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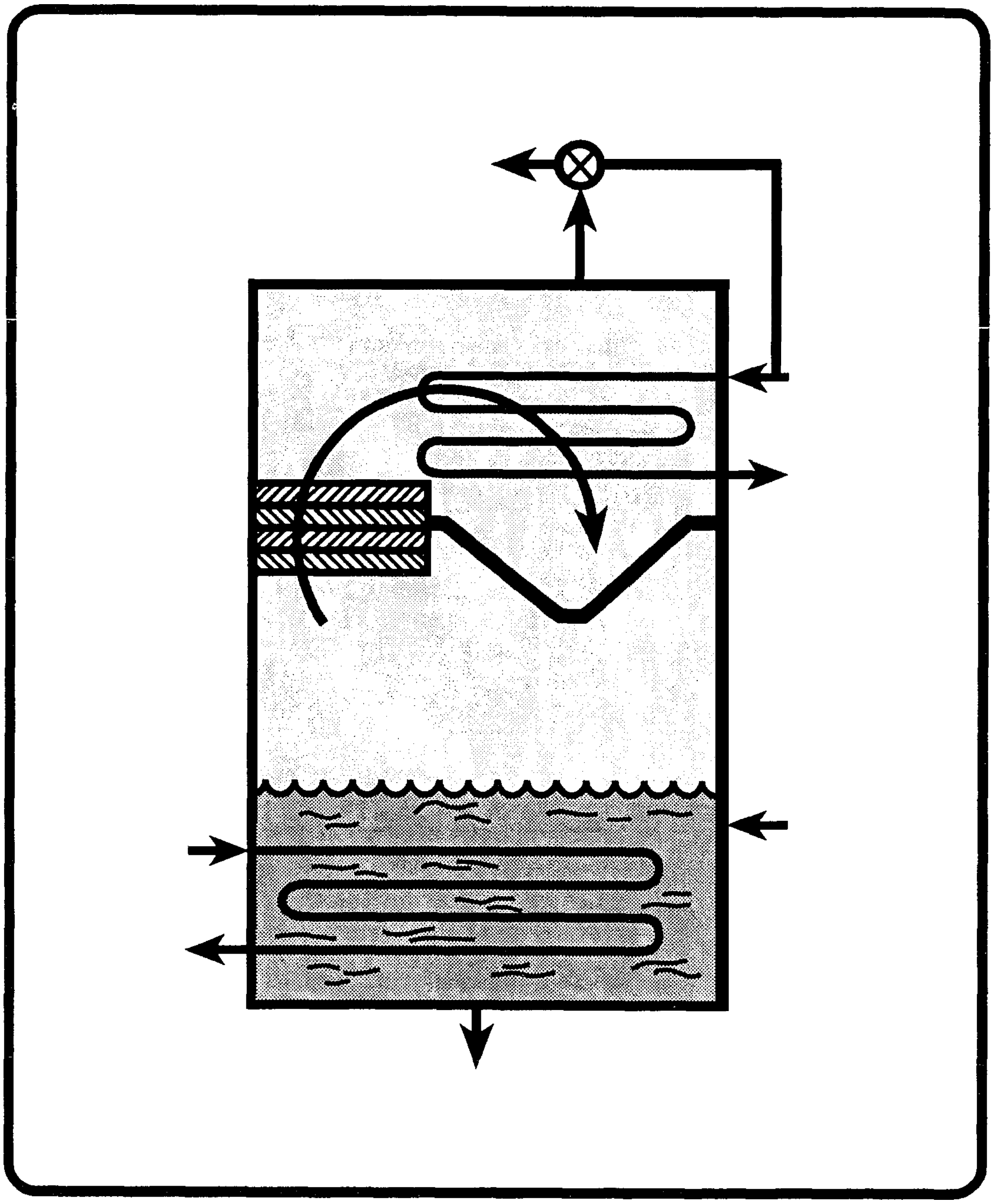
September 1996

Technology Transfer

Capsule Report

Evaporation Process



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Center for Environmental Research Information
National Risk Management Research Laboratory
Office of Research and Development
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Cincinnati OH 45268

Contents

Introduction

A failure analysis has been completed for the evaporation process. The focus was on process failures that result in releases of liquids and vapors to the environment. The report includes the following:

- A description of evaporation and coverage of process principles.
- Applications of evaporation for treatment of effluent waters from the metal finishing industry.
- Descriptions of equipment and operating and maintenance procedures.
- Failure analysis that includes types of failures and causes.
- Key questions that can be used in software development
- A bibliography on evaporation applications in the metal finishing industry.

