a very short time period with a small, temporary footprint would be preferable to several large concrete and steel structures. The authors believe that this is likely to still be the case, assuming that the cost of the two systems is brought to comparable levels.

A semiportable ASH/CN unit could be moved from one site at the end of operations to another site with very little cost at either end. This would not be the case with a Cyanisorb unit. While this is a distinct advantage, salvage value or teardown cost at the end of a long project would have little effect on the net present value of either in a cash-flow comparison.

Processing conditions and procedure

Three one-week series of field tests took place in 2002 and 2003 at the Ken Snyder Newmont Gold Mine mill and cyanidation plant near Midas, Nevada. The mobile ASH system was installed on the concrete delivery load-out adjacent to the thickener floor berm near the CCD circuit and the INCO process reactor (Fig. 1). The system was operated daily for 6 to 12 hours. Besides examining processing efficiency using actual barren cyanide solution, field tests were devoted to the identification and elimination of the scaling problem. Plugging of the porous tube in the stripping ASH was reduced but not eliminated; however, a new ASH design to diminish plugging during absorption and stripping was evaluated. To secure minimal resistance to the flow of the gas phase, the porous tube was replaced with stainless steel mesh. A tangential air inlet provided more uniform flow of gas through the mesh.

For the third round of tests at Midas, the mobile ASH system was equipped with new 152.4- and 50.8-mm (6 and 2-in.-) diameter ASH units that were used in several arrangements (Table 1). The airflow rate was changed from 2.2 to 3.7 m^3/min (60 to100 scfm), and in most tests the barren solution flow rate was 13.2 L/min (3.5 gpm).

The concentration of cyanide was measured using the argentometric (titration with $AgNO_3$ in the presence of rhodanine) and picric acid (PA) methods. The calibration curve for the PA method was prepared using a cyanide standard (940 ppm, diluted 1:100), which was restandardized on site by titration — with good agreement. The absorbance at 520 nm was measured with Thermo Spectronic Genesis[TM] 8 Spectrophotometer. Samples were collected in 250-mL PE bottles and treated with alkali (NaOH) pellets before analysis. Besides laboratory analysis, an industrial quality CN^- ion sensitive electrode was calibrated using barren solution and used on line.

To evaluate the rate of deposition of scale on the wire mesh screen, which served as the sparger, the change in mass of the screen was measured before and after completion of the experiments.

Two pH meters, a CN^- ion sensor, a HCN sensor and electronic thermometers were installed in the mobile system, which allowed for on-line measurements. All analytical instruments functioned correctly, although only the HCN monitor and cyanide ion sensor were industrial grade. Staff members were equipped with two personal HCN monitors with audible cyanide alarms set for 10 and 25 mg/m^3.

A negative pressure was maintained in the system to prevent HCN release to the surroundings prior to absorption. In the HCN absorption stage, a 5% to 10% NaOH aqueous solution was circulated and drained at the end of the tests.

The 152.4- and 50.8-mm (6- and 2-in.) ASH units served for absorption of HCN. The alkaline solution was fed to the cyclone through a conventional Krebs header and a custom-made header that allowed one to feed the ASH at a lower flow rate but still with an entry velocity of 6 to 7 m/s. The alkalinity of the solution in the third tank was adjusted to a value between pH 12.4 to 13.2, and the flow rate of the alkaline solution was changed within 7.6 to 18.9 L/min (2 to 5 gpm).

