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A document prepared for ASME - JPGC 2001 CONFERENCE at New Orleans, LA, USA from 6/3/2001 - 6/7/2001.

DOE Contract No. **DE-AC09-96SR18500**

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Abstract

The Savannah River Site Evaporators have run with limited operation problems for almost 40 years. In October 1999, one evaporator was shut down due to the inability to lift the concentrate solution from the pot. Visual inspection showed a significant buildup of solids or scale deposits on all of the exposed surfaces of the evaporator pot. A chemical cleaning flow-sheet to remove the scale deposits has been developed: (1) water soak of pot, (2) acid soak of pot, (3) transfer to neutralization tank (4) transfer to receipt tank and (5) repeat of Steps 2,3,4 as needed. Among these, Step (2) acid soak of pot is the most critical because the scale is slowly dissolved during this step.

To perform Step (2) acid soak of pot, the nitric acid solution is added to the evaporator pot, heated from 30°C to 90°C and held at 90°C temperature to dissolve the scale materials for 32 hours and then the pot liquid is cooled down to 30°C before being sent to the neutralization tank. A series of batch processes continue as needed. Different methods of pot liquid heating (A), (B), (C) and cooling (D) of Step (2) were evaluated:

(A) steam heating from tube bundle and warming coil with sparger air,
(B) lance line direct steam injection and using warming coil steam,

(C) different pressures of warming coil steam heating and air sparger.

(D) water cooling through tube bundle, lance air and cell ventilation.

Based on the extensive heat balance calculations and analysis, it has been concluded that the optimum heating and liquid mixing can be achieved by Method (A) using tube bundle steam and the optimum cooling can be achieved by Method (D) using tube bundle cooling water during acid soak of evaporator pot.

Evaporator Description and Normal Operation

2H Evaporator is located in H-Tank Farm Area of Savannah River Site. The evaporator vessel pot is a 304-L stainless steel vessel 8 feet diameter and 16.5 feet tall with a normal operating capacity of about 2000 gallons. The shell-side vessel design pressure and temperature are 15 psig and 160°C, respectively. **Figure 1** shows the evaporator vessel during normal operation. The conical shape at the bottom of the vessel is designed for efficient removal of concentrated waste.

The evaporator has two heat sources: the 25 psig steam warming coil and 150 psig steam tube bundle. The warming coil is used to maintain the waste temperature in the evaporator pot during shutdown and to heat the contents during a desalting and descaling operation. The tube bundle is used to heat the evaporator to the boiling point

during normal operation. The purpose of the 2H Evaporator System is to reduce the amount of liquid volume of high-level radioactive waste resulting from the nuclear processing. The boiling action in the evaporator causes the non-radioactive liquid to separate from the waste. The separation of the liquid from the waste reduces the waste volume to about 1/3 of the original volume. By removing 2/3 of the original volume of the non-radioactive liquid by evaporation, fewer storage tanks are required.

Scale Deposition History

For almost 40 years, the SRS tank farm evaporators have run with limited operational problems. In late 1996, salt scale buildup started to cause lifting problems of concentrate waste from the evaporator vessel. In July 1997, the evaporator was shutdown due to the inability to lift the material from the vessel. Inspection of the Gravity Drain Line (GDL) showed a scale deposit coating the inside of the line. A sample of the material was obtained and analysis indicated the deposit was a sodium aluminosilicate scale. The GDL was successfully cleaned with a pressure washer using an 8000 psi water stream. The evaporator ran more smoothly after the cleaning, and subsequent inspections in October 1997, December 1997, January 1998 and March 1998 showed little to no scale deposit in GDL. The lift remained operational until June 1998, when the evaporator was again shut down due to the inability to lift the material. The GDL was again cleaned with a pressure washer in June 1998. The evaporator resumed operation after the cleaning. For the rest of 1998 and the first part of 1999, the 2H Evaporator operations continued to experience poor lift performance. Finally In December 1999, the 2H Evaporator was shut down due to the inability to lift the concentrate from the vessel. The majority of the solids deposition centers around the feed line and extends outward from the feed line to cover 2/3 of the

circumference of the evaporator, below the tube bundle.

Evaporator Cleaning Process Overview

Both chemical and mechanical techniques were considered to remove the scale deposits from the inside of the evaporator vessel. Chemical cleaning with dilute nitric acid was chosen as the best option. **Figure 2** shows the process configuration of the system during chemical cleaning.

