NEW LOGIC RESEARCH

Case Study

V✧SEP Filtration of Acid Mine Drainage

A cost-effective and efficient processing solution

Overview

Since their development as lab filters in the early 1960s, polymeric membranes have grown in the number of uses at exponential rates. Membrane architecture and process design itself has undergone significant advancement. A unique membrane filtration system, known as V✧SEP (Vibratory Shear Enhanced Process), was developed by New Logic of Emeryville California. The technology employs vibrational oscillation of the membrane surface to improve the relative throughput per area of membrane used. This oscillation is used to prevent colloidal fouling of the membrane surface.

One unique benefit of the shear created by vibrational oscillation is the resiliency of the membrane system against fouling from crystallization of mineral salts. Studies recently conducted have shown that crystallization occurs out in the boundary layer of suspended solids as filtrate is removed and solubility limits are reached. Once precipitated, these insoluble mineral salts become just another suspended solid and can be easily washed from the membrane system with laminar crossflow of the process feed.

With conventional static or crossflow filtration subject to colloidal fouling, mineral scale formation would severely inhibit performance. As a result, these membranes have low tolerance for mineral hardness and would require elaborate pretreatment and chemical dosing to inhibit crystal formation using antiscalants. Even with pretreatment and chemical dosing, conventional membranes would be limited in the % recovery of filtrate that is possible.

It is because of this key limitation that membranes have not been used to a great degree in the processing of Acid Mine Drainage, until now. New Logic's V✧SEP has the ability to perform membrane separations not possible using conventional membrane systems. Wastewater treatment systems that are compact, economical, and reliable are now possible for the mining industry.

Mining Regulation

One of the challenges of today's mining operations is that heavy metals which pose a potential environmental hazard are naturally occurring elements in the ore that is removed for processing. For a typical Copper mine, one ton of waste rock can contain several pounds of copper, five ounces of zinc, three ounces of lead, and two ounces of arsenic. On average, the earth's crust has background levels of about 2 ppm of arsenic. Limits currently exist for heavy metals in industrial wastewater discharge. As a result of the Clean Water Act, the EPA is currently developing new tighter regulations on these metals. Since the average soil contains 2 ppm of arsenic, almost any water that has come in contact with soil and is then discharged to sewer could violate the new regulations.

Current EPA Target Limits for Discharge:

Regulated Metal	Symbol	Monthly Ave.
Cadmium	Cd	0.09 ppm
Chromium	Cr	0.55 ppm
Copper	Cu	0.58 ppm
Lead	Pb	0.09 ppm
Manganese	Mn	0.10 ppm
Molybdenum	Mo	0.49 ppm
Arsenic	As	0.05 ppm
Nickel	Ni	0.64 ppm
Silver	Ag	0.06 ppm
Tin	Sn	1.40 ppm
Zinc	Zn	0.17 ppm

The EPA is considering new industrial discharge regulations as a result of the "Clean Water Act"

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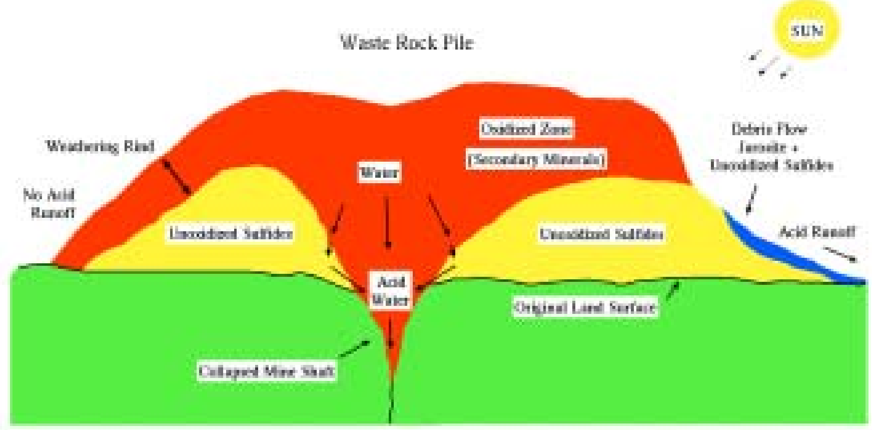
The mining industry is one of the most heavily regulated by the EPA. Mining does nothing at all to increase the amounts of naturally occurring substances in the rock. Ore removed for processing can contain nearly all of the 650 elements and chemicals regulated as hazardous waste by the EPA. Unfortunately, the simple act of moving it from one place to another qualifies as a "release to the environment."

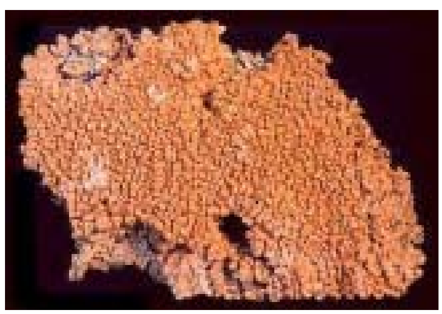


The Life Cycle of Acid Mine Drainage

If you take the parts per million concentrations of controlled substances in the waste rock and multiply them by an average mine's daily tonnage of rock mined, the amounts increase dramatically. A copper mine's total "release" of all TRI reportable chemicals can be approximately 450 million pounds of hazardous materials per year. With the current laws, it makes no difference whether the materials are released to the environment or are stored in government permitted waste rock repositories and tailing impoundments. Either way the movement of the earth must be reported as a "release to the environment"

Many mining companies are forced to clean up historic wastes from mining in the 19th century. Again, the act of moving this material constitutes a "release" according to the EPA's method of reporting, even though the historic mining wastes are being placed in state or federally-approved impoundments that are safer for the environment than if the wastes remained in their current location.