The barren solution was continuously fed at 13.2 L/min (3.5 gpm) to the acidification tank (Fig. 2). From there it was pumped to the stripping ASH and after that to a separate 946-L (250-gal) PE tank containing caustic pellets. The solution was drained periodically to the floor sump. Intense agitation through the recirculation pump secured rapid mixing of acid with the feed solution. HCN was reabsorbed in caustic
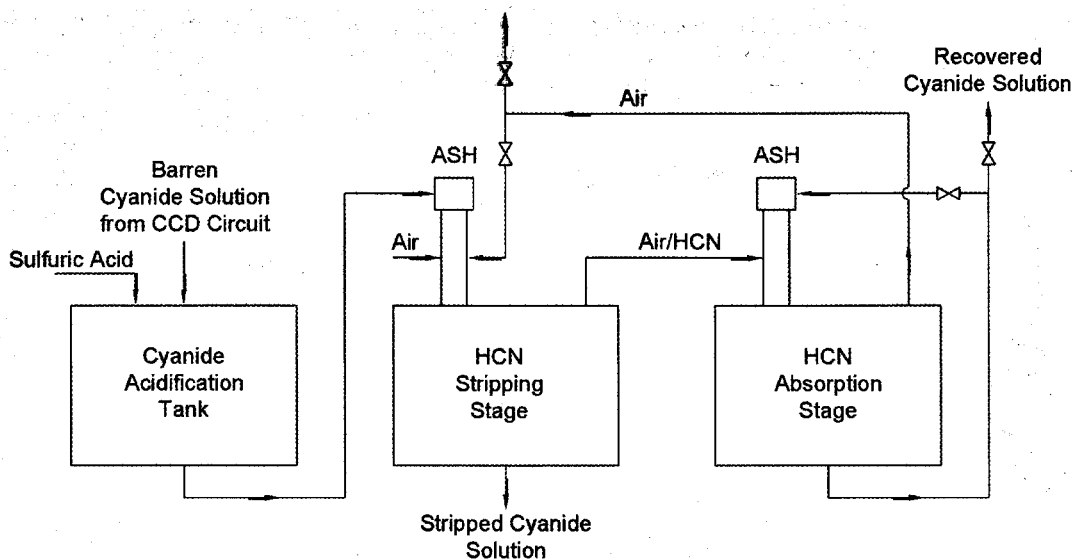
Figure 2 — Simplified flowsheet for cyanide recovery using ASH technology.

solution using the 152.8-mm- (6-in.-) ASH, which was later replaced with the 50.8-mm (2-in.) ASH.

The barren solution was transparent and colorless. The temperature of the barren solution entering the stripping ASH varied from 10° to 32°C, depending on the season. The pH was 11.2. The consumption of sulfuric acid was evaluated from the titration curve. To acidify one liter of the barren solution to pH 6 required 1.25 g of 96% sulfuric acid and required 2.22 g of acid to reach pH 3. The concentration of free cyanides varied from 380 to 430 mg/L. The concentration of soluble substances was 6.2 g/L.

Results

From the safety and the processing efficiency standpoint, most significant was the performance of the HCN reabsorption unit. The gas phase from the absorption stage (Fig. 2) was recycled or discharged to the immediate surroundings of the mobile system and monitored for HCN content by an on-line Dragger analyzer and two personal Dragger monitors carried by staff members.

The HCN content in the discharged gas phase was smaller when a 50.8 mm (2-in.) ASH unit was used instead of 152.8-mm (6-in.) ASH unit for absorption, i.e., less than 15 ppm for pH 13 and 0.042 m³/s (90 scfm) gas flow rate. The required alkaline solution flow rate was much smaller for the 50.8-mm (2-in.) unit (Fig. 3). The required pumping pressure for the alkaline solution at 10.6 L/min (2.8 gpm) was 34.5 kPa (5 psi). The pressure drop in the ASH unit for the gas phase was from 250 to 500 Pa (1 to 2 in. H_2O). The stainless steel mesh was not susceptible to plugging. The gain of weight of the stainless steel mesh sparger after 27 hours of operation was 100 mg. Recirculation of the gas phase resulted in smaller consumption of caustic solution due to absence of carbon dioxide.

The HCN stripping conditions and efficiency data are shown in Table 2. The symbol Q^* represents dimensionless volumetric ratio of the gas phase flow to the aqueous phase flow. Q^* values for complete removal assuming equilibrium conditions were calculated from Henry's Law constant at a given temperature and are shown for comparison. If the actual Q^* is equal to or greater than the required Q^*, complete equilibrium stripping of HCN might be expected. In fact,
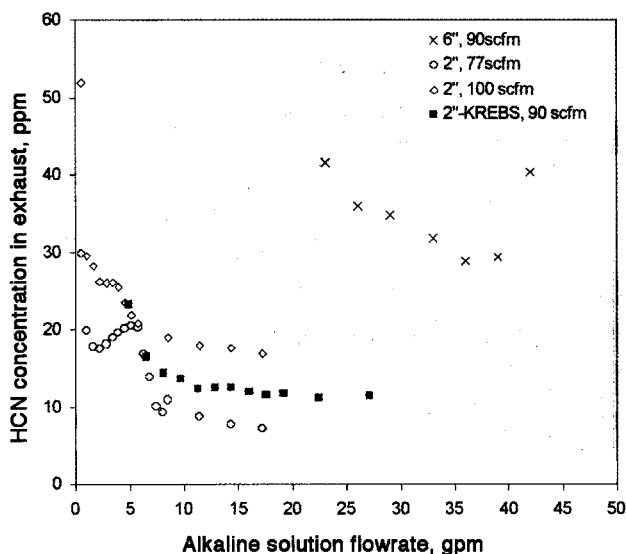

