PROJECT E-1441

ENDERS' EVAPORATOR

May 1, 1992.

OPERATING INSTRUCTIONS

for

TWO (2) SINGLE EFFECT

FORCED CIRCULLATION EVAPORATORS

BOTH MOUNTED ON THE SAME SKID

EACH EVAPORATING 1554 LBS/HR WATER

FROM PLATING SHOP EFFLUENT

end user: NAVAL AVIATION DEPOT
NAVAL AIR STATION
PENSACOLA, FLORIDA 32508-5300

purchaser: NAVAL SUPPLY CENTER
PENSACOLA, FLORIDA 32508-6200

contract: N68860-90-C-0022

F O R E W O R D

Good evaporator operation is based on a thorough and complete knowledge of all phases of the system. To assist the operator in becoming more effective, this manual has been prepared. It contains a flow sheet of the process found within the overall system, a general mechanical description of the evaporator itself, a detailed description of the process controls and a set of general operating instructions. These are intended to be used as a guide by the operator since these instructions do not constitute the only course of action open to the operator. Experience and a general knowledge of liquor behavior in evaporators cannot and should not be overlooked.

In addition, this manual will provide a reference source for the operator, should he be desirous of reviewing a specific aspect of evaporator operation.

EVAPORATOR IDENTIFICATION

EVAPORATOR	A & B
MODEL / No. OF EFFECTS	STHFC / 1
SERIAL No./ DATE	E-1441 / JUNE-91
SIZE OF EVAPORATOR	1554 Lbs / Hr.
CUSTOMER	U.S. NAVY
PURCHASE ORDER #	N68860-90-C-0022

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I. THEORY OF OPERATION:

The function of this two body single effect evaporator is to evaporate 1554 lbs/hr of water in each body (total of 3108 lbs/hr) from a plating shop effluent

This evaporator is a specialized type of heat transfer equipment. Each evaporator body (effect) consists of a tubular heat exchanger which is used to transfer heat from condensing steam or vapor on the outside of the tubes to the liquor being evaporated on the inside of the tubes. The design of evaporators is based on the following fundamental rate equation of heat transfer:

$$Q = UA\ T \qquad \text{EQN \#1.}$$

where Q = Heat Transfer Rate (BTU/HR)
U = Heat transfer coefficient (BTU/HR/Sq. Ft./oF)
A = Heat Transfer Surface Area (Sq. Ft.)
T = Available temperature drop (oF)

The above equation indicates that the capacity of an evaporator is determined by the following three factors:

1) The overall heat transfer coefficient (U)
2) The amount of heat transfer surface area (A)
3) The total available temperature drop (T)

In designing an evaporator the required amount of heating surface is determined from the following information:

1. The required rate of heat transfer (Q) which is based on evaporation requirements. The total amount of heat transferred is calculated by a heat and material balance on the complete evaporator system.

2. The temperature drop (T) which is determined from the available steam pressure for the evaporator in the first effect and the operating vacuum in the condenser. A complete heat and material balance determines the steam pressure while operating vacuum is determined by the desired boiling temperature of evaporating water.

3. The heat transfer coefficient (U) is subject to many variables and their assigned values are based on previous experience in design of evaporators.

Laws governing the flow of heat may be expressed in similar manner to the flow of electric current. Thought of in this way, the heat transfer coefficient is the reciprocal of the resistance to heat flow and T is the driving force or potential. Equation (1) can be rearranged as

Q/A (rate of heat transfer) = T (driving force)
(Unit area) 1/U (resistance)

Consider a steam-heated evaporator with tubular heating surface. The resistance to the flow of heat is divided into three parts;

1. The condensate film resistance between the steam and the metal tube wall.
2. The resistance of the metal tube wall.
3. The liquor film resistance between metal wall and the bulk of the liquor.

The three resistances are in series, and when added together, result in a sum which is inversely proportional to the heat transfer coefficient. This is shown graphically in Figure No. 1.

In most cases, the resistance due to the metal tube wall is relatively minor. The condensate film resistance is also generally a small part of the overall resistance. In the case of clean evaporator tubes, the greatest resistance to heat transfer in the liquor film (See Figure 1-a.)

The liquor film coefficient (reciprocal of the resistance) is directly proportional to the thickness of the stagnant film of liquor on the tube metal surface. The Liquor film thickness, and consequently, the liquor film resistance is affected by many factors, the more important of which are:

1) the liquor viscosity;
2) the turbulence of liquor in the tube.

The higher the concentration of the liquor and the lower the temperature the greater will be the viscosity and the lower will be the film coefficient and therefore the heat transfer rate. The amount of liquor turbulence similarly affects the heat transfer rate in that higher liquor turbulence result in higher liquor film coefficients.

The above analysis has assumed that metal tube surfaces are clean and that no scale or other deposit is present on the tube wall. In actual practice, the tube surfaces both inside and out may become coated with deposits of scale or organic materials with low thermal conductivities. This can add a relatively large resistance to the flow of heat and greatly reduce heat transfer rates. This is shown graphically in Figure No. 1.

When scale is on the tube wall, less heat can be transferred from the water vapor on the outside of the tubes to the liquor on the inside of the tubes with a given temperature drop or driving force than for an operation with clean heating surfaces. Viewed in another way, a larger temperature drop is required to transfer a given amount of heat because of the additional scale resistance.