The problem can be even more difficult if the mining involves rare earth metals where Uranium, Radium, or other radioactive elements can be found. As long as the radioactive elements are not disturbed, there is not classification as a hazardous material that needs superfund attention. But if the rock is moved from one place to another, a release of radioactive materials has occurred and must be reported.



Copper Ore from Arizona

Copper Mining Process

Rocks are blasted to break them into smaller pieces and loaded into large trucks for transport to the processing locations. The ore goes either to concentrating and smelting or to leaching and electrowinning. It depends on how much copper and the types of minerals it contains.

In one copper production process, rock that comes from the mine is crushed into smaller and smaller pieces by heavy steel balls in machinery called mills. Concentrating Ground up rock is mixed with water, air bubbles and small amounts of chemicals. The chemicals allow copper minerals to rise to the top and stick to floating air bubbles. The remaining mixture of crushed rock and water – called tailing – separates from the copper bearing bubbles. The copper minerals are skimmed off and dried to form copper concentrate, a powder-like material.

In the smelter, copper concentrate is melted and copper is separated from other substances in the concentrate. Molten copper is poured into molds called anodes. The unwanted material cools to a glass-like substance called slag. The natural metals that remain in slag are reported under EPCRA.

Processed Gold Ingot

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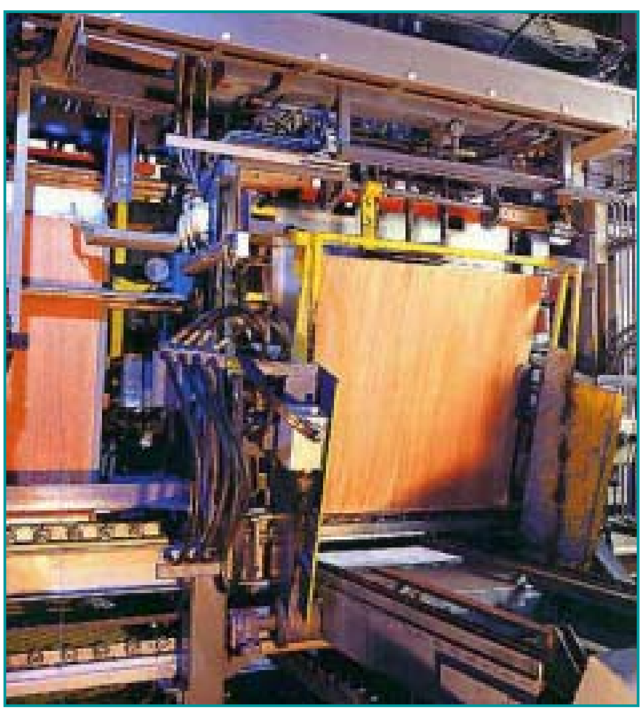
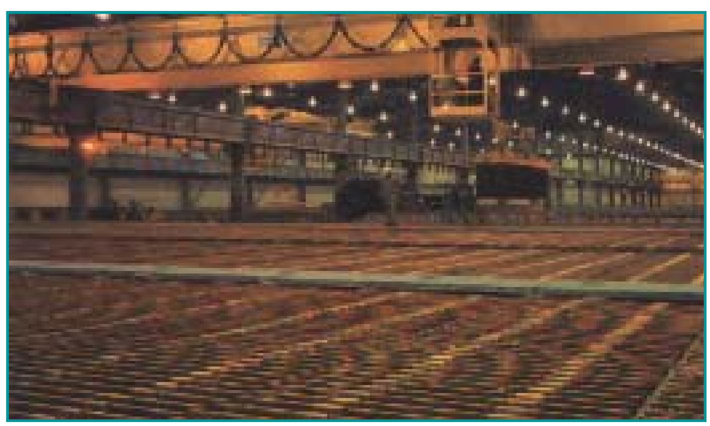
In an alternate copper production process, rock is taken from the mine directly to stockpiles. A solution of slightly acidic water is dripped on the stockpiles, percolating down through the rock and dissolving copper along the way. The solution containing the copper is collected and piped to holding ponds. In tanks, the copper-bearing solution is mixed with chemicals that transfer the copper to a more concentrated solution called electrolyte. The electrolyte is pumped to steel tanks. Starter sheets hang in the solution and, using an electric current, the copper is plated from the electrolyte on to the sheet, forming 99.99 percent pure copper plates. All solutions used during this process are recycled. Producing copper and other hard metals also takes a lot of water, which is why water management is such a crucial part of any mine's operations.