Evaporation Process

Process Description

In the evaporation process, wastewaters from metal finishing processes are heated until a water vapor is formed. This vapor is continuously removed and condensed as an overhead product. In this manner, clean water is recovered and the solutes contained in the original wastewater are concentrated. The solutes may be contaminants, or useful chemicals or reagents, such as copper, nickel, or chromium compounds, which are recycled for further use. The batch evaporation process, based on the use of steam as the energy source, is illustrated in Figure 1.

If the evaporation process is properly designed and operated, the clean condensate generally contains no more than 10-20 ppm contamination from wastes containing up to several percent of dissolved solutes. By using mechanical vapor recompression (MVR) or multiple stages, evaporation can be made energy efficient; however, the initial capital investment tends to be higher to include these options.

Evaporation is an established technology. There is little risk and it has a low capital cost. Using the proper process configuration, evaporation can achieve a high degree of water removal. However, water removal is normally limited by the ability to pump the solution. When wastewaters contain volatile organics with boiling points that coincide with that for water, product condensate can be contaminated with organics. Removing these organics requires further treatment, consisting of a carbon bed or other polishing process. Other obstacles occur at evaporation temperatures with foaming, scaling, fouling, and corrosion all possible. Finally, pretreatment chemicals may be needed to reduce scaling and fouling.

Applications

Due to its reliability and economics, evaporation has proven to be one of the better processes for treatment of wastewaters (dragout) from the metal finishing industry. Evaporators are inexpensive to purchase, install, and operate, making them a powerful

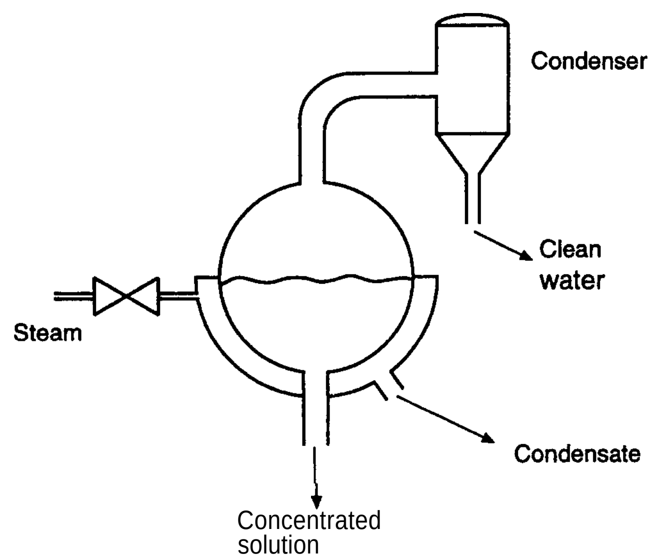

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Figure 1. Jacketed batch evaporator.

tool for reduction in the cost of water treatment. The greatest problem is the control of contaminants in the concentrated solution. However, processes are available to remove contaminants, allowing evaporative recovery to be used on many metal finishing waters.

Process solutions that have been successfully treated using evaporative techniques include zinc, cadmium, copper, nickel, and chromium plating baths, and phosphoric acid from aluminum bright wastewaters. Even though these waters become contaminated by excessive drag-in, dropped work, impure makeup water, or by chemical reaction resulting from process operation, these impurities can be controlled, reduced or removed without excessive equipment costs (Spearot, 1987; Yates, 1986; Brown, 1984).

Applications for evaporators in other industries include concentration of liquors in the paper industry and recovery of potable water from salt water and brines. Evaporation is also used to recover water from various types of wastewaters including cooling tower blowdown, ion exchange regeneran! wastes, boiler blowdown, and industrial rinsewaters.