As mentioned earlier, steam film resistance is relatively small. This has assumed that air or other noncondensable gases are not present in sufficient quantities to cause the formation of a gas film on the tube wall which greatly inhibits heat transfer rates. The following table indicates the effect of varying quantities of air in the heating steam on the overall heat transfer coefficient (U) of an evaporator surface condenser:

% Air in Steam	Heat Transfer Coefficient (BTU/HR/Sq. Ft./oF)
0%	500
1%	420
3%	360

The effective Delta T or temperature drop across the heating surface is the steam temperature minus the boiling liquor temperature. The temperature of liquor may be several degrees higher than that of the vapor in the evaporator. This is caused by the dissolved substances in the liquor. For example, suppose an evaporator is boiling liquor under vacuum of 26" Hg., the saturated vapor temperature of which is 125oF and assuming the steam temperature on the other side of the tubes is 150oF. In this case, the apparent temperature drop would be 25oF. Due to the boiling point rise (which increases with concentration) of the liquor, however the boiling temperature might be 130oF. Therefore, the true working temperature drop or effective delta T would be 20oF.

The principles of evaporation are based on the physical laws governing boiling liquids. Consider a closed vessel containing a boiling liquid at a given temperature. The pressure of the vapor in equilibrium with the boiling liquid is determined by the liquid temperature. The boiling temperature of all liquids decreases with decreasing vapor pressure.

Heat transfer occurs in an evaporator in the following manner: Steam condenses on the heat transfer surface (on the out side wall of the tubes), and the latent heat of condensation is transferred through the tube wall to the liquid inside the tube. A portion of the heat may be used to rise the temperature of the liquid to the boiling temperature at the pressure existing in the vapor chamber (if the liquid is not already at this temperature) and the remainder of the heat is used for evaporation.

In a single effect (with no vapor recompression) latent heat in the vapor generated is not reused for additional evaporation. The purpose of a multiple effect evaporator is to use the latent heat in the vapor for further evaporation by condensing it in another effect operating at a lower pressure and temperature.

II. SCALE FORMATION:

Composition of scale from evaporators in the main, is inorganic salts. Because of its inverse solubility, Calcium is often the most troublesome. Scale formation is accelerated by boiling of liquor at the heat transfer surface (inside the tube).

Nucleate boiling occurs within the stagnant liquor film. The hottest area inside the tube is the tube wall and consequently the hottest liquor is the liquor film (see Figure 1). During nucleate boiling a minute amount of water will turn to vapor leaving inorganic salts behind to deposit on the hot tube wall.

In this single effect forced circulation evaporator bulk boiling of the liquor occurs because of the small liquor head over the heating element. The resulting turbulence, however resists formation of inside tube wall deposits. It also improves heat transfer.

Liquor turbulence from the high velocity recirculation liquor will also resist scale formation, by sweeping the inside tube wall with bulk liquor. This will effectively reduce theoretical film thickness on the inside of the tube wall and consequently film temperature.

High viscosity liquor, on the other hand, will enhance scale formation by increasing theoretical stagnant liquor film thickness at the tube wall. Evaporative capacity can be improved when evaporating viscous liquors (more concentrated liquors) by operating at higher temperatures since viscosity decreases with higher temperature. Unfortunately, some liquors, particularly those containing organics, will scale tubes walls faster when operating at higher temperatures.

The formation of deposits on tube walls will resist heat transfer in the evaporator heating element and consequently reduce capacity of the evaporator. The evaporator design incorporates additional heat transfer surface area to compensate somewhat for resistance to heat transfer from tube deposits. The fact is, when evaporating most liquors, as evaporator operation time increases, evaporator capacity decreases. Once it declines below design capacity the scale should be removed either chemically of mechanically.

III. EQUIPMENT DESCRIPTION (See Drawings 10):

The Enders' Evaporator employed for The Naval Aviation Depot at Pensacola, Florida is a Two (2) Body Single Effect Forced Circulation Horizontal Tube. Evaporator Process & Instrumentation and General Arrangements are shown on :

Drawing #	Revision #	Description
10	1	Process & Instrumentation
110	1	General Arrangement 2.
120	1	Side Elevation - Gen'l Arrgt.

Each effect consist of a vapor head with mesh pad entrainment separator, forced circulation horizontal type heating element, circulation pump, surface condenser, vapor piping, liquor piping recirculation liquor piping, condensate piping, condensate pump, vent piping & discharge pump. One vacuum pump serves both effects.

VAPOR HEADS:

Vapor Head A, and Vapor Head B are constructed of T-316L stainless steel with tangential inlet liquor nozzle. They are designed to operate at a pressure of 5.99 psia (a vacuum) which is equivalent to a water boiling point of 170oF. WARNING: DO NOT EXCEED FIFTEEN (15) PSIG POSITIVE PRESSURE IN VAPOR HEADS.

Both vapor heads are Thirty inches (30") in diameter with a straight side of nine feet (9'). Each is equiped with a mesh pad type entrainment separator with water wash system. Mesh pads are accessable by unbolting the top cover.