The first step of evaporator pot cleaning is water soak which provides water checkout of equipment and may remove some upper deposits. After finishing water soak, a preparation of acid soak will begin.

Addition of acid solution

The nitric acid will be fed to the evaporator pot through the well water addition line, which is normally used to add well water to lower the specific gravity or cool the contents of the pot.

Heating of acid solution

Approximately 3000 gallon of evaporator vessel pot liquid will be heated to 90°C from 30°C by the selected optimum heating method using (a) 150 psig steam through the tube bundle and (b) 25 psig steam through the warming coil and (c) agitated with the air lance during the dissolution of the scale material.

Maintaining at 90°C and cooling

The pot liquid will be maintained at 90°C for 32 hours and then will be cooled in the evaporator using the cooling water through the tube bundle. **Figure 3** shows Evaporator Vessel During Heating and Cooling.

Once cooled to 30°C, the pot liquid will be transferred to a separate tank through the first portion of the Receipt Tank Gravity Drain Line. This line will be modified to direct waste to and from the neutralization tank. Once in the neutralization

tank, the material will be mixed with an agitator and re-circulated while a caustic stream is added to neutralize the solution. After the caustic is added, the solution will be sampled and pumped to the Receipt Tank through the second portion of the GDL.

Process Steps

The description of process steps shown here are based on the Savannah River Site Report titled "TECHNICAL BASIS FOR THE 242-16H EVAPORATOR CLEANING PROCESS(U)" by C. Boley.

This section outlines the general steps needed for a batch cleaning of the evaporator as shown in Figure 4.

Step 1 - Water Soak

The evaporator pot will be filled to about 87 inch true level with well water and allowed to sit 12 hours. The pot will already be filled to about 44 inches with well water, and water will be added on top of that. The solution will then be pumped to the neutralization tank and then to the Receipt Tank.

Step 2 - Acid Solution Make-up

The nitric acid solution in the tankers that is considered to be process waste of the canyon facility. The desired final concentration of nitric acid is 1.5 moles.

Step 3 - Acid Addition to Evaporator pot

The acid cleaning solution will be pumped from the tanker to the evaporator pot through the well water addition line.

Step 4 - Heating the Evaporator Pot

After the acid cleaning solution has reached the desired level, the evaporator will be heated to 90°C with the tube bundle and warming coil steam. A heat balance of the system shows that the vessel will require about 2 hours to reach 90°C from 30°C. The pot liquid should be held at temperature for at least 32 hours.

Step 5 - Cool Down

The pot liquid should be cooled to 40°C for the first batch or 30°C for others. Data taken during the neutralization of the initial batch may change the temperature to which the contents must be cooled.

Step 6 - Sampling

During or following the cool down, the evaporator pot contents will be sampled.

Step 7 - Transfer to Neutralization Tank

After cooling, the contents of the evaporator will be transferred to the neutralization tank. Ensuring that there is space for the caustic addition is critical so that the material can be neutralized effectively.

Step 8 - Addition of Caustic to Neutralization Tank

A concentrated 50 wt% caustic will be added to target a pH of 10-14 in the pot. The caustic addition rate should be 50 gpm or as high as pumping capability will allow.

Step 9 - Pump Material to Receipt Tank

Tank 42H is the preferred choice as the receipt tank for the material.

Step 10 - Water Rinse of Neutralization Tank

After the material has been pumped out of the tank, about 1000 gallons of well water will be used to flush the vessel. The material should be sent to Receipt Tank 42H.

Step 11 - Visual Inspection of Evaporator Pot

After 5 batches at 1.5 mole acid, the evaporator pot interior will be remotely inspected. The inspection will confirm the salt dissolution process and identify if any process operation changes are needed.

Step 12 - Caustic Rinse of the Pot, Tank and Lines

Once the evaporator has been cleaned

adequately, all equipment that has come in contact with nitric acid solution will be rinsed with inhibited water of 1 mole caustic. This will ensure that the equipment is free of any low pH material.

Purpose of Evaporator Pot Heat Balance Analysis

In the above Step 4 - Heating as a part of 2H evaporator pot cleaning process, the mixed chemical nitric acid liquid in 2H vessel pot must be heated and maintained at 90°C for 32 hours and then be cooled in Step 5. The purpose of this analysis is to select the optimum method of evaporator pot liquid heating and maintaining the specified temperature for the required time and cooling for each batch process.