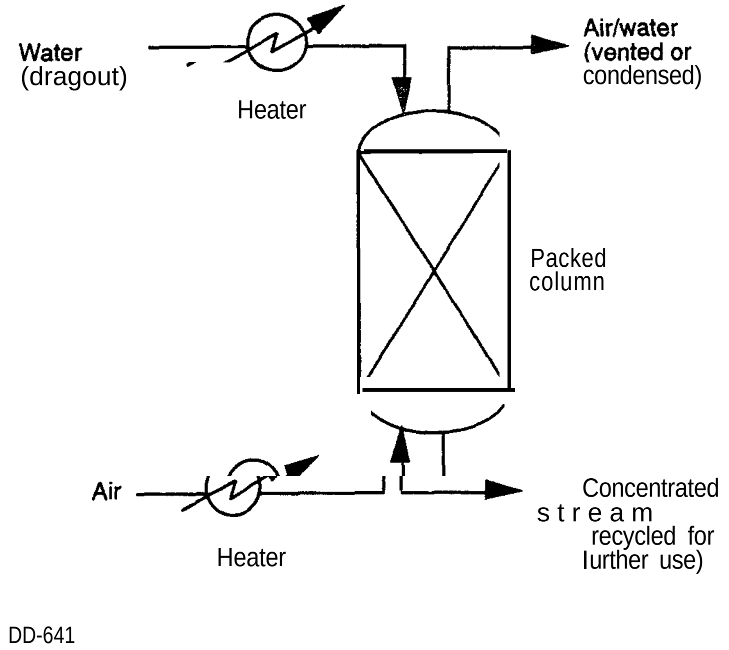

Figure 2. Evaporation using a packed column.

Equipment

Evaporation may be accomplished operating at a vacuum or at atmospheric pressure. Atmospheric evaporators are used when components in the wastewater are thermally stable. Vacuum conditions reduce boiling temperatures and prevent decompositions. Decompositions can readily occur in zinc and cadmium cyanide solutions.

Evaporation Using a Packed Column

Atmospheric evaporators may consist of a packed tower with a heated feed mixture fed to the top of the tower and air (or hot air) fed to the bottom of the tower. In this process, as the hot air contacts the water, evaporation takes place, thereby concentrating the wastewater (see Figure 2). The wastewater is concentrated and recycled to the process. Because contaminants are concentrated by this process, special attention may be required for their removal.

Packaged Evaporators

Packaged evaporators, which are available from a number of suppliers, are used in both atmospheric and vacuum operations (Lavis, 1994). Most purchases for packaged evaporators are for film evaporators, with forced-circulation evaporators ranking next. Film evaporators are normally used to concentrate solutions up to the point where the solubility limits of the solutes are reached and significant amounts of suspended solids develop. Forced circulation evaporators are designed to handle solutions containing suspended solids **(Worral,** 1988). A number of good references are available on how to select and design evaporators (Lavis, 1994; Worral, 1988; Mehra, 1986; and APV Crepaco, 3rd Ed.). Both film and forced circulation evaporators are described below.

Film Evaporators

In film evaporators, the process liquid is distributed as a film on the heat transfer surface (see Figure 3). The process liquid occupies only a thin film on the tube wall, resulting in low liquid holdup. Film evaporators are limited to low viscosity fluids, because at high viscosities the film is thickened and results in low heat-transfer coefficient. The practical upper limit of viscosity for film evaporators is 1 **00-**500 centipoise (Dedert Corp., 1994).

The amount of heat transferred from the heating medium to the **wastewa**ter depends on the temperature difference between the process fluid and heating medium, area of heat transfer surface, and the heat transfer coefficient.

$$Q = U A Dt \qquad (1)$$

where

Q = amount of heat transferred to aqueous wastewater from heating medium, **Btu/hr.**

U = overall heat transfer coefficient, **Btu/hr/sq ft/°F.**

A = area of heat transfer surface, sq ft.

Dt = $t_s - t_p$, °F.

t_s = **temperature** of heat source, °F.

t_p = temperature of process, “F.

For a given heat load and temperature difference, Equation **(1)** may be used to estimate the required heat transfer area of the evaporator. **Heat-**transfer coefficients for film **evapora-**

