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INNOVATIVE METHODS OF MANAGING ENVIRONMENTAL RELEASES AT MINE SITES

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INNOVATIVE METHODS OF MANAGING ENVIRONMENTAL RELEASES AT MINE SITES

1.0 INTRODUCTION

As a National policy, the Environmental Protection Agency (EPA) is integrating the concept of source reduction and recycling in many of its activities. Both the Resource Conservation and Recovery Act (RCRA) and the Pollution Prevention Act of 1990 (PPA), encourage the reduction in volume, quantity and toxicity of waste. While RCRA focuses primarily on the reduction in volume and/or toxicity of hazardous waste, the PPA encourages maximum possible elimination of all waste through source reduction.

In addition to source reduction and recycling, environmental improvement may come from the development of new and innovative ways to manage wastes and prevent releases. Recognizing that unique issues are associated with the mining industry, such as large volumes of raw materials used and waste generated, EPA has prepared this report to describe source reduction and recycling practices and innovative techniques for waste management currently used in mining. Many of these practices may, in addition to their environmental benefit, realize significant cost savings. It is EPA's intent to identify these practices and foster technology and information transfer throughout the mining industry. In addition, the Agency is seeking additional sites where new and innovative practices or technologies are currently being implemented.

In the Pollution Prevention Act of 1990, Congress defined source reduction as any practice that:

> (i) reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise releases into the environment (including fugitive emissions) prior to recycling, treatment, or disposal; and
>
> (ii) reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants.
>
> The term includes equipment or technology modifications, process or procedure modifications, reformulation or redesign of products, substitution of raw materials, and improvements in housekeeping, maintenance, training, or inventory control.

According to the statute, "source reduction does not include any practice that alters the physical, chemical, or biological characteristics or the volume of a hazardous substance, pollutant, or contaminant through a process or activity which itself is not integral to and necessary for the production of a product or the providing of a service."

This report is organized into the following sections:

Source Reduction,
Recycling,
Other Practices.

In the context of non-coal mining (extraction and beneficiation), source reduction can include process control to produce a purer product while reducing hazardous constituents in a waste stream (Process Control at DOE Run and ASARCO) and production of a new saleable product while reducing hazardous constituents in a waste stream (Pyrite Flotation at Superior Mine). Each of these practices reduces the amount of a hazardous substance being released to the environment and is integral to production of a product. Although the overall reduction of hazards to public health and the environment is not easily measured, improvement is at least incrementally positive in nature. The section on metal parts washing also presents source reduction opportunities.

Recycling opportunities unique to mining include slag reprocessing at San Manual, tailings reprocessing at Pinto Valley and pipe recycling at an IMC Phosphate mine in Florida. Recycling opportunities that are more generic include used oil burned for energy recovery and tire recycling, although these may have unique implementation considerations at mine sites. The "Other Practices" section addresses topics of a more general nature and includes a description of best management practices for water management and the facility pollution prevention plan prepared by the Cyprus Baghdad Mine. Each of these practices may present a better alterative to simple disposal of wastes and, in addition to reducing the threat to human health and the environment, may result in substantial cost savings to industry.

In preparing these reports, EPA collected information from site visits to specific facilities, conversations with interested parties, and from publicly available documents. EPA has not conducted an independent verification of the data. Detailed economic analyses were not obtained due to confidential business information concerns. Each of the subsections of this report were released as separate reports for comment and have been revised accordingly. These reports were first presented to the public at the Pollution Prevention Conference held in Snowmass, Colorado in August, 1993. Two reports initially prepared as part of this effort have not been included in this compendium. EPA found that utilization of used oil in ANFO is not currently practiced, therefore this report has not been presented here. In addition, a report on the INCO cyanide treatment process was prepared; this report has been integrated into another draft report on treatment methods for cyanidation wastes.

To assist with technical questions and issues, a list of technical contacts familiar with each technology is provided, however, this listing is not to be considered an endorsement by the U.S. Government or the U.S. Environmental Protection Agency (EPA).

2.0 SOURCE REDUCTION

2.1 FLOTATION PROCESS CONTROL

An automatic process control system can be defined as any arrangement of sensors, computing elements, and control units designed to minimize the difference between the observed and desired behavior of the process in question. In general, the operator specifies the desired values of process variables as a set of *setpoints*, and the sensors measure the current values of those same variables as a set of numbers describing the *state* of the process. The differences between the setpoints and the current state are known as the *variances*. The computing elements in the control system attempt to minimize the complete set of errors by altering the positions of valves, changing the speeds of motors, or manipulating other variables which may affect the state of the process. Controllers may be as simple as a float valve, which reduces the flow of liquid to a tank as it approaches the desired level. Alternatively, they may involve a host of sensors feeding information to one or more computers which interpret the observed state of the system via detailed models before deciding on a set of appropriate responses. Simple control schemes are usually reliable and easy to maintain. However, they cannot provide the sorts of optimum response to plant-wide upsets that are required in process industries today. The level of control obtainable from a control scheme is generally related to the level of process knowledge incorporated into its design. This report focuses on the application of relatively advanced process control technology to mineral flotation.

Application to Flotation Mills

Flotation mills separate metalliferous minerals from waste rock (gangue) by causing finely ground mineral particles to float to the top of a frothing bath of aerated ore slurry. Surfactants are used to cause air bubbles to attach themselves to the valuable minerals, but not to the gangue. Froth from the final stage of a cascade of floatation cells is dewatered to produce an ore concentrate, which is shipped to a smelter. The goal of flotation mill operators is twofold; they must maximize the amount of material floated to the concentrate, while simultaneously minimizing the concentrate's gangue content. In addition, many of the major resource suppliers have stated their intention of improving environmental quality (e.g., The Doe Run Company, 1987). In order to meet this commitment, the mill operators must also minimize the amount of surfactants and heavy metals in the waste stream fed to the tailings pond. Parameters that may be varied in order to achieve this goal include the rate of addition of surfactants, the rate of sparging of air into the flotation cells, relative pumping rates of overflow and recycle streams within the cascade, and the particle size distribution in the incoming ore slurry. The problems of control are compounded when the ore contains more than one valuable mineral and each must be separated from the others and from the gangue to form a high-purity concentrate. Reliable on-line measurements of metals content at various points throughout the mill is necessary in order to effect control of the operation.

X-Ray Fluorescence

X-Ray Fluorescence (XRF) is an analytical technique designed to rapidly measure the metals content of a sample. When atoms of the heavier metals are bombarded with X-rays, electrons lying in low orbitals close to the nucleus may be ejected. Electrons from the outer shells will jump to fill the gaps, emitting radiation in the form of X-rays. Radiation emitted by electrons in these high-energy transitions is characteristic of the atom and is essentially unaffected by the atom's chemical environment. In a XRF analyzer, the intensities of the emitted X-rays are measured by spectrometers coupled to diffracting crystals. One crystal/spectrometer assembly is provided for each metal to be measured. A typical arrangement for an analyzer in a lead-zinc mill would include assemblies for lead, zinc, copper, and iron. Excitation of the sample is provided by an X-ray tube incorporated in the analyzer. When slurry samples are to be analyzed, the sample is passed through a sample cell. Since fluorescence is a surface phenomenon, the sample cell is designed to induce thorough mixing so that the average metal content determined over the measuring period is characteristic of the bulk sample.

In industrial X-ray analyzers, sample lines are constructed to bring slurry samples from various parts of the mill to the analyzer. A sequencer within the analyzer causes the machine to switch from one sample to the next every 1-2 minutes. The switching may be done by opening valves to feed the desired slurry sample through a single sample cell, or by causing the analyzer unit to move along a line of sample cells depending on the analyzer used. Output from the analyzer is in the form of a digital electronic signal, suitable for input to a computer. Units of this type are marketed in North America.

Evolving Level of Control

In flotation mills without X-ray analyzers, mill operators typically collect slurry samples from flotation cells by hand. They then swirl each sample in a pan similar to those used by gold miners to remove the lighter constituents. Visual inspection of the minerals left behind gives them an indication of the mineral content and the particle size. Armed with this information, they can manually adjust surfactant addition rates and other parameters in order to meet their operating goals. This approach to process control has the advantage of requiring the operators to become intimately familiar with the characteristics of the ore and the behavior of the mill. Over time, the operators collectively become a valuable repository of process information, not all of which can easily be quantified.

In mills with on-line X-ray analyzers, operators can base their responses to process upsets on absolute determinations of the metals content of each stream sampled. In the simplest scheme, the operator reads the output from the analyzer, which is generally updated every 10-15 minutes, and uses that information together with readings from flowmeters and level gauges in making manual adjustments to valve settings and motor speeds. Few, if any, mills with X-ray analyzers operate in this manner. In most cases, the operators establish setpoints for low-level controllers which regulate flowrates and levels as desired. In the next stage of development, the low-level control loops are implemented in software by a central process control computer, which also provides a visual display of the state of the mill. This level of control is the focus of this section of the report. At the present time, some mills are moving to a more advanced approach in which the central computer uses historical data and/or a detailed model of the total process to establish new setpoints automatically. This is typically referred to as an expert system. The operator may override the computer when necessary, or may alter the process model. The same sequence of developments has occurred in many other sectors of industry, including power generation, oil refining, and chemical manufacturing.

A large number of companies market process control hardware and software for a variety of applications. X-ray analyzers can be interfaced with hardware from most of these companies. Some purchasers may appreciate the possibilities made available by buying components from more than one company. Others may prefer to purchase an integrated package from a manufacturer that specializes in mining applications.

Review of Current Implementation

Figure 1 shows the main features of the control scheme implemented at the Doe Run Fletcher mill. The arrangement reflects the mill circuit as of November, 1992. The facility beneficiates a mixed sulfide ore that averages 5.5% galena (PbS), 1% sphalerite (ZnS), and 0.3% chalcopyrite ($CuFeS_2$). Gangue minerals include dolomite, calcite, pyrite, and marcasite. The ore is extracted by underground mining, and lead content may vary by 50% over a short period of time. The mill has only one ore feed from the mine to the grinding circuit, providing limited buffering of variations in mine output. The flotation system must therefore be capable of adjusting rapidly to cope with substantial changes in feed composition.

Coarsely crushed ore from the underground primary crusher is stored in a single ore bin on the surface. Ore from the bin is fed to a secondary cone crusher. The temperature inside the crusher, the pressure on the cone, oil pressure, and electric power consumption are monitored to ensure that it is operating within its mechanical limits. Crushed ore is fed to a rod mill, together with water and flotation reagents. The flotation reagents introduced at this point are a xanthate collector to float sulfide minerals, zinc sulfate ($ZnSO_4$) to depress sphalerite (ZnS), and sodium cyanide (NaCN) to depress pyrite (FeS). The rate of addition of these components is monitored by flowmeters on each line and controlled by pneumatically driven valves. Each valve is connected to a pressure/current (P/I) converter, which receives a 4-20 mA analog signal from the process control computer. Output from the rod mill goes to a cyclone. Oversize material falling through the cyclone is reground in a ball mill. Material leaving the grinding circuit averages 53% <200 mesh. This stream passes through a nuclear density gauge and a particle size monitor before entering the first flotation unit. A sample of this slurry is drawn off every 10 minutes and fed automatically to a XRF analyzer.

The feed slurry is fed together with a frothing agent to the lead rougher cells. Air is sparged into the cells from below. The lead rougher consists of two sets of three cells; each set has its own pulp level control. In each of the two control loops, pulp level is monitored by a float. The position of this float is input to a simple Proportional-Integral-Derivative (PID) controller, which adjusts the position of a dart valve within the cells. The tailings stream leaving the lead rougher is assayed by the XRF analyzer. The froth collected in the launder is fed to a lead cleaner and recleaner cells. The cleaner is equipped with pulp level control, but the recleaner is not (pulp level control is to be added to the recleaner in the future). Tailings from the cleaner are recycled to the rougher.

Overflow from the recleaner launder is piped to a lead-copper absorber unit. Sulfur dioxide, starch, and caustic soda are added at this stage to depress the floatation of galena while allowing the chalcopyrite to float in the copper circuit. The copper circuit is run as warranted to separate chalcopyrite from galena. Slurry leaving the absorber is fed to the copper rougher. Overflow from this unit is piped to the copper cleaner and thence to the recleaner. Each of these units has automatic pulp level control. Sodium dichromate is added between the cleaner and recleaner to depress galena. The tailings stream from the copper rougher is assayed by the XRF analyzer before entering the lead thickener. In the thickener, the suspended solids settle out to form a lead concentrate. A level indicator and a torque indicator are mounted on the shaft of the thickener rake. The level indicator gives some indication of the depth of settled material and the torque indicator provides warning should the rake begin to seize. The lead concentrate is dewatered on a rotary vacuum filter. Filter cake is collected in a bin which is mounted on a load cell. Froth leaving the copper recleaner is similarly thickened and dewatered to produce copper concentrate.

The zinc flotation circuit is fed by tailings from the lead rougher. Ammoniated cupric chloride is added to activate the previously depressed sphalerite before the slurry enters the zinc rougher. Frothing agent and additional collector are also added at this point. Tailings from the rougher are assayed by XRF and pumped to the tailings pond. The zinc circuit differs from the other two circuits in that cleaning is performed by a pair of air-sparged column cells. Differential pressure is measured at three levels within each of the cells. The pH is monitored on the first column. Lime may be added to the rougher launder if the pH is too low. Froth from the second column is assayed before being thickened and dewatered to form zinc concentrate. Copper and zinc concentrates are produced using the same filter. Since copper is a minor constituent of the ore, the filter is devoted to zinc concentrate production for most of its operating hours.

Assay data from the XRF unit is sent to a process control computer. Flowmeter readings from all of the reagent addition lines are also sent to the computer, as are the outputs from the particle size monitor on the grinding circuit, the pH meter on the zinc circuit, outputs from the thickener level and torque indicators, and the concentrate bin load cells. The computer also receives signals representing the position of the valves on each reagent line. The computer displays most of this data on an operator console in the mill control room. Based on the data presented, the operator can vary the reagent addition rates to try to obtain a better separation among the minerals. Warnings of abnormal conditions are also displayed on the console. An example of the computer printout for the Fletcher mill from September 23, 1991, is presented in Figure 2. The report shows recoveries of lead and zinc from the ore feed to be 97.22 percent, and 76.29 percent, respectively. Because of the low copper content in the feed assays, the copper circuit was not running on this day. The computer system maintains an archive of the systems's state as a function of time. Electric motors, including those on pumps and blowers throughout the mill, are controlled by a motor control center. With appropriate controller cards, the computer could also be used to control the speeds of some of these motors. Where the historical behavior of the mill has been recorded and analyzed, mill managers can specify empirical formulae relating reagent needs to assay results.

The ASARCO Sweetwater mine extracts a lead/zinc/copper ore similar to Fletcher's mine. The mill currently beneficiates only lead and zinc minerals, but is planning to add a copper circuit in the near future (the ore averages 0.3 to 0.4 percent copper). The mill through put is 290 tons per hour nominally, and operates four days per week. The Sweetwater mill has two fine ore bins. Each bin has three feed hoppers from which the mill selects ore. This ability gives the operator more control in preparing a uniform feed to the grinding and subsequent flotation circuits. A more uniform feed to the flotation circuit improves recovery. The system, with information from the XRF, provides immediate warning of changes in ore grade and allows the operator to respond by adding or reducing reagents as needed.

Figure 2. Fletcher Mill Daily Report

(Source: The Doe Run Company)

DAY ENDING
24-SEP-91 06:30

ROD MILL RUN TIME:	11.40	HRS	% OPERATING TIME:	47.5
TONS MILLED (WET):	2645	TONS	% COPPER CIRCUIT ON:	56.0
MILLING RATE:	232.1	TPH		

	ASSAYS				DRY TONS	RECOVERIES			
	%PB	%ZN	%CU	%FE	PRODUCED	%PB	%ZN	%CU	%FE
FEED	6.07	0.46	0.08	1.52	2566.1				
PB CONC	81.07	0.72	0.46	1.51	170.2	97.22	9.87	37.51	6.51
ZN CONC	3.89	54.79	1.14	2.66	14.5	0.37	76.29	8.63	1.42
CU CONC	4.14	0.23	29.67	27.62	0.0	0.00	0.00	0.20	0.01
TAIL	0.21	0.15	0.05	1.52	2383.8	2.46	13.75	52.58	91.79
					2568.6				
BACK CALCULATED									
BULK CONC	81.32	0.62	0.45	1.39	7.3	TPH			
ZINC FEED	0.66	0.46	0.06	1.53	102.7	TPH			

	PB REAGENTS			ZN REAGENTS			CU REAGENTS	
	cc/min	lb/ton		cc/min	lb/ton		cc/min	lb/ton
XANTHATE	313	1.53	3894	12	3.24	STARCH	4103	2.51
ZNSO4	1151	345.60	CUSO4	108	36.15	DICHROMATE	368	0.56
NACN	58	0.0083	DICHROMATE	484	6.43			
FROTHER-PB	60	0.061	FROTHER-ZN	37	0.404	pH/SO2	5.67	

	MINIMUM ASSAYS					MAXIMUM ASSAYS				
	%PB	%ZN	%CU	%FE		%PB	%ZN	%CU	%FE	
FEED	3.44	0.11	0.04	0.43		9.46	0.81	0.14	1.93	
PB CONC	75.57	0.34	0.09	0.96		82.77	1.74	1.05	6.44	
ZN CONC	1.67	48.86	0.67	0.58		7.02	57.89	4.38	7.42	
CU CONC	3.45	0.20	29.12	27.47		4.15	0.25	30.18	27.96	
TAIL	0.10	0.03	0.01	0.82		1.90	3.70	0.14	1.74	
RECOVERIES	94.42	26.40	0.00	0.00	TPH	97.90	84.50	16.01	264.2	TPH

COURIER 30	PB	ZN	CU	FE	SO	PB	ZN	CU	FE	SO
NORM FACTOR	0.9677	0.9832	0.9527	0.9800	0.9396	1.0571	1.0544	1.0386	1.0413	1.0338
H2O DIAGNOS	17.3	10.9	5.8	7.3	68.7	251.5	73.5	27.2	30.2	1380.7

Table 1. List of Measured Variables Monitored by the System at ASARCO's Sweetwater Mill
(Source: ASARCO)

Description	Range	Description	Range
Rod Mill Feed	0 - 400 TPH	Copper Sulfate	0 - 2100 cc/min
Rod Mill Water (Fisher valve, Honeywell flowmeter)	0 - 750 GPM	Zinc Sulfate	0 - 6000 cc/min
Sump Level (Mittronics)	0 - 100 %	Crusher Tonnage	0 - 100 TPH
Sump Water (Mittronics Sonic Ear)	0 - 1500 GPM	Cyclone Feed Density (Texas Nuclear)	1.000 - 1.875 S.G.
Flotation Feed Density (Texas Nuclear)	32.0 - 47.0 % solids	Cyclone Feed Flow (Fisher Porter)	0 - 500 GPM
Lead A Tub Level	0 - 100 %	Particle Size (Autotronics)	5 - 25 % 100 MES
Lead B Tub Level	0 - 100 %	Particle Size (Autotronics)	0.0 - 55.0 % Solids
Zinc Tub Level	0 - 100 %	Secondary Crusher Motor	0 - 75 Amps
Lead Cyanide	0 - 1000 cc/min	Tertiary Crusher Motor	0 - 75 Amps
Zinc Cyanide	0 - 300 cc/min	Rod Mill Motor	0 - 300 Amps
Lead Xanthate	0 - 1920 cc/min	Ball Mill Motor	0 - 300 Amps
Zinc Xanthate	0 - 500 cc/min	Cyclone Feed Motor	0 - 300 Amps
Lead Frother	0 - 200 cc/min	Final Tail Motor	0 - 300 Amps
Zinc Frother	0 - 120 cc/min	Speed Hydrastroke	0 - 100 %

Information provided by the ASARCO Sweetwater mill was limited due to Company proprietary information. Consequently, only information pertaining to integration with existing equipment and inputs and outputs to the process control equipment are discussed here. Measured variables (inputs and outputs) for the system are listed in Table 1. When known, the type of sensor and manufacturer are identified. In addition to these variables, five samples are pumped to the XRF analyzer every 10 minutes. The relative concentrations of metals are then sent from the analyzer to the system. The first sample is taken from the cyclone overflow before it inters the lead circuit. The second sample is taken from the lead scavenger tailings prior to entering the zinc circuit. The third sample is from the second lead cleaner launderer. The two remaining samples for XRF analysis are taken from the second zinc rougher tails and the third cleaner tail. Two additional sampling points will be added when the copper circuit comes on line.