Copper Ore being Loaded





"Electrowinning" - is electroplating of dissolved copper onto metal anodes using electrical current

Finished Copper Anodes ready for transport as sale

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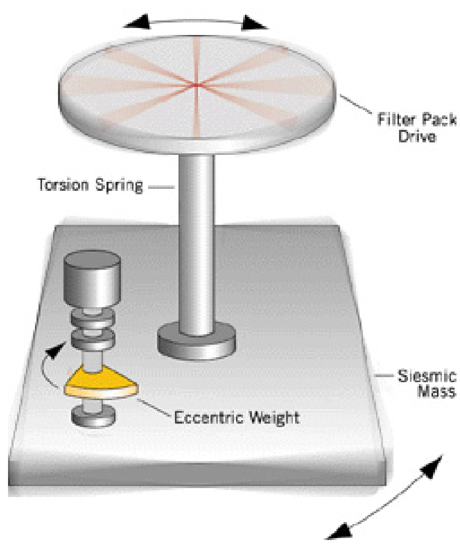
Vibratory Shear Process

V✧SEP's unique separation technology is based upon an oscillating movement of the membrane surface with respect to the liquid to be filtered. The result is that blinding of the membrane surface due to the build up of solids is eliminated and free access to the membrane pores is provided to the liquid fraction to be filtered. The shear created from the lateral displacement caused suspended solids and colloidal materials to be repelled and held in suspension above the membrane surface. This combined with laminar flow of the fluid across the membrane surface keeps the filtered liquid homogeneous and allows very high levels of recovery of filtrate from the feed material. In the case of Acid Mine Drainage, up to 97% of the water can be filtered in a single pass filtration using V✧SEP. Flux is inversely related to % recovery, so the optimum % recovery may vary for each application. Other methods like filter presses are done in batch mode with operators opening and cleaning the filter cake on a regular basis. V✧SEP is a continuous automated process requiring very little operator attendance.

The industrial V✧SEP machines contain many sheets of membrane, which are arrayed as parallel disks separated by gaskets. The disk stack is contained within a Fiberglass Reinforced Plastic (FRP) cylinder. This entire assembly is vibrated in torsional oscillation similar to the agitation of a washing machine. The resulting shear is 150,000 inverse seconds, which is ten times greater than the shear in crossflow systems. High shear has been shown to significantly reduce the fouling of many materials. The resistance to fouling can be enhanced with membrane selection where virtually any commercially available membrane materials such as polypropylene, Teflon, polyester, and polysulfone can be used.

V✧SEP Resonating Drive System



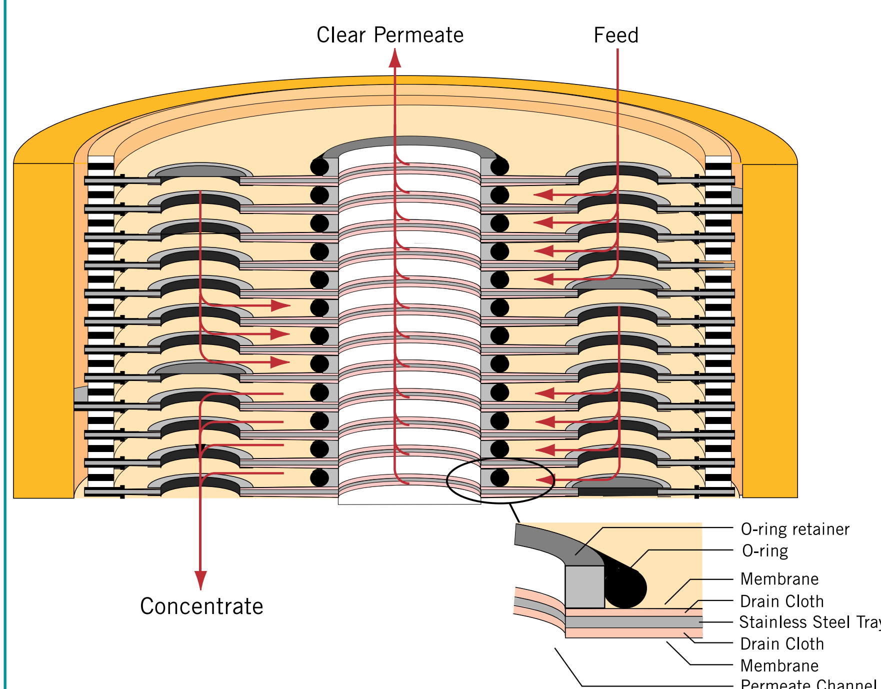
An eccentric weight induces a wobble that resonates at about 50 Hz giving vibration to the Filter Pack above