Vapor heads are designed to separate circulating liquor from water vapor generated in the heating element. Water vapor and liquor enter the vapor head tangentially where the two, by cyclonic action, are separated. Water vapor is further separated from entrained liquor by gravity as both flow up the vapor head toward the entrainment separator where essentially all remaining entrained liquor is separated.

HEATING ELEMENTS:

Heating Element "A" and Heating Element "B" each are horizontal forced circulation and have 220 3/4" O.D.by 18 gauge average wall T-316L stainless steel, welded, 8 feet long tubes expanded into 1 1/8" thick, T-316L stainless steel tubesheets. This is equivalent to 346 square feet of heat transfer surface area based on the outside of tubes. Both heating elements are designed for four (4) pass operation on the liquor side (tube side) and one (1) pass operation on the steam side (shell side) of the heat exchanger.

Design liquor velocity inside the tubes is 4.8 fps

Both shell and tube side of both heat exchangers are ASME code stamped and constructed for 75 psig pressure at 320oF. and full vacuum. Both shells are constructed of 18", Sch 20, welded, carbon steel pipe. WARNING: DO NOT EXCEED SEVENTY FIVE (75) PSIG POSITIVE PRESSURE IN THE HEATING ELEMENTS.

RECIRCULATION PUMPS:

Both recirculation pumps are designed to pump recirculation liquor at 45% total solids (55% water) 180oF & specific gravity of 1.20, from the vapor heat, through the heating element and recirculating back to the vapor head. Pump duty is 275 gpm @ 72 feet total dynamic head with net positive suction head required of 2.5 feet.

Manufacturer is R.S. Corcoran Company of New Lenox, Illinois. Pump Model 5000F (A70-2) Size 4 x 3 FF FL with 9" impeller. Seal is 1 3/4" type 40-D/V (Silicon Carbide vs. Tungsten Carbide, Viton elastomers & T-316 stainless steel). Construction of T-316L & T-316 stainless steel liquor contact parts.

Pump Motor is 15 HP; 1750 RPM; TEFC; Frame 254T; 460/230 VAC; 3 ph 60 Hz.

SURFACE CONDENSERS:

Surface Condenser "A" and Surface Condenser "B" each are vertical tube and have 146 3/4" O.D. by 18 gauge average wall T-316L stainless steel, welded, 5 feet long tubes expanded into 1" thick, T-316L stainless steel tube sheets. This is equivalent to 143 square feet of heat transfer surface area based on the outside of tubes. Both heating elements are designed for two (2) pass operation on the cooling water side (tube side) and one (1) pass operation on the condensing vapor side (shell side) of the heat exchanger.

Design cooling water velocity inside the tubes is 4.08 fps at design cooling water flow of 310 gpm. The 310 gpm figure assumes a 10oF cooling water temperature rise through the condenser.

Both shell and tube side of both heat exchangers are ASME code stamped and constructed for 75 psig pressure at 320oF and full vacuum. Both shells are constructed of 14", Sch 10S, welded, T-316 stainless steel.

VAPOR PIPING (6"-VP13-S & 6"-VP14-S):

Vapor piping on each evaporator is 6" Sch 10S T-316L stainless steel and channels water vapor discharging entrainment separators to their respective surface condenser. Vapor piping is flanged at the surface condenser inlet nozzle to allow easy removal of the vapor head bolted cover.

LIQUOR PIPING (3/4"-WL-11S, 3/4"-WL12-S, "-HL05-S, "-HL07-S, "-HL06-S & "-HL08-S).

Liquor piping for both evaporators consist of feed liquor piping and discharge liquor piping. Flow control loops 1 & 2 including the control valve are in the feed liquor piping while the density sensor for control loops 3 & 4 as well as discharge pump P-5 and P-6 are in the discharge liquor piping (Odd numbers refer to evaporator "A" while even refer to evaporator "B").

Discharge pumps P-5 and P-6 each have an operator, which varies the flow rate through the pump in response to vapor head liquor level controller LIC-5 and LIC-6 respectively.

RECIRCULATION PIPING (6"-HL01-S & 6"-HL02-S)

Recirculation piping for both evaporators consists of pump suction piping which channels recirculating liquor from the bottom of the vapor head to the recirculation pump suction. In addition, pump discharge piping channels recirculating liquor to the tangential liquor inlet on the vapor head.

CONDENSATE PIPING (3/4"-VC15-S & 3/4"-VC16-S):

Condensate from each surface condenser discharges the shell side and is channeled to the suction side of it's respective condensate pump. Piping includes one isolation gate valve.

CONDENSATE PUMPS:

Each condensate pump is designed to pump condensate discharging the surface condenser at 100oF. to customer's condensate storage tank. Pump duty is 4 gpm @ 60 feet total dynamic head with net positive suction head required of 7.5 feet.

Manufacturer is Price Pump Company of Sonoma, California. Pump Model IMS50-SS-33, Size 1/2 x 3/4 x 4 with 4.12" impeller. Construction of T-316 stainless steel condensate contact parts.

Pump Motor is 1/2 HP; 3450 RPM; TEFC; 460/230 VAC; 3 ph 60 Hz.

