Evaporation: A Wastewater Treatment Alternative

by Tom M. Pankratz

Evaporation is being considered as an alternative process in an increasing number of wastewater treatment applications. It can be effective for concentrating or removing salts, heavy metals and a variety of hazardous materials from solution. Also, it may be used to recover useful by-products from a solution, or to concentrate liquid wastes prior to additional treatment and final disposal. Most applications of the technology also produce a high quality, reusable distillate—a very important feature where water conservation is a priority.

During evaporation, a solution is concentrated when a portion of the solvent, usually water, is vaporized, leaving behind a saline liquor that contains virtually all of the dissolved solids, or solute, from the original feed. The process may be carried out naturally in solar evaporation ponds, or through the use of commercially available evaporation equipment.

Solar evaporation ponds usually are limited by land availability and cost, potential odor problems, or meteorologic and climatological conditions, whereas mechanical evaporators are relatively compact, reliable and efficient.

Design and Operation

The evaporation process is driven by heat transferred from condensing steam to a solution at a lower temperature across a metallic heat transfer surface. The absorbed heat causes vaporization of the solvent, usually water, and an increase in the solute concentration. The resulting vapor may be vented to the atmosphere, or condensed for reuse.

Mechanical evaporation is an energy-intensive way to concentrate liquids, and various energy alternatives should be considered in the selection of the most efficient evaporator. In an ideal system, one kilogram of condensing steam will evaporate one kilogram of water from the solution. Such a system has a steam efficiency, or *economy*, of 1:1 (1 kg of water removed for every kg. of steam applied). A simple evaporator