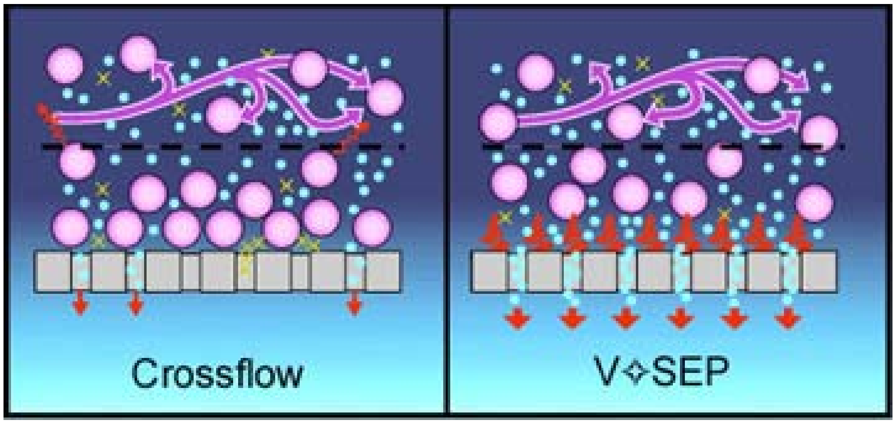
Each Series i system contains up to 2000 square feet of membrane filtration area. A single V✧SEP unit is capable of processing from 5 to 200 U.S. gallons per minute while producing crystal clear filtrate and a concentrated sludge in a single pass. This large throughput capability can be accomplished with a system, which occupies only 20 square feet of floor space and consumes 15 hp.

Conventional vs. V✧SEP

The main difference between V✧SEP and traditional crossflow membrane filtration is the mechanism by which the foulants are prevented from accumulating on the membrane surface. A traditional crossflow system relies on

Filter Pack Cross Section





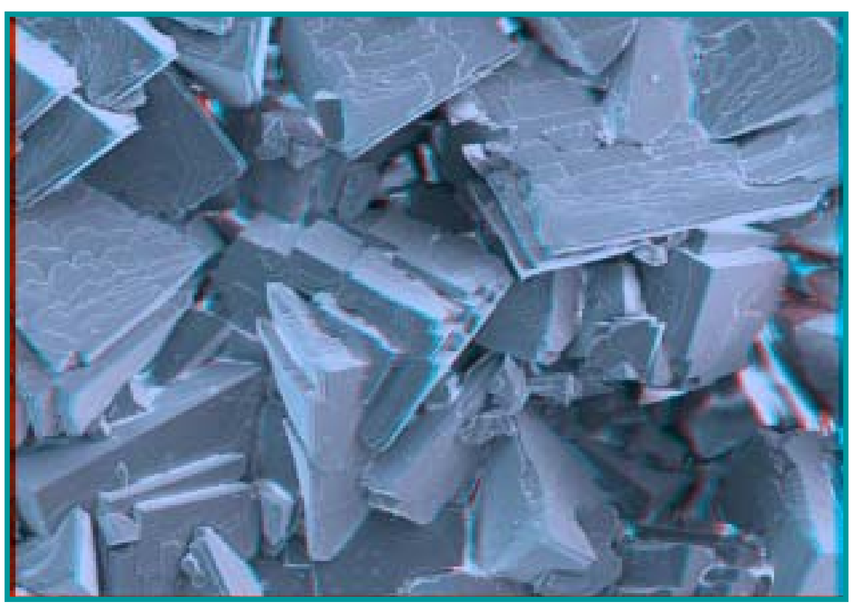
An illustration showing the shear energy at the membrane surface for conventional crossflow systems and for V✧SEP

the fluid velocity of the feed material alone to create shear forces needed to reduce fouling. This mechanism assists in slowing the fouling process but because a thin, stagnant boundary layer remains on the membrane surface, the foulants from the stream will accumulate over time and deteriorate the throughput rate. On the other hand, a V✧SEP system utilizes a patented vibratory drive mechanism that vibrates the membrane surface creating a shear force that disrupts the boundary layer. The resulting motion of the vibration drive is a 3/4 inch peak to peak displacement, which constantly repels solids and other foulants away from the membrane surface. This mechanism enables the filter module to maintain higher, sustained throughput rates and process larger volumes of material economically. Rather than simply preventing fouling with high-velocity feed, V✧SEP reduces fouling by adding shear to the membrane surface with vibration. This vibration produces shear waves that propagate sinusoidally from the membrane's surface. As a result, the stagnant boundary layer is eliminated which increases the filtration rates.

Scaling Resilience of V✧SEP

Torsional oscillation is a very effective method of colloid repulsion as shear waves from the membrane surface help to repel oncoming particles. The result is that suspended solids are held in suspension hovering above the membrane as a parallel layer where they can be washed away by tangential crossflow. This washing away process occurs at equilibrium. Pressure and filtration rate will determine the thickness and mass of the suspended layer. Particles of suspended colloids will be washed away by crossflow and at the same time new particles will arrive. The removal and arrival rate will be different at first until parody is reached and a state of equilibrium is reached with respect to the boundary layer.

This layer is permeable and is not attached to the membrane and is actually suspended above it. In V✧SEP, this layer acts as a nucleation site for mineral scaling. Mineral scale that precipitates will act in just the same way as any other arriving colloid. If too many of the scale colloids are formed, more will be removed to maintain the equilibrium of the diffusion layer. Conventional membrane systems could develop cakes of colloids that would grow large enough to completely blind the membrane. In V✧SEP, no matter how many arriving colloids there are, and equal number are removed as the diffusion layer is limited in size due to the gravitational pull (G forces) of the vibrating membrane.