VENT PIPING (3/4"-VT31-S, 3/4"-VT32-S, 1"-VA29-S, 1"-VA30-S, & 1-VA33-S):

Vent piping on each evaporator consist of piping which vents the shell of each heating element to the atmosphere and piping which caries non-condensables from each surface condenser to the vacuum pump. A throttling globe valve is in the former while isolation gate valves are in the latter. Line #33 includes a check valve just before entering the vacuum pump to hold vacuum in the evaporator in the event the vacuum pump stops pumping.

DISCHARGE PUMP:

Each discharge pump is designed to pump concentrated liquor discharging the vapor head via the recirculation piping at 180oF. to customer's concentrated liquor storage tank. Pump duty is 1/3 gpm @ 120+ feet total dynamic head.

Manufacturer is Chemcon, Incorporated of South Attleboro, Massachusetts. Pump Model 21P1-E230-4121 simplex metering pump. with Teflon diaphragm. Construction of T-316 stainless steel condensate contact parts.

Pump Motor is 1/4 HP; TEFC; 1750 RPM, 115/230 VAC; 1 ph 60 Hz.

VACUUM PUMP (One Pump Serves Both Evaporators):

The vacuum pump is designed to reduce pressure in each evaporator to 5.99 psia (a vacuum with water boiling point @ 170oF.) by pumping non-condensables out of each evaporator. Pump duty is 15 pounds per hour of free dry air plus the moisture of saturation at 100oF.

Manufacturer is Kinney Vacuum Company of Canton, Massachusetts, Model MLR-15 close coupled liquid ring.. Construction of T-316 stainless steel.
Pump Motor is 2.5 HP; 3450 RPM; TEFC; 460/230 VAC; 3 ph 60 Hz.

COOLING TOWER:

The cooling tower is designed to cool a flow of 660 gpm of water at 95oF from both condensers to 85oF at a wet bulb temperature of 78oF, with 0.005% maximum water drift loss.

The cooling tower is a Marley model NC201 induced draft, vertical discharge, double flow, single cell complete with cold water basin with combination 4" drain and overflow, hot water open type distribution basins with removable plastic diffusing type metering orifices and removable steel covers, fan with removable steel wire guard, polyvinyl chloride film type fill, integral lovers and 3-pass drift eliminators, galvanized coating, access door and 10 HP 230/460 volt 3 ph, 60 Hz. TEFC fan motor.

The cooling tower is mounted on the roof and the cooling system circulates cooling water through both evaporator condensers by use of a cooling water circulation pump (described below).

COOLING TOWER WATER CIRCULATION PUMP:

Cooling tower water circulation pump is mounted underneath, and pumps water from the cooling tower cold water basin.

Cooling tower water is circulated to the two evaporator condensers and back to the cooling tower hot water basin, using an ITT Marlow Model 4-9SC centrifugal pump, of all iron construction, size 5 x 6, close couipled with a 9" impeller. Pump is complete with a 15 HP 1750 rpm, 460/230 volt, 3 phase, 60 Hz, TEFC motor.

Pump duty is 660 gpm @ 68' TDH. Pump has NPSH required of 10'

IV. LIQUOR FLOW (See Figure 2.):

The weak liquor from the customer's feed tank enters vapor head "A" via control valve, CV-1 and flow element, FE-1. Liquor flow rate is controlled at set point by control loop 1. Accumulated liquor from vapor head "A" is continually recirculated through recirculation piping, heating element "A" and back to the vapor head by recirculation pump P-1. Water vapor, formed in the heating element, is removed from the liquor entering the vapor head while concentrated liquor is discharged from the recirculation piping via density element, DE-3 and discharge piping by discharge pump, P-5. Liquor level in vapor head "A" is sensed by level element, LE-5 and controlled at set point by control loop 5.

Likewise, the weak liquor from the customer's feed tank enters vapor head "B" via control valve, CV-2 and flow element, FE-2. Liquor flow rate is controlled at set point by control loop 2. Accumulated liquor from vapor head "B" is continually recirculated through recirculation piping, heating element "B" and back to the vapor head by recirculation pump, P-2. Water vapor, formed in the heating element, is removed from the liquor entering the vapor head while concentrated liquor is discharged from the recirculation piping via density element, DE-4 and discharge piping by discharge pump, P-6. Liquor level in vapor head "B" is sensed by level element, LE-6 and controlled at set point by control loop 6.

V. STEAM AND CONDENSATE FLOW (See Figure 3.):

Live steam enters the shell side of heating element "A" via control valve, CV-3 where it condenses on the outside of the tubes, transferring its heat to the liquor inside the tubes. Steam flow rate is controlled by control loop 3 (Loop 3 senses specific gravity of liquor discharging the evaporator and will close CV-3 proportionately if specific gravity is above set point). Live steam condensate discharges the shell side of heating element "A" via a steam trap and steam condensate piping. Vapor genrerated by evaporation is separated from the liquor in vapor head "A" and channelled from there via the vapor piping to surface condenser "A" where it is condensed. Vapor condensate is pumped from surface condenser "A" by condensate pump, P-3 to customer's vapor condensate storage tank.