Operational Requirements

Use of an on-line X-ray analyzer coupled with a process control computer greatly simplifies the operation of a mill. One mill required 24 operators, 3 engineers, and 3 supervisors before this technology was introduced. It now requires about 8 staff to operate. Some additional skills are needed to use the new technology effectively. The mill managers should have some familiarity with the basic concepts of computer programming in order to be able to customize the software to their best advantage. The XRF unit is very reliable. From time to time, X-ray tubes will degrade and must be replaced. The mill will need to stock a variety of spare parts for sensors and control elements. Most of the electronic signals both to and from the computer are in analog form, and maintenance of the wiring will not present any difficulty to an industrial instrument technician.

Costs and Benefits

Benefits associated with process control technology may include the following: 1) a decrease in reagent consumption as a result of rapid response in reagent addition rates in accordance with mill feed grade and throughput fluctuations; 2) a stabilized process resulting in increases in the amount of lead and zinc produced through higher metal recoveries (constrained by concentrate grade); and 3) more effective grinding control which would allow an increase in mill tonnage throughput (Jones 1991, Heitman, undated). The reduced use of reagents is viewed as an environmental benefit. Further, since more metal is recovered using this system the ratio of waste to final product has been reduced.

Installation

Purchase and installation of the process control system for the Fletcher mill cost approximately $600,000 in 1989. Only a limited amount of additional money was spent on training because many of the staff had already worked with the system at the Buick mill. The actual installation was completed by Doe Run personnel.

Integration with Existing Facility

The process control system at the Fletcher facility was installed between 1989 and 1990. The Doe Run Company had gained experience with the use of X-ray analyzers and process control at their Buick mill facility. The Buick mill installed a computerized process control system in 1981, using a XRF unit and a computer system. Construction of the control system at Buick required much time and effort. Once the Buick system was completed, transferral of the technology to the Fletcher mill was relatively straightforward.

Operational Requirements

Prior to the installation of the control system, operation of the mill required 3 operators and 1 supervisor per shift. Currently they are using 2 operators and 1 supervisor per shift. The reduction in staff needs was much more dramatic at Buick, where the mill is larger. Other requirements, such as energy, are negligible. Doe Run maintains a stock of parts for all their mill facilities on the Trend totaling $200,000 to respond to equipment failures. Most of these are sensor parts; the balance are X-ray tubes and computer equipment.

Benefits

The new control system has allowed Doe Run to obtain a better separation of metalliferous minerals from gangue. This means, in principle, that lesser amounts of gangue and other wastes are being sent to the smelter. There is also a slight reduction in the average metal load disposed of in the tailings impoundment. From the operators' point of view, the new system has made it easier to respond smoothly to sudden changes in ore grade. The main benefit perceived by the company is an economic one: the metal concentrates are of higher purity than they were before the mill was modernized. Costs savings are summarized as follows:

- Reduced reagent costs by 14 percent per year, saving $75,000,
- Improved lead metallurgy by $100,000 per year,
- Improved zinc metallurgy by $330,000 per year,
- Improved copper metallurgy by $270,000 per year.

These amount to a total annual savings of $785,000 (Jones 1991). Savings in labor costs were not identified.

Waste Reduction

Use of the control system has resulted in production of higher quality concentrates being sent to the smelter. Thus, by reducing the gangue content of the final concentrate, the volume of slag generated at the smelter is reduced. In addition, Doe Run estimates that the metal concentration in the tailings waste stream was 0.2 percent before the process control system was installed. The average metal concentration in the tailings now is 0.15 percent. This amounts to a reduction of 4,500 to 5,000 pounds of metal entering the tailings pond per day.

Limitations

The use of on-line XRF analysis and computerized process control will not necessarily solve all of a mill's control problems. The XRF unit determines the total content of each metal in a stream. In some cases, the same metal may be present as two different minerals which behave differently in the flotation cells. Such a situation could occur in copper mines, where both sulfide and oxide ores are encountered. It may be necessary to use another type of probe to obtain additional information about the feed before determining the required dosage of reagents.

Future trends in flotation mill control seem to be in the direction of incorporating more and more of the mill functions into a centralized control scheme and toward the use of expert systems. Many mill owners who have invested in a centralized control system initially configured it to control reagent addition rates based on

XRF assay data. These are the most critical parameters affecting the flotation process. Some of these owners are now planning to add additional control loops, for example, motor speed control and pulp level control to their process control system.

For mill owners who have built up an archive of operating data, the use of an expert system may offer new possibilities. An expert system is a software tool that can be interfaced with the mill control software. Based upon analysis of historical operator responses to changes in the behavior of the mill, the expert system can propose a set of responses to a new situation. The operator can then choose to accept the system's judgement or try an alternative course of action. Over time, the system builds an increasingly reliable empirical model of the process in the form of rules and equations. In theory, the system should allow novice operators to benefit from all of the accumulated wisdom of their colleagues. However, effective use of an expert system requires a commitment on the part of both mill managers and operators to work with the system on a regular basis until it has been "trained" sufficiently.

Conclusions

Process control is applicable and probably advantageous to many milling systems requiring continuous monitoring. The benefits include better information, and thus control of a mill, depending on the level of instrumentation available. Examples presented here relate specifically to flotation of lead/zinc/copper ores. Different sensors may be more suitable for monitoring other mill systems. Process control equipment is particularly well suited to underground mines where the ore grade received by the mill is variable. On-line monitoring of mill feed allows quick, and in some cases instantaneous, response to changing feed grades. In a simple cost/benefit analysis, the facilities visited to prepare this report suggest that payoff can occur quickly with increased concentrate quality and reduced reagent consumption.

Environmental benefits can also be realized. While the metal load to the tailings impoundment was reduced in one of the facilities visited, the reduction was marginal compared to the total volume generated per unit time. Greater reductions in wastes are seen at the smelter, where a higher purity concentrate generates less waste in the form of slag. Also, the reduction in reagent usage is significant and has its own benefits in the form of costs savings and a reduction in the total waste stream either to the tailings impoundment or the smelter. The facilities visited contend that the reagents stay with the concentrate (adhering to the mineral surfaces) and do not generally end up in the tailings impoundment.

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EPA Response to Comments

The Doe Run Company submitted comments on this report, requesting minor editorial changes. EPA responded to these comments and revised the report.

The U.S. Bureau of Mines submitted comments, which have been addressed as appropriate.

2.2 PYRITE FLOTATION

At the Superior Mine in Superior, Arizona (Figure 3), Magma Copper Company is currently producing a high grade pyrite product by subjecting copper tailings to an additional flotation circuit. Instead of generating a tailings high in sulfide, the facility produces less reactive tailings and two products, a fine micronized pyrite (99% iron disulfide) and a coarse pyrite concentrate (45 - 47% iron and 48 - 50 % sulfur). The pyrite products are packaged and sold for a variety of uses.

The ore body is a vein deposit, and according to facility personnel, has one of the highest copper concentrations of any ore mined. The ore body is unique, with total copper concentrations of 4.32 to 4.48 percent, compared to other copper mines in Arizona where the total copper concentration average is 0.58 percent for the same time period[1] (Arizona Department of Mines and Mineral Resources 1990). Another factor making the ore body unique is its pyrite content. Most copper operations are typically mining ore with up to 5 percent pyrite; on the other hand, the Superior ore body has as much as 25 percent pyrite. According to facility personnel, the ore has little or no impurities which also contributes to its uniqueness. Specifically, the ore is high in pyrite (FeS_2) with little or no arsenopyrite (FeAsS) and unusually low concentrations of heavy metals other than copper. This allows a high quality pyrite product to be produced containing little or no undesirable heavy metals.

Mining was conducted at the facility from 1912 until 1982 when the mill and mine shut down due to depressed copper prices. The mine was reopened in 1990. Current underground mining uses the undercut and fill method and is conducted at the 3400 - 4200 levels. Present production is 1000 tons of ore per day which yields 50,000 tons of concentrate per year. From this, approximately 15,000 tons of copper is produced annually. The volume of pyrite produced was not available. Gold and silver by-products are also produced from the Superior Mine operations (6300 and 275,000 ounces, respectively) (Magma Undated).

Figure 3. Map of the Superior Mine and Mill
Source: Geologic Map of Superior Mining Area, Arizona
Arizona Bureau of Mines, 1943

General Description

In 1986, while the mine remained shut down, Magma started a unique pyrite flotation circuit using existing equipment to remove pyrite from tailings at the site. In August of 1990, the mine re-opened and the operation re-started copper production. At this time, the feed to the pyrite flotation was changed from old tailings to the newly generated tailings as they exit the copper flotation circuit, with no other operational changes in the pyrite flotation operation. In either case, this operation served to recover as a saleable product, a material (pyrite) typically discharged as a component of waste. Currently, the operation of pyrite flotation is demand

[1] Reported for the years 1980-1982, when Superior was operating. The average is the weighted average grade of ore milled, based generally on an assay of total copper.

driven, with the pyrite circuit used only as needed to meet the demand for the pyrite product. At other times, the pyrite is discharged with the tailings to the tailings impoundment.

Magma produces pyrite in two sizes. The coarse pyrite product (+200 mesh) is sold in 50, 100, and 200 pound bags for use in the steel and glass industries. The fine, micronized pyrite is pulverized to 50 percent passing 2.34 microns and sold for use in the manufacture of grinding wheels. At times, pyrite is also sold in bulk form.

Pyrite, (FeS_2) easily oxidizes to form sulfuric acid and, at many mine sites, is associated with acid generation from tailings piles and other mining activities. Removing the pyrite prior to discharging the tailings will decrease the potential for acid generation from tailings, which may in turn, minimize possible waste treatment and remediation costs. These activities can be conducted while generating additional income for the facility. Because this facility is currently operating the pyrite flotation circuit on an as needed basis to supply demand, pyrite-bearing tailings are discharged periodically to the tailings impoundment. A description of the technical aspects of the pyrite flotation operation is provided below.

Pyrite Flotation and Drying

The pyrite flotation operation at Superior uses pre-existing equipment. The system manipulates the pH of a normal copper flotation operation in order to float pyrite. After first adding collectors and frothers and raising the pH to depress pyrite and to concentrate copper (typical practice), Magma adds sulfuric acid to drop the pH of the copper tailings, making the pyrite float. According to facility personnel, the tailings generated after pyrite flotation are primarily hematite. Using existing equipment idle during the mill shutdown, Magma purchased little new equipment other than a holoflight furnace for drying the pyrite concentrate. The same operation was used to float both the old tailings and to float tailings currently being generated. Presented below is a detailed description of the flotation operation in the context of current operating procedures.

Ore is mined underground and then brought to the surface for processing. The ore is crushed and ground to 70 percent passing 200 mesh and sent for initial copper flotation. The copper froth flotation circuit is similar to that used at most other copper flotation facilities, with both rougher and scavenger circuits. The Superior operation uses Minerec (M200) as the collector and MIBC as the frother. The equipment used for this initial copper flotation consists of standard froth flotation cells installed at the facility in the 1970s. The estimated capacity of the Superior copper operation is 42,000 short tons of recoverable copper per year[2]. Available data from 1980 and 1981 set copper recovery efficiencies at approximately 95% and 93% respectively (Arizona Department of Mines and Mineral Resources 1990). Data on current copper recovery efficiencies and the number of flotation cells in use for copper were not obtained.

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[2] Represents an estimate of the productive capacity of primary recoverable copper in concentrates, precipitates and cathodes based on historic production figures and capacity of concentrator. Does not represent smelter or refinery capacity.

The tailings from the scavenger copper flotation circuit are discharged to a cyclone where sands are separated from slimes. When the pyrite flotation is not operating, the copper tailings sands go to the underground mine area and the tailings slimes are discharged to the tailings impoundment. When the pyrite flotation is in operation, the tailings sands, which are the underflow of the cyclone, go to the pyrite flotation circuit.

The pyrite flotation circuit is similar to the copper flotation circuit and uses existing flotation equipment, which was available due to over capacity of the mill compared to the current rate of mining. To produce pyrite concentrate, Magma introduces the copper tailings sands into standard flotation cells, adding water, additional flotation reagents (the same reagents used in the copper flotation circuit) and sulfuric acid (See Figure 4). The sulfuric acid causes the pH of the copper tailings to drop from the pH of 11 or 12 used for copper flotation to a pH of 5.5. At pH 11, pyrite is depressed and does not float, making concentration of the copper possible; however, as the pH drops below 9, pyrite begins to float. At pH 5.5, pyrite is no longer depressed and floats in a manner similar to copper. In the pyrite flotation operation, Magma uses seven 100-cubic foot flotation cells in the rougher circuit and two 50-cubic foot flotation cells in the cleaner circuit. According to facility personnel, the rougher circuit discharges tailings for disposal and provides a pyrite concentrate product with 48 to 50 percent sulfur. The pyrite flotation tailings are primarily hematite although specific constituent analysis was not obtained. Adding the cleaner circuit produces a pyrite concentrate of 99 percent purity, with underflow or tailings from the cleaner circuit directed back to the rougher circuit for additional flotation. The pyrite removal efficiency of the flotation circuits was not obtained.

Once pyrite concentrate exits the flotation circuit, it is pumped to a settling pond for dewatering. Retention time for concentrate in the pond was not determined. As the pyrite dries, it is excavated from the pond and sent to the plant, where it is dried, sized, and bagged for sale. Equipment at the plant reflects the only capital expenditure for this project, with the purchase of a "used" holoflight dryer, "used" bagging equipment, and design and development of pulverizing equipment. The holoflight dryer, where a large internal screw pulls material through a heated compartment, dries the concentrate to four percent water content. The coarse pyrite concentrate product, separated from the fines by screening, is immediately bagged for sale while additional grinding takes place to produce the fine concentrate product. The fine concentrate is produced by pulverizing or "micronizing" the finer particles to 50 percent passing 2.34 microns, with the overall size specification range of 1.9 to 3.1 microns. This material is sorted and bagged, with special care taken to avoid the addition of moisture. At this grain size, pyrite is a hazardous material because it is flammable and will ignite with the addition of moisture. Specific details on the micronizing operation were withheld due to confidential business information concerns.

The coarse pyrite products are bagged in 50, 100 or 200 pound bags and in some cases coarse pyrite is sold in bulk form where the pyrite is loaded directly onto the customer's truck. Fine pyrite product is containerized under special conditions (due to flammability) into 30-gallon drums.

The copper flotation circuit operates on a 10 and 4 schedule (10 days on, 4 days off) with maintenance conducted while the mill is down. Operation of the pyrite circuit is dependent on product demand; the specific operating frequency was not obtained. Drying and bagging the pyrite concentrate typically occurs 5 days per week with overtime during the wet season due to the increased drying time necessitated by weather conditions. Magma sells a total of approximately 500 tons of pyrite concentrate per month. The majority of the pyrite product is sold through a broker.

Costs

Magma initiated the pyrite flotation project using existing flotation equipment and limited capital investment in a "used" dryer and bagging system. The only new equipment purchased was that used for "micronizing," sorting and packaging the fine concentrate product. Details on capital and operational cost, as well as revenues, were withheld due to confidential business information concerns on the part of Magma; however, the existing equipment and characteristics of the ore and available tailings were significant in making the project financially feasible.

According to facility personnel, no special permitting requirements or compliance costs are associated with the project and some savings were potentially realized by cutting down on tailings water treatment costs by reducing the amount of tailings and tailings discharge water that is treated under the facility's existing NPDES permit.

Figure 4. Pyrite Flotation Circuit Flowsheet
Source: Magma 1992

Benefits

Conceptually, the pyrite flotation operation provides the opportunity for benefits, both financially and environmentally. Magma sells approximately 500 tons of pyrite concentrate per month. The price of the concentrate and other information on costs and revenues generated by this operation were withheld due to confidential business concerns. However, according to facility personnel, financially "breaking even" with the pyrite flotation project is a satisfactory result because of the resultant savings or avoidance of waste treatment costs associated with acid generation caused by the pyrite in the tailings. Specific waste treatment costs and the amount of saving generated by avoiding those costs was not obtained.

With respect to environmental benefits, removing pyrite prior to discharging tailings may serve to prevent acid generation by removing one of the agents of acid drainage. Because the Superior facility is currently operating the pyrite flotation circuit on an as needed basis to supply demand, details on the effectiveness of this operation in preventing acid generation typically associated with high sulfide tailings were not available. Data on the removal efficiency of the pyrite flotation, the amount of pyrite remaining in the tailings after pyrite flotation, the frequency of operation of the pyrite flotation circuit, the rate of flow through the pyrite flotation circuit, and the total amount of tailings generated compared to the amount of tailings subjected to pyrite flotation were not obtained.

Limitations

Limitations to Technology Transfer

According to facility personnel, the Superior pyrite operation has some unique characteristics that make it especially feasible to float and produce pyrite as a product. According to facility personnel, one of the main factors is the uniqueness of the Superior Mine ore. At most copper mines, pyrite concentration in the ore is on the order of 5 percent, with pyrite in the Superior ore reaching as high as 25 percent. The lower pyrite concentrations in other ore may make pyrite flotation more difficult and at the least, relatively more expensive. In addition, according to facility personnel, the Superior Mine has a unique ore in that there is little or no arsenopyrite and other heavy metal constituents in the ore, making it simpler to produce a purer product. With the above described flotation operation, the fine pyrite is 99 percent iron disulfide (pyrite, FeS_2), with 0.2 to 0.3 percent silica (quartz) and less than 1 percent of remaining constituents (Magma 1992a). Specific constituent concentrations were not obtained.

Another potential limitation to wide implementation of the type of operation practiced at Superior Mine includes the fact that the operation is demand driven. The operation removes pyrite only from a portion of the copper flotation tailings (exact amount not obtained). According to facility personnel, some marketing studies show that Magma may have cornered approximately 90 to 95 percent of the U.S. pyrite market. Although removing pyrite from tailings by flotation may be a viable option to prevent or minimize acid generation at certain sites, managing the concentrated pyrite may become an issue. Managing large volumes of concentrated pyrite may pose challenges in terms of containment and final disposition. Information on other uses or markets for pyrite or its derivatives was not obtained.

Site-specific Technical Issues

The specific technical problems or limitations of Magma's Superior pyrite operation include the holoflight dryer. Because the pyrite is extremely abrasive, the stainless steel screw in the holoflight dryer receives excessive wear that causes the dryer to require a lot of maintenance. In addition, during the wet season, use of the drying operation approaches its design limits. With drying capacity identified as a major concern by facility personnel, the first major change in the system would be to revise the drying procedures. Additional technical considerations include managing the fine pyrite concentrate, due to its ignitability when in contact with water or in high dust conditions. The availability of equipment, such as excess flotation circuits, at other facilities would also be a factor in determining suitability.

Conclusions

In 1986, Magma started a pyrite flotation circuit to recover the pyrite as a saleable product; the operation used existing equipment to remove pyrite from existing tailings and from newly generated tailings. Prior to this development, pyrite was typically discharged as a component of the waste. Production of pyrite generated additional income for the facility.

With respect to environmental benefits, removing pyrite prior to discharging the tailings may reduce acid generation in tailings. At the Superior Mine, data on the removal efficiency of the pyrite flotation, the amount of pyrite remaining in the tailings after pyrite flotation, the frequency of operation of the pyrite flotation circuit, the rate of flow through the pyrite flotation circuit, and the total amount of tailings generated compared to the amount of tailings subjected to pyrite flotation were not obtained. Because the operation is demand driven, with the pyrite circuit used only as needed to meet the pyrite demand, tailings containing pyrite continue to be sent to the tailings impoundment. As a result, details on the effectiveness of this operation in reducing acid generation typically associated with high sulfide tailings were not assessed.

According to Magma personnel, they have secured the majority of the U.S. pyrite market with sales of approximately 500 tons per month. However, at the Superior Mine financially "breaking even" with the pyrite flotation project may be a satisfactory result because of the resultant savings or avoidance of waste treatment costs or remediation associated with acid generation potentially caused by the pyrite in the tailings. Although removing pyrite from tailings by flotation may be a viable option to prevent or minimize acid generation at certain sites, managing the concentrated pyrite will still need to be addressed.

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EPA Response to Comments

Magma Copper Company submitted written comments on this report to EPA in a letter dated July 6, 1993. Magma requested that minor editorial changes be made to correct factual information regarding their operations. EPA corrected the draft to incorporate all of Magma's recommended changes. The U.S. Bureau of Mines submitted comments on this report, which have been addressed appropriately.

2.3 METAL CLEANING TECHNOLOGY

Metal parts cleaning is a surface preparation process used to remove organic compounds, such as grease, waxes, soils, metal fines, fluxes, and oils from the surface of parts made of metal such as diesel engine or electric motor parts. The predominant chlorinated solvents used in metal cleaning are trichloroethylene (TCE), methyl chloroform, perchloroethylene, methylene chloride, and CFC-113 (D'Ruiz, 1991).