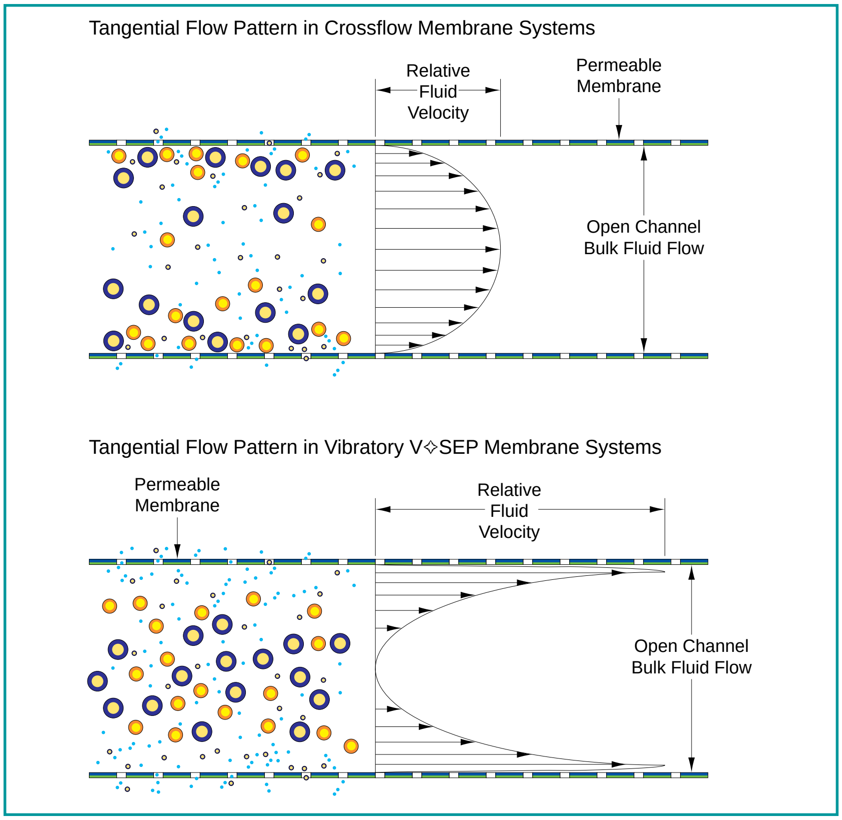
Calcium Carbonate Crystals

membrane is possible and has plenty of time to develop and grow.

Results using V✧SEP

V✧SEP's Reverse Osmosis membrane module is capable of treating Acid Mine Drainage and providing a filtrate, which is free from suspended solids and low in Sulfates and Heavy Metals. The V✧SEP process does not involve any chemical addition, except for pH adjustment using Lime, and meets the process engineers' needs for automated PLC controlled production. V✧SEP modules containing about 1300 SF (120m2) of filtration media are modular and can be run in parallel as needed to meet any process flow requirements.

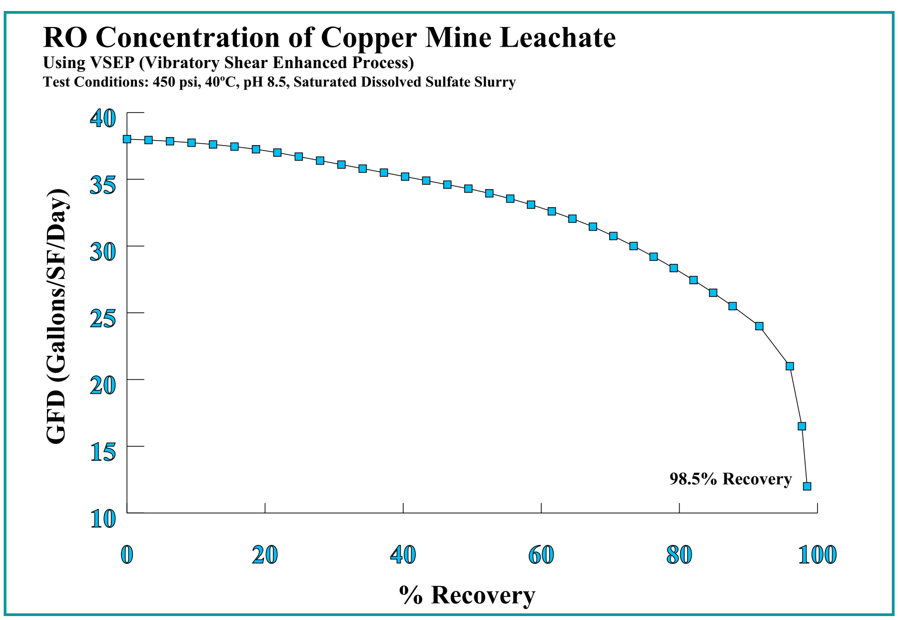
Each 84" V✧SEP module can produce 20 gpm of clean water from the leachate pond. Since the units are modular and can be used in parallel or in series, the number of V✧SEPs needed can be calculated based on the amount of material to be processed, (GPD or GPM). At 40°C the membrane flux is about 20-



High fluid velocity and shear energy at the membrane surface inhibits mineral salt crystallization

One other significant advantage is that the vibration and oscillation of the membrane surface itself inhibits crystal formation. Just as a stirred pot won't boil, lateral displacement of the membrane help to lower the available surface energy for nucleation. Free energy is available at perturbations and non-uniform features of liquid/solid interfaces. With the movement of the membrane back and forth at a speed of 50 times per second, any valleys. Peaks, ridges, or other micro imperfections become more uniform and less prominent. The smoother and more uniform a surface, the less free energy is available for crystallization. Crystals and scale also take time to form. The moving target of the membrane surface does not allow sufficient time for proper germination and development.