Fig 1: Single Effect Evaporator

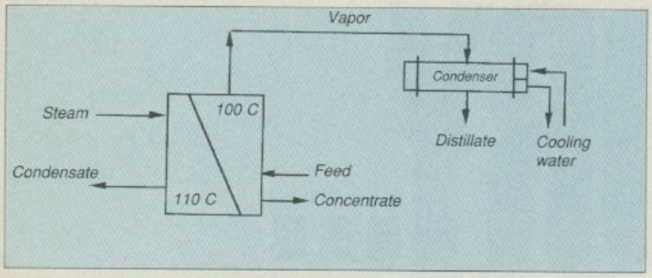


Fig 2: Multiple Effect Evapoartor

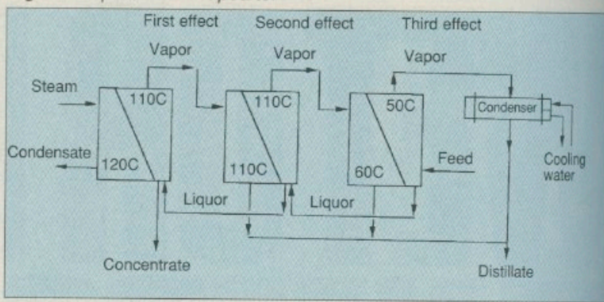


Fig 3: Vapor Compression Evaporator

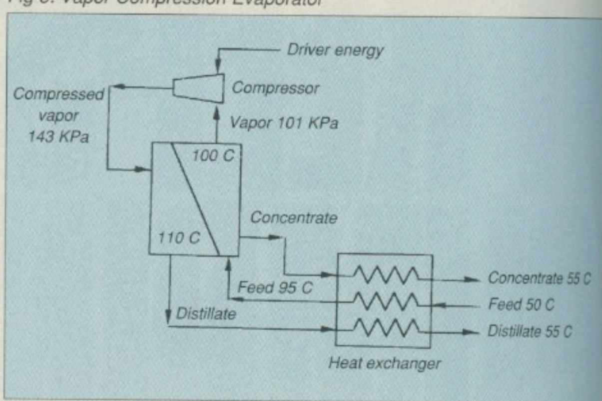


Fig 4: Falling Film Evaporator

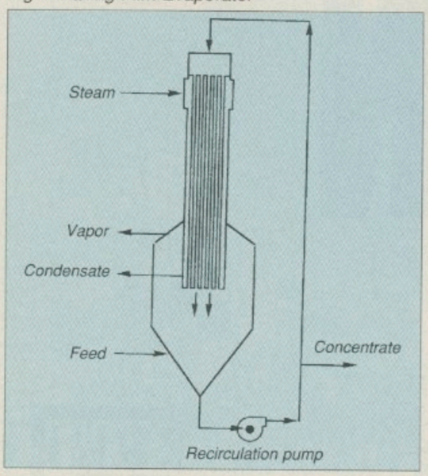


Fig 5: Spray Film Eaporator

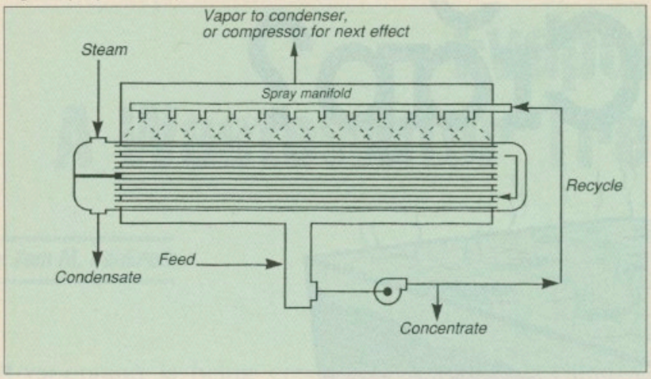
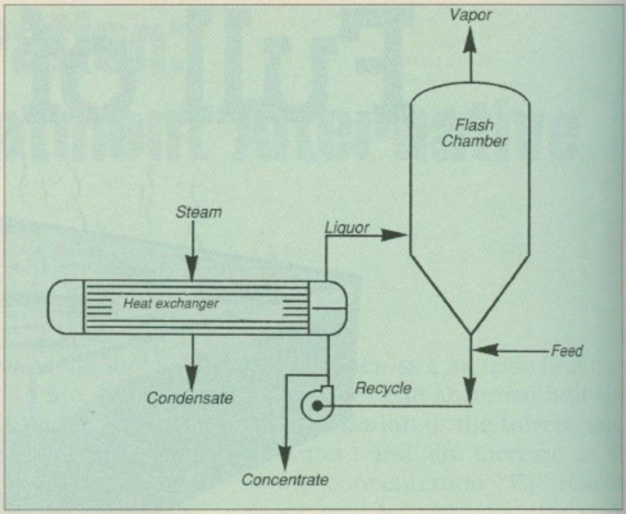


Fig 6: Forced Circulation Evaporator



system (Fig 1) has a single evaporation chamber, or *effect*, and is said to have an "economy of one."

Evaporator economy can be increased by increasing the number of effects. A *multiple effect system* (Fig 2) uses the vapor from the first effect as the steam source for each subsequent effect. As the temperature decreases in each succeeding stage, evaporation continues because the pressure and boiling point also are reduced.

The use of each additional effect increases the system's energy efficiency. For example, a double-effect evaporator requires approximately 50 percent of the steam consumed by a single effect unit, and has a theoretical economy of 2. The number of effects can be increased to the point where the capital cost of the next effect exceeds the savings in energy costs.

The use of vapor compression is another proven technique for reducing energy input. In this approach (Fig 3), vapor discharged from the evaporator chamber is compressed to the pressure/temperature values required in the heat exchanger.

Mechanical compressors are used most frequently for accomplishing vapor compression. Compressors may be of the positive displacement, centrifugal, or axial type. An evaporator system using mechanical vapor compression often will require only an outside steam source to initiate operation. This usually can be supplied by a small boiler or resistance heater in the evaporator feed tank. A steam jet thermal compressor using high pressure steam also may be considered. The use of a thermal compressor is approximately equivalent to adding an additional evaporator effect.