Competing alternatives for reducing chlorinated solvents in metal cleaning operations include control practices such as solvent conservation and recovery, and alternative cleaning processes that use non-chlorinated solutions (D'Ruiz, 1991). Conservation and recovery has evolved into a logical short-term response to a chlorinated solvent supply that is rapidly diminishing due to increased regulation. Since alternative cleaning solutions are subject to less regulation and appear to exhibit less harmful environmental and human health effects than chlorinated solvents, their use will most likely continue to increase. In fact, many industries that rely on metal parts cleaning are switching from chlorinated solvents to alternative cleaners.

In addition, many metal parts cleaner manufacturers produce non-chlorinated cleaning solutions for use in their cleaning equipment. These companies are promoting their cleaners as environmentally compatible alternatives to chlorinated solvents currently used in the metal cleaning industry. Non-chlorinated cleaners can be grouped in two general categories: semi-aqueous and aqueous cleaners.

Semi-Aqueous Cleaners

This section briefly describes the two categories of semi-aqueous cleaners: terpenes and hydrocarbons.

Terpene Cleaning Solutions

Terpenes are chemical compounds extracted from plants such as the bark of trees or citrus fruit skins. While possessing excellent solvency characteristics, there are factors, such as safety that must be considered. In general, terpenes cannot be sprayed in an open tank because the vapor has a relatively low flashpoint. This generally limits open tank liquid heating to 100 F degrees or less (CFC Alternatives, July 1991). In addition, terpenes are not as easily recycled as aqueous cleaners. (Waste Reduction Resource Center, August 1992)

Hydrocarbon Cleaning Solutions

Hydrocarbons, usually combined with a surfactant and rust inhibitor, are effective in removing soils, coolants, greases, and waxes. These compounds can be effectively recycled. But, like terpenes, all hydrocarbon cleaners have low flash points that must be considered and planned for in equipment selection. (Waste Reduction Resource Center, August 1992)

Aqueous Cleaners

Aqueous cleaning is a process that combines the cleaning action of a water-based cleaning solution with some type of mechanical cleaning action. Aqueous cleaning technology is widely available and used by many types of industries to clean metal parts. Aqueous cleaning is currently viewed as a viable alternative to solvent-based cleaning because the majority of aqueous cleaning solutions are not formulated with solvents and do not result in solvent emissions. (D'Ruiz, 1991)

Chemical detergents used in aqueous cleaning are available in many different formulations and may also be custom formulated for particular applications. Formulations may be powders or liquids that are added to water in concentrations that depend on the formulation and the cleaning application. These detergents are available from aqueous cleaning equipment manufacturers as well as from companies that specialize in formulating cleaning solutions. The size of equipment and type of cleaning (automatic or manual) depend on the operation and the degree of cleanliness needed. Aqueous cleaners can be grouped into three categories: acidic, emulsion, and alkaline.

Acidic Cleaning Solutions

Acidic cleaners are commonly used to remove rust and scale, but can also be used to remove oxides, flux residues, corrosion products, and tarnish films. Acidic cleaners can also be used to clean aluminum, a metal susceptible to etching when cleaned with strong alkaline detergents (D'Ruiz, 1991). However, acidic cleaners are not widely used by industry.

Emulsion Cleaning Solutions

Aqueous cleaners that contain emulsifiable solvents are classified as emulsion cleaners. These cleaners consist of a solvent suspended in a water-based cleaning solution. Emulsion cleaners combine the cleaning abilities of solvent and aqueous cleaners, and tend to be used in applications involving organic contaminants. The solvents used in emulsion cleaners are usually organics such as alcohol, methylene chloride, or methyl chloroform. (D'Ruiz, 1991) Emulsion cleaners are not widely used.

Alkaline Cleaning Solutions

Alkaline cleaners are formulated and used with appropriate cleaning equipment to remove the same organic or inorganic contaminants as chlorinated solvents. Contaminants encountered in maintenance cleaning operations, including dirt and carbonized oil and grease, can be removed by alkaline cleaners. (D'Ruiz, 1991) However, most cleaning situations require the addition of other compounds to increase the solution's cleaning efficiency. These additives perform functions such as:

- Penetrate soils to wet surface
- Emulsify solids into solution (can be filtered out or rinsed off)
- Neutralize
- Saponify (change insoluble fats and fatty acids into water soluble soaps)
- Oxidize (loosen rust and stains for easy removal)
- Precipitate (convert soils to heavier form for removal as sludge)
- Coagulate (to assist in removal of suspended soils by filtration)

- Float (cause soils to migrate to surface for skimming) (W.R. Grace and Company).[3]

Metal Cleaning Equipment

Switching to aqueous or semi-aqueous cleaners and processes generally requires modified or additional equipment, multiple cleaning and rinsing steps, and drying equipment depending on the cleaning level needed (Waste Reduction Resource Center, August 1992). Metal parts cleaning equipment manufacturers produce various sizes of cleaning equipment along with the necessary cleaning solutions. The company purchasing the services of the cleaning equipment manufacturer can select whatever size of equipment and cleaning solution that would best handle the needs of their operation. In fact, many metal cleaning equipment manufacturers customize their equipment for specific facility needs. Some of this equipment has been used at mine sites. The Newmont Rain facility staff indicated to EPA their satisfaction with their equipment.

In reference to cleaning applications attainable with aqueous cleaning, various types of equipment are available for use. (This report only elaborates on cleaning applications used with aqueous solutions because they are the most widely used cleaning solutions.) The main differences between the types of aqueous cleaning equipment is the way in which they generate the mechanical energy to clean the parts, and their size. This class of cleaning equipment is divided broadly into two categories: immersion and spray cleaners.

Immersion Cleaners

Aqueous immersion cleaning usually depends on aqueous detergents used in a mechanical cleaning process (D'Ruiz, 1991). Immersion cleaning equipment consist of one or more tanks, with still or agitated solutions. Immersion cleaning equipment varies widely in size and can have wash tank capacities anywhere from several gallons to hundreds of gallons; however, immersion cleaning equipment is generally too small to use at a mine site.

Spray Cleaners

Immersion cleaning equipment tends to deliver less mechanical energy to contaminated parts than spray cleaners. This is because spray machines run at higher pressures and allow faster travel of contaminated parts through the machinery. Three general types of spray machines exist: rotary, conveyor, and batch.

Rotary Spray Equipment

[3] However, problems can result from the use of alkaline cleaners with additives. Special handling, health, safety, treatment, and disposal must be considered in a process design and cleaner selection. Some additives, such as certain glycol ethers and esters have unanswered health and safety questions. When selecting any cleaning solution, a facility should review its material safety data sheet (MSDS), biological oxygen demand (BOD), and chemical oxygen demand (COD). (Waste Reduction Resource Center, August 1992)

Rotary spray equipment employs a drum with a partition that spirals along the inner surface of the drum. As the drum rotates, the metal parts are transported along the length of the drum. Rotary spray machines are designed to clean small equipment parts, such as screw machine parts. Rotary equipment can clean a large volume of parts, but the parts must be able to tolerate the tumbling action of the rotating drum. (CFC Alternatives, February 1991)

Conveyor Spray Equipment

Conveyor spray equipment is generally used in manufacturing applications in which the parts only need a quick cleaning cycle and the parts have flat, controlled surfaces (CFC Alternatives, February 1991). Conveyor spray equipment is not well suited for mine operations.

Batch Spray Equipment

Batch spray machines are typically used in maintenance applications. This is because cleaning equipment for maintenance purposes usually requires lower cleanliness standards than other cleaning applications, such as manufacturing. Batch spray cleaning may be done in a single spray chamber (CFC Alternatives, February 1991). Batch spray cleaning is excellent for heavy greases and tars. In addition, batch spray machines are readily designed to accommodate objects as large as train electric motors and engines (D'Ruiz, 1991; CFC Alternatives, February 1991). Batch spray equipment is essentially the only type of spray unit suited for large maintenance applications, such as those found at mine sites.

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3.0 RECYCLING

3.1 SLAG REPROCESSING

Magma Copper Company operates the San Manuel mine, mill, and smelter facilities located in Pinal County, north of Tucson, Arizona. Operations began at San Manuel in the 1950's. The facility encompasses approximately 12,000 acres of patented land with operations that extract, beneficiate, and process both sulfide and oxide ores to recover copper and molybdenum (See Figure 5). Oxide ore operations consist of an open pit mine and an *in situ* leach operation, a lined leach pile containing ore mined from the open pit, and a solvent extraction/electrowinning facility. The sulfide ore operations consist of an underground mine, a mill facility for copper and molybdenum flotation, and a smelter and electrolytic refinery.

The facility is located in the semi-arid southwest desert; annual rainfall is 13 inches with an evaporation rate of 117 inches per year. A mining town, also named San Manuel, was built near the mill and houses up to 5000 residents. Deep wells supply drinking and process water for the town and facility.

In general, the copper smelting process has several features. Heat is applied to melt ore, flux, and other copper bearing materials, principally in a primary smelting furnace. The furnace produces copper matte, slag containing waste products, and impurities. The molten copper matte, containing copper, iron, sulfur, and minor impurities, is processed in a separate converting furnace where metalic copper is separated and a converter slag produced. The metalic copper may be further purified in a refining furnace with return of molten impurities to prior process steps.

The separation of copper from sulfur is one of the more important aspects of the smelting process. Sulfur in ore, and consequently in slag, is important because it provides a fuel value as well as acting as a reducing agent during smelting. In a flash furnace, the type of smelter used at San Manuel, dry concentrates are fed to the furnace. Sulfide reacts with forced oxygen (an exothermic reaction) causing oxidation of the concentrate material and melting of the reacting particles. A matte is formed containing primarily copper, iron, and sulfur with lesser amounts of impurities such as arsenic, bismuth, nickel, lead, antimony, zinc, gold, and silver. From the flash furnace, the matte goes to the converters where it is oxidized and impurities, primarily iron and sulfur, are removed. Slag is generated in both the flash furnace and the converters; typically, copper concentrations in converter slag are much higher than in flash furnace slag (Weiss, 1985; Wiley and Sons, 1980).

At San Manuel, the slag reprocessing operation was designed to extract copper values from slag using an existing flotation operation. Prior to flotation, slag is cooled, crushed, and milled. The flotation operation uses one of the eight existing ore flotation circuits in the mill to produce a copper concentrate which is then re-smelted.

Slag from the converter at San Manuel contains from 5 to 7 percent copper. Slag generated from the flash smelter furnace contains approximately 2 percent copper (1.8% to 2.36% are mentioned in various references) (Weiss, 1985; Magma, 1992c; Magma, 1988). Both slags generally contain a higher copper concentration than the original ores, with ore currently mined from the underground San Manuel mine containing approximately 0.7 percent copper. Because of the comparatively high copper content of the slag (both furnace and converter slag), Magma is reprocessing this waste for material recovery.

Slag Reprocessing

The opportunity for slag reprocessing at Magma's San Manuel facility came about because of excess capacity caused by a decrease in the production of ore, the availability of stockpiled slag, and the decrease in the quantity of copper within the ore. The number of flotation circuits to allocate to slag was determined by the excess capacity of the flotation operation.

Initially, the facility was disposing of slag on the ground without any containment. Currently, to recover copper, Magma grinds the slag, removes the copper through the flotation process, and disposes of the remaining finely ground material in the tailings impoundment. Although the copper has been removed, information on remaining constituent concentrations and their mobility in the tailings was not assessed.

Prior to the implementation of their slag reprocessing operation, slag generated from Magma's original reverberatory furnaces was considered a waste and disposed of in piles at an unspecified onsite location. No information was provided indicating the volume of accumulated slag prior to 1974.

In 1974, Magma began reprocessing piles of reverberatory slag. Between 1974 and 1988, the existing stockpiled reverberatory slag was reprocessed through the grinding, flotation, and smelting stages. An Outokumpu flash furnace replaced the reverberatory furnaces in 1988. This technological upgrade uses less fuel, produces a richer grade of copper matte, emits less offgas, and is beneficial for the sulfuric acid plant. All slag generated from the flash furnace is currently reprocessed.

At San Manuel, the Outokumpu flash furnace and the converter furnace together generate slag at a rate of approximately 1900 short tons per day (stpd), or 693,000 short tons per year. The flash furnace generates a larger percentage of the total at approximately 1500 stpd, while the converter furnace generates the remaining 400 stpd. (See Table 2) Prior to 1988, the reverberatory furnaces yielded 1500 stpd of slag.

Table 2. Copper Values from Slag at San Manuel
Source: Magma, 1992c

Type of Slag	stpd	% Copper	stpd Copper
Flash Furnace Slag	1526	1.80	27.5
Converter Slag	396	7.00	27.7
Combined Slags	1922	2.87	55.2
Slag Concentrate	163	30.0	49.0
Slag Tailings	1759	0.35	6.2

Based on information obtained from Magma's response to EPA's *National Survey of Solid Waste from Mineral Processing Facilities*, slag from the flash furnace contains the following constituents: copper (2.39%); iron (46.95%); total sulfur (0.77%); aluminum (1.70%); and silicon (14.71%). The survey did not include a list of concentrations of constituents in converter furnace slag, however, main constituents are similar with the copper content being higher (5 to 7%). Additional data on slag constituent concentration was not available (Magma, 1988).

Slag Cooling

Copper recovery from slag is dependent on the treatment of the material prior to beneficiation at the mill. Slow cooling in the initial stages is imperative to allow copper particles to coalesce and crystallize. According to facility personnel, the first eight hours of cooling are the most critical for optimum copper recovery.

Molten slag from the flash smelter and converter furnaces is transferred to slag cooling pits to allow slag to harden and for copper minerals to crystallize. Slag from the flash furnace is transported in a 40 ton ladle carrier (Kress slag pot carrier) to one of 168 flash furnace cooling pits, each approximately 26.5 feet long and 14.5 feet wide. Each pit holds one ladle; slag from one ladle typically forms a layer 20 to 24 inches thick.

Slag from the converter furnaces is placed in one of 72 converter slag cooling pits which are smaller than the flash furnace pits: the converter slag pits have a capacity of only 26.6 tons and are each 26.5 feet long and 11 feet wide.

Both the converter and the flash furnace slag pits are arranged in large blocks. Each block is separated by areas large enough to allow vehicle access. The cooling pits are constructed of crushed slag that creates berms around each pit. The pits are filled on a continuous cycle to optimize their usage so at any one time there is likely to be pouring of molten slag, air cooling, water cooling, dozer ripping and preparing of pits for the next cycle occurring.

After slag has been placed in the cooling pits, the slag is left to air cool for 8 hours. This is followed by variable periods of water cooling and additional air cooling for a total of 2-3 days. A water spray system is used for the water cooling sequence. A main water line (6" to 8" diameter) delivers water to 18 spray nozzles that run down the center of each block of cooling pits. Water spray to individual blocks can be controlled so that spray is kept off unused pits. A process flow diagram provided by Magma (Figure 6) lists the normal flow rate of water used in slag cooling as 1100 gallons per minute (gpm), with a design flow of 1500 gpm. The timing of water application is dependant on smelter demands; originally, 96 hours of cooling was planned, but due to the increased rate of slag generation, Magma decreased the total period of cooling.

When the slag has hardened, a dozer-ripper is used to break up the solidified slag. A front-end loader then picks up crushed slag and transfers it via trucks to a 50-ton hopper. The hopper is equipped with a 24-inch grizzly, with a crushing plant underneath. Slag is reduced in size to minus 8-inch pieces by a 32 x 42-inch jaw crusher. The jaw crusher is dedicated to the slag processing system, although it is the same type as that used for ore. Crushed slag is discharged from the jaw crusher to a 36-inch belt conveyor that passes to a 48-inch belt conveyor before discharging to the crushed slag stockpile, which has a 2000 ton capacity. Front end loaders remove crushed slag from the stockpile for transport to the concentrator crushing and grinding circuit (Magma, 1992c).

Until 1991, Magma operated a vibrating screen (5 x 16-foot single deck) for separation of fines less than 1/2-inch size. This separating equipment was a high maintenance item, with frequent breakdowns requiring frequent repairs; therefore it was removed from the crushing system. Although the fines were initially reused as building material for berms between individual cooling pits, they are no longer segregated and all material, including material less than 1/2-inch is subjected to flotation.

Flotation

San Manuel operates two separate, two-stage froth flotation systems, one for ore and another for slag. Of the eight flotation circuits at San Manuel, one is dedicated to slag flotation. The ore and slag flotation circuits are exactly the same except that a different primary collector, Dithiophosphate 55741, is used in slag flotation. Methylisobutyl carbonol (MIBC) is used as a frother in both flotation circuits. Collectors in the ore circuit include sodium xanthate, fuel oil (jet fuel A, which is used as a molybdenum collector), and VS M8, a proprietary flotation agent containing carbon disulfide. The underflow from both the slag and ore flotation circuits is sent to the tailings thickener and onto the tailings impoundment.

The eight flotation circuits include a total of ten 2,000 cubic foot rougher cells, and 143 rougher cells of smaller dimensions (300 cubic feet). Cleaner flotation takes place in sixteen 39-foot high column flotation cells that concentrate the slag/ore to 30 percent copper. The overflow from rougher flotation is transferred to a cleaner/column flotation stage in each circuit, while underflow goes to Magma's tailings thickeners (Figure 7). In each circuit, the second stage of flotation occurs in the 39-foot high, 40 cubic feet cleaner/column cells. In seven of the eight circuits (ore circuits), the overflow from the ore cleaner cells goes to separate collection launders for transport to the molybdenite plant. (The underflow goes to the ball mills and is returned to the rougher for additional flotation.) Slag concentrate, produced in one of the eight flotation circuits, goes directly to dryers and is not sent through the molybdenite plant. Slag concentrate has a copper concentration of approximately 30 percent; identification and concentrations of other constituents was not obtained.

Slag concentrate fed to the furnace composes approximately 7 percent of the total furnace feed. The exact amount of slag concentrate feed ranges from 3 to 10 percent and is adjusted as necessary for the proper feed composition. Variables affecting the furnace feed rate include the amount of sulfur, iron, and silica in the slag concentrate. Details on how furnace feed is controlled were not discussed.

According to facility personnel, the slag reprocessing system now operates at a slag feed rate of 110-120 tons/hour, but Magma will soon process 130 tons of slag per hour. Because of the increase in slag generation, Magma plans to expand the number of slag cooling pits.

Slag reprocessing generates slag tailings which are combined with the ore tailings. According to Magma, primary constituents in slag tailings are silica, iron, magnesium, sodium, and smaller amounts of copper, lead, and zinc, as well as other trace elements. Specific data on the constituents were not discussed.

The amount of slag tailings as a percentage of total tailings disposal at San Manuel is approximately 3 to 6 percent. According to Magma, 65,000 short tons of slag tailings were generated and disposed in 1990, and 69,200 short tons in 1991. The total quantity of tailings generated (slag and ore combined) in 1990 was 17,000,000 short tons and 17,689,000 short tons in 1991.

Tailings from the mill are typically 30 percent solids and after the thickeners, are sent to the tailings impoundments as 50 percent solids slurry. Slag tailings are co-disposed with ore tailings into tailings impoundments, located approximately 1/2 mile west of the San Pedro River. According to Magma, San Manuel's water reclaim system reclaims most tailings water, leaving only 12.5 percent moisture content in the tailings. The tailings liquid has a pH of 8.4.

Because all slag is reprocessed, there is no permanent disposal of slag at the Magma site. Slag pits are used to allow cooling of the slag prior to crushing, flotation, and re-smelting. According to facility personnel most of the cooling water evaporates. Any remaining water runs off the cooling pits through unlined washes or shallow culverts to the tailings ponds. During the site visit white evaporite residue was observed in and along the drainage.

Costs

According to facility personnel, since the slag reprocessing operations involve the use of existing equipment, no purchase of new equipment/materials, installation/site preparation, or engineering and procurement costs were necessary for application of the process to begin. No specific cost information on the construction of the cooling pits or equipment was obtained.

Detailed breakdown of costs were not provided by Magma, but facility personnel indicated a general cost of $5/ton of slag processed through the mill circuit. No information was provided on energy or labor costs. Water costs were reported by Magma to be minimal; the facility reuses water from its tailings ponds for use in cooling water, dust suppression, plant make-up water, etc.

Magma stated that there were no cost savings that it was aware of, such as reduced disposal fees, decrease in raw materials, etc. During the site visit, however, facility representatives pointed out that the reprocessing of slag reduced the volume of ore that needs to be mined, thus resulting in an unspecified savings in mining costs. By reducing the volume of ore required for full mill operation, the facility is also extending the life of mine based on the existing volume of minable ore. According to facility personnel, approximately one ton of slag displaces two tons of ore; however, resolution of this ratio is unclear as slag has a copper concentration of 2.8% while the ore has approximately 0.7% copper.

Benefits

The key benefit derived from San Manuel's slag reprocessing operation has been the economic recovery of additional copper. Not only has the slag reprocessing operation provided a source of copper, but it has been provided by what is normally a waste material. It is important to note however, that while the facility has eliminated one waste stream (slag), there is an increase in tailings disposal.