Other stationary features within V✧SEP present a much more favorable nucleation site. Whereas, with conventional membranes that are static, scale formation on the



30 GFD (Gallons per Square Foot per Day). System throughput is also a function of the extent to which the feed is concentrated.

Process Description

The mining leachate is collected and stored in holding tanks. Lime is added to raise the pH and to precipitate calcium sulfate and other slightly soluble mineral salts prior to filtration. After proper residence time, the Feed Liquor is pumped into the V✧SEP system for filtration. The viscosity of the material plays a big part in the rate of filtration. Heat will help to decrease the viscosity of the slurry and therefore improves the throughput of the V✧SEP system. Counter-current heat exchangers and recovery boilers are used to warm the feed material.

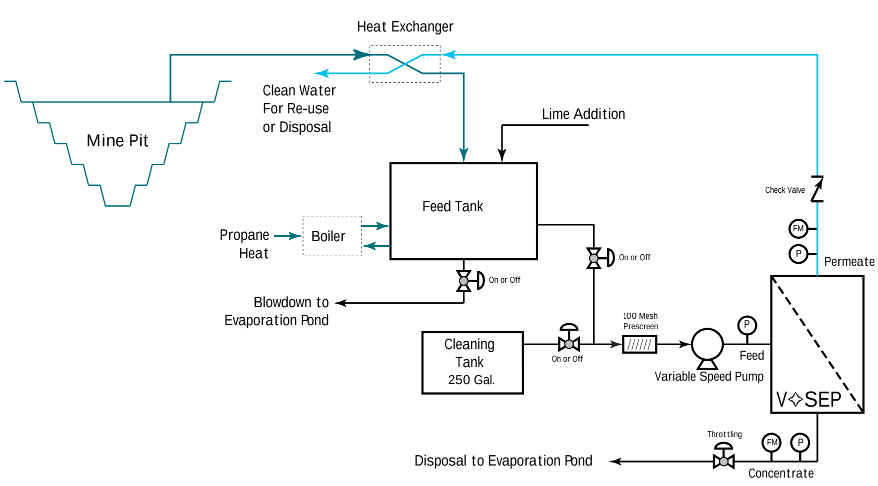
The heated leachate is pumped into the V✧SEP Filter Pack at about 450-psi. The contents of the feed tank are taken out of the side of a cone bottom tank so that settled solids are excluded. The resulting permeate is sent to a process water storage tank for reuse in the operations. The reject material, about 15% of the volume, is sent back to the leachate pond or on to evaporation ponds for disposal.

When the permeate rate drops off, the Filter Pack is cleaned using New Logic's formulated membrane cleaners out of a Clean in Place tank of about 260 gallons. Cleaning solution is recirculated with pressure and vibration to dissolve foulants that have found their way to the membrane. Actual site conditions at various mine locations have shown that the membrane can be cleaned easily and the results from week to week are predictable and stable.

Table 1: Acid Mine Drainage Sample Analysis

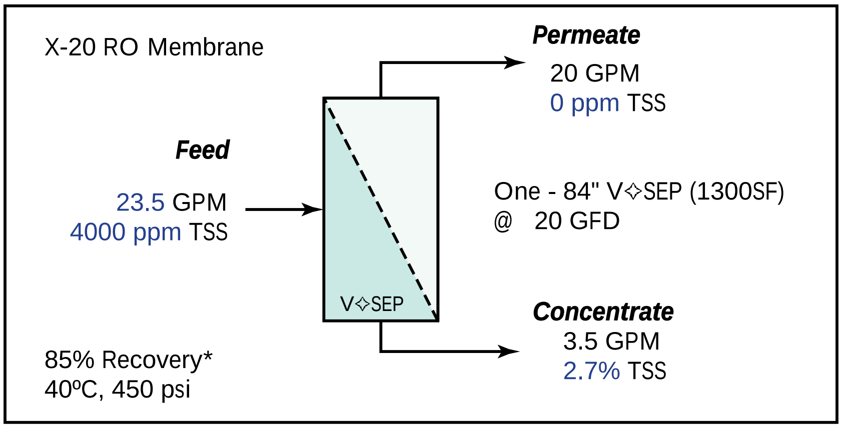
	Untreated	Limed	V✧SEP*
TDS	10,000 ppm	3,000 ppm	240 ppm
pH	2.7	8.5	8.5
Calcium, Ca	490 ppm	600 ppm	36 ppm
Magnesium, Mg	420 ppm	350 ppm	18 ppm
Sodium, Na	70 ppm	70 ppm	6 ppm
Iron, Fe	1,100 ppm	0.1 ppm	<0.1 ppm
Manganese, Mn	182 ppm	3.6 ppm	<0.1 ppm
Copper, Cu	186 ppm	<0.1 ppm	<0.1 ppm
Zinc, Zn	550 ppm	<0.1 ppm	<0.1 ppm
Sulphate, SO4	8,000 ppm	2,000 ppm	100 ppm

*40ºC, 85% Recovery, 450 psi



System Operation:
This process is run almost completely automatically. Miscellaneous recirc lines and instrumentation are not shown for clarity.
Control Valves opening initiates the feed pump at minimum frequency and gradually spins up to set point.
The concentrate valve then throttles to maintain flow. Once pressure reaches 30 psi, vibration initiates.
Once all other functions are operating, the throttling concentrate valve initializes to open and close at preset time intervals.
Shut down reverses all these steps.