Likewise, live steam enters the shell side of heating element "B" via control valve, CV-4 where it condenses on the outside of the tubes transferring its heat to the liquor inside the tubes. Steam flow rate is controlled by control loop 4. (Loop 4 senses specific gravity of liquor discharging the evaporator and will close CV-4 proportionately if specific gravity is above set point). Live steam condensate discharges the shell side of heating element "B" via a steam trap and steam condensate piping. Vapor genrerated by evaporation is separated from the liquor in vapor head "B" and channelled from there via the vapor piping to surface condenser "B" where it is condensed. Vapor condensate is punped fron surface condenser "B" by condensate pump, P-4 to customer's vapor condensate storage tank.

VI. COOLING WATER FLOW (See Figure 4.):
Water from the cooling tower basin is transported by the cooling tower circulation pump to the tube side of each surface condenser ("A" or "B"). There it makes two passes (one pass up and one down), absorbing heat from the condensing water vapor on the shell side of the condenser. Heated water exits the surface condensers and, via the cooling water piping, flows to the cooling tower entering through a feed nozzle on top. In the cooling tower, the hot water flows downward over a series of PVC "louvers" where it is counter currently contacted with air flowing upward. A portion of the water flowing downward is evaporated into the air stream which, in turn, cools the water as it falls. A fan is mounted on the top to draw air in through the bottom of the cooling tower sides and up through both cooling tower and fan. The cooled water falls into the cooling tower basin where it is collected and discharged back to the suction side of the cooling tower circulating pump.

Evaporation and entrainment losses are made up using plant water which flows into the basin automatically via a float valve when basin water level is low.

VII. PLANT WATER FLOW (See Figure 4.):

In addition to cooling tower make-up water, plant water is used as vacuum pump seal water and for each of the mesh pad spray wash systems. The spray wash water is piped into each vapor head ("A" or "B") and held behind a normally closed valve. When this valve is opened, water enters the vapor head and impacts the bottom of the mesh pad at a high velocity via the wash water spray nozzle located just under the mesh pad in each vapor head. High velocity water loosens fibers and other material accumulating on mesh pads from the liquor. These accumulations unless washed off will eventually plug the mesh pad.

VIII. VENT GAS AND VACUUM FLOW (See Figure 5.):

Steam from the boiler enters the shell side of heating element "A" where it is condensed and removed via the steam trap and condensate piping. The steam will contain a small amount of air which unless vented from the heat exchanger, accumulates to prevent steam from condensing. A small amount of uncondensed steam, is removed through the vent nozzle along with the air being vented from the heating element shell side (Shell side pressure must be greater than atmospheric before air can be vented).

Air and other non-condensable gas contained in the feed liquor is carried over along with the evaporation vapor from vapor head "A" to the shell side of surface condenser "A" . The vacuum pump (P-7) removes these non-condensables from the shell side of surface condenser "A" through the vacuum piping via a check valve (valve #23). Condensate pump, P-3 removes the condensate.

To control boiling temperature in the vapor heads, a pressure relief valve (PV 11), designed to proportionately bleed a little atmospheric air into the vacuum pump as vacuum becomes greater than 17.73"Hg (pressure required to boil water at 170oF.). Gasses are then pumped through vacuum pump P-7 to discharged the system.

Likewise, steam from the boiler enters the shell side of heating element "B" where it is condensed and removed via the steam trap and condensate piping. The steam will contain a small amount of air which unless vented from the heat exchanger, accumulates to prevent steam from condensing. A small amount of uncondensed steam, is removed through the vent nozzle along with the air being vented from the heating element shell side (Shell side pressure must be greater than atmospheric before air can be vented).

Air and other non-condensable gas contained in the feed liquor is carried over along with the evaporation vapor from vapor head "B" to the shell side of surface condenser "A" . The vacuum pump (P-7) also removes these non-condensables from the shell side of surface condenser "B" through the vacuum piping via a check valve (valve #23). Condensate pump, P-4 removes the condensate.

IX. REQUIRED INSTALLATION OF SAFETY EQUIPMENT

Pressure inside each vapor head must not exceed 14 PSIG. To insure that this will not happen, install a pressure relief valve in the main live steam line feeding lines 4"-ST19-C & 4"-ST20-C which, in turn, feed the heating elements.

X. GENERAL OPERATING PROCEDURES

Since both evaporators are the same, the following discussion applies to either evaporator. It is recommended that the initial start up be on water. Plant water is introduced through the feed liquor connections. Once the liquid level in the vapor head is above set point (about 34" above recirculation pump suction centerline) the recirculation pump is turned on. Before recirculation is established, the remaining, unfilled portion of the heating element and recirculation piping must fill up. This will decrease the vapor head liquid level which is made up with some additional feed. When vapor head liquid level is at 30"-32" above recirculation pump suction centerline with pump on, feed flow is shut off. Once recirculation flow has reached a steady state, live steam is slowly fed to the heating element. Vacuum is applied by proper positioning of valves and turning on the vacuum pump. Cooling tower water is circulated through the surface condenser by:

1) Making sure water in the basin is at the proper level
2) Opening applicable valves
3) Turning on cooling tower circulation pump
4) Turning on cooling tower fan
5) Checking air flow through the cooling tower.

Next the liquor discharge pump is turned on and the feed flow is adjusted such that the discharge pump is discharging at about 3/4 capacity (capacity is 20 GPH).

Water recirculating through the heating element will reach boiling temperature after a while. Once this happens, condensate will begin to accumulate in the shell side of the surface condenser. At this time the condensate pump is turned on and the pump suction valve opened.