Currently, to recover copper, Magma grinds the slag, removes the copper and disposes of the remaining finely ground material in the tailings impoundment. Although the copper has been removed, no data were available on the remaining constituents in the tailings and their mobility.

According to the Magma representatives, since all revenues (from processing of slag into concentrate) are accounted for as internal toll costs between the smelting and milling units, it is impossible at this time to determine a set value on revenues generated or saved due to the reprocessing of slag.

Limitations

The success of copper recovery from slag reprocessing operations at San Manuel is due in large part to the availability of an existing, fully integrated facility with both a mill and a smelter. At other locations, without such a set-up, the operation would be much more difficult to establish and potentially cost prohibitive. A substantial capital investment would be required if the equipment were not already on-site; Magma's capital costs related to reprocessing were low.

Obviously, the percent copper in slag, or other waste material, is a significant factor in determining its suitability for reprocessing. As for the minimum content of copper that could feasibly be recovered, Magma indicated that there were too many variables, including distance from slag source to mill and smelter, rate of cooling, type of furnace, and economic factors such as the selling price of copper, etc. to identify a specific concentration.

The rate of slag cooling and subsequent crystal growth was identified as a major technical factor determining the success of slag reprocessing. Because the cooling rate of the slag is crucial to the successful recovery of copper, not all slag is suitable for slag reprocessing. This is especially so when considering reprocessing of existing stockpiles of slag as opposed to reprocessing of currently generated slag.

Other limitations that may be encountered include rising energy and maintenance costs. Other sites may have additional technical limitations, for example, reprocessing with reverberatory slag is not as favorable as with flash furnace slag: reverberatory slag is harder to grind and to crush.

Conclusions

The opportunity for slag reprocessing at Magma's San Manuel facility came about because of excess capacity caused by a decrease in the production of ore, the availability of stockpiled slag, and the decrease in the quantity of copper within the ore. The number of flotation circuits to allocate to slag was determined by the excess capacity in the process. Based on available information presented by Magma, with the general cost of

$5/ton of slag quoted by Magma and a derived copper value (from the slag) of approximately $0.082/pound, slag reprocessing appears to be a profitable operation.

According to the *1990 Report to Congress on Special Waste from Mineral Processing*, two other facilities, in addition to San Manuel, utilize the concentrator to recover copper values from smelter slag: Copper Range in Michigan and the Kennecott Mine in Utah. Unlike the Utah facility that operates a separate slag flotation operation, San Manuel and Copper Range each use similar operations for slag and ore which result in co-generation of slag tailings (another special waste) and ore tailings from the operation.

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EPA Response to Comments

Magma Copper Company submitted written comments on this report to EPA in a letter dated July 6, 1993. Magma requested that minor editorial changes be made to correct factual information regarding their operations. EPA corrected the draft to incorporate all of Magma's recommended changes.

The U.S. Bureau of Mines submitted comments on the report. These have been responded to as appropriate.

3.2 TAILINGS REPROCESSING OPERATION

Magma Copper Company's Pinto Valley Division (Pinto Valley) consists of two operations. The Miami Unit, located adjacent to the town of Miami, in Gila County, Arizona, is a tailings reprocessing operation, the focus of this section of the report, and an *in situ* leaching operation. Pinto Valley's second operation, the Pinto Valley Unit, consists of an open pit mine and associated facilities located five miles west of Miami. The reprocessing operation started in 1989 and is proposed to continue through 1997. The reprocessing operation, including the *in situ* leaching operation, employs 70 people. The site is located approximately 60 miles east of Phoenix, Arizona (Figure 8). The area is characteristic of the semi-arid southwest region. The tailings reprocessing operation involves reprocessing the Miami #2 tailings pile, which covers 210 acres and contains 38 million tons of tailings. The pile was deposited between 1911 and 1932 (McWaters, 1991).

Pinto Valley hydraulically mines the tailings pile, leaches the tailings and produces copper by using a solvent extraction/electrowinning facility. After leaching and washing of the slurried tailings, the remaining slurry is piped overland approximately five miles to the Copper Cities Deep Pit for final disposal.

Miami #2 Tailings Pile

The Miami #2 tailings pile was deposited during the operation of a Miami Copper Company mine and mill. The operation used a gravity mill and later flotation to separate copper from the ore. The tailings were deposited in six canyons adjacent to the mill using launders and spigot valves. Eventually, five canyons filled and one tailings pile was formed; it is now referred to as the #2 tailings pile.

The efficiency of the gravity separation method at the time is reflected in the copper content of the tailings through the depth of the pile. The oldest tailings contain 0.72 percent copper while those deposited most recently contain 0.11 percent copper; the average copper content is 0.33 percent. Typically, the oldest deposits are at the lowest portions of the #2 tailings pile. Approximately 55 percent of the copper is in an oxide form with the remainder being in the form of sulfides.

Because the top lifts of tailing deposition have very low copper contents (due to increased efficiency of copper concentration), Magma pre-strips the top layer in order to get to an economically recoverable zone. In general, the copper content increases with depth (and age) in the tailings pile. Magma still reprocesses this pre-stripped layer, although the copper recovered is extremely low.

Hydraulic Mining

The hydraulic mining system simplifies the remining operation in three ways. First, the hydraulic system eliminates the need for excavating and hauling equipment normally associated with conventional mining. Second, the energy produced by the water jets serves to break down clay aggregates allowing more efficient separation, and finally, the hydraulic action and acidic solution provide the appropriate slurry necessary for the subsequent hydrometallurgical beneficiation.

Two sets of two, four-inch monitors (water canons) apply solution (raffinate), with a pH of 1.8, to the upstream face of the tailings pile at a pressure of 300 to 350 psi at a rate of 2,400 gpm. Originally, the system was designed to operate at a pressure of 435 psi, but Magma has reduced the operating pressure.

The monitors wash tailings down the face of the pile into a sump. Eductors, a type of vacuum pump that can pump air and water, generate a slurry that contains approximately 32 percent solids by weight. The two eductors pump the slurry at a rate of approximately 500 tons per hour (McWaters, 1991).

The monitors, sumps and eductors advance as the face of the tailings pile recedes. The equipment is advanced frequently so that the slurry paths are kept short, which in turn, prevents the solution from migrating through the pile and into the groundwater (Hartman, 1992). The eductors move the slurry from the sumps to a grizzly. The grizzly is equipped with a screen that rejects material such as scraps of wood and other debris in the tailings, larger than 1/2 inch. The undersized material passes through the grizzly into a tank where it is pumped to the processing plant.

Magma conducts periodic blasting of the tailings face to prevent large, unstable blocks from sloughing. The blasting is done for safety reasons and to protect the monitor stations from being buried.

Leaching

The low pH of the solution used in the monitors actually begins the leaching as the slurry is washed off the face of the tailings pile. The first step within the plant is the leach tank (dimension of 20' x 30'), where the pH of the slurry is lowered to 1.5 using sulfuric acid. The initial plan of the operation called for 14.5 lb of sulfuric acid and 0.04 lb of flocculent per ton of tailing. The maximum capacity was proposed to be 12,000 tons per day. Figure 9 shows the leach tank and thickeners in a process flow diagram. From the leach tank, the slurry goes to the first of two thickeners. The overflow from this thickener becomes the pregnant leachate solution (PLS), which goes into a vessel where it is flocculated and clarified at a rate of 3,000 gpm. This solution is then sent to a pregnant leach solution pond and on to the solvent extraction circuit. The underflow from the first thickener is pumped to a second vessel, washed with raffinate, and pumped to the second thickener. The overflow from the second thickener is ultimately returned to the mining circuit as feed for the monitors. The underflow is pumped into a vessel, washed with raffinate, and then pumped into the tailings disposal area (McWaters, 1991). The first and second thickeners are 375 feet and 180 feet in diameter, respectively.

Through a single control room, a computer is used to monitor and control most of the operations throughout the facility. A printout of the computer screen showing instantaneously adjusted flow rates is presented in Figure 10. Explanation of volumes and rates depicted in the Figure were not obtained.

Solvent Extraction

The pregnant solution pond (HDPE-lined) is fed by both the overflow from the first thickener and the pregnant solution from the *in situ* operation (McWaters, 1991). The 6,000 gpm combined flow is fed into four "trains" of solvent extraction. Within the solvent extraction tanks, over 90 percent of the copper is transferred into the organic phase. The organic phase solution consists of a 7 percent (by volume) liquid ion exchange agent (LIX® 984) in kerosene.

After loading, the organic phase is pumped through two trains of mixer/settler vessels in series that cause the copper to transfer to an electrolyte. The barren organic is then returned to the extractor vessels. Magma uses the same SX/EW operation for reprocessed tailings and its *in situ* leach operation. There is no difference between the SX/EW operation for the reprocessed tailings solution and other SX/EW plants in use at other copper sites.

Electrowinning

The amount of copper in the pregnant solution is concentrated approximately fifty fold in the process of being transferred to the electrolyte. Prior to electrowinning, the electrolyte is subject to flotation to remove any entrained organic; additional information on the type of flotation was not available. The electrolyte solution is then heated using steam and the internal heat of electrolysis. Prior to passing into the electrowinning tanks, particulates are removed from the electrolyte as it is passed through a bedded filter. In electrowinning cells, the copper in the electrolyte is readily electrowon onto stainless steel cathodes. The copper cathodes produced are normally shipped to Magma's San Manuel facility for manufacture of copper rod.

Wastes

It is assumed that tailing reprocessing will continue as long as copper prices warrant. Ultimate disposal of the reprocessed mine tailings is in the Copper Cities Deep Pit. The Copper Cities Deep Pit is an abandoned, open copper pit approximately 700-feet deep. The bottom of the pit is at 3250-feet mean sea level (Figure 11). The pit will ultimately be filled to the 3760' level. According to Magma and its consultants, Dames and Moore, this disposal was made possible due to the hydrogeologically isolated location of the deep pit.

Waste generated from the tailings reprocessing system consists of the underflow from the second thickener. Four centrifugal pumps direct the underflow from the second thickener through a 4.7 mile long pipeline to the Copper Cities Deep Pit. Magma worked with the U.S. Bureau of Land Management and Inspiration Consolidated Copper Company to procure right-of-way easements.
The tailings slurry consists of 50 percent solids, and is pumped at a rate of 2,710 gpm and has a pH of 2 to 2.2. The 13-inch diameter, high density polyethylene (HDPE) pipeline is placed in unlined containment ditches, and operates at a maximum pressure of 360 psi.

After the tailings slurry is discharged, solids settle out in the Copper Cities Deep Pit. Barge pumps located in the Copper Cities Deep Pit pump liquid from the surface back to the facility through 12 and 14 inch HDPE pipelines that parallel the slurry pipeline. The liquid returning from the pit is added back into the system at the mining supply stage, i.e., the monitors. The pipelines' pressures and flows are monitored to identify and limit leaks within the system (McWaters, 1991).

According to Dames and Moore (1987), because of the geology and faulted conditions that isolate the area of the Copper Cities Deep Pit from surrounding rock masses, and the relatively high aquifer level; water or other liquids placed in the pit will not flow/commingle or contaminate the underlying and surrounding aquifers. EPA did not obtain additional information; technical review of the hydrogeologic reports was not conducted.

Prior to initiating tailings reclamation at the #2 tailings pile, Magma was required to prepare a Groundwater Protection Plan in order to obtain the necessary permit from the State of Arizona. The permit states how full the Deep Pit may be filled. There are five groundwater monitoring wells that are sampled quarterly at the Copper Cities Deep Pit; data were not available for this review.

Costs

In 1981, a site-specific study showed that 57 percent total copper recovery could be economical, but that additional recovery would not be economically justified (McWaters, 1991). Magma started the operation in July 1989. Details were not made available because of confidential financial business information concerns.

In order to reprocess the Miami #2 tailings, Magma had to expand its existing SX/EW plant and refurbish two thickeners. Capital expansions involved increasing the number of electrowinning tankhouse cells from 60 to 104. The plant was estimated to cost $19.6 million in 1988 (McWaters, 1991). In order to run the plant continuously, handling 12,000 stpd of tailings, Magma needed to hire 23 additional people. Additional cost information was not provided.

Operating costs are 50 to 55 cents per pound of copper; with depreciation, the cost is 84 cents per pound. According to facility personnel, this is one of the highest operating costs of any Magma operation. The cost of power is $100,000 per month. Initially, the electrical energy consumption per pound of cathode copper was calculated by Magma to be 3.0 kwh. Additional operating cost information was not obtained.

According to facility personnel, the Pinto Valley operation is essentially a closed loop system for water usage. Because there is a high evaporation rate in the area, 66+ inches annually, there is speculation by some Magma representatives that towards the end of the life of the reprocessing operation there may be a problem with excessive evaporative loss from the surface of the Copper Cities Deep Pit.

Benefits

The environmental benefit derived from the operation results from the removal of the tailings pile located in a drainage adjacent to the town of Miami and redepositing the tailings in an abandoned open pit in a relatively remote location. Information confirming whether this removal and redeposit will provide a net environmental benefit was not obtained. According to facility personnel, recently, the operation has been economically profitable due to the recovery of copper and is expected to continue to be profitable in the future.

Limitations

Limitations to Technology Transfer

Magma credits two reasons for success of tailings reprocessing at this facility: (1) the high concentration and amount of copper that is present in the tailings, and (2) the tailings have had a long time to oxidize, thus making the copper more readily available. Other sites may have a lower percentage of copper in the tailings, which may make reprocessing less economical. Newer deposits may also be less economical.

Additional copper recovery may be possible by extra oxidation, flotation or elevated temperature leaching circuits, however, at Pinto Valley, they were not determined to be economically attractive.

Site-Specific Technical Issues

Some of the problems encountered at Magma's Pinto Valley tailings reprocessing operation have been moving the hydromonitors around. Placement of the monitors involves careful planning in choosing a site where there is an even mix of slimes and coarse grain material. The high pressure hoses experience frequent leaks and require constant attention.

A critical factor is the amount of time the slurried solution is in the tanks. The consistency of the slurry is another important operating parameter and is described as the slime vs. coarse content of the slurry. For example, if there is not enough slimes, the slurry sticks and does not flow smoothly through the system. If there is not a good mix of slimes and coarse grain then it is difficult to control the thickeners. In order to control the grain mixture, Magma tries to keep two of the four monitors in the slimes and two in a sandy area.

Magma reports that initially, there were start-up problems associated with the electrowinning circuit, and with the refurbished thickeners (details not provided). Earlier attempts to mine and then slurry the tailings by conventional methods proved unsuccessful in part because of clay balling. The use of a hydraulic monitoring system avoids clay balling by breaking down the strong clay bonds between particles through use of the high energy, high pressure monitor stream.

There have been occasional releases and spills from the slurry pipeline system and Magma has responded as necessary to such releases.

Conclusions

Since 1989, Magma has recovered copper from a waste source, its Miami #2 tailings pile at Pinto Valley. Recently, the operation has been economically profitable. By reprocessing the tailings, Magma is removing a large volume of waste that sits adjacent to the Bloody Tanks Wash, which is perched on the edge of the town of Miami.

According to Magma facility personnel, the Copper Cities Deep Pit, where the reprocessed waste will be disposed of, is a hydrogeologically isolated unit and that waste will not be in contact with the surrounding aquifers. However, sufficient information to provide an independent evaluation of the environmental impact of the final deposition of waste tailings is not available.

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EPA Response to Comments

Magma Copper Company submitted written comments on this report to EPA in a letter dated July, 15, 1993. Magma requested that minor editorial changes be made to correct factual information regarding their operations. EPA corrected the draft to incorporate all of Magma's recommended changes.

The U.S. Bureau of Mines submitted comments. These have been addressed as appropriate.

3.3 PIPE RECYCLING/REUSE

IMC operates eight phosphate rock mines and plants that cover an area of 115,854 acres in Polk, Hillsborough, and Manatee counties in West Central Florida (this includes leased and owned land under IMC's control, of which only portions are actively mined at any one time). Phosphate rock is the raw material used for the manufacture of phosphate fertilizer, animal feed supplements, and industrial chemicals including phosphoric acid, trisodium phosphate, and sodium tripolyphosphate. IMC's Florida operations have a capacity of 23 million tons per year, which is 13 percent of world capacity and 35 percent of U.S. capacity.

The climate, availability of water, topography, and physical characteristics of the deposit make the use of large dragline excavators and hydraulic pumping systems the most economical mining method to mine the phosphate zone, which consists of a mixture of phosphate, sand, and clay, normally containing 20 to 25 percent moisture (collectively known as "matrix"). IMC operates up to 18 draglines (14 at the time of the site visit). The draglines have a reach of up to several hundred feet and buckets with capacities up to 65 cubic yards. A dragline excavates a 200 to 400 foot wide semicircular area before moving and mining the area it evacuates. The ore or matrix, which is typically 5 to 20 feet thick, lies under 20 to 40 feet of overburden. The dragline first strips the overburden, placing it into adjacent mined areas for later use in reclamation. Alternatively, when mining at the perimeter of an area that will later be used as a clay settling pond (whose cells are typically about one mile square), overburden may be used to construct the raised dams that surround the pond.

Once the overburden is removed from over the matrix, the dragline excavates the matrix itself. With each bucketful, the dragline pivots and dumps the matrix from the bucket into a "well." The well is simply an excavation about 50 feet in diameter and 10 to 15 feet deep. In the well, two hydraulic monitors blast the matrix with 10,000 to 15,000 gpm of water at 150-250 psi, which further breaks up the matrix and forms a slurry. Water from the monitors is pumped through steel pipelines from clay ponds near the beneficiation plants.

After being blasted by the monitors, the matrix slurry passes through an 8-inch grizzly to screen out oversize materials, which are further broken up by the monitors. A pit pump lifts the slurry, which has 30-40 percent solids, from the well into a steel pipeline at a rate of 1,800-2,000 gpm for transport to the beneficiation plant. Because the areas being mined and the beneficiation plants are some distance apart--from one to over six miles as of mid-1992--a number of intermediate "lift pumps" are necessary to keep the matrix moving through the pipelines at about 19 feet per second. The first lift pump is generally within 1,500 feet of the well and additional lift pumps are placed every 2,900 to 4,000 feet along the pipeline's length. Because the dragline moves, the well, pit pump, and the first section of the pipeline (i.e., the section between the well and the first lift pump) are moved every three to four days to allow the well to remain in the dragline's boom reach.

Once it reaches the beneficiation plant, the matrix is separated into clays, fine product, pebble product, and oversized debris. The two major wastes, tailings (which are fine, well-sorted rounded sands) and clay are transported to their respective disposal sites. The tailings are transported by pipeline to areas that will be reclaimed after mining is completed, and then used to backfill the mined areas; they also may be transported and stored in piles prior to being used for such purposes as dam construction. The clays--again as a slurry--are transported by pipeline to the onsite clay disposal impoundment. As can be seen, pipelines are used for nearly all materials that are transported on and around IMC's operations.

Program Description

IMC's waste minimization program that was the focus of EPA's examination involves the reuse and recycling of the steel pipe that is used to transport matrix slurry, water, tailings, clay, and other materials. At IMC's operations in July 1992, there were approximately 194 miles of steel and polyethylene pipe in use and in inventory.

IMC obtains maximum use from steel pipe in a number of ways:

- Pipe used for matrix and clay transport is periodically rotated to ensure that wear is evenly spaced over the full diameter of the pipe
- To the extent possible, pipe no longer suitable for the most demanding use, in matrix pipelines, is then used in other less demanding pipelines, such as tailings or hydraulic pipelines
- Pipe no longer suitable for use in pipelines is either used for other purposes (e.g., culverts) or sold for off-site reuse or as scrap.

Table 3 shows the amount of the various types of pipe on hand in July 1992. Information on how much of the total inventory consisted of steel pipe and how much was polyethylene was not available. Each year, IMC purchases approximately 183,000 feet (35 miles) of 3/8-inch thick steel pipe in 50-foot sections. The pipe has a 75,000 psi tensile strength, 45,000 psi yield strength, and a Brinell hardness of 180 minimum. Pipe with varying diameters is purchased, with most pipe purchased in 1991 being 18-inch. The 18-inch size steel pipe is the most widely used, as can be seen in Table 4: in 1991, 110,000 feet or 60 percent of all pipe purchased was the 18-inch size, but the amounts and sizes needed reportedly varies from year to year. Table 4 shows the various sizes and uses as of September 1992.