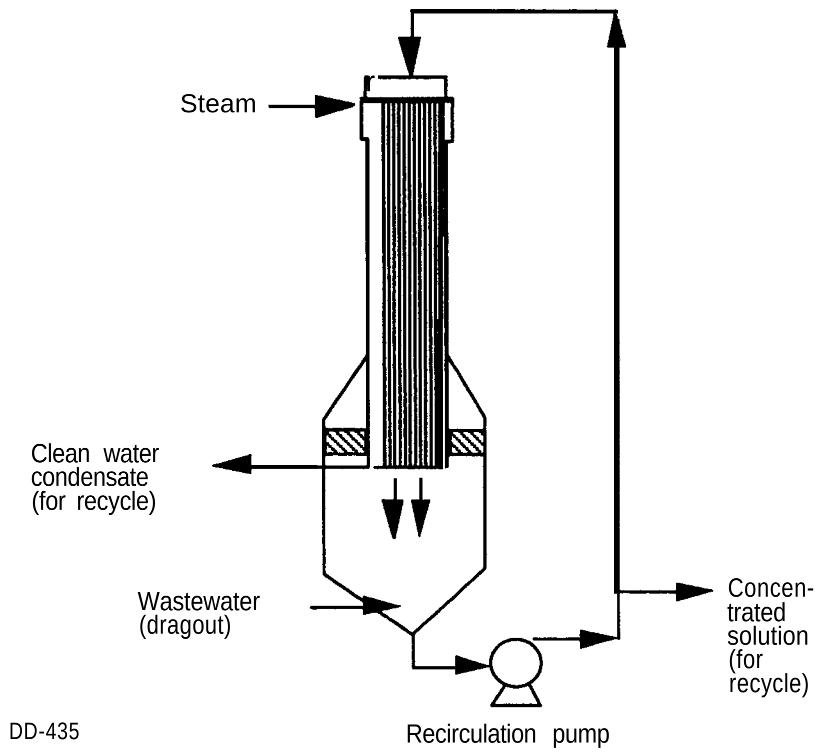

Figure 3. Falling film evaporator.

tors are based on operating experience or pilot plant testing. Assuming that the heat source is condensing steam, overall heat transfer coefficients range from 500 **Btu/h/sq ft/°F** when processing water-like materials to 100 **Btu/h/sq ft/°F** for high viscosity fluids.

Film evaporators come in rising or falling film configurations. In the falling film evaporator, liquor is supplied at the top of the evaporator and is distributed to the tubesheet by nozzles. The liquor then falls downward by gravity along the tube wall. Steam supplied on the outside of the tube in a shell-and-tube configuration causes evaporation of the film; then vapors pass along the center of the tube while the film progresses down the tube wall. As the liquid-vapor mixture enters the main body of the evaporator, liquid falls to the bottom while vapors rise. Following entrainment separation, vapors exit the evaporator. Liquid is discharged as a concentrate from the bottom of the evaporator body.

Forced Circulation Evaporators

Solutions containing significant amounts of suspended solids are better handled in a forced-circulation evaporator. In this type of evaporator, process liquid circulates through the heat exchanger at a very high rate. As the process liquid is heated, boiling is suppressed by back pressure created by the static head of the piping at the heat exchanger exit. As the liquid leaves the heat exchanger, the pressure is reduced, and the liquid flashes in the evaporator body. In the evaporator body, vapor is removed and concentrated liquid is recirculated. The elements of the forced circulation evaporator are illustrated in Figure 4.

High velocities in the heat exchanger increase the heat-transfer coefficient and reduce fouling but increase the pressure drop. Design considerations for forced circulation evaporators include balancing heat exchanger requirements versus pumping requirements. Heat exchangers for forced circulation evaporators are usually of the shell-and-tube design with the process fluid nearly always on the tube side. Plate heat exchangers offer higher heat transfer coefficients than the shell-and-tube exchangers, and a more compact design, but they are more expensive.

Energy Savings

Because evaporation is an energy intensive process, it is important to explore ways for energy conservation. Common ways to save energy in evaporation include using mechanical vapor recompression (MVR) and multiple stages. While both options increase capital costs, energy savings may justify the expenditure when energy is expensive or at remote sites, where thermal energy may be sparingly available.

Mechanical Vapor Recompression

Energy for evaporation may be reduced by 95% using MVR, though adding the necessary compressor adds to mechanical complexity. Evaporators equipped with MVR are commonly used in the food industry (Iverson, 1980 and Centec Corp., 1980). In MVR, the vapor leaving the evaporator is compressed to the pressure that corresponds to the saturation temperature required on the steam side of the heat exchanger. In most cases, steam is not required once the system is running. MVR was popular in the early 1980s when energy was costly, but lower energy costs have made new installations less common. The falling film evaporator equipped with MVR is illustrated in Figure 5.