Assumptions

- a) The physical properties of pot liquid, inlet air of the concrete cell and sparger air of the lance such as specific heat, density, viscosity and conductivity are changing with temperatures. The average value of changing physical properties was selected and used here for simplicity.
- b) The heat absorbed by underground soil is insignificant and excluded.
- c) The humidity effect of the concrete cell ventilation is negligibly small.
- d) The temperature of heated elements such as pot liquid, vessel wall and insulation are taken as average or mean bulk temperatures for modeling simplicity.

Calculation Method

The calculation was performed by using Heat Balance Method which includes:

- a) upper tube bundle steam or cooling water heat removal through tubes

- b) warming coil steam heat
- c) radiolytic decay heat
- d) sparger air heat loss
- e) evaporation heat loss from liquid-vapor interface
- f) concrete cell ventilation heat loss
- g) heat absorbed by pot metal
- h) heat lost to concrete wall
- i) heat absorbed by tank content or pot liquid which results in temperature change -
- j) thermowell temperature reading which can be different from pot liquid temperature.

Heating Methods of Step 4

Several methods of 2H Evaporator pot liquid heating from 30°C to 90°C have been evaluated. The heating methods we have analyzed are:

- (a) •140 psig steam heat from tube bundle at 500, 1000, 1500, 2000 lbs/hr and
 - 25 psig warming coil steam at 300 lbs/hr and
 - 150 cfm sparger air
- (b) •25 psig lance line direct steam injection at 300 lbs/hr and
 - 25 psig warming coil steam heat at 300 lbs/hr
- (c) •25, 85, or 140 psig warming coil steam at 300 lbs/hr and
 - 10 or 150 cfm air sparger.

Calculation Results And Conclusions

A comparative heating analysis and optimum heating & cooling calculation results is summarized in **Table 1**. Based on the calculation results shown in this table, it can be concluded that the quickest or optimum heating and liquid mixing can be achieved by using the first method (a)-Case 1.

a) Optimum Heating from 30°C to 90°C:

- 140 psig tube bundle steam at 2000 lbs/hr
- 25 psig warming coil steam at 300 lbs/hr
- 150 cfm sparger air
- 837 cfm air cell ventilation for standard safe operation

The estimated heating time of the pot liquid (~3000 gallons) from 30°C to 90°C is about 2 hours if the warming coil outside surface has an average of 0.5 inch of sodium aluminosilicate scale deposit (see Case 1).

b) maintain 90°C for 32 hours

Upon reaching 90°C temperature, the tube bundle steam will be cut off but the warming coil steam and air sparger will be kept on to maintain the temperature for 32 hours.

- 25 psig warming coil steam at 300 lbs/hr
- 120 cfm air sparger
- 837 cfm air cell ventilation

c) Liquid Cooling from 90°C to 30°C

The most practical optimum pot liquid cooling of Step 5 can be achieved by using cooling water through tubes, air ventilation through evaporator cell and air sparger.

- 14 gpm cooling water at 27°C through tube bundle
- 837 cfm air cell ventilation
- 10 cfm lance air

The estimated cooling time from 90°C to 30°C is approximately 16 hours.

The selection of optimum pot liquid heating and cooling method and evaporator pot liquid temperature vs heating and cooling time is shown in **Figure 5**.

References

- 1) C Boley, M. Thompson, W. Wilmarth, K Brown, WSRC-TR-2000-00211, Rev.2, Technical Bases For The 242-16H (2H) Evaporator Cleaning Process(U), Dec. 2000.
- 2) K. Kwon, HLW-STE-2000-00267, 2H Evaporator Pot Liquid Heating with Warming Coil, June, 2000.
- 3) K. Kwon, HLW-STE-2000-00323, 2H Evaporator Pot Liquid Cooling With Tube Bundle, Lance Air, Cell Ventilation and Wall Heat Loss (U), Aug 2000.
- 4) J. Keenan, F. Keyes, Thermodynamic Properties of Steam, 1967.
- 5) F. Kreith, Principles of Heat Transfer, 1965.