Table 3. IMC Inventory of Pipe In Use or Available, July 1992

Type of pipe	Purpose	Length (feet)
Matrix	Slurry from mines to plants	248,350
Hydraulic	Water from clay ponds to mines	129,800
Tailings	Slurry from plants to storage/ reclamation areas	190,625
Feed	In-plant, from washers to float plant	41,900
Debris	From old debris area to plant	8,750
Waterjack	Transport mine water from pit to system or discharge	30,625
Overburden	Slurry from deeper mines (below where dragline can reach)	19,200
Clays	Transport clays from plant to clay ponds	70,600
Spare	Stored for use in pipelines--some new, some used	233,775
Scrap	Stored for other on-site uses or sale to scrap dealer	51,050
TOTAL		1,024,675

Table 4. Sizes and Uses of Pipe by IMC

Diameter (inches)	Type of pipe	Approximate footage	Major Uses (> 10 %)	Minor Uses
8	Not determined	1,000	Hydraulic (100%)	
10	Not determined	1,000	Feed (100%)	
12	Steel	34,000	Matrix (51%)	Tailings (30%), Waterjack (6%), Debris (13%)
	Polyethylene			
16	Steel	18,000	Tailings (67%)	Hydraulic (25%), Waterjack (7%)
18	Steel	328,000	Matrix (32%), Tailings (41%), Feed (12%)	Waterjack (5%), Overburden (6%), Hydraulic (4%), Debris (<1%)
	Polyethylene			
20	Steel	131,000	Matrix (70%), Tailings (21%)	Hydraulic (<1), Waterjack (3), Debris (2%), Overburden (4%)
22	Steel	33,000	Matrix (100%)	
24	Steel	104,000	Hydraulic (94%)	Clays (4%), Waterjack (1%)
30	Steel	8,000	Hydraulic (63%)	Waterjack (37%)
32	Polyethylene	< 1,000	Clay (100%)	
36	Steel	7,000		
	Polyethylene			
40, 48	Not determined	3,000		
42	Steel	50,000		
	Polyethylene			

NOTE: Figures reflect pipe in use, July 1992, not spare pipe, scrap pipe, or pipe in inventory. Thus, the total here does not match Table 1 since Table 1 includes those categories of pipe.

Once purchased in 50-foot lengths, IMC joins the lengths of steel pipe using one of two methods. If the pipe is to be used in applications that will be subject to excessive wear or moving, IMC first welds steel flanges to both ends of each length (an undetermined percentage of pipe is flanged). The flanges allow lengths of pipe to be bolted together, using 20 or more 1-inch diameter bolts, and then unbolted for movement or replacement. Once a length of flanged pipe can no longer be used because of wear or damage, the flanges are removed by IMC and the pipe itself may then be used for another onsite purpose (e.g., as culvert) or sold to a scrap dealer. Lengths of pipe that are expected to remain in the same use throughout their useful lives, on the other hand, are not flanged but are welded together. This occurs with an undetermined percentage of the steel pipe.

Not all pipe is used at all times, even pipe not classified as "spare" or "scrap," since draglines and mines may go out of service for short or extended periods and pipelines remain in place. The amount of pipe used in any area also changes over time as different areas are mined, as draglines move, and as operations change. For example, the specific operations underway at any one time affect pipe usage: overburden pipe is used only when mining deeper deposits that lie below a dragline's reach (and is used to move the overburden that lies below the dragline's reach), and debris pipe is used to mine material that was formerly disposed as debris from one or a few areas.

As Table 4 indicates, IMC also uses various sizes of hard polyethylene plastic pipe. Although less expensive than steel, the plastic pipe cannot take the pressures necessary for matrix transport due to its 150 psi burst strength. In addition, the plastic pipe is not as mobile and is more expensive to cut and reattach than steel pipe. It also is much more responsive to changes in temperature, becoming too inflexible and brittle for some uses in cold weather and too flexible for some uses in the heat of summer. In cases where pipe is laid more or less permanently, and where the disadvantages are overcome by economics, however, plastic pipe has proved satisfactory. Each of the major uses of pipe at IMC's central Florida operations is described below.

Matrix Pipe

Matrix slurry is pumped from the well adjacent to the mine to the beneficiation plant in steel pipelines at a rate of 19 feet per second. The matrix, which is basically one-third phosphate, one-third sand, and one-third clay, is mixed with enough water to ensure movement over the long distances necessary (up to eight miles) to the beneficiation plant. Because of the morphology of the matrix components coupled with the line pressure, there is considerable scouring and wear on the inside of the pipe. Scouring is most severe on the bottom quadrant of the pipe and over a period of months can simply wear through the entire thickness of the pipe. If not prevented or avoided, pipe failure interrupts the flow of matrix to the plant and necessitates unscheduled and costly shutdowns. To obtain the maximum length of service possible for matrix pipe while minimizing pipe failure, IMC has developed a matrix pipe management program, which involves the periodic rotation of matrix pipe.

IMC's matrix pipelines ranged from slightly over one mile to 6.2 miles in length in September 1992, and can reach eight miles or more depending on the area being mined. The pipelines are made of steel pipe 12, 18, 20, or 22 inches in diameter, as shown in Table 5. The size is based on the rate at which matrix is pumped from the mine(s) to the plant, which in turn is a function of the capacity of the specific dragline serving the mine (in some cases, matrix from two draglines enters the same pipeline). Each 50-foot length of matrix pipe is flanged on both ends; the flange on each end of each 50-foot length of pipe is joined to the flange on the next length by 20 or more bolts that are 1 to 1.5 inches in diameter.

Table 5. Size and length of matrix pipelines (September 1992)

Mine	Number of draglines	Size pipe (inches in diameter)	Length of pipeline(s)
Noralyn	2	18 inches	21,250 feet
Phosphoria	2	20 inches	23,300 feet
Kingsford	4	18 inches	47,650 feet
Haynsworth	2	18 inches	37,700 feet
Four Corners	4	22 inches 20 inches	32,800 feet 43,650 feet
Hopewell	1	12 inches	17,400 feet
Clear Springs	2	20 inches	24,600 feet
TOTAL			248,350 feet

During the service life, sections of matrix pipe are turned three times to encompass four positions. The first roll is 180°, the second roll is 90°, and the third and final roll is 180°. This ensures that each quadrant of the pipe is subject to more or less equal scouring and wear. The sections of bolted 50-foot lengths that are tracked and rotated together consist of the sections between lift pumps, which can be several thousand feet, as well as shorter sections across streams or under roads.

IMC has developed a computerized model to predict the amount of time a section of pipe can remain in each position and when it needs to be turned. This is based on the specific matrix being pumped, the pipe size, and other factors: the key variable for each pipeline is the amount of matrix pumped through the pipeline, in millions of cubic yards. Pipe used in the Hopewell pipeline, for example, is estimated to have an average life of four to seven million cubic yards, while the Four Corners line is expected to allow an average of 20 to 25 million cubic yards to be pumped before replacement. The actual length of service can range from 15 months to over two years, depending on the amount and nature (e.g., pebble content) of matrix pumped through the pipe. Under ideal circumstances, according to IMC, matrix pipe would be worn from its original 3/8 inch thickness (0.375 inches) to 0.009 inches at the four thinnest spots in its circumference (i.e., at the four locations that had been at the bottom) after a full rotation schedule. In practice, this ideal pattern of wear may not be attainable, although the rotation schedule does allow greatly extended service (for example, if pipe is worn through in its first position, IMC would only have gained one fourth of the maximum use that the length of pipe could otherwise provide). IMC's database contains information, on each section of pipe in each matrix pipeline, the amount of matrix that has been pumped through each section and the date(s) on which the section has been rotated.

When each section (this typically means the section between each pumping station, up to several thousand feet) of pipe is laid, the installation date is recorded and a code to indicate the pipe's position (i.e., how many times, if at all, it has been turned) and the date is painted directly on each 50-ft length in the section. This information is then entered into IMC's computer program. Each month, IMC issues a monthly yardage statement that inventories the pipe at each mine and indicates which sections of pipe are due to be rolled and when. This is based on the amount of matrix that has been pumped through the pipe, with about one-fourth of the "yardage life" allocated per quadrant.

When the turn date approaches, or when field measurements or judgment indicate that pipe should be rotated, the line foreman awaits a routine shutdown (generally, the beneficiation plant shuts down for eight hours every three weeks for routine maintenance, and there also are other unscheduled shutdowns that may provide opportunities) so that the pipe section can be turned without disrupting operations. Because of the weight of the pipe, a specially modified piece of equipment is used. When the pipe has been rolled, a new code and position marker are painted on each 50-foot length of pipe in the section and the information is recorded to ensure an accurate inventory. While the rolling schedule is pre-established based on the model's predictions, unforeseen circumstances (e.g., ruptures, leaks) can require that a section of pipe be rolled sooner or later than planned or be replaced. Thus, an aggressive field program is critical to IMC's operations: line crews inspect and measure the remaining thickness of pipe with a calibrated sonic sensor to assess the degree of wear (the schedule of inspection/measurement was not determined) and the results of these measurements often requires early rotation or replacement. When individual lengths of pipe within a section require replacement, the remaining lengths of pipe in the section are used in "mixed pipe" sections, as described below.

Rolling a section of matrix pipe is not a trivial task. Each 50-foot length of pipe in a several thousand foot section must be unbolted from its neighboring length, turned 90 or 180 degrees depending on the schedule, realigned with connecting lengths, and rebolted. This all must occur within the relatively short scheduled downtimes, which generally are about eight hours, and several sections may require rolling during these short periods. Thus, the entire exercise is carefully planned and executed by IMC.

In general, pipe nearest the dragline/well is subject to the most wear, with wear decreasing with distance from the mine (this is the result of coarser materials being broken up as they travel through the pipeline and thus subjecting the pipe to somewhat less wear). The first section of pipe in each matrix pipeline, the one running between the well and the first lift pump, is not only subject to especially heavy scouring but also must be moved periodically to accommodate the moving dragline and well. This frequent handling often damages 50-foot lengths of this section: besides the risks inherent in moving such pipe (new 18-inch pipe weighs about 72 pounds per foot, or 3,600 pounds per 50-foot length), after such pipe has been rolled one or more times, portions of it are less than full thickness and is much more subject to bending or other damage when being lifted and moved. Thus, individual 50-foot sections of pipe in the first section often require replacement. Because IMC rotates entire sections of pipe at one time, and because this can be accomplished only with equal-age sections (i.e., sections with equal-age 50-foot lengths), the first section of matrix pipelines is generally composed of what IMC calls "mixed pipe" (which generally consists of lengths of pipe from sections that were previously broken up, as noted above). It was not determined how IMC establishes a rotation schedule for "mixed pipe" sections, although it may be based entirely on line crew inspections.

(Because these sections are typically within the disturbed areas near the draglines, IMC noted that failures in these sections could present more operational than environmental problems.)

After a section of matrix pipe is sufficiently worn in its fourth position, the pipe section is scheduled to be replaced. When the operation is shut down, as noted above, the pipe is replaced with new pipe. All or some of the 50-foot lengths of the pipe may then be made available for use for other purposes, depending on the structural integrity of the pipe. Pipe that is still fairly strong, for example, may be used for water or tailings transport. Otherwise, it may be used for culverts or other on-site purposes or sold for reuse or recycling. Information on the amount and proportions of matrix pipe that are reused in other applications was not available, although IMC did indicate that "most" has some reuse potential.

Tailings Pipe

Since the tailings consist of a sand slurry, much less scouring of tailings pipe occurs since the sands are well weathered and graded (rounded), which reduces the amount of scouring. Of the 190,625 feet of tailings pipe, an undetermined amount is polyethylene. Of the steel pipe, some has previously been used for matrix transport (the percentage was not available). Previously used matrix pipe is used for tailings transport only within the actual tailings disposal area, where failure of the pipe would not release tailings to undisturbed areas. After use for tailings transport, which can be for six years or more, if the pipe still has structural integrity, it may be used to transport water, or it can be sold as scrap, sold as piping, or used for culverts onsite. No information was obtained on the amount of tailings pipe that is reused or recycled, on-site or otherwise.

Clay Pipe

Only large pipe is used for clay transport (nearly all is over 32 inches in diameter, as shown in Table 2). Some pipe lengths are flanged similarly to matrix pipe, and others are butt-welded into long sections; information on the amounts and proportions that are flanged was not available. Clays also scour the inside of pipe a certain amount, but the wear is more evenly spread than in matrix pipe. As a result, flanged pipe used to move clays is rotated twice, so that clay pipelines occupy three positions during their lives (except butt-welded pipelines, which remain in the same position and are not rotated). Apparently, the clay pipe rotation schedule is less well developed than the matrix schedule--at least, IMC did not provide information on the rotation schedule. After pipe used for clay transport reaches the end of its useful life, which is generally after three to ten years of service, it is sold as scrap or for piping, or used as culverts, depending on the degree of wear. No information was obtained on the amount of clay pipe that is reused or recycled, on-site or otherwise.

Water Pipe

A total of 129,800 feet of pipe is used to transport water from the clay ponds to the wells adjacent to each dragline; as Table 2 indicated, many different sizes of pipe are used. IMC indicated that at least some hydraulic pipelines contained lengths of hard polyethylene pipe as well as steel pipe. These hydraulic lines, as might be expected, experience relatively little wear. The end nearest the draglines do require moving as the wells move, so some pipe in these areas is occasionally damaged. Because it is the least demanding use, much of the steel pipe used in hydraulic pipelines has been used for other purposes previously; an undetermined amount of the 129,800 feet has been used for other purposes. Lengths of pipe in hydraulic lines are often welded together, although some sections, including those nearest the draglines, are flanged. No information was obtained on the amount, if any, of hydraulic pipe that is reused or recycled, on-site or otherwise.

Other Pipe Uses

As shown in Table 3, pipe is used for a number of other purposes by IMC. These include in-plant feed pipe from washers to flotation circuits, debris pipe, waterjack pipe, and overburden pipe. Although some portions of these lines consist of previously used pipe, the precise amount was not determined. In addition, IMC has over 233,000 feet of "spare" pipe in inventory, ready for use in pipelines. Some of this is new pipe, but much has been used for other purposes previously. Finally, IMC's mid-1992 inventory showed over 50,000 feet of scrap pipe on hand, ready for off-site sale.

Flange Reuse/Recycling

IMC purchases new steel pipe and attaches recycled flanges through an assembly-line welding process. Pipe that is to be sold as scrap or as piping first has its flanges cut off. A service contractor picks up the flanges, removes the welded pipe section, cleans the flange, and returns the cleaned flange back to IMC for reuse on new piping. Because the flanges are not subjected to scouring, they have a significantly longer service life.

Off-site Reuse and Recycling

Matrix pipe and other pipe that can no longer be used for materials transport (e.g., the pipe is worn out, thinned too much, bent, or broken) is sent to a staging area. At the staging area, any undamaged portions of pipe are removed. These portions can then be either reused onsite as culvert or sold to a local scrap dealer as useable pipe (reportedly for culverts, fence corner posts, gateposts, and low-volume water pumping). Damaged pipe is sold to the scrap dealer to be remelted into other steel products. A single contractor takes all the pipe except for that reused onsite. IMC reported that reusable pipe fetches a higher price than pipe sold for scrap. According to IMC, pipe scale has not proved to be a problem. The scouring experienced in matrix pipelines prevents any buildup in pipe used for that purpose. Some clay lines may experience sufficient ferrous oxide scaling to impede flow somewhat, but rotating the pipe allows any buildup to be scoured. IMC indicated that water lines generally do not experience a significant buildup and in no cases is buildup serious enough to impede flow. No information was obtained on scaling in tailings or other lines.

No information was obtained on the occurrence of naturally occurring radioactive materials (NORM) in IMC pipe or scale. The Florida Department of Health and Rehabilitation Services (HRS) regulates some scrap dealers because of concern over NORM but does not regulate radioactive materials at mineral operations (i.e., mines). According to HRS, there have been isolated problems with various isotopes (of uranium, thorium, and radium, particularly radium-226 in metal) from phosphate mining, but there was no indication that this was true of IMC operations. Scrap dealers that do not have an HRS license (which is required, for example, if they do handle 15 pounds or more of radioactive material at any one time) are not required to monitor for NORM and are inspected or otherwise monitored by HRS on a case-by-case basis (e.g., as the result of a tip or complaint). It was not determined if the dealer who receives IMC pipe is licensed by HRS.

Costs and Benefits

Piping represents a significant operational cost to IMC. For example, in 1991, 183,000 feet (35 miles) of piping was purchased at a cost of $5.5 million. Expenditures for pipe would be dramatically greater if the piping were not reused or recycled. The cost of new pipe (1991) averages about $38 per foot. By reusing pipe onsite, IMC estimates that approximately $1.5 million is saved each year. IMC does not track the cost of the pipe rotation program, so the costs of implementation were not available.

Most pipe that is sold to the area scrap dealer for reuse as pipe fetches approximately $1.50 per foot although scrap pipe that is still round fetches up to $2.25 per foot. In 1991, $316,000 was received for pipe that could be reused offsite. Finally, 4,200 tons of scrap piping was sold (for remelting) at the market price of about $10 to $20 a ton, or an estimated total of $42,000 to $84,000. Other reuses on site (e.g., culverts) have not been calculated, but certainly result in a cost savings. The hard polyethylene pipe is not recycled.

Although not quantifiable, costs avoided are a direct benefit of IMC's pipe management program. That is, pipe that is properly inspected and/or is rotated on time is less apt to suffer from excessive deterioration and subsequent failure.

Other Waste Minimization Activities

IMC reported that the pipe flange recycling program results in an estimated 60 to 80 percent cost savings over purchasing new flanges (amounts were not available). This cost savings takes into account the costs of having a contractor pick up, clean, and deliver the recycled flanges.

In addition, IMC is assessing the potential to recycle pump shells. Each matrix lift pump has a useful life of approximately seven months. The shell, which comes into contact with the matrix, and is subject to heavy wear, is a cast alloy of molybdenum, nickel, and chromium. It is possible that the shells may be melted and recast, thus realizing potentially significant cost savings.

As noted above, IMC uses "flexibles" as connections between various pieces of equipment, wells, pumps, and piping. Many of these flexibles cannot be reused because of their unique configuration. Although they could be resold as scrap, IMC has donated these pieces to environmental groups to be used as artificial reefs in estuaries.

Conclusion

The pipe reuse/recycling program at IMC was reported to be necessary to ensure and/or enhance economic profitability. IMC originally introduced the program more than ten years ago solely for economic reasons. The program reduces capital expenditures (i.e., reduces the amount of pipe that must be purchased) as well as operating costs (i.e., by avoiding costly shutdowns when pipes fail). IMC staff are currently seeking to improve the pipe management system by further automating the system. To improve efficiency of the system, for example, IMC intends to establish a more accurate inventorying/tracking system of the miles of pipe, particularly pipe not in use. IMC indicated that they needed to refine the system of determining where certain sections are, the amount of wear sections have experienced (e.g., by including field measurements or other data in the pipe rotation calculations), and projecting future uses of certain sections of pipe. While the current method involves painting codes on each pipe length and maintaining a computer database that tracks each section, IMC indicated they were considering a project that would assess the feasibility of a bar code system; it was hoped that such increased automation could reduce labor costs and increase the efficiency and accuracy of the system by extending the automated tracking system to individual pipe lengths and by increasing the amount of information on each length and section.

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EPA Response to Comments

The U.S. Bureau of Mines provided comments, which have been responded to as appropriate.

3.4 RECYCLING MINE TIRES

Heavy equipment at mine sites using these large tires include earth movers, graders, and loaders. The tires vary in size depending on the type of equipment, ranging in size from five feet to more than ten feet in diameter and two to three or more feet in width. These vehicles typically endure long hours on unpaved roads, and in the case of haul trucks, operate up to 24-hours per day. Tire manufacturer and mining industry personnel refer to this type of tire as off-the-road, off-highway, and giant. For this discussion they will simply be referred here to as large tires.

Data on the number of large tires scrapped each year are not widely available. However, the Rubber Manufactures Association (RMA) does maintain sales statistics on "Off-The-Road" tires (these statistics include a wide range of non-standard tires). According to the RMA, 284,967 OTR tires were sold domestically in 1992. Of these, 15,526 tires had a rim diameter of 48 inches or more. Tread life of large tires and the rate at which scrap tires accumulate are important variables to consider when assessing alternatives.

Diligent maintenance practices increase tire life resulting in fewer scrap tires. Also, a strong incentive to properly maintain tires and road surfaces is the cost of new tires. For example, mine representatives have estimated the price of one large tire to range from $10,000 to $16,000, or over $100,000 to fit one large piece of equipment (Rayrock Yellowknife Resources Inc. 1992). The Barrick Goldstrike mine, moving 315,000 tons of ore per day, purchases an estimated 300 to 400 new tires (all sizes) per year (American Mines Handbook 1992, American Barrick Resources, Inc. 1992).

Economic variables that affect the potential for resource recovery include primarily the availability of markets, sources of supply, and costs associated with generating a marketable product. Two major impediments to the recycling of mine vehicle tires are the distance to existing resource recovery markets and the size of these large scrap tires. In particular, large mining operations are not usually located near their potential markets in larger cities. Encouraging exceptions to this relationship are sand and gravel and crushed stone operations. Also, tires from facilities may be suitable for use as either tire derived fuel (TDF), or as construction material. At least two companies in Minnesota process scrap mine tires from the iron range for profit. For remote mine location, some ingenuity and encouragement may be necessary to find or develop markets.