The system should now be evaporating water as evidenced by condensate flow through the condensate pump. In addition, liquid level in the vapor head should be controlled at set point to approximately 30" above the recirculation pump suction centerline. Below this level the recirculation pump will likely cavitate.

Because specific gravity of the evaporator discharge will be one (1) while operating on water, the steam control loop cannot be used to control steam flow (until the evaporator is put on plating waste solution and specific gravity of discharge is above 1.10).

By operating on water, the operator can confirm that all systems are functioning as designed. He should make a thorough check of the operating evaporator (temperatures, control loops, valve positions, etc.). If all conditions are normal, the evaporator is ready to operate on plating solution. Water flowing to the feed line is shut off and weak plating solution is introduced into the feed connections. At this point, however, the operator must adjust the feed flow rate such that little or no plating solution is discharged from the evaporator until it reaches desired concentration (44%). At this concentration, feed rate is increased to maintain discharge liquor concentration.

The operator should continue to adjust the feed liquor flow and the steam flow until the product liquor reaches steady state flow and concentration. At discharge concentration of 44%, feed flow should be about 3.13 gpm (1565 lbs/hr) while discharge flow rate should should be 1.2 gallons per hour (10.7 lbs/hr).

Specific gravity of the discharge liquor is now within range of the specific gravity sensor (1.1 to 1.3) and consequently the control loop which controls specific gravity of the discharge liquor by throttling steam flow, can now be activated.

The evaporator should now be on stream and at steady state. The operator should routinely inspect the evaporator system while it is in operation to see that all equipment is functioning normally.

XI. Initial Operation:

The following assumes that the complete evaporator has been checked for leaks (vacuum test) and that the heating element has been water tested to check for tube tightness.

Initial operation should be carried out using water instead of plating solution to make sure that all components of the system are functioning properly and that control loops are properly tuned.

1) Check all pumps for proper rotation, lubrication, and alignment. Check for and remove any foreign material or objects in pump

2) Position valves in the liquor piping as follows (see figure 2):

Evaporator	"A"	"B"
Feed Control Valve, CV-1	Open	
Feed Control Valve, CV-2		Open
Feed Valve, V-1	Open	
Feed Valve, V-2		Open
Discharge Valve, V-7	Closed	
Discharge Valve, V-8		Closed
Dump Valve, V-15	Closed	
Dump Valve, V-14		Closed

3) Position valves in steam and condensate piping as follows (see figure 3):

Evaporator	"A"	"B"
Steam Control Valve, CV-3	Open	
Steam Control Valve, CV-4		Open
Steam Valve, V-3	Closed	
Steam Valve, V-4		Closed
Vapor Condensate Valve, V-9	Open	
Vapor Condensate Valve, V-10		Open

4) Position valves in cooling water & plant water piping as follows (see figure 4):

Evaporator	"A"	"B"
P-7 Seal Control Valve CV-16	Closed	Closed
P-7 Seal By-Pass Valve V-20	Closed	Closed
P-7 Seal Shut Off Valve V-19	Open	Open
Mesh Wash Valve, V-17	Closed	
Mesh Wash Valve, V-18		Closed
Cooling Water Valve, V-16	Closed	
Cooling Water Valve, V-11		Closed
P-8 Drain Valve, V-21	Closed	Closed

5) Position valves in vent and vacuum gas flow piping as follows (see figure 5):

Evaporator	"A"	"B"
Heat Element Vent Valve, V-5	Closed	
Heat Element Vent Valve, V-6		Closed
Condenser Vent Valve, V-11	Open	
Condenser Vent Valve, V-24		Open
Condenser Vent Valve, V-13	Closed	
Condenser Vent Valve, V-12		Closed
P-7 Relief Block Valve, V-22	Closed	Closed

6) Fill the evaporator with water:

A piping system or system using a hose is constructed for introducing plant water, under slight pressure, into the feed piping upstream of valve, V-1 (V-2). A connection is then made and plant water is fed to evaporator "A" ("B") vapor head at the rate of approximately 2 gpm by opening valve, V-1 (V-2) adjusting flow rate set point on flow controller, FIC-1 (FIC-2). The vapor head "A" ("B") is allowed to fill until liquid level reaches approximately 34" as indicated on liquid level controller, LIC-5 (LIC-6). The liquid level controller indicates liquid level above the horizontal centerline of the recirculation pump, P-1 (P-2).

With liquid level at about 34" the recirculation pump, P-1 (P-2) is turned on and plant water feed flow is shut off. Because a portion of the heating element and recirculation piping will be empty before the recirculation pump is started liquid level will decline some when the pump is turned on. With pump running, adjust liquid level in the vapor head to about 32" by adding more feed if level is low and discharging some water if level is high. Adjust set point on liquid level controller, LIC-5 (LIC-6) to 32" and turn on discharge pump P-5 (P-6) to discharge water from the vapor head.

7) Apply live steam to the heating element:

Steam flow, when controlled automatically, is throttled by density controller, DIC-3 (DIC-4). This control loop cannot be used when the evaporator is operating on water because specific gravity of water discharging the evaporator is always one (1). Consequently we use steam valve, V-3 (CV-4) to throttle steam when on water and open steam flow control valve, CV-3 (CV-4).