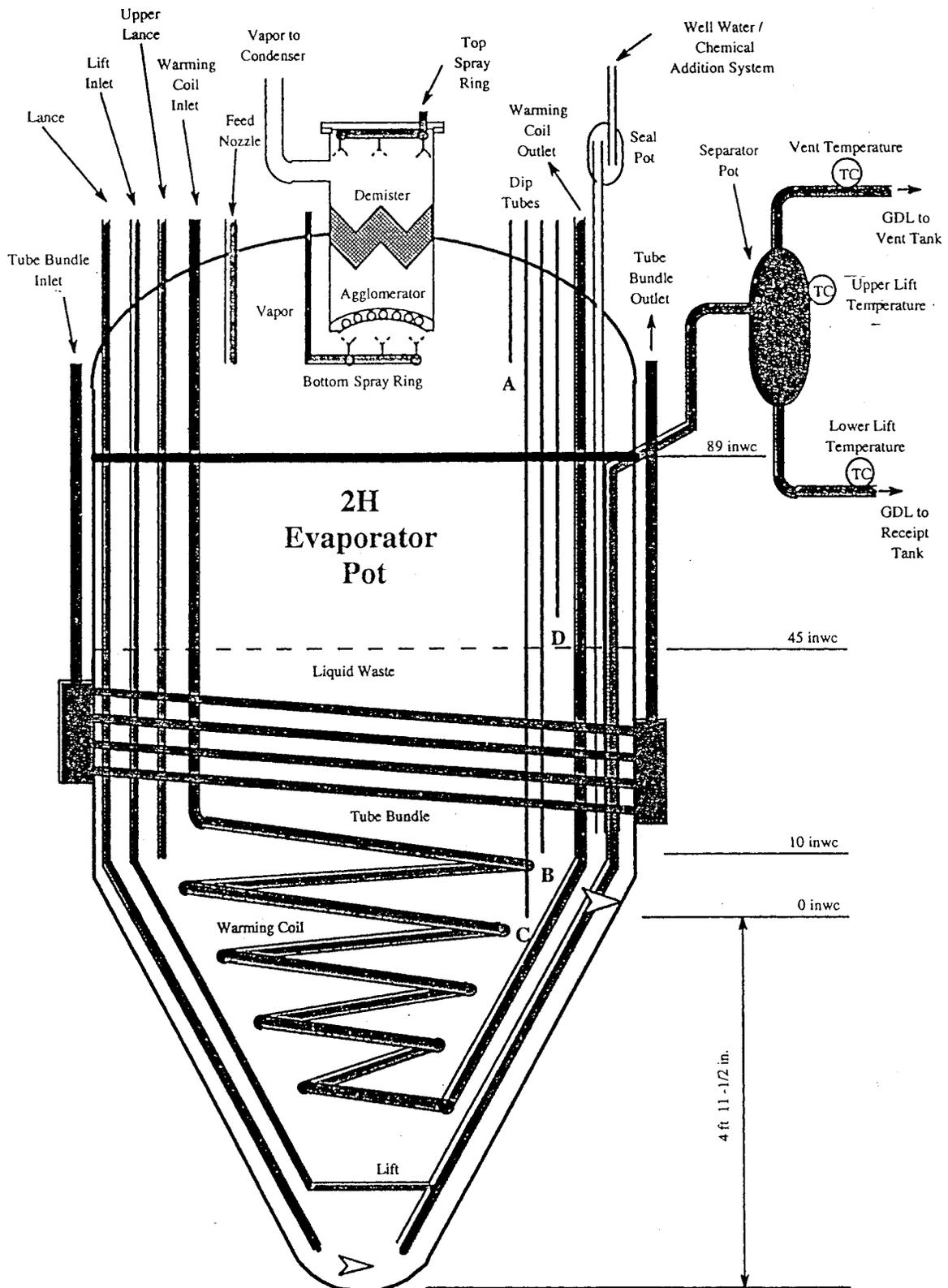


Figure 1. Evaporator Vessel During Normal Operation

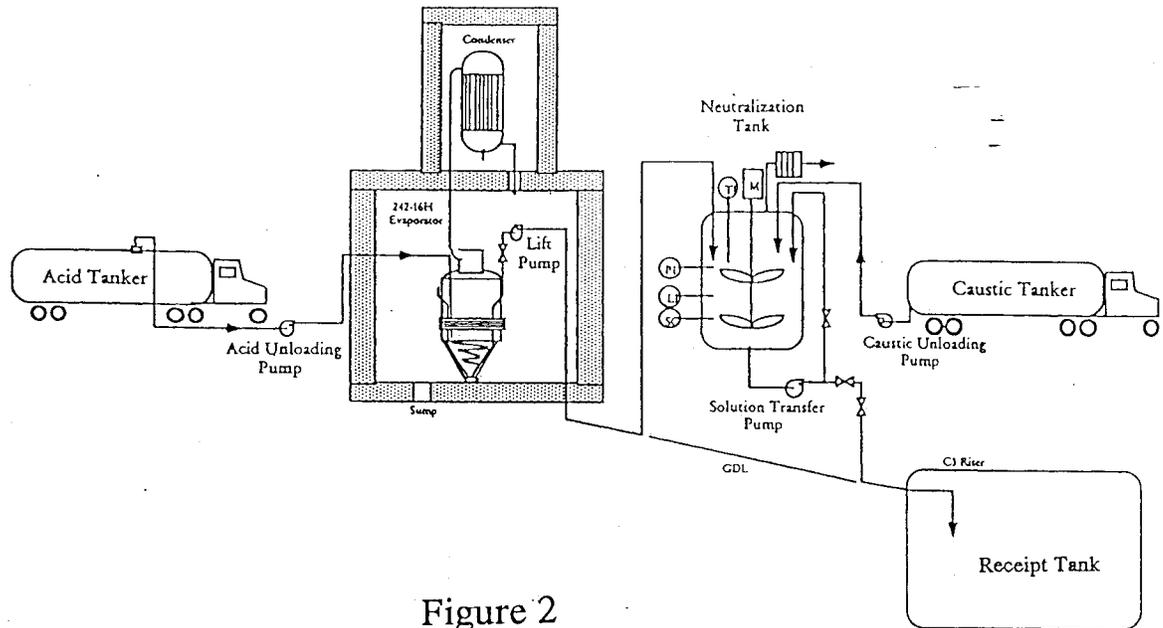