Two new Federal regulations will increasingly effect the scrap tire industry markets. The new Clean Air Act Amendments have redefined TDF as a fuel, no longer considering it a waste fuel. Indications that this and other regulatory driven changes will increase the demand for TDF are already visible. In 1990, about 10 percent (27 million) of the scrap tires were used as TDF or in civil engineering application. In 1992, about 27 percent, or 65 million scrap tires were used. Projections for 1994 are that 50 to 55 percent of scrap tires, or 141 million tires, will be needed to meet market demand. According to the Scrap Tire Management Council (STMC), the market is just starting to takeoff. Similarly, the Intermodal Surface Transportation Efficiency Act (ISTEA) requires that five percent of all Federally funded road projects use rubber from scrap tires in 1994. Use of scrap tires must expand five percent annually until 1997, when it tops out at 20 percent. By 1995, 17 million scrap tires will be required in Federal road projects; by 1997 the number increases to 50 million.

Recycling and resource recovery alternatives address both whole tire and processed (reduction in size) tire options. Whole tire recycling includes retreading, for example; whole tire resource recovery includes all civil engineering applications, and tire derived fuel (TDF). Processed tires are sheared or shredded for use in civil engineering or as TDF. This report provides information on these and other alternatives to disposal of large mining tires.

Management Options Scrap Large Tires

This Section discusses several recycling/resource recovery alternatives for scrap large tires that are currently available to mining companies. Retreading whole tires seems to be the most promising option for large tires. However, the market for processed tires of any size is increasing according to the Scrap Tire Management Council. Most of the demand will be for TDF and in civil engineering needs.

Recycling Options for Whole Tires

Several alternatives for recycling or reuse of whole large tires exist. One alternative is retreading the tires for reuse. Market indicators show a recent increase in truck tire retreading (EPA 1991). There are also a number of other potential uses for whole tires that are discussed below.

<u>Retreading</u>:

Tire retreading reduces the demand for new tires and thus conserves resources; retreading a used tire requires less than 40 percent of the fossil fuel used to manufacture a new tire (Getz and Teachey 1992). A worn tire may be retreaded provided the tire is not overworn and still has a good casing. Retreaded tires typically have manufacturer guarantees and performance ratings comparable to new tires (Getz and Teachey 1992). The Tire Retread Information Bureau (TRIB) reported that retreaded truck tires may deliver more miles than new truck tires (Getz and Teachey 1992). In fact, most truck tires are designed to be retreaded (Martin 1991). The purchase price for retreaded tires is less than new tires, providing an additional savings incentive.

Mining companies may be able to access the tire retreading market through their current tire vendors who may be willing to accept used tires suitable for retreading. Depending upon their condition and suitability for retreading, some vendors may offer reimbursement for used tires (Rayrock Yellowknife Resources, Inc. 1992). Other vendors may still require payment for scrap tire removal. Cobre, a tire vendor for the Dee Gold Mine, performs evaluations of used tires on site to determine each tires potential for retreading. If a tire is retreadable, Dee Gold mine is reimbursed $500 per tire. However, if the tire is unsuitable for retreading, Cobre will remove the tire from the site for no additional fee. The primary limitations to retreading large tires are costs to transport tires to a retreading facility and the market potential for retreaded tires.

<u>Other Whole Tire Reuse Options</u>

In addition to retreading, whole scrap tires are used in civil engineering applications, including construction, erosion control, and agricultural uses. However, the potential for reuse of whole large tires in any of these applications depends on proximity of the mine to the user since transportation costs increase with distance. With the exception of retreading, all of the potential markets for whole tire reuse appear to be small in comparison to recycling/resource recovery markets for shredded tires.

Construction: Waste tires can be used to build artificial reefs and breakwaters. Though a popular method of reuse in the 1970's, minimal numbers of scrap tires are currently being used to construct artificial reefs; most of the tires being used for this purpose are passenger car tires. The demand is met by local supply. Other uses include tieing scrap truck tires together to make heavy rubber mats ("Terra Mats") for use as temporary roads for heavy trucks. Construction, logging, and oil and gas industries may find terra-mats particularly useful (BioCycle 1991). Some whole tires are used as play equipment (EPA 1991).

Erosion Control: Scrap tires are used as erosion control devices in highway construction projects to stabilize soils on disturbed slopes. They are low cost alternatives to other erosion controls, such as rock, gabon, and concrete. However, the demand is limited with fewer than 10,000 scrap tires per year used as erosion control devices. The large size of mine tires may discourage their use for this application (EPA 1991).

Agricultural Uses: In the mid-west, the agricultural industry has found a use for large scrap tires by splitting them in half to create livestock feed troughs.

Resource Recovery Options for Processed Tires

Processing scrap tires increases the options for resource recovery and thus the number of potential markets. The major market for processed tires are as TDF and in civil engineering applications. In 1991, 10 percent of all tires scrapped were used, in 1994 this number is projected to grow to 50 or 55 percent (STMC 1993). Processing involves shearing, cutting and/or shredding tires into smaller pieces. Processing tires on-site may reduce transportation costs by 30 to 60 percent. According to an EPA estimate, transportation costs for 100 whole tires ranges from $.15 to $.20 per mile. In contrast, transportation costs for processed tires range from $.045 to $.12 per mile (EPA 1991). Transportation cost estimates for large tires from mining facilities were not available.

Large Tire Processing

There are approximately 200 commercial shredders operating in the United States that accept used tires for shredding. The only states in which there are no commercial shredders are North Dakota, South Dakota, Rhode Island, Delaware and Alaska. In order to shred most whole large tires, a shredder must be custom built. Typically, costs for shredders are based on the size of the item to be shredded. A representative from one of the companies that supply shredding equipment indicated that used shredders (size not specified) are available for sale, or lease, and would be less costly than new equipment. A representative from Bridgestone/Firestone recommended that mining companies explore leasing options for shredders, since the volume of scrap tires generated at mining sites is not sufficient to warrant purchase of a very large shredder.

A cost effective alternative to a large custom shredder may be shears used to cut large tires into pieces more suited to a standard size shredder. One company manufactures mobile shears which attach to the hydraulic articulated arm of an excavator type Caterpillar. These shears have been used in the past to snip steel I-beams and can be used to reduce large tires down to manageable size. The shears are powered by the hydraulic system on standard mining equipment. They are more portable than shredders and generally less expensive. Reducing the size of large mine tires by shearing may address some of the problems associated with size and handling difficulties.

Capital/Operating Costs for Processing Equipment: Although the Agency does not have accurate cost data, in general, shear costs increase with tire size and operation costs increase with tire size.

Markets For Processed Tires

Markets for processed large tires include major energy users as well as those for construction applications. Heat energy from TDF is currently being used by power plants and cement kilns, both energy intensive industries. Incentives in the Clean Air Act Amendments and ISTEA will encourage these markets to develop in the future. Three categories of processed tire markets are discussed below: use as TDF; crumb rubber; and pyrolysis.

Use as Tire Derived Fuel (TDF): Scrap tires are an excellent fuel source. Rubber tires average between 12,000 and 16,000 BTUs per pound, or about 80 percent as much as crude oil (EPA 1991). A scrap tire (weighing 20 pounds) from a standard vehicle contains as much energy as 2.5 gallons of gasoline. According to one source, the energy value per ton of tire is approximately 30 million Btu, which is 50 percent more than an equivalent weight of coal (Mecozzi 1988). In recent years, there have been major increases in the use of scrap tires as fuel by a number of industries, including power plants, cement kilns, pulp and paper mills, and tire manufacturing facilities.

Some facilities burn TDF mixed with another fuel such as coal; others burn only TDF. For some uses, the steel cable beading and belts must be removed, increasing costs. While most facilities burn shredded rubber, some incinerators are capable of burning whole tires. Whole tire incinerator combustion chambers are typically best suited to conventional sized tires; large mine tires may not be compatible in the combustion chamber. Consequently, large tires usually need to be reduced in size for use as TDF.

Power Plants: Existing steam electric plants can be adapted to burn tires in place of, or in addition to, traditional fossil fuels such as coal, oil and natural gas. According to a Goodyear representative, cyclone boilers, wet bottom boilers, and other systems at fossil fuel-burning power plants can be retrofitted to burn used tires for less than $1 million dollars. For $450,000, Ohio Edison retrofitted one of its oldest coal-fired steam electric plants, making it capable of burning six million scrap tires per year. Some power plants are built specifically to burn whole tires to convert waste to energy such as those operated by Oxford Energy of New York. Another company, Continental Power Systems, has plans to build a similar tires-to-energy plant in Ohio (Cooney and Davis, undated, Mattheis 1988).

Oxford Energy operates a number of whole tire-to-energy facilities throughout the country. The largest of these plants is their Sterling, Connecticut facility, which is capable of burning 9-10 million tires per year, generating 26.5 megawatts of power (EPA 1991). Most of Oxford Energy's plants accept whole tires, but the tires must be less than 48 inches in diameter. The Sterling plant also accepts shredded tires. Factors involved when weighing the feasibility of tire to energy facilities include ample supply, buy-backs from utilities, and controlled air emissions (EPA 1991).

Cement Kilns: Cement kilns must maintain a very high temperature (2,600 $^\circ$F) during the calcining phase, making them well suited to burning TDF. Ash from the combustion process is typically incorporated into the cement product. Of the cement kilns operating in the United States, about 50 are equipped with precalciner/preheaters that make them best suited for burning TDF. According to statistics compiled by EPA, seven cement kilns are currently using TDF successfully in combination with other fuel. This number represents an increase in TDF use by cement kilns, with only four operating in 1989, and is an indication of a growing market. The primary limiting factor to this expansion is the current low cost of petroleum-based fuels. (EPA 1991)

Pulp and Paper Mills: For relatively low capital costs, pulp and paper mill furnaces can be retrofitted to burn tire chips in place of wood chips. There are approximately a dozen pulp and paper mills (concentrated in Washington, Oregon, and Wisconsin) burning TDF in the United States according to 1991 data. Like cement kilns, pulp and paper mills may be discouraged from retrofitting due to the low cost of alternative fuels. In addition, because the wire in TDF tends to clog the feeding system, some mills will only use wire-free TDF, which costs more (EPA 1991).

<u>Crumb Rubber</u>: Crumb rubber is made by reducing the tire size either mechanically or cryogenically, using liquid nitrogen, into 3/4 inch tire chips (EPA 1991, Martin 1991). The source of the rubber is tire buffings and peels obtained from retread shops. Making crumb rubber requires the removal of steel wires and polyester fragments contained in the tires. Primary uses of crumb rubber include the production of rubberized asphalt and miscellaneous rubber products.

Rubberized Asphalt: There are two basic types of asphalt that use processed tires: rubber modified asphalt concrete (RUMAC) and asphalt rubber. RUMAC is produced by combining crumb rubber in place of aggregate or stone in asphalt paving mixtures. Before it can be used as aggregate, wire and polyester must be removed from the rubber. Asphalt rubber is produced by mixing crumb rubber with asphalt at high temperatures and is often used to make and repair damaged road surfaces (Getz and Teachey 1992). The addition of rubber in either of these asphalt products improves their longevity, strength, and wear properties such as skid resistance and de-icing (Cooney undated, BioCycle 1989). The use of rubberized asphalt for highway construction is currently being evaluated by several states and the federal government.

Rubber Products: Crumb rubber is incorporated into a variety of rubber sheet and molded plastic products, including floor mats, vehicle mud guards, garbage cans, athletic surfaces such as running tracks and rubber play surfaces, and carpet padding (EPA 1991). Crumb rubber may be used in place of asphalt or wood timbers as a road surface adjacent to railroad crossings. Although the initial cost to produce rubber railroad crossings is higher than that for asphalt or wood, one manufacturer claims that rubber railroad crossings may last up to 15 years longer (EPA 1991).

Pyrolysis: Pyrolysis involves subjecting used tires to high temperatures in order to chemically decompose the tires into their primary components of oil, carbon black, and gas. To date, this process has not demonstrated commercial success, hindered by the low cost of oil and the soft market for carbon black (Cooney and Davis, undated). Additionally, the carbon black must be upgraded to be marketable, which further increases cost of the product (EPA 1991).

According to data compiled by EPA, only one commercial pyrolysis plant was operating in the United States in 1990, although several other companies were experimenting with the process (EPA 1991). While pyrolysis may not presently represent a viable market for large mine tire recycling, the market may expand in the future.

Texaco, Inc. has tested a method using tires and waste oil as feed stocks in a multistage process to make electricity cleanly. Texaco believes the process is both technically and economically feasible. By-products include gas and light oil for refining and steel for recycling. In the process, tires are heated in an oil bath to 700 degrees F. This melts the rubber from the steel belts and produces a thick oily slurry that can be gasified. In the gasification reactor the slurry is converted into gases and sulfur, as well as some ash and slag. (Wald 1992)

Conclusions

There are several recycling/resource recovery alternatives available for managing scrap tires at mine sites. In the past, recycle markets were essentially non-existent and landfilling was the most effective form of tire disposal. While whole large tire recycling options are limited, markets for processed tires may offer cost effective options for resource recovery. Markets for TDF and other processed rubber products are available and growing (STMC 1993). Some of this expansion is a result of changes in Clean Air and other Federal regulations.

Two major impediments to pursuing these alternatives include the distance to recycling markets and the large size of these scrap tires. The costs associated with scrap tire recycling or resource recovery and proximity of the mines to markets will be significant factors in determining the overall viability of these options. The economic feasibility for the options presented here is not readily available and must be taken into account. In addition to economic considerations, the potential environmental impacts on air quality from burning waste tires should be considered.

Several mines in a region may consider sharing one set of shears and/or a portable shredder thereby reducing capital and operating/maintenance costs. Use of a tire shear in conjunction with a standard size shredder on site could produce a marketable resource. Once reduced in size, tire pieces are more easily handled and less expensive to transport off-site than whole tires. They would also be more acceptable in existing commercial markets. For example, the product could be suitable for direct sale to the TDF market. The decision to purchase shearing or shredding equipment would be based on a solid understanding of market prices for used tires, the distance to markets, and the number of tires needed to cover equipment costs.

Several on site alternatives to disposal may exist for scrap tires. Whole tires may be used to construct temporary road surfaces, similar to the "Terra-Mats". Processed tires could be used in rubberized asphalt for building new access roads in an area where mining is concentrated. This would require cooperation between mining companies and an asphalt supplier. Alternatives must be analyzed on a site-specific basis, weighing the cost of equipment against the number of used tires generated per year and the distance to and availability of potential markets.

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Attachment 1
Activities at Dee Gold Mine

EPA contacted Dee Gold Mine to inquire about a tire return agreement with their tire supplier as cited in a September/October 1992 issue of *Mining World News*. Mr. Jones of Dee Gold explained that Rayrock Yellowknife Resources, Inc., operator for mine (as well as for Pinson and Marigold mines), has a contract with COBRE, a tire supplier, who provides new tires and removes old tires for retreading or disposal. The contract pertains only to large mine tires, and does not include smaller tires used on their fleet of lighter vehicles. Cobre's contract with mine covers the entire fleet of loaders and haul trucks. (It is not clear if "fleet" pertains to equipment used at Pinson and Marigold Mines.) Through the "fleet deal" the cost of each large tire ranges from approximately $8,000 to $10,000. According to Mr. Jones, more mainstream prices could range from approximately $14,000 to $16,000 per tire. (Barrick-Goldstrike also quoted tires in the $14,000 to $16,000 price range.)

Cobre supplies the mine site with a stockpile of new tires and a tire-changing truck with which to replace old tires. Mr. Jones did not know how often the stockpile was replaced or the number of tires used/removed per year. The fleet of vehicles includes 3 loaders, using 4 tires per vehicle, and 5 large haul trucks using 6 tires per vehicle.

Cobre performs onsite evaluations of used tires and pays $500 for each tire that can be retread. If the tire is used to the extent that retreading is not an option, Cobre will still remove the tire for disposal, but will not reimburse for them. Dee Gold Mine does not purchase retreads from Cobre. According to Mr. Jones, they have had better success with new tires which tend to last longer.

4.0 OTHER PRACTICES

4.1 WATER MANAGEMENT AT MINE SITES

Water management provides opportunities for innovative methods of managing environmental releases at mine sites. Current programs exist for the management of water at mine sites, and new ones are presently being developed. Each program has its own regulatory definitions of terms such as "storm water", "discharge", etc. Terms used in this report are not based on statutory definitions to allow for a broader discussion of the topic. This report focuses on a broad picture that overlaps many aspects of the existing programs.

Non-process water discharge sources may be the result of any water flow, however diffuse, at the site. Precipitation is the primary source, resulting from rainfall and/or snow melt. Intermittent creeks and arroyos are apt to carry runoff. Groundwater seeps may also form runoff at the surface. In addition, some water sources may be created by the operator, such as irrigation, equipment washing, dust suppression and cooling waters. Any area that is disturbed by excavation, road building or other activities is a potential source of contaminated runoff. One of the major concerns regarding runoff from mining activities is the potential for acid generation and metals mobilization in waste associated with mining. In addition, sediment (without toxic constituents) can cause significant adverse impacts on stream quality and thus, is regarded as a pollutant when discharged.

Sources of potentially contaminated non-process waters at a mine site include, but are not limited to:

- Seepage from underground mine workings
- Runoff/seepage from abandoned/inactive mine workings
- Runoff from waste rock, overburden, and sub-ore piles
- Runoff from tailings piles
- Overflow from ponds or pits, especially during high precipitation or snow melt events
- Seepage from dump piles and tailings
- Runoff from chemical storage areas
- Runoff from co-located slag dumps
- Runoff from contaminated soil areas near co-located smelter operations
- Flue dust pile runoff
- Runoff from smelters, mills and other structures
- Former mining & processing areas with contaminated residue
- Vehicle access and haul roads, rail lines
- Truck and vehicle equipment maintenance wash
- Leaks from liquid/slurry transport lines
- Runoff from other areas disturbed by mining operations

Facility areas and activities not traditionally associated with mining activities:

- Infiltration and runoff from irrigation and grounds maintenance
- "Urban runoff" from parking lots, roadways, contains salts, oils, mining residue
- Site construction projects, will produce increase sediment load, greater erosion
- Landfills (municipal/solid waste type or hazardous)
- Sewage/wastewater treatment facilities
- Vehicle fueling locations
- Petroleum tank storage areas

Dust suppression activities
Cooling water
Boiler blowdowns
Floor drains & wash downs

In controlling or preventing contaminated water discharges there are two principal factors: (1) the volume of water discharged and (2) the water quality, or concentration of pollutants in the water. Discharges to surface water caused by runon/runoff can be reduced by addressing one or both of these factors. Many of the control techniques available for management and control of runoff are described in Appendix A.

Regulatory Background

The Clean Water Act regulates discharges to waters of the United States. Discharges from mine sites are addressed under two principal regulatory programs: the NPDES permit program (for process water and storm water point source discharges) and the Non Point Source program.

NPDES Point Source Program

A *Point Source* is defined in Section 502(14) of the Clean Water Act as "any discernable, confined and discrete conveyance, included but not limited to, any pipe, ditch, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft from which pollutants are or may be discharged." The Water Quality Act amendments of 1987 added discharges from "landfill leachate collection systems" to this definition. All point source discharges to waters of the U.S. must be addressed by NPDES permits.

Per the Clean Water Act Sections 304(b), 304(c) and 306, EPA has promulgated effluent limitation guidelines for discharges from mine sites mining metalliferous ores (see 40 CFR Section 440). These guidelines include specific technology-based numeric effluent limits that must apply to point source discharges of process wastewater as well as most storm water generated at mine sites.

Storm Water is defined in 40 CFR 122.26(b)(13) as "storm water runoff, snow melt runoff, and surface runoff and drainage." *Storm water associated with industrial activity* is defined in 40 CFR Section 122.26(b)(14) as the discharge from any conveyance which is used for collecting and conveying storm water and which is directly related to manufacturing, processing, or raw materials storage areas at an industrial plant. Section 402(p) of the Clean Water Act generally requires EPA to issue NPDES permits for point source discharges of storm water associated with industrial activity, including active and inactive mines. At mine sites, Section 402(1)(2) specifically limits the permit requirements for storm water that has come into contact with any overburden, raw material, intermediate products, finished products, byproducts, or waste products located on the site of the operation.

EPA is currently developing a storm water program for those point source discharges from active and inactive mines not already permitted. Several states are also currently developing general storm water permits for mine sites and anticipate facility applications during the next year. A few states have issued draft permits.