Process Flow Diagram for a typical V✧SEP Installation



*Recoveries up to 97% can be done with reduced throughput

System Components

The V✧SEP system is configurable for manual mode where the operator would initiate operating sequences, or for full automation including seamless cleaning operations with round robin cleaning or multiple units. The V✧SEP has a PLC (Programmable Logic Controller) which monitors pressure, flow rate, and frequency. It also provides the safety in operation by monitoring conditions and initiating an alarm shut down should some configurable parameters be reached. The control stand contains the PLC, Operator display and terminal strips for wiring connections to instrumentation.

X-20™* Reverse Osmosis Membrane

Composition	Polyamide Urea
Nominal Salt Rejection	99.0%
Operating Pressure	0-600 psi
Continuous pH Range	4-11
Max Flat Sheet Temp	60ºC

*X-20 is manufactured by Trisep corporation under license from Dupont

The Filter Pack is mounted on the V✧SEP base unit and contains about 1300 SF, (120m2), of membrane area and is constructed out of high temperature materials. The V✧ SEP drive system, which vibrates the Filter Pack, is engineered using space age alloys and materials to withstand the applied stress from a resonating frequency of about 50 Hz. Each base unit is fully stress tested and the factory prior to shipment. The V✧SEP drive system is made up of the Seismic Mass, Torsion Spring, Ecentric Bearing, and Lower Pressure Plate.

Project Economics

The table below shows the operating costs for the installation of one V✧SEP module as currently configured. The V✧SEP is uniquely energy efficient. It comes with a 20 HP dive motor and a 10 HP Pump Motor. Operators interface and maintenance is limited to starting and stopping the unit and a periodical cleaning of the membrane after an extended run. The membrane replacement is the largest operating cost and it is estimated that the life of each module is approximately 2 years. Operator care can improve the life and additional savings could be yielded if the Filter Pack lasts more than 2 years.

V✧SEP Operating Costs

Description	Description
V✧SEP System Power Consumption*	$ 7,180
System Maintenance & Cleaning	$ 8,640
Annual Production (at 20 gfd)	10,500,000 gal/yr

*based on 0.05 $/kW electricity cost

Mining Leachate Options

EPA may not even consider data from treatment systems that exceed 50 mg/L of total suspended solids (TSS). If your results are well under 50 mg/L with your current discharge, a metals spectrum analysis should be done to determine compliance.

Wetlands & Natural Bioremediation
Suitable as treatment, but requires large areas of land and huge amounts of water that may not be readily available in arid western states. In addition, there are environmental risks that still linger as leaching into groundwater and local wellwater systems are a considerable liability. In addition, wildlife and habitat can be at risk of exposure to heavy metal poisoning.

Chemical Flocculation/Clarification
The drawbacks with this option will me the uncertainty of the final discharge amounts of the various metals over the long term. Variations in the effectiveness of the chemical precipitation and throughput to the clarifier leave open the possibility of process upsets and fines.

Ion Exchange Resins
An effective treatment system, but cannot handle more that 500 ppm TDS and therefore must be used in tandem with other pretreatment systems.

Conventional Membrane Systems
Also suffer from limits on TDS, TSS, and organic constituents. Depending on the process conventional membrane systems would be a part of a multi stage treatment process. Also, crossflow systems will require high fluid velocity to avoid diffusion polarization of the membrane and consequently reduced flux. The result of this is poor % recovery of filtrate, which can be sewered. The reject from conventional membrane systems could be further treated by yet another treatment process or hauled as waste. Since operating costs such as hauling are part of any equipment purchasing decisions, the % recovery with crossflow filters is not very attractive.

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Installed V✧SEP Mining Applications

Acid Mine Drainage
Phosphate Fertilizer
Radioactive Nuclei Removal
Mixed Metals Removal from wastewater
Arsenic Removal
Titanium Dioxide Concentration
Calcium Carbonate Dewatering
Kaolin Clay Concentration
Bentonite Clay
Railcar Washwater
Product Recovery from Wastewater