Figure 2

Process Configuration of the System During Chemical Cleaning

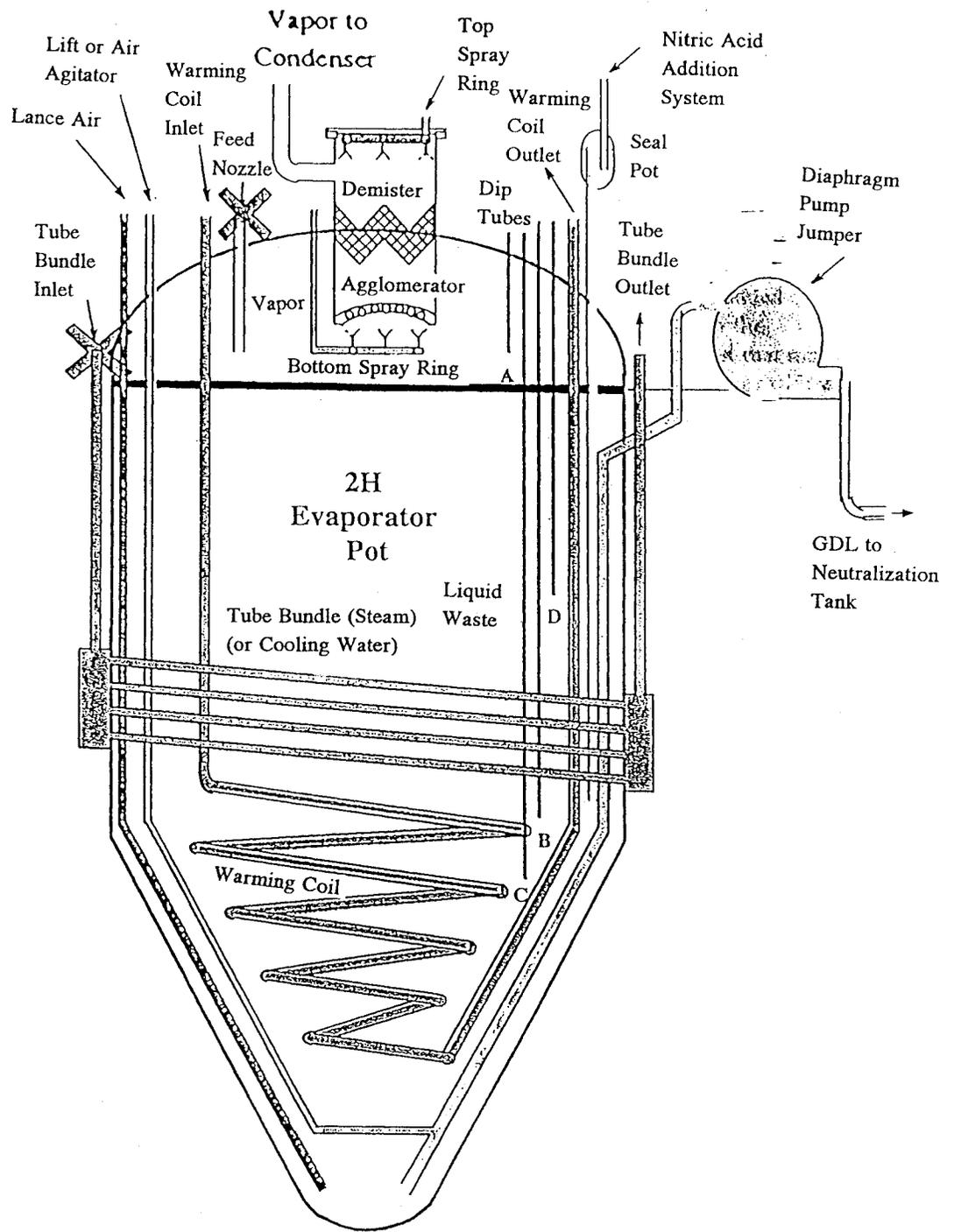