Non Point Source Program

Non-point sources of pollution are addressed under sections 208 and 303(d) of the Clean Water Act of 1972. Non-point source pollution is caused by runoff from diffuse sources, and is generally caused by rainfall or snow melt. Non-point source discharges may be to streams, lakes, rivers, wetlands, or to groundwater. Major non-point source pollutants include sediments, oil and grease, metals, and nutrients.

Section 319 of the Clean Water Act requires EPA and states to take a variety of actions to address non-point source discharges. However, non-point source program development and implementation is almost exclusively performed by states. EPA's role is generally limited to providing guidance and issuing grants to states to implement non-point source management programs.

Specific best management practices (BMPs) requirements for non-point source control at mine sites have not been promulgated at the national level nor has any national guidance manual been issued, however, individual states are currently developing programs for storm water management at mine sites. Idaho recently (November 1992) prepared a document entitled "Best Management Practices for Mining in Idaho" that describes practices to minimize non-point source water quality impacts.

General BMPs have been developed for other non-mining industries and sources of non-point discharges such as urban and agricultural runoff. Many state programs have focused on their applicability to a specific watershed or body of water.

Case Studies

Four case studies were selected as examples of how some facilities are approaching water management at their operations. The facilities selected include one new facility that has been operating for less than a year and has incorporated water management into its reclamation plan; a facility with an existing seepage problem that is using capping and wetlands treatment methods; a site that diverted a stream channel; and one that has taken an integrated facility-wide approach.

Hayden Hill Project, LGMI/Amax Gold, Lookout California

Hayden Hill is a new mining operation; construction began in October 1991 and operations started in June 1992. The Hayden Hills project is operated by Lassen Gold Mining, Inc. (LGMI), a subsidiary of Amax Gold Inc. The site is approximately 55 miles northwest of Susanville, in Lassen County, California.

Amax Gold won the 1992 DuPont/Conoco Environmental Leadership Award for environmental excellence in the precious metals industry and a California Mining Association award for its facility reclamation plan. (Mining Engineering, Dec. 1992).

Process operations include an open pit mine (gold and silver), waste rock disposal area, one heap leach pad, mill processing facilities, a gold and silver processing plant, solution containment ponds, one tailings impoundment, and ancillary facilities. The heap leach will be used for lower grade ore, while higher grade ore will be milled (carbon-in-pulp circuit). Life of the mine (ore production) is forecast as 8 years. (EIS, 1991)

Activities at the site will disturb 6.55 acres of wetlands, 80 linear feet of permanent stream and 1,315 linear feet of intermittent stream. Hayden's obstacle was to design a mining facility that would least impact the surrounding area. Proposed actions include creation of 18.5 acres of seasonally inundated wetlands adjacent to the site. Activities will meet Clean Water Act Section 404 permit requirements. Several of the storm water control measures incorporated into the Hayden Hill project design are included in Table 8 or described below.

Table 6. Hayden Hill Control Measures

Double liner and leak detection for heap leach pad
Double liner and leak detection for the processing ponds
Lined tailings impoundment
Erosion control measures throughout construction and operation of the mine, i.e., retention ponds to intercept runoff and promote settling, stream crossing constructed during low flow periods
Stream crossing design had least change to stream bottom
Protection of 500 feet of stream bank (near road crossing) to protect from grazing impacts
Groundwater seeps (springs) near the open mine pit will be rerouted
Diversion of natural drainage around the heap leach pad
Solution pipes located in lined ditches
Routine inspection of sediment control devices to ensure proper functioning (i.e. no blockage)

As part of the design studies, modeling of sediment yields was performed to evaluate cumulative watershed impacts. The study concluded that there would be no significant increases in sediment impacts downstream of the project. (EIS, 1991, by reference FES, 1991) The design involves extensive erosion control methods, both as interim measures during operations and as part of the facility's permanent concurrent reclamation plan. The facility has incorporated baseline and continual monitoring of groundwater and surface water (pre-, during, and post- mining activities) to ensure BMP measures are working according to design standards.

Diversion ditches will surround the heap leach pad and the tailings facility. The heap leach area has process solution ponds, the perimeter ditch and the heap leach pad. Reclamation activities will add riprap chutes to channel runoff from the heap leach area to a series of sedimentation ponds. The tailings facility is self-contained, with solutions and storm water remaining within the tailings impoundment itself or a process water pond located nearby. The tailings impoundment has a freeboard berm surrounding the area of deposition to protect against runon and overflow.

All runoff from the shop and warehouse areas are collected in a storm water collection ditch. The design includes perimeter containment berms around the fuel loading and wash bays, to protect against runon and to keep its storm water separate from other areas of the facility. Above the mill area are storm water diversion ditches to route storm water around the mill to avoid potential contact with material at the mill.

A waste rock dump basin is designed with interior benches that slope in a "V" towards the inside of the basin to allow storm water to be captured as it flows across the bench. "V" ditches will drain the runoff to a heap toe drain. The waste rock dump drainage system incudes storm runoff chutes for long vertical stretches. An energy dissipation basin is located at the toe of the dump; it is a widened channel constructed with riprap that flows via natural drainage channels to a sedimentation basin.

As the concurrent reclamation activities begin, grading will be conducted to create suitable drainage patterns to facilitate collection of storm water and break up of the overland flow. Revegetation will be an important step in the concurrent reclamation and, to aid in that effort, various erosion controls will be used including: riprap in shallow interception ditches, sediment collection basins, rock dikes, and straw bales as check dams around culverts.

Expectations are to return the site to livestock grazing, watershed protection, wildlife habitat, and recreational use after completion of mining activities. In its reclamation plan, LGMI focused on designing seed mixtures tailored to specific areas and specific post-mining land uses, realizing that regrowth on disturbed land can differ from growth on the original undisturbed lands. As part of this effort, LGMI studied historic mining disturbances in the area and their regrowth patterns.

Costs of implementing this program were not obtained. The Hayden Hill Project represents storm water control measures, or BMPs, that are incorporated into the initial design of the facility and into its concurrent reclamation activities (concurrent with mining). LGMI/Amax Gold won a recent award from the California Mining Association for its reclamation plan that addressed these concerns.

Dunka Mine, LTV SMCo, Minnesota

Background

The Dunka mine site is an example of a facility using wetlands treatment methods to mitigate an existing seepage problem. Although the activities at Dunka are the result of enforcement actions taken by the State, the measures that are being used could be appropriate at other sites. Because of the potential applicability of these measures, a discussion of the Dunka site is highlighted below.

The Dunka site is an iron ore mine operated by LTV Steel Mining Company (LTV SMCo). Mining activities at the site have generated vast stockpiles of waste rock, lean taconite ore stockpiles, and surface material stockpiles. A specific type of waste rock found at the site is the Duluth Complex, an acid generating gabbro, which is unique to the Dunka site.

The facility has experienced seepage from the Duluth Complex waste rock stockpiles. The seepage has shown elevated levels of copper, nickel, calcium, magnesium, and sulfate. Most of the seepage from the waste rock piles has flowed to an unnamed creek that flows into Bob Bay in Birch Lake. A 1977 study found elevated concentrations of metals (copper, nickel, cobalt, zinc) in Bob Bay. The study estimated 500 million gallons a year discharge from the Dunka watershed to the creek.

The facility is currently working with the state on a strategy to mitigate leachate generation and releases of trace metals specifically associated with the Duluth Complex materials. Technologies currently under study include pile capping, channeling to limit infiltration, active wetlands treatment to remove metals, and neutralization of collected runoff to increase pH and precipitate metals. These measures are discussed further below. The ultimate goal is a system of passive controls that will require little or no maintenance.

Stockpile Capping

The facility is developing methods to cap the Duluth Complex stockpiles to reduce infiltration. Surface materials at the site have been screened to three sizes. Oversized material (plus 3-inch) is used to cover the side slopes of the stockpile. A buffer layer of plus 1/2-inch to minus 3-inch material is placed on top of the stockpile followed by a primary barrier capping of 18 inches of minus 1/2-inch material. The cap is finished with a layer of the plus 1/2-inch to minus 3-inch material as a growth media. LTV SMCo then seeds the top of the pile.

Channel Diversion

As part of the mitigation plan, the facility constructed a channel in the unnamed creek. Originally, the headwaters of the unnamed creek flowed directly through one of the Duluth material stockpiles and into the pit. Upstream of the stockpiles, the unnamed creek now has been diverted to the pit. Additional ditches have been constructed to divert runoff from the Duluth material stockpiles. The facility has also contoured slopes in the area to further reduce the runon to the Duluth Complex materials. Total rechanneling costs have been estimated to be $600,000.

Wetlands Treatment

Studies conducted at the site indicated effectiveness of wetlands treatment methods for removal of metals from runoff/seepage from the Duluth Complex stockpiles. Water analyses indicated 30 percent removal of nickel and 100 percent removal of copper by peat sequestration. Overall mass analyses indicated more than 80 percent of copper entering the wetlands were retained.

Neutralization/Metals Precipitation

The facility also operates a lime treatment system for removal of metals from collected waste rock runoff/seepage. The system includes lined equalization basins to contain the seepage material until it is pumped to a treatment plant where lime is added. Flocculants are added and the material flows to a thickener. Overflow passes through a sand filter prior to discharge to the unnamed creek, while the thickened sludge is sent to a filter press. As of August 1991, the facility was evaluating markets for the thickened sludge.

The Dunka mine site is using wetlands treatment, neutralization, metals precipitation, capping, and stream diversion methods to mitigate existing seepage problems and to control future discharges. Measures used at the Dunka site can be appropriate as strategies at other mining facilities when adapted to individual site characteristics.

Bagdad Mine, Cyprus Bagdad Copper Corporation, Baghdad, Arizona

The Cyprus Bagdad facility is an example of an integrated approach to water management at an existing facility. Cyprus Bagdad's water management plan is included as part of its pollution prevention plan. The pollution prevention plan was prepared in response to Arizona Department of Environmental Quality (ADEQ) requirements. The pollution prevention plan addresses many areas of the facility including non-mining activities such as vehicle fueling stations, and provides implementation strategies, such as training and inspections. The pollution prevention plan describes an NPDES Best Management Practices Program.

A non-storm water discharge assessment was conducted by facility personnel in August 1992 identifying areas of potentially contaminated runoff at the utilities and facility support operations. The assessment was conducted during a rainfall event in order to observe actual contaminated runoff and areas of potentially contaminated runoff. Observed releases included oil film in runoff entering a storm drain from a vehicle storage area (leakage from a parked truck); oil film and food debris in runoff from an unloading zone behind a facility grocery; and small amounts of sludge from a sludge drying bed associated with the facility wastewater treatment plant. Potential sources of contaminated runoff included: tank filling areas; vehicle fueling; equipment storage area located 100 feet from a creek (assorted scrap pipe, anodes, old tanks, etc.); and open drums at chemical storage areas.

The committee addressed each of the identified sources and potential sources of contaminated runoff and suggested appropriate controls. Resolutions included modifying trash pickup schedules and repairing hydraulic leak problems in trucks and continual visual monitoring of the vehicle storage area. Facility operators notified the gas station lessee to use drip pans under leaking valves at the diesel tank, to check once a day for leaks until a new tank is installed, and required lessee to replace and upgrade rubber used oil hoses. Other controls implemented at the Cyprus Bagdad facility are listed below and in Table 9.

Table 7. Cyprus Bagdad Control Strategies

Construction of a lined impoundment and oil/water separator, at truck wash area
Diversion ditches to carry potential storm runon away from SX leach and tailings disposal areas
Maintenance of pumping systems for the prevention of accidental discharges from collection systems
Visual leak/spill inspections of tailing disposal, reclaim water, seepage return, and leaching systems
Redirection and control of water from mine shop parking lot
Upgrade fuel islands & refueling practices (new containment structures for hoses, automatic shut-offs)
Collection & recycling of spilled fuel and oil
Berm area for mothballing old equipment
Monitor equipment areas for oil contamination
Develop procedures for decommissioning of equipment (washing, draining, etc.)
Construct transformer receiving & handling area at the mine electrical shop storage area
Cover copper-concentrate trucks with heavy tarps and bag molybdenum to prevent in transit losses
Store molybdenum bags on pallets (polyethylene bags)
Store copper concentrate on concrete and asphalt pads
Recycle water at the tailings dam back to mill process

Cyprus uses diversion ditches to carry runoff away from the solvent exchange (SX) leach and tailings disposal areas. The pollution prevention plan calls for regular inspections and necessary repairs of the ditches. At other areas, runoff or spills are directed to collection basins and surge ponds. Cyprus has plans for upgrading many of its existing ponds with double liners and leak detection systems. A sloped concrete pad was suggested as a simple, low-cost solution for containment of the kerosene unloading pad in order to prevent spillage from being discharged and to contain runoff.

Cyprus uses earthen berms around petroleum tanks to prevent runon from coming in contact with the tank and surrounding area. Additionally, if any spills or discharges from the tank occurs, the berms would contain any contaminated runoff.

To reduce hydrocarbon and product residues from adhering to vehicles and to reduce potentially contaminated runoff from being discharged, Cyprus plans for construction of truck washes equipped with lined impoundments and oil/water separators to collect wash-water and runoff. Chlorinated solvents will no longer be used at the truck wash, which eliminates a contaminant source.

The facility has designated and bermed an area for mothballing old equipment. Berming protects against oil and other residue from being discharged to surface water. This area will be monitored for contamination and procedures for decommissioning, washing, draining of equipment will be developed to prevent further contamination.

Copper concentrate trucks are covered with heavy tarps and molybdenum is bagged in polyethylene bags to prevent in transit losses to road ways (losses can become contaminated runoff). Molybdenum bags are stored on pallets and copper concentrate on concrete and asphalt pads in order to reduce contact with runoff.

Part of Cyprus's integrated approach is its wide variety of activities throughout its operations; another aspect of its integrated approach is the level of detail. The Cyprus pollution prevention plan clearly states project descriptions, rationale, and performance goal summaries for each suggested control measure. Goals includes percent volume reduction and target dates. The plan provides measures for tracking progress via environmental steering committee meetings, tracking of construction projects through budgetary process, supervisors keeping monitoring logs, periodic management reviews, tracking assigned projects via employee performance reviews, and training of employees. Strategies identified include outlining the frequency of routine maintenance and inspections, and identifying what items should be inspected such as testing of emergency backup systems, monitoring pump rates, pond and dam elevations, depth measurements of liquid present in collection systems, visually inspecting HDPE liners, checking pump performance by motor amperage readings, piping and sumps to ensure all systems are performing to design.

Valdez Creek Mine, Cambior Alaska, Inc, Cantwell, Alaska

The Valdez Creek Mine is a placer gold mine operated by Cambior Alaska and Camindex Mines, and is located 110 miles south of Fairbanks, near Cantwell, Alaska. Mining in the Valdez Creek area has occurred since 1903. The current pit has been in service since 1984.

In 1990-1991, operational changes occurred at the mine site. In order to access additional ore sources beneath the active stream channel, Valdez Creek was diverted. A diversion dam was constructed upstream of the active pit. The dam impounds water, which then flows through the diversion channel approximately one mile until rejoining with the stream. The diversion channel is lined with a synthetic liner and rip-rap to prevent erosion and incision (downcutting) of the channel. The creek is then returned to its original channel below the mine, before entering the Susitna River.

To assist water management in the active area of the pit, the facility maintains two small diversion ditches on either side of the valley above the mined area to intercept runoff before it reaches the pit. Water from these diversion ditches flows to two settling ponds. The facility's diversion system is designed to control flows produced by up to a 25 year storm event. By utilizing the lined diversion channel for Valdez Creek and the two small diversion ditches and settling ponds, the impact to the downstream environment is minimized by the reduction in turbidity and sedimentation in Valdez Creek caused by the mining operation.

Like many placer mines in Alaska, Cambior Alaska Inc, has used stream diversion techniques at the site. However, at this facility the stream diversion not only prevents stream discharges, but also improves access to the ore and has lowered operating costs by reducing pit dewatering requirements. Specific operating costs and construction costs were not obtained.

Costs

Costs were not obtained for the specific activities described in the above-mentioned case studies. Although cost data for the case studies are not available, there are some general costs that can be considered to be similar. The following tables present costs associated with certain water management and control technologies.

Table 8. Costs of Drainage Management Systems for Construction Sites

Source: EPA Storm Water Program Baseline General Permit

Drainage Management System	Cost for 5 acre developed area	Cost for 20 acre developed area
Wet ponds	$5,770	$16,300
Dry ponds	$12,000	$29,330
Dry ponds with extended detention	$5,950	$15,500
Infiltration trenches	$8,500	$34,100

Cost estimates for construction activities that may apply to mining can be consulted, in order to provide a relative cost comparison. Two major costs associated with discharge control activities include the costs of drainage management systems (see Table 10), and the cost of sediment and erosion controls (see Table 11). The cost estimates were developed by EPA's storm water program Baseline General Permit. It should be noted that the costs have not been adjusted to reflect the accessibility issues that frequently arise at mine sites.

Table 9. Sediment and Erosion Control Costs

Temporary Seeding	$5,000 per acre
Permanent Seeding	$5,000 per acre
Mulching	$6,000 per acre
Sod stabilization	$4.00 per yard
Vegetative buffer strip	$5,000 per acre
Earth dikes	$5.50 per linear foot
Straw bale dikes	$5.00 per linear foot
Silt fences	$6.00 per linear foot
Drainage swales - grass	$3.00 per yard
Drainage swales - sod	$4.00 per yard
Drainage swales - riprap	$45.00 per yard
Drainage swales - asphalt	$35.00 per yard
Drainage swales - concrete	$65.00 per yard
Check dams - rock	$100 per dam
Check dams - covered straw bales	$50.00 per dam
Level spreader - earthen	$4.00 per yard
Level spreader - concrete	$65.00 per yard
Subsurface drain	$2.25 per linear foot
Pipe slope drain	$5.00 per linear foot
Temporary storm drain diversion	Variable
Storm drain inlet protection	$300 per inlet
Rock outlet protection	$45.00 per yard
Sediment traps	$500 to $7,000 per trap
Temporary sediment basins	$5,000 to $50,000 per basin
Sump pit	$500 to $7,000
Entrance stabilization	$1,500 to $5,000 per entrance
Temporary waterway crossing	$500 to $1,500

Source: EPA Storm Water Program Baseline General Permit

Conclusions

It is possible to minimize releases of wastes by managing runon/runoff in a manner that avoids or minimizes generation of potentially contaminated water. In cases where contact of water with contaminant sources has occurred, or cannot be feasibly or cost effectively prevented, measures can be employed to collect, contain, and treat the runoff. These activities can be accomplished by developing, implementing, and maintaining an integrated approach to water management at a mining facility.

This report has briefly outlined a few case studies where many practices have been implemented. Actual facility implementation of the reclamation and water management plans, however, was not investigated for this study. Activities like those discussed in the case studies, as well as many other techniques, can be incorporated into existing facilities throughout the mining industry. Initial facility design considering runon/runoff controls is a good example of planning. In addition, one important aspect to success is the daily, routine implementation of the correct management practices.

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Attachment

Techniques for Management and Control of Runoff

Management and Control of Runoff

Effective practices for the management and control of runon/runoff are also known as best management practices, or BMPs. BMPs can be defined as measures or practices used to reduce the amount of pollution entering surface water, air, land, or groundwater, and may take the form of a process, activity, or physical structure. BMPs may include schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce discharges of pollutants to waters of the United States. BMPs include treatment requirements, operating procedures, and practices to control plant site runoff, spillage or leaks, waste disposal, drainage from raw material storage or other disturbed areas.

There are two ways to reduce the potentially contaminated discharges from a facility. First is avoidance; it is often preferable to minimize contact of water with contaminant sources. Second is to reduce the volumes of wastewater and pollutant concentrations in the wastewater. BMPs applicable to mine site discharges can be divided into three general areas: (1) construction/reclamation, (2) management and housekeeping, and (3) treatment. Specific techniques in each of these areas include:

Construction/Reclamation Techniques
- diversion ditches and drainage systems
- rip-rap
- dikes & berms
- grading or terracing
- collection basins
- capping or sealing
- vegetation & mulching
- silt fences

Management & Housekeeping Techniques
- proper handling procedures
- immediate spill cleanup
- inspection
- training & education
- routine maintenance
- comprehensive pollution prevention plan
- periodic reviews of systems

Treatment Techniques
- sedimentation basins
- oil/water separators
- neutralization
- artificial wetlands

In a hierarchy of preferred strategies, it is generally most desirable to avoid contact with exposed materials. This is done by preventing runon from flowing onto the site or coming into contact with individual contamination sources (using practices such as dikes or berms). Second if contamination does occur, BMPs can be used to promote infiltration and reduce contaminant loadings. Finally, runoff can be collected in basins for sedimentation or treated by other means. A brief discussion of the various construction/reclamation techniques and treatment systems follows.

Construction/Reclamation Techniques

Construction/reclamation techniques are divided into structural, vegetative, and capping/sealing practices in the following subsections.