Multiple Stages

In multiple-stage evaporation, the water vapor from one stage is used as the heating medium for another stage operating at lower pressure. Multiple-stage evaporation is commonly used for recovery of potable water from seawater (Darwish et al., 1989). Most of the separation takes place in the first stage, but as many as six or eight stages have been used

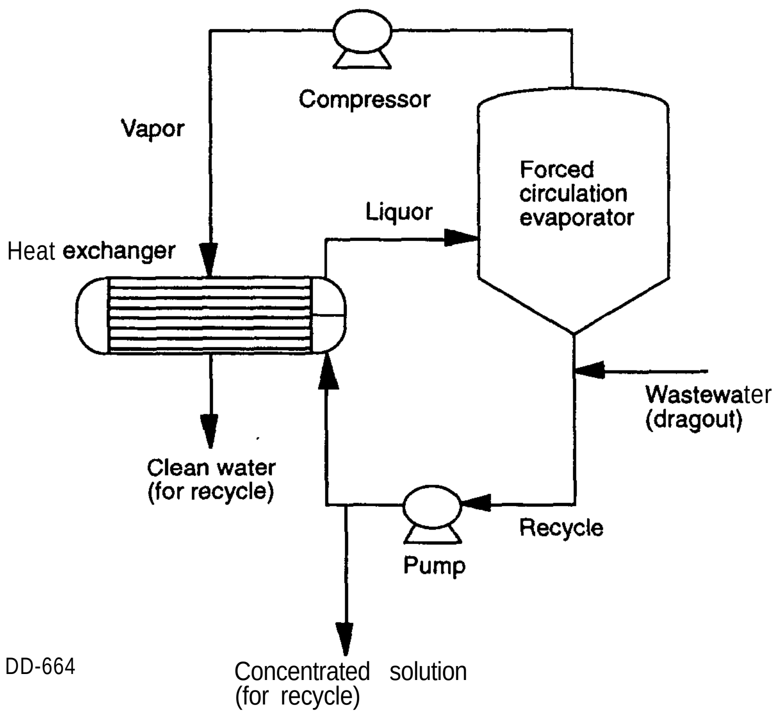

Figure 4. Forced circulation evaporator with mechanical vapor recompression.

in one system. To illustrate energy savings, three stages require slightly less than half the energy than a single-stage operation. The process is illustrated in Figure 6 for three stages.

The lower steam requirement of the multiple-staged evaporator is accompanied by a higher equipment cost. The available temperature difference at any single heat exchanger is considerably lower than that available in a single-stage evaporator. Thus the total heat transfer surface area is greater. In addition, the multiple-stage evaporator requires more vessels, pumps and piping. As in other processes, the trade-off between capital and operating costs is the key consideration.

Operation And Maintenance

Pretreatment chemicals may be required for the evaporation process, depending on the characteristics of the wastewater. Chemicals are used to prevent corrosion and fouling of the evaporator. Other operations include adding acids to reduce alkalinity, removing carbon dioxide to enhance performance, adjusting pH to control precipitation, and removing oxygen to reduce corrosion. Should precipitation occur, calcium sulfate (or other crystals) are needed, solids and scales deposit on the crystals rather than on heat transfer surfaces. Materials of construction must be selected to minimize corrosion and provide long equipment life.

For moderate fouling, film evaporators are acceptable if cleaned often. All film evaporators have a minimum liquid wetting rate, to assure that the surface gets coated. If the required rate is above the product flow rate, one must recirculate material back to the heat exchanger to maintain the minimum wetting rate.

Failure Analysis

High Probability

Seals

Seal or o-ring failures may occur in the evaporator feed pump, chemical feed pumps, or the air compressor, which delivers instrument air to instruments and control valves. Possible causes of seal failures include overheating and mechanical stress. Visual inspection will confirm spraying or leaking of wastewater at the pumps or compressor.

Valves and Pipe Fittings

This type of failure is more prevalent in older plants than in newer ones. Generally, leaks in evaporator systems are likely to be small because evaporators operate at low pressures (atmospheric and vacuum). Causes for this failure include mechanical stress, improper maintenance procedures, and freezing during cold weather.

Miscellaneous Spills During Daily Operations

Spills of pretreatment chemicals and wastewaters can occur when tanks are replenished. They may also occur when the system is shut down for maintenance. In evaporation systems, pretreatment chemicals include acids, bases, and phosphates.

Relief Valves (Vapor)

Tanks are equipped with vapor relief valves to maintain a constant tank pressure. These valves will release contaminated vapors to the atmosphere as tank levels (and tank pressures) increase. These releases are small but they occur frequently.