When available, waste heat from other process streams also may be captured to lower evaporation costs. For example, hot process fluids may be pumped through the heating tubes instead of steam, recovering heat and transferring it to the fluid to be evaporated, or energy from hot flue gases can be converted to steam in a reboiler and subsequently used in an evaporator.

Types of Evaporators

Evaporators can be categorized according to the arrangement of their heat transfer surface and the method used to impart energy (heat) to the solution. Some common types of evaporators include

Vertical tube falling film: Recirculating liquid is introduced at the top of a vertical tube bundle and falls in a thin film down the inside of the tubes. The liquid absorbs heat from steam condensing on the outside of the tubes and the water in the liquid is vaporized. This type of evaporator usually is selected for higher viscosity liquids and for concentrating heat-sensitive solutions that require low residence times (Fig 4).

Horizontal tube spray film: Recirculating liquor is heated and sprayed over the outside of a horizontal tube bundle carrying low pressure steam, condensing water vapor inside the tube. Vapor from the evaporator chamber can be used as steam in a subsequent effect, or mechanically compressed and reused as the heating medium in the stage where it was generated (Fig 5).

Scale forming on the outside of the tubes can be removed periodically through chemical cleaning. Horizontal tube designs can be applied in locations with low headroom requirements, and are especially beneficial in indoor installations.

Forced circulation: Recirculating liquor is pumped through a heat exchanger under pressure to prevent boiling and subsequent scale formation in the tubes. The liquor then enters a separator chamber operating at a slightly lower pressure or partial vacuum, causing flash evaporation of water, and formation of insoluble crystals in the liquor (Fig 6).

Forced circulation evaporators, or crystallizers, are often used for applications requiring high solids concentration or crystallizing, or in applications involving large amounts of suspended solids. Energy costs for forced circulation units can be more than for other evaporation systems because of their high recirculation rates.

Combined and hybrid systems: Combining different types of evaporators, or combining them with other processes to reduce capital and operating costs, or meet specific treatment objectives, often is possible. One fairly common arrangement uses a falling film evaporator followed by a forced circulation crystallizer. In this scheme, an evaporator concentrates the wastewater stream to 20 to 30 percent solids, and a crystallizer further concentrates it to a solid. Energy costs may be reduced by using steam vented from the evaporator to operate the crystallizer.

Hybrid designs are becoming more common in zero liquid discharge applications. A hybrid system may consist of an evaporator or evaporator/crystallizer preceded by a reverse osmosis or electrodialysis preconcentration step. The concentrate, or *reject*, from the preconcentrator becomes the feed for the evaporator.

Although a hybrid system adds complexity, it can reduce the size of the evaporator unit, as well as the system's energy needs. But note that not all wastewaters, especially those with high scaling tendencies, are candidates for hybrid systems. Table 1 shows the energy savings obtained by selecting an 85 gpm hybrid system.

Table 1: 85 gpm evaporator system energy comparison

	Hybrid	Conventional
RO system	22 kwh/hr	N/A
Evaporator	145 kwh/hr	354 kwh/hr
Crystallizer	15 kwh/hr	15 kwh/hr
Total Energy Required	182 kwh/hr	369 kwh/hr

Table 2: Cost comparison

	Evaporation	Chemical Precipitation
Capital Investment ($000)		
System	1,086.9	1,500.0
Support facilities	3,113.1	2,000.0
Total capital investment ($000)	4,200.0	3,500.0
Operating expenses ($000/yr)		
Electricity	105.0	15.0
Natural Gas	47.5	N/A
Chemicals	8.1	60.1
Residue disposal	60.0	176.9
Concentrate Disposal	5.4	73.7
City Water	N/A	51.8
Total annual operating cost ($000/yr)	226.0	377.5
Annualized capital cost ($000/yr)	459.0	383.3
Total annual cost ($000/yr)	685.9	760.8
Cost of equivalent rinsing ($000/yr)	2.0	2.3