Structural Practices

Discharge diversions provide the first line of defense in preventing the contamination of discharges and are installed to divert flow, store flow, or limit runoff. Diversion structures are often designed to prevent water from crossing disturbed areas where contact may occur between run-on and significant materials. These measures may be particularly effective for former mining areas and stockpiles. Measures to prevent contact include diversion structures, such as dikes, berms, or ditches to channel runon away from or around a potential contaminant source. Materials used to construct dikes, curbs, and berms include earthen materials (eg. clay), concrete, synthetics, metal or other low permeability substances. Additionally, diversion structures can be used to collect or divert waters for later treatment, if necessary. The usefulness of diversion measures are limited by such factors as the size of the area to be controlled, and volumes of runoff to be diverted.

Drainage Systems

Drainage systems are designed to control drainage by redirecting channel flow, slowing velocity and controlling volume, in order to improve or prevent infiltration or reduce erosion. A drainage system may consist of structures such as subsurface drains, leachate collection systems, etc. Drainage systems may be lined with grass, rip-rap, asphalt, or concrete.

Drainage systems are effective when used in conjunction with outlet velocity dissipation devices designed to slow the flow of water discharged from a site in order to lessen the amount of erosion. Some examples of the more effective velocity dissipation devices include check dams, rock outlet protection, and level spreaders. These are discussed below.

<u>Check Dams</u>. Check dams are small temporary dams constructed across swales or drainage ditches to reduce the velocity of runoff flows, thereby reducing erosion and potential failure of the swale or ditch. This slowing also allows sediments to settle. Materials used to construct check dams include: rock, timber, sandbags filled with pea gravel, and straw bales.

Check dams also may be used as a passive treatment mechanisms, particularly for acid mine drainage. By incorporating alkaline containing materials (i.e., limestone rock or mix materials with neutralizing properties with pea gravel in the sand bags), acid mine drainage can be treated. Additionally, incorporating a sorbent into the sand bags will assist in absorbing organics.

Rock Outlet Protection. Rock protection at the outlet of culverts, channels, or ditches reduces the depth, velocity, and destructive energy of water. As with check dams, rock outlet protection may also be used as a passive treatment mechanism by using rocks containing limestone or other alkaline materials to neutralize acidic discharges.

Level Spreaders. Level spreaders are outlets for dikes and diversions consisting of an excavated depression constructed at zero grade across a slope. Level spreaders convert concentrated high velocity, concentrated flows into diffuse runoff that is released onto areas stabilized by existing vegetation (thereby promoting infiltration).

Infiltration Controls

Infiltration controls are surface or subsurface measures such as trenches and basins, that promote rapid infiltration of precipitation and runoff. Infiltration devices can be used to reduce discharge volumes and provide for groundwater recharge. Treatment may be incorporated within the trench/basin. Limestone or soda ash can be used for neutralization of potentially acidic discharges.

Straw bale dikes, silt fences, and brush barriers are temporary barriers used to intercept sediment in runoff from small areas of disturbed soil. Silt fences consist of geotextile fabric (filter cloth). Silt fences are generally more effective in preventing discharges of sediment than straw bales. Brush barriers are temporary sediment barriers composed of tree limbs, weeds, vines, root mat, soil, rock, and other cleared materials placed at the toe of a slope. A brush barrier is effective only for small drainage areas, usually less than 1/4 acre, where there is sheet flow, and the slope is minimal.

Vegetative Practices

Vegetative practices involve covering or maintaining an existing cover over soils. The cover may consist of grass, trees, vines, shrubs, bark, mulch and/or straw. A vegetative cover reduces the potential for erosion at a site by reducing flow through infiltration. Vegetative practices include permanent seeding, mulching, soil conditioning, contouring or grading, and the use of vegetative strips.

Permanent seeding stabilizes the soil to reduce sediment in runoff from the site. Mulching is most effective when used in conjunction with a permanent seeding program. When permanent seeding is not feasible, exposed soils can be stabilized by applying plant residues or other suitable materials to the soil surface. Soil conditioning or topsoiling may be necessary to improve the area on which permanent vegetative practices will be established. Conditioning is often necessary where soil is of poor quality. Surface contouring creates horizontal grooves, depressions, or steps that run with the contour of the land. Slopes may also be left in a roughened condition to reduce discharge flow and promote infiltration.

In some cases, revegetation of an entire site is unfeasible. In such cases, revegetation in buffer strips may be a more appropriate control measure. Vegetative buffer strips are strips of vegetation at the top and bottom of the slope of a disturbed site. Vegetative buffer strips can slow runoff flows at critical areas, decreasing erosion and promoting sedimentation.

Capping and Sealing

Elimination of a pollution source through capping, plugging, or sealing contaminant sources may be the most cost effective control measure for discharges from former and inactive mining operations, including tunnels, adits, and surface mine workings as well as from waste rock and tailings.

Capping/sealing is designed to prevent infiltration, as well as to limit contact between runoff and potential sources of contamination. Ultimately, capping should reduce or eliminate the contaminants in discharges. In addition, by reducing infiltration, the potential for seepage and leachate generation may also be lessened. This practice could be applicable to pits, waste rock piles and tailings piles (particularly acid producing materials). Cap/liner materials include soil, clay, and/or synthetics.

Plugging of mine adits provides control and reduction of waste generation and migration. Once the adits are plugged, water will rise and flood the void space behind the plugs. Inundation of high sulfide mineral zones behind the plugs will prevent or reduce the chemical reactions that generate acid and release metals from the minerals, thereby reducing the contamination of water within the mineralized zones. Plugs will serve to prevent surges of water, sludge, and sediment from tunnels to surface waters, as well as preventing the introduction of precipitation into subsurface areas.

Leachate Control and Collection

Leachate control and collection techniques may be appropriate for managing leachate/seepage from mine adits, mine waste units, and heap and dump leach piles. Leachate collection and removal systems are commonly sand drainage layers, synthetic drainage nets (i.e., geonets) or granular drainage layers with perforated collection pipes installed in gravel-filled trenches above the liner at the base of the disposal unit. The collection system is drained by gravity to a sump or series of sumps or to storage tanks or ponds from which the leachate is withdrawn for treatment or disposal.

Treatment Techniques

Treatment practices are those controls that result in a reduction of pollutant concentrations in discharges. Most treatment systems are based on relatively simple passive technologies such as settling of solids, and neutralization, and are designed to collect and temporarily store on-site runoff to meet the demands of a 10-year, 24-hour storm, or 25-year, 24-hour storm event.

Discharge Detention Structures (Sediment ponds)

Discharge detention structures can achieve a high removal rate of sediment and metals. Additionally, ponds have the capacity to promote degradation of organic contaminants. Detention ponds may also act as surge ponds to reduce or eliminate discharges during major storm events or high snow melt periods.

Organic Treatment

Biological processes are typically used to remove organic contaminants. These processes can include anaerobic filters, anaerobic sludge bed reactors, aerated lagoons, rotating biological conductors and trickling filters. Organic removal can also be effectively accomplished by other physical/chemical treatment methods, including air and steam stripping, carbon absorption, and oxidation with calcium hypochlorite or ozone.

Chemical Treatment for Metals

Physical/chemical treatment can also be accomplished in the detention structures described above. This most common type of chemical/physical treatment involves the addition of lime or other caustics to provide neutralization and/or precipitation of metals. Typically, pH levels of 9 to 12 standard units are required to achieve desired precipitation rates. Acid addition may be necessary to reduce the pH if discharge to surface waters is necessary. Polymer addition can also be used to enhance settling.

Lime and calcium fluorophosphate admixing provide an alkaline environment that helps to prevent bacterial oxidation of pyrites in waste materials while neutralizing the pyritic material that is oxidized. Admixing is most effective when used in infiltration trenches filled with different gradients of limestone or soda ash.

Oil/Water Separation

Oil and water separation can be accomplished by use of an API or similar type of treatment device which acts to skim oil and settle sludge. Passive oil/water separators constructed of concrete can also be used to separate oil and water by gravity separation. Absorbent booms are also sometimes used to collect any oil contained in runoff.

Artificial Wetlands

Artificial wetlands are designed to maintain a permanent pool of water. Artificial wetlands will be most cost-effective when used to control runoff from larger, heavily developed sites. Artificial wetlands are created to provide treatment. Artificial wetlands are currently being researched by the Bureau of Mines as a means of mitigating acid mine drainage.

4.2 CYPRUS BAGDAD POLLUTION PREVENTION PLAN

Arizona has established a multifaceted pollution prevention program to encourage generators of hazardous waste to prepare a Pollution Prevention Plan. The Company issued a Plan in December 1992 that integrates pollution prevention planning for the entire facility with existing emergency response plans, such as their Spill Prevention Control and Countermeasures (SPCC) Plan and others.

The State encourages companies to prepare pollution prevention plans by reducing environmental permit filing fees 50 percent. Cyprus estimates that this amounts to a saving of $10,000 to $20,000 per year. As stated in the Plan, Cyprus is committed to identifying, measuring, and reducing pollution from its facilities. While acknowledging the need to use chemicals in many phases of their operation, they have obligated themselves to reduce the amount of hazardous substances used and hazardous wastes generated.

According to a facility representative, Cyprus management initiated preparation of the Pollution Prevention Plan in response to the State requirement. The Company Vice President on site issued a statement promoting the importance of pollution prevention and requesting full employee support. Cyprus Bagdad's Plan was designed as a workforce based plan with the environmental department acting more as a facilitator in the process. The Plan was implemented through top-down and bottom-up training. Management was trained in pollution prevention concepts and an environmental steering committee was formed. The environmental steering committee coordinated employee training in pollution prevention and enlisted their help at their regular safety meetings in implementing the Plan. Both management and employees worked to identify projects. The facility's environmental staff conducted an internal audit for regulatory compliance and made recommendations to management. Their current function is to help management setup a tracking system for new ideas submitted by the employees and to monitor the status of ongoing projects. According to Cyprus, they are receiving one or more ideas each week. A status report was submitted to the State in July, 1993.

Plan Components

The Cyprus Pollution Prevention Plan was structured as a composite of existing plans and new material combined into three new plans. The three plans, prepared by the Mine, Mill (with the SX-EW plant as a sub-area), and Community Services operations, were designed to encourage departmental initiatives, identifying projects within their area that support the Company's goal of pollution prevention. Projects identified for the Community Services Operation are not included in this report since they are not related to mining activity. For existing plans (e.g. SPCC plan) best management practices and waste minimization goals were also identified. The general goals of the Pollution Prevention Plan, as stated by Cyprus are: (1) inventory all chemical and petroleum products at each location; (2) identify and develop substitute product recommendations; (3) develop methods for mass balance on chemical and petroleum products, and; (4) develop employee training and heighten awareness. New contract language with contractors, vendors, or service companies requires compliance with Cyprus Bagdad's Pollution Prevention Plan.

In this summary, projects identified in each operation's plan are grouped into one of two categories; those unique to mining and those best described as good housekeeping. The following text summarizes these projects grouped by these two categories. Within these categories, the project's orientation is identified (e.g. source reduction, spill prevention, etc.). Descriptions of the projects include information as it is available from the Plan in the individual operation's description. Where applicable, planned completion dates and regulatory requirements are given.

Projects Unique to Mining

Of the projects identified as part of the Plan, none are uniquely related to the operation of the mine. However, one project planned for the mill and three projects planned for the Solvent Extraction-Electrowinning (SX-EW) plant can be considered unique to extraction and beneficiation operations.

Mill personnel have observed that the zinc liners in the secondary crushers could be recycled more effectively. While zinc mantle liner pieces are currently recycled at the facility (the method of recycling was not discussed), they sometimes get misplaced in the scrap metal bin used for steel. According to Cyprus, more careful segregation could reduce 1993 zinc purchases as much as 20 percent of those in 1992 (up to 1,900 pounds at $0.87 per pound).

Two of the projects are identified for the SX-EW facility involve upgrading solution impoundments and adding leak detection systems. The pregnant leach solution (PLS) surge pond is to be upgraded to double-lined containment with a leak detection system. The raffinate pond will be upgraded by adding a leak detection system. Work on the PLS surge pond and the raffinate pond are required for compliance with Arizona Department of Environmental Quality (ADEQ) aquifer protection limits. A third project is to recover kerosene exiting the solvent extraction stream (the method was not specified). Personnel are investigating installation of a recovery system for entrained organics in the raffinate stream.

Good Housekeeping Projects

Most of the projects proposed by the plan are good housekeeping measures. The predominant source reduction techniques employed are product changes and source control. Recycling and waste treatment are also employed in addition to source reduction. Of the 25 good housekeeping measures, the mine identified seven, the mill identified eleven, and the SX-EW plant identified seven. All of the practices could potentially be applied at other mine sites.

Mine

Of the seven projects identified by the mine, some are currently underway. Fuel spillage will be controlled (source control) around the fuel islands and new re-fueling procedures are to implemented. This project calls for design and installation of a containment structure for hoses and an evaluation of automatic shut-offs. Spilled fuel and oil will be collected and recycled whenever possible. Cyprus also plans to site, design, and construct a bioremediation facility for petroleum contaminated soil. According to the Plan, soil will be returned to the waste dump or used as landfill cover when hydrocarbon contamination drops below the current regulated level of 100 ppm.

The mine is investigating using bulk containers instead of 55 gallon drums for lubricants to eliminate residual product in the drums. Lubricant suppliers will be contacted to determine if bulk reusable containers are available and written procedures will be developed for their use. Other projects call for elimination of chlorinated solvents in the truck wash facility. The mine shop will reduce use of chlorinated solvents 25 percent. As part of this activity, the sedimentation basin will be closed and remediated and a lined impoundment with an in-line oil/water separator will be built. Storm drains from the mine shop parking lot will be controlled and diverted to the impoundment. Water will be redirected to the mine (additional details on this project were not provided in the Plan).

Another project to be implemented will be selecting a storage site and developing written procedures for decommissioning used equipment (e.g. washing, draining fluids, etc.). The storage area is to bermed and monitored for oil contamination. Finally, a transformer receiving and handling area at the mine electrical shop storage area will be built.

Mill

Mill projects focus on recycling and source reduction. Like the mine, some of these are intended to meet ADEQ regulatory requirements. The Company is asking lubricant suppliers to recycle spent products. As part of this project, the purge and collection system for oil and grease will be revised to use bins. The current system was not described. Freon from refrigeration units will be recycled to minimize evaporation of chlorinated compounds. Cleaning solvents in the maintenance area will also be recovered and recycled. Safety Solvent will be filtered and recycled; this should reduce purchases by 20 percent.

The maintenance shop will recover and recycle metal scrap. Bins for metal were placed in the shop area. Cyprus estimates that 10,000 lbs of scrap bolts etc. should be collected annually. Scrap metal is recycled off-site.

Truck washes will collect hydrocarbons and sediment. Hydrocarbons will be recycled whenever possible or sent to the bioremediation facility. The warehouse is also investigating options to sell paper and cardboard to a recycling plant and plans to reuse packing materials where possible.

Examination of source reduction opportunities have resulted in a number of projects. The mill uses lime to condition water reclaimed from the tailings impoundment. By adjusting the pH of feed water from 10.5 to 10.0, lime consumption will be reduced 5 percent. This will result in a minor cost savings and should not pose a scaling problem. In the past, the mill has added chlorine to tailing seepage water to prevent excessive biogrowth; 800 pounds of calcium hypochlorite was added in 1992). Cyprus will discontinue this practice since no benefit was observed. Another goal for source reduction is the elimination of chlorinated solvents. Some chlorinated solvents have already been eliminated from stock (e.g. trichloroethane was eliminated), and others were reduced 50 to 70 percent (usage was not specified). Storage and use of toluene-based spray paint will also be discontinued. Hand painting with non-toluene based paint will be encouraged.

The mill's laboratory inventoried their chemicals on hand. A selected stock of chemicals have been, or will be, reduced or eliminated. Following a January 1992 inventory, a licensed chemical disposal firm removed 122 chemical species from the laboratory. Additional chemicals are to be removed. The laboratory also eliminated use of xylenes to dilute analysis oils and substituted kerosene.

SX-EW Plant

Projects at the SX-EW plant are intended to control surface contamination and encourage source reduction. Several of the projects at the facility are designed to meet ADEQ requirements. The Flood Basin will be upgraded by installing double-lined containment with a leak detection system. The facility also plans to build a containment structure around the kerosene unloading pad to contain any spills which occur during unloading. The acid storage area will be relocated and upgraded so that drainage would enter the leach feed solution. Details on the design were not specified. Spills outside the Electrowinning (EW) facilities, and from the sulfuric acid storage tanks, will report to the raffinate pond in the future.

A variety of source reduction projects are underway. To eliminate empty waste drums and the need for disposal on site, Cyprus is investigating the use of recyclable containers for bulk chemical delivery. The laboratory is revising their analytical techniques to reduce reagent consumption. For example, potassium iodide consumption could be reduced 60 percent each year by optimizing the short iodide method for copper analysis. Atomic absorption and chloride colorimetric methods for copper analysis will be investigated as replacements for the short iodide method.

Costs and Benefits

According to a facility representative, the current costs associated with implementing the Plan exceed savings. Cyprus expects that the benefits of the program to equal the costs in the long term. The search for substitutes to replace chlorinated solvents and the costs for disposal of these existing solvents has its associated costs. When the chlorinated solvents are replaced, these costs are expected to be reduced substantially. Environmental benefits are realized by containing process solutions in lined impoundments and bioremediation onsite. The potential to reduce costs by recycling zinc liners, scrap metal, and other material and the reduction or elimination of chemicals such as lime, calcium hypochlorite, and chlorinated solvents are also incentives. Current savings are in the form of incentives from the State for having prepared the Plan. The Company estimates they are saving between $10,000 and $20,000 in State hazardous waste disposal fees as a result of a 50 percent discount on these fees (the type and volume of wastes transported off site were not specified).

Summary and Conclusions

The Cyprus Bagdad Copper Company prepared an integrated Pollution Prevention Plan. This was accomplished and continues to evolve with the support of Company management and individual employees. Based on implementation of all the Plan's activities, information on the inventory and mass balance of all chemical and petroleum products would provide a solid basis to organize and focus future projects. A portion of the Plan consists of other plans (e.g. Spill Prevention Control and Countermeasures) required at mine sites as part of State regulations. These Plans are integrated into the Pollution Prevention Plan and themselves contain Best Management Practices.

The approach used by Cyprus of evaluating all operations is sound. Cyprus is not only reducing its environmental liability, but may also reduce its operating costs.

Phone Contacts

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Comments

The U.S. Bureau of Mines and the Cyprus Minerals Company submitted comments to EPA on an earlier draft of this document.

EPA Response to Comments

The U.S. Bureau of Mines submitted comments. These have been responded to as appropriate.

EPA Response to Cyprus Comments

Comment 1: The introduction implies that there is uncertainty as to whether or not pollution prevention/waste minimization is currently practiced in the mining industry.

Response: EPA believes that the introduction clearly states that the mining industry is currently practicing forms of pollution prevention/waste minimization. The purpose of these reports is to identify practices currently in use at mine sites, and encourage their use where ever possible.

Comment 2: The Background section leaves the pejorative implication that the only reason a pollution prevention plan was prepared was that it was required by the State and makes a point that it was not conceived and prepared as part of the environmental program.

Response: The text has been amended to reflect the fact that Cyprus went to considerable lengths to involve its workforce in the preparation and implementation of it's plan. EPA is aware that the submittal of such a plan is a requirement established by the state. EPA is not implying however, that Cyprus prepared the plan only because it was a regulatory requirement.

Comment 3: Section 3: Cyprus Bagdad deliberately structured its Plan for each separate area as separate plans. ADEQ disagreed with this approach.

Response: Text has been changed to reflect this position.

Comment 4: Section 3: Cyprus has gone beyond notice to contractors, vendors, and service companies. Language has been inserted into their contracts to require them to comply with the Plan.

Response: Text has been changed to reflect this information.

Comment 5: Section 3: Cyprus sends its scrap metal off-site for recycling. Reference to ore in this section is unclear.

Response: Text has been changed to reflect this information.

Comment: Section 3: Page 4 states that truck washes collect hydrocarbons and product residuals. Only hydrocarbon residuals and sediment are collected. The sediment is not recyclable.

Response: Text has been changed to reflect this information.

Comment: Section 4: The summary and conclusions section does not seem to offer any summary and conclusions.

Response: EPA believes this section adequately summarize the Cyprus Bagdad Copper Corporation's Pollution Prevention Plan.

Comment: Section 4: The summary erroneously states that Bagdad is not in compliance with existing Arizona environmental regulations.

Response: Text has been changed to reflect this information.

Comment: Section 4: The discussion of cost savings appears out of place. Cyprus expects the benefits of the program to equal the costs in the long term.

Response: The discussion of costs and benefits has been moved from the Summary to a new subsection in Chapter 3.