Evaporator Failures

An evaporator can fail for a number of reasons but failures are due mostly to foaming or entrainment. When foaming occurs, wastewater foam fills the body of the evaporator and ultimately contaminates the clean condensate. Foaming is caused by the presence of surface active agents, though such agents are often difficult to detect and measure. With entrainment, wastewater drops are physically carried overhead by the flowing

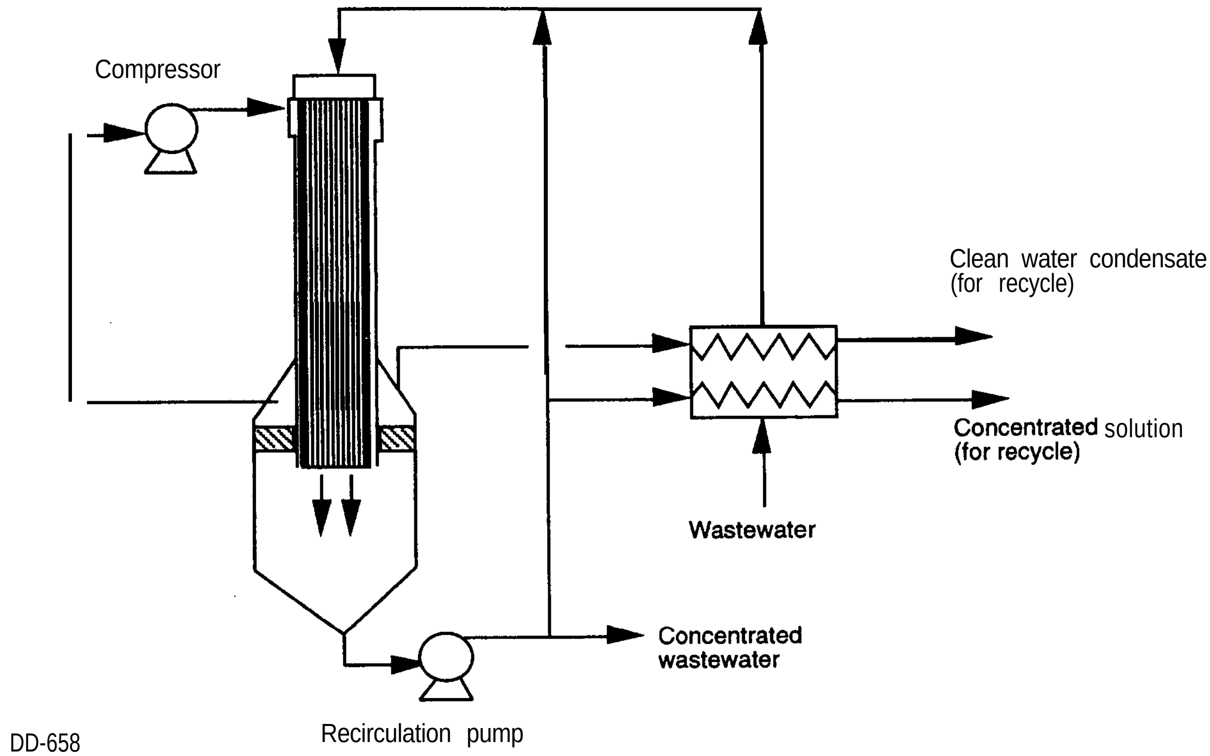

Figure 5. Falling film evaporator with mechanical vapor recompression.

vapor with the condensate being contaminated by the wastewater drops. Entrainment is caused by operating at vapor rates higher than design capacity.

Moderate Probability

Relief Valves *(Liquid)*

Relief valves are included in evaporation systems to protect piping and fiiings from overpressure. They are less numerous and less likely to fail than in reverse osmosis because evaporators are operated at low pressures (atmospheric and vacuum).

Tank Overflows

Tank overflows can result in a significant release of wastewater or chemicals to the environment. They occur mostly during startups and shutdowns.

Low Probability

Tank Ruptures

A tank can rupture, possibly because of mechanical failure or freeze damage. Though this type of failure is rare, a rupture can result in the release of large quantity of wastewater or chemicals to the environment.

Piping Ruptures

Possible causes of rupture include mechanical stress, freezing, and improper maintenance procedures. Significant leaks are possible with this type of failure.

The types and causes of failure and associated questions for subsequent software development are presented in Table 1.