While the recirculation pump is on and vapor head liquid level is about 32", gradually open steam valve, V-3 (V-4) about 1/4 open. Check steam pressure in the heating element, as measured by PI-9 (PI-10). With clean tubes the gauge will likely read near zero.

8) Apply vacuum to evaporator:

Turn on vacuum pump and check for seal water flow. Make sure condenser vent valves are positioned so no air is leaking through valves into the evaporator and that air from the vapor head can flow through the vacuum pump.

9) Recirculate cooling tower water through condenser:

The cooling tower manufacturer is The Marley Cooling Tower Co. The operator should have studied Marley operating instructions before now and be able to start up the cooling tower. Operator:

1) makes sure water in the basin is at the proper level
2) opens cooling water valve, V-16 (V-11)
3) turns on cooling tower circulation pump
4) turns on cooling tower fan
5) checks air flow through the cooling tower.
6) checks for water flow through the condenser.

10) Begin discharge flow from evaporator:

Open discharge valve, V-7 (V-8) and turn on discharge pump, P-5 (P-6). Next adjust feed flow set point on feed flow controller, FIC-1 (FIC-2) to one third (1/3) gpm; maximum capacity of the discharge pump.

Check to make sure liquid level in the vapor head is at set point and that water is discharging through discharge pump, P-5 (P-6).

11) Check vacuum:

Once vacuum reaches 17.7" Hg. as indicated on gauge, PI-11, P-7 relief block valve, V-22 is opened. This will insure that vacuum will go no lower than 17.7" Hg. since relief valve, PV-17 will now bleed air into the vacuum pump if vacuum becomes higher than it's set point (17.7" Hg.)

12) Check recirculating water temperature:

Water recirculating through the heating element should be increasing, as indicated by TI-7 (TI-8) when switched to thermocouple, TE7-9 (TE8-10). Temperature should increase to boiling. Boiling temperature should be 170oF if vacuum is at 17.7" Hg. (at sea level).

If temperature is increasing to slowly, more steam is required to bring water temperature to the boiling point faster. Open steam valve, V-3 (V-4) a little more until recirculating water temperature increases at a rate of approximately one degree every second.

13) Discharge vapor condensate from evaporator:

Water recirculating through the heating element will reach boiling temperature after a while. Once this happens, condensate will begin to accumulate in the shell side of the condenser. At this time vapor condensate valve, V-9 (V-10), located in pump suction piping is opened and the condensate pump P-3 (P-4) is turned on.

14) Bring evaporator up to capacity:

The system should now be evaporating water as evidenced by condensate flow through the condensate pump. In addition, liquid level in the vapor head should be controlled at set point to approximately 30" above the recirculation pump suction centerline (below this level the recirculation pump will likely cavitate).

Additional feed must be added to compensate for the amount of evaporation in order to maintain liquid level in the vapor head. As long as water is discharging through the discharge pump the level is at set point. However if no liquid is discharging there is not enough feed to compensate for evaporation.

In this event slowly increase set point on the feed flow controller, FIC-1 (FIC-2) until water discharges from the evaporator again.

By alternately but slowly increasing steam flow a little with steam valve V-3 (V-4) and then feed flow with flow controller FIC-3 (FIC-4) to maintain evaporator discharge flow, the evaporator is brought up to near design capacity. Maximum feed flow rate should be 3.2 gpm (1565 lbs/hr.).

Check evaporator liquor discharge flow. If there is none add a little more feed but only if feed flow is below 3.2 gpm, otherwise cut back on the amount of steam flow by closing steam valve V-3 (V-4) a little bit.

If the recirculation pump P-1 (P-2) begins to cavitate it means that there is not enough liquid level in the vapor vapor head.

Check vapor condensate flow which should account for almost all of the feed flow. Feed flow rate into the evaporator is equal to vapor condensate flow rate out plus evaporator discharge flow rate.

Operate in this manner for a couple hours and adjust the control instruments.

15) Introduce plating solution liquor into the evaporator feed piping instead of plant water.

Once the evaporator is at steady state with plant water as feed, plant water is shut off and plating solution immediately introduced into the evaporator feed piping instead. Minor flow adjustments are made to achieve steady state again.

16) Automatic control of discharge liquor density.

Evaporation proceeds until specific gravity of the discharge liquor reaches 1.2 as indicated by density controller, DIC-3 (DIC-4). At this point, controller set point is adjusted to 1.2 and steam valve V-3 (V-4) is opened fully.

17) Operation of evaporator under design conditions:

The operator should continue to adjust feed liquor flow and steam flow until the product liquor reaches steady state flow and concentration. Assuming feed concentration of 1000 ppm, at discharge concentration of 44%, feed flow should be about 3.13 gpm (1565 lbs/hr) while discharge flow rate should should be 1.2 gallons per hour (10.7 lbs/hr). This is equivalent to an evaporation rate of 1554 lbs/hr. (design evaporative capacity).

XII. START-UP AND OPERATION ON PLATING SOLUTION:

Start-up and operation of the evaporator for processing plating solution liquor is the same procedure as for initial operation, detailed above with the following exceptions:

1) Plating solution is pumped to the feed inlet piping just up stream of feed valve, V-1 (V-2) instead of water.