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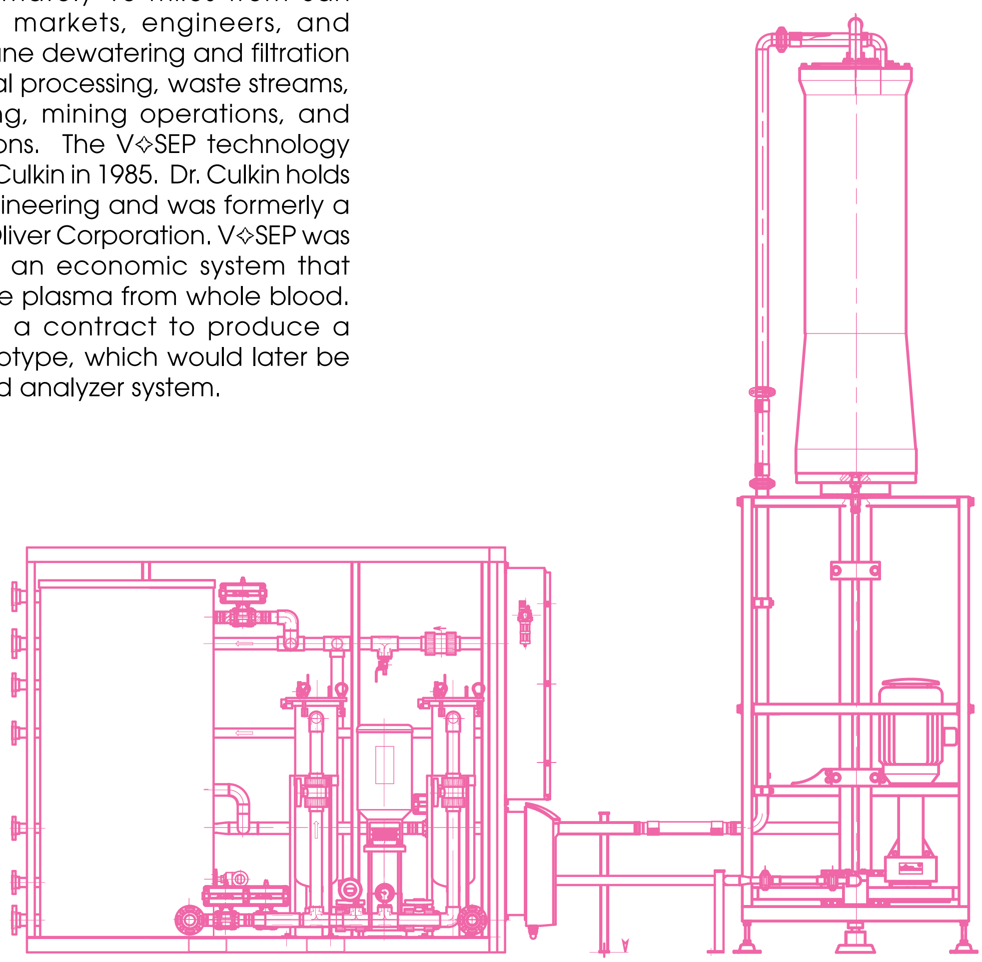
Company Profile

New Logic is a privately held corporation located in Emeryville, CA approximately 10 miles from San Francisco. New Logic markets, engineers, and manufactures a membrane dewatering and filtration systems used for chemical processing, waste streams, pulp & paper processing, mining operations, and drinking water applications. The V✧SEP technology was invented by Dr. Brad Culkin in 1985. Dr. Culkin holds a Ph. D. in Chemical Engineering and was formerly a senior scientist with Dorr-Oliver Corporation. V✧SEP was originally developed as an economic system that would efficiently separate plasma from whole blood. The company received a contract to produce a membrane filtration prototype, which would later be incorporated into a blood analyzer system.



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Copper Mining Glossary

Anode - fire-refined copper cast at the smelter into slabs weighing 600 to 1200 pounds of about 99.5% purity; shipped to an electrolytic refinery for final purification.

Ball mill - a rotating horizontal steel cylinder loaded with steel balls which grind the ore to a fine powder consistency.

Beneficiation - concentrating the copper content of the ore; the crushing, screening and grinding of ore and removal of copper-bearing minerals by a flotation process prior to smelting the copper concentrates.

Cathode - refined from anodes in the electrolytic refinery into plates of 99.99% pure copper; these are shipped to factories to be melted and cast into shapes ready for rolling, drawing, or extruding into finished products.

Concentrate - copper-bearing material from the flotation process; contains 15% to 30% copper plus various quantities of sulfur, iron and other impurities.

Elecrowinning - electrolytic winning process, wherein copper from copper sulfate (leach) solution is electroplated onto cathodes, ready for market.

Flotation - the process of mixing powdered ore with water and chemical reagents to separate the metallic particles from the waste rock; the metallic particles are collected and dried and this concentrate is sent to the smelter for fire refining.

Gangue - undesired minerals associated with ore; that portion of the ore rejected as tailing in the flotation process.

Leaching - a process of using a weak sulfuric acid solution to dissolve copper from low-grade oxide ores; may take place in vats, heaps, dumps or in situ (in place).

Matte - a mixture of sulfur, iron, and copper, containing approximately 20% to 45% copper, tapped from reverberatory furnace in the smelter.

Mill - the facility containing rod mills (if used), ball mills, and flotation cells where the ore is ground and copper concentrate extracted. Also called the concentrator.

Open pit mining - A surface mining method in which overlying rock and soil are removed to expose the ore body, which is then drilled, blasted and loaded into trucks or railroad cars for haulage from the pit.

Ore - rock containing enough mineral value to warrant the expense of mining it.

Slag - waste rock from the smelter. The black lava-like material is primarily iron and silica.

Smelter - the plant in which fire refining takes place.

Sulfide ore - ore composed of copper, sulfur, and usually iron along with the various other minerals making up the host rock.

Tailings - the finely ground residue or waste materials contained in the ore remaining after floating off the copper- bearing concentrate.