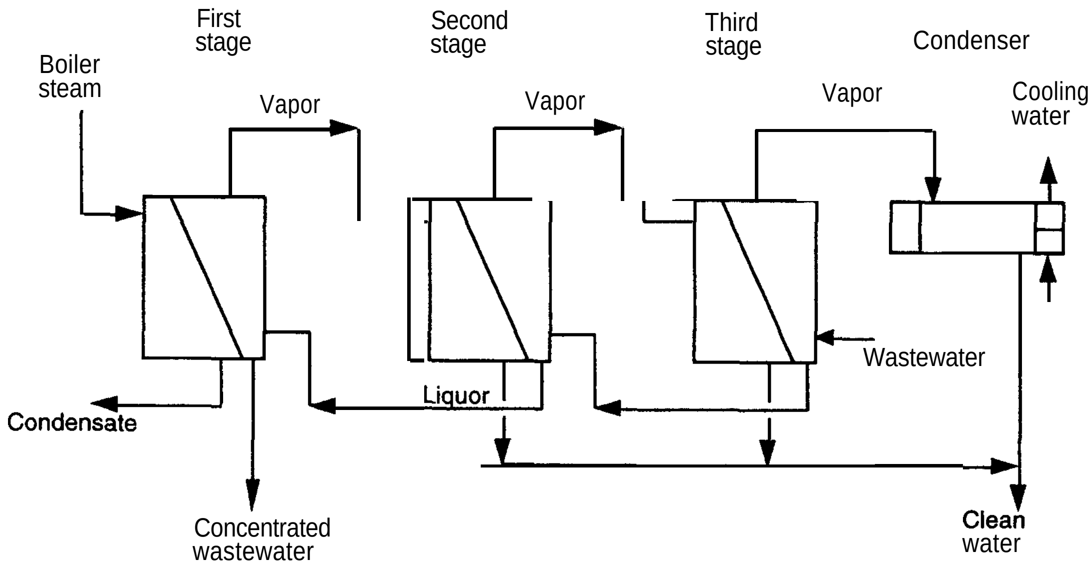

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Figure 6. Three-stage evaporation process.

Table 1. Failure Analyses for Evaporation System

Failure	Cause(s)	Questions for Software Development
	High Probability	
Seals	- Overheating - Mechanical stress -Abrasive wear	What is the expected quantity of leaks through seals (gallons)? What is the disposition of these leaks (i.e. Do they go to a capture system, process sewer, or are they lost directly to the environment?
Valves and pipe fittings	- Mechanical stress - Improper maintenance procedures - Freezing	What is the expected quantity of leaks through valves and pipe fittings (gallons)? What is the disposition of these leaks?
Miscellaneous spills during daily operations	-Spills during filling of tanks (due to faulty gages and equipment and mistakes by operators). Spills can include wastewater and pretreatment acids and bases. - Faulty maintenance procedures	What is the expected quantity of leaks from spills (gallons)? (Base on plant experience and operating records). What is the disposition of these spills?
Relief valves (vapor)	- Increases in tank levels -Changes in ambient temperature	What is the expected quantity of leaks through vapor relief valves (standard cubic feet/hour)? What is the disposition of these leaks?
Evaporator failures	- Foaming - Entrainment (operating at above design capacity)	What is the expected quantity of leaks through evaporators (gallons)? What is the disposition of these leaks?
	Moderate Probability	
Relief valves (liquid)	- Overpressures during startups, upsets, and shutdowns (for evaporators operating at pressures of atmospheric and above) -Key control valves failing in closed position - Plugging of valves, piping, and membrane modules due to buildup of solids. Hollow-fiber and spiral membrane modules are most susceptible to fouling.	What is the expected quantity of leaks through liquid relief valves (gallons)? What is the disposition of these leaks?
Tank overflows	-Occur mostly during unstable conditions (during startups and shutdowns). Overflows can include wastewater and pretreatment acids and bases.	What is the expected quantity of tank overflows (gallons)? (Base on plant experience and records). What is the disposition of these overflows?
	Low Probability	
Tank ruptures	- Mechanical failures - Freezing	What is the expected quantity of releases due to tank failures (gallons)? (Be sure to include the concentrated waste if it is stored **onsite).** What is the disposition of these releases?
Piping ruptures	- Mechanical failures - Freezing	What is the expected quantity of losses due to pipe ruptures (gallons)? What is the disposition of these losses?

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