Figure 3 — HCN concentration in exhaust gas vs. flow rate of alkaline solution, with a temperature of 15.5° to 25.0°C and a pH 12.5 to 13.4 for a 50.8-mm (2-in.) ASH, and a temperature of 7.5° to 9.1°C and a pH 13.3 to 13.4 for a 152.4-mm (6-in.) ASH.

equilibrium conditions could not be achieved in a short period of time; therefore, stripping yields smaller efficiencies. In this regard, the *actual removal* was obtained from the difference in cyanide concentration in solution before and after stripping and related to the initial concentration. The *removal efficiency* pertains to the *actual removal* divided by the *theoretical removal* (not shown in Table 2) and represents the process efficiency expressed in percent. For example, in run No. 13 (Table 2) the *actual Q** (214) is approximately equivalent to the *required Q** (206) as determined from the Henry's constant. The *removal efficiency* indicates that the achieved HCN stripping (in less than one second because this is the residence time in the ASH unit) was 35% of the expected value,

Table 2 — Processing conditions and efficiency of HCN stripping in single 50.8-mm (2-in.) ASH unit using stainless steel mesh inserts.

No.	Gas flow rate, scfm	Water flow rate gpm	Stripping temp., °C	pH	Initial CN⁻ conc., ppm	CN⁻ conc. after one pass, ppm	Actual Q*	Required Q*	Actual removal, %	Removal efficiency, %
1	40	3.5	20	4.4	371	292	85	213	21	53
2	42	3.5	20	3.9	406	329	90	213	19	45
3	42	3.5	20	3.9	329	276	90	213	16	38
4	45	3.5	20	4.0	390	328	96	213	16	36
5	71	3.5	21	4.2	385	244	152	206	37	50
6	71	3.5	21	3.0	385	218	152	206	43	58
7	71	3.5	22	2.2	385	250	152	199	35	46
8	77	3.5	21	4.0	380	260	165	206	32	40
9	80	3.5	19	3.9	380	291	171	221	23	30
10	90	3.5	20	4.1	390	276	192	213	29	32
11	90	2.0	21	4.1	385	208	337	206	46	28
12	90	5.0	21	4.1	385	296	135	206	23	35
13	100	3.5	21	4.0	380	244	214	206	36	35
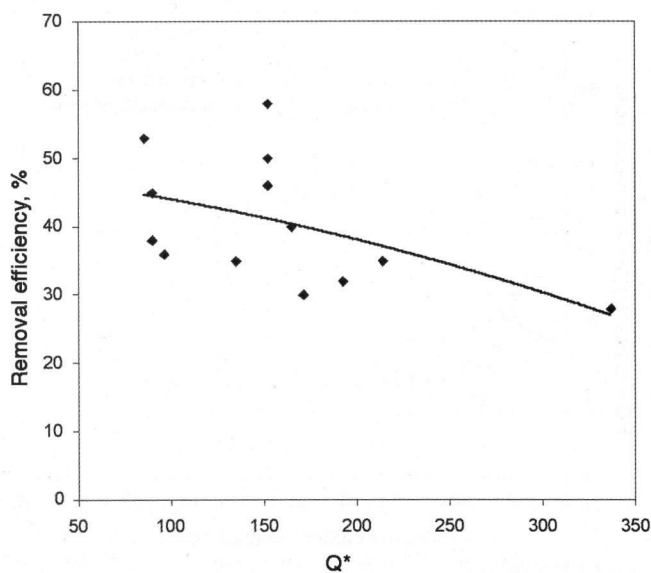
Figure 4 — HCN removal efficiency vs. air/liquid ratio, with an airflow rate of 0.019 to 0.072 m³/s (40 to 100 scfm), a stripping solution flow rate 7.6 to 18.9 L/min (2 to 5 gpm), a stripping temperature of 19° to 22°C and a pH of 2.2 to 4.4.
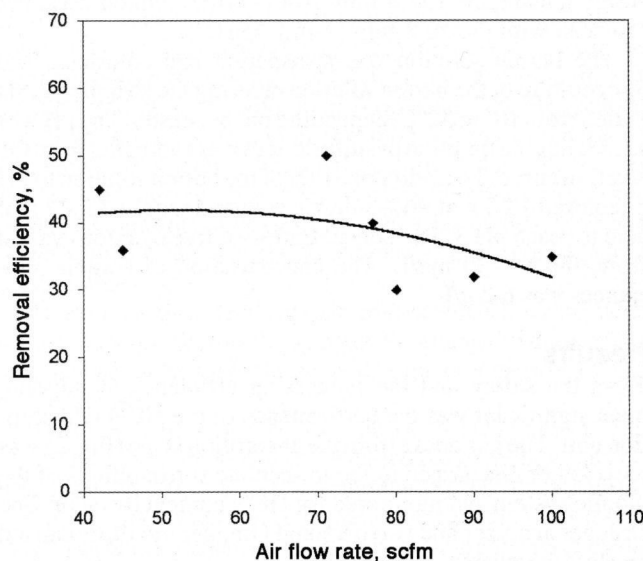
Figure 5 — HCN removal efficiency vs. airflow rate, with a stripped solution flow of 13.2 L/min (3.5 gpm), a temperature of 19° to 21°C and a pH of 3.9 to 4.2.