2) In item 10 (above) liquor discharging from the evaporator will be very dilute. It is recommended that this liquor be recycled back to the feed tank

3) Since solids are entering the evaporator during all phases of start-up, concentration of discharge liquor will reach 44% soon after evaporation begins (see item 13) and control loop 3 (loop 4) is activated (see item 16).

4) Obviously since there is no plant water in the feed piping, it cannot be shut off (see item 15).

XIII. EMERGENCY SHUTDOWN PROCEDURES:

In the event of electrical power failure, instrument air supply failure or other abnormal condition that would interrupt evaporator operation, the following shutdown procedures should be followed as soon as possible.

1) Close steam valve V-3 (V-4) to stop steam flow.

2) Close feed valve V-2 (V-2) to stop feed flow.

3) Turn off recirculation pump, P-1 (P-2).

4) Turn off condensate pump, P-3 (P-4)

5) Turn off discharge pump, P-5 (P-6)

6) Turn off vacuum pump, P-7.

7) Break vacuum by slowly opening condenser vent valve, V-13 (V-12).

8) If the evaporator will be down for a period longer than 8 hours, dump contents of the vapor head and heating element by opening evaporator dump valve V-15 (V-14). Caution! liquor discharging through the dump valve will be at 170oF This liquor will be fully concentrated and should be piped (or pumped) to the product liquor storage tank.

9) Once evaporator is drained, close evaporator dump valve V-15 (V-16) and open mesh wash valve, V-17 (V-18) to fill evaporator vapor head to 34" level as indicated on liquid level controller, LIC-5 (LIC-6). Then shut off mesh wash valve V-17 (V-18).

10) If operator has power turn on recirculation pump to flush the tube side of the heating element for approximately 20 minutes.

11) This flush water is, of course contaminated with plating solution and consequently should be evaporated. It can be either dumped into the feed tank for evaporation later or stored in the evaporator if corrosion is determined not to be a problem.

12) After the abnormal condition is corrected, the evaporator should be returned to service by following the procedure outlined under "XII. Start-up and Operation on Plating Solution:"

XIV. TROUBLE SHOOTING GUIDE:

All evaporators are subject to operational problems. This trouble shooting guide has been developed to assist the operator in correcting some of the more common problems encountered. It goes without saying that this guide is by no means a list of all of what can go wrong with the evaporator.

The operator must also recognize that "unusual" problems can develop due to pump coupling failures, tramp material in the process stream from broken valves and fittings, a line blow-out and other phenomena can and will likely occur.

The operator should watch all of the instrument records and his routine test carefully. Any abrupt change in a pressure, temperature, flow, or other variable usually indicates an abnormal situation developing and every effort should be made to analyze the condition and evaluate it in terms of its effect on the operation of the evaporator. There is no substitute for a thorough knowledge of the principles of evaporator operation.

EVAPORATOR TROUBLE SHOOTING GUIDE

SYMPTOM	POSSIBLE CAUSE	REMEDY
1. Product liquor gets too weak	1a. Insufficient steam flow	1a. Check steam flow control valve and steam supply pressure
	1b. Evaporator feed liqour flow is excessive	1b. Reduce evaporator weak liquor feed
	1c. Evaporators are dirty	1c. Boil evaporators with water to remove water soluble residue
	1d. Evaporators are scaled up and heat transfer rates are inadequate	1d. Clean evaporators chemically.
	1e. "Vapor Lock" in shell side of the heating element.	1e. Vent more gas from shell of heating element.
	1f. Mesh pad is partially plugged	1f. Shut down & flush or clean mesh pad
2. Product liquor gets too concentrated.	2a. Evaporator steam pressure and flow too high.	2a. Reduce steam pressure and flow.
	2b. Insufficient feed liquor flow	2b. Increase feed liquor flow
	2c. Failure of the liquor to discharge the evaporator	2c. Execute emergency shutdown procedure Repair problem and resume operation

EVAPORATOR TROUBLE SHOOTING GUIDE (Page 2)

SYMPTOM	POSSIBLE CAUSE	REMEDY
3. Evaporator "carries over" (Entrainment)	3a. Liquor level too high 1) Level controller set point 2) Control loop malfunction 3) Low/no discharge flow 4) High feed flow rate	3a. Reduce feed liquor flow 1) Lower controller set point 2) Repair control loop. 3) Establish discharge flow 4) Reduce feed flow rate.
	3b. Evaporation rate high.	3b. Reduce steam & feed flow rate.
4. Cannot establish vacuum	4a. Leaks in piping & flanges	4a. Repair leaks.
	4b. Insufficient seal water to vacuum pump.	4b. Reestablish seal water flow.
	4c. Vacuum pump malfunction.	4c. Repair vacuum pump
	4d. Condenser operating too hot	4d. Cooling water hot or tubes dirty.
5. Evaporators won't take enough steam.	5a. Vapor lock	5a. Vent plugged or restricted line.
	5b. Steam chest filled with condensate	5b. Check trap & condensate piping. Repair as required
	5c. Liquor level below heater tubes (Recirculation pump may be cavitating.	5c. Fill vapor head to proper level.
	5d. Liquor concentration to high.	5d. Increase feed flow to dilute

APPENDIX
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