Evaporator Applications

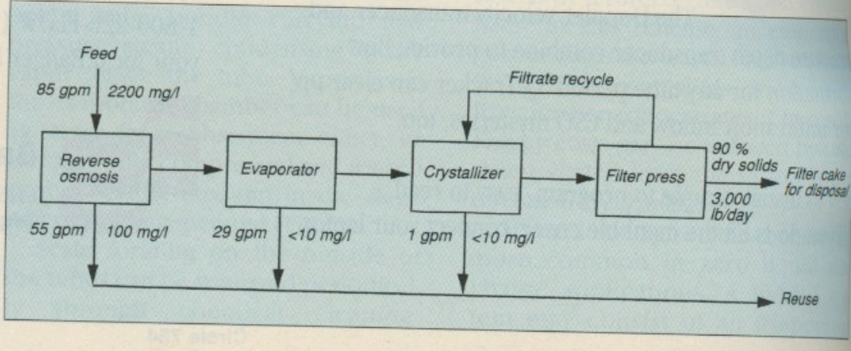
Because evaporation is an energy- and capital-intensive process, the selection and design of an evaporator system must be carefully considered for each application.

Evaporators have been used successfully in many industrial wastewater treatment applications, e.g., power and chemical plant wastewaters, metal finishing wastes, spent pulp liquors, emulsified oil streams, high soluble BOD (sugar) streams, and nonvolatile aqueous organic or inorganic streams containing dyes, acids and bases.

Zero liquid discharge: Federal, state and local regulations governing industrial wastewater discharges continue to become more stringent. All direct dischargers must obtain a National Pollutant Discharge Elimination System (NPDES) permit that sets the maximum permissible limit for regulated pollutants. NPDES permits are subject to renewal, and permitted discharge levels may be lowered to reflect changes in the receiving water body. Dischargers therefore must take into account their wastewater production as well as possible future variations.

In many industrial plants, evaporators can be installed to achieve zero liquid discharge of wastewater. These systems often consist of a falling film evaporator followed by a crystallizer and filter press (Fig 7). A rotary spray dryer may take the place of a crystallizer. However, precautions must be taken to control fugi-

Fig 7: Hybrid Zero Liquid Discharge Water Balance



tive dust emissions. Figure 7 illustrates the water balance for a hybrid zero liquid discharge system used to treat a power plant's cooling tower blowdown.

Water reuse: In this area evaporation has several advantages over conventional physical-chemical processes, one of the most significant being the high quality of the distillate. Most installations can produce a distillate TDS of less than 10 mg/l, and in some cases, less than 2 mg/l.

Not only does the recovered water from an evaporator meet most discharge specifications, it can almost always be recycled for reuse in manufacturing or cooling applications. In one metal finishing installation, distillate was recycled as process rinse water at a volume ten times less than the quantity of city water required to do the job.

Evaporators can minimize the production of regulated waste residues, and increase the potential for recovering valuable metals from those wastes. Unlike ion exchange, evaporation is not as sensitive to traces of oil, and does not produce regeneration wastes that require additional treatment.

Metal finishing: The metal finishing industry today makes use of the "electroless" plating process, for instance in the manufacture of printed circuit boards. This produces a hard-to-treat waste stream that contains chelating agents such as organic acids (e.g., EDTA) or ammonia, which prevent the normal precipitation of heavy metal hydroxides. Additional chemicals must be added to break down the chelating agents prior to conventional treatment. However, evaporation has been used successfully on these wastes without the need for other reagents.

Operating Cost Evaluation

A cost comparison of two wastewater treatment alternatives considered for use at a metal finishing facility in the Northeast is shown in Table 2. The preliminary study evaluated several treatment approaches, but concluded that an evaporation system (evaporator/crystallizer) and a conventional chemical precipitation system (neutralization/precipitation/polishing), both would be capable of producing a satisfactory effluent. However, only the evaporation system could produce water of a high enough quality for reuse. While the precipitation system was rated at 395 l/min, the evaporation system was rated at 190 l/min, reflecting its ability to reuse evaporator distillate as process rinse water. ■

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