assuming that equilibrium for the gas and liquid phases was reached.

The data in Table 2 indicate that the maximum *actual removal* reached 46%. For larger Q^*, the *actual removal* of HCN from the barren solution was better. However, an increase of the *actual removal* with increased airflow rate from 0.033 to 0.047 m³/s (70 to 100 scfm) was minimal (a few percent), which does not justify the high airflow rate in the present design of the stripping ASH.

Process efficiency, shown in Fig. 4, indicates that besides Q^* other processing parameters have a firm impact when steel mesh is used as the sparger. Referring to the data in Table 2, most impact can be expected from the stripping pH and the barren solution flow rate. The previously recommended inlet

velocity 6 to 7 m/s, corresponding to a 13.2 L/min (3.5 gpm) flow rate, has confirmed to be an important factor for design purposes. Another set of experimental data is presented in Fig. 5. The removal efficiency depends more pronouncedly on the airflow rate above 0.033 m³/s (70 scfm). Due to narrower pH range (3.9 to 4.2) and neglecting the effect of water flow rate, the scatter of the experimental data is smaller than in Fig .4.

Scaling. The barren cyanide solution contained several grams per liter of dissolved salts. The mill experiences, therefore, severe scaling problems in several areas. It is not surprising that the stripping ASH underwent rapid plugging as well when polyethylene porous tube was used. The plugging rate of the stripping ASH porous tube increased when the airflow rate

was changed from 0.028 to 0.057 m^3/s (60 to 120 scfm). Such dependence, supported by other phenomena, indicates that the mechanism of plugging is evaporation of water at the internal surface of the porous tube. Plugging happened despite removal of all particles less than 1 μm by bag filtration. Plugging was diminished when hydrochloric acid was used for acidification, scale-control chemicals were added to the barren solution and mist of deionized water was introduced with the gas phase to the PE porous tube. Simultaneous application of hydrochloric acid and descalant extended the lifetime of the porous tube for more than 8 hours. However, particularly effective was injection of 3.78 L/h (1 gph) of deionized water to the gas stream.

It should be noted that the 50.8-mm (2-in.) ASH unit, which underwent severe plugging when a polyethylene porous wall was used as the sparger, functioned without any pressure drop increase through the entire week of tests with the new stainless steel insert.

Final remarks

The operating parameters of the absorbing ASH indicate that it can substitute for an absorbing column. Rapid absorption of 99% of HCN from the gas phase can be designed in one stage. Taking into account the fact that HCN reabsorption was carried out in a single ASH, the performance of the unit was exceptionally effective, and its potential for industrial application was shown.

A new design of the stripping cyclone, with tangential inlet for the gas phase and with the use of a mesh screen as a sparger, makes it suitable for contacting voluminous stream of gas with small stream of an aqueous phase.

ASH units equipped with stainless steel sparging inserts were not susceptible to plugging, allowing design of fully automated system.

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