Figure 3

Evaporator Vessel During Heating and Cooling

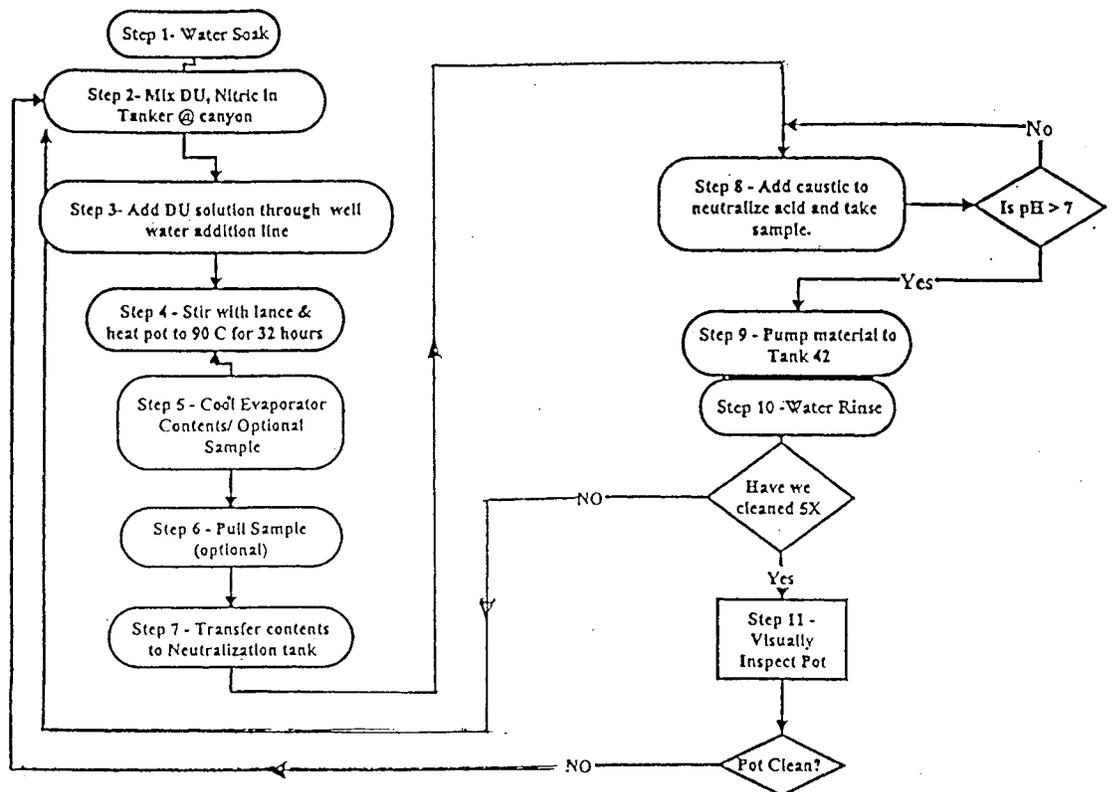


Figure 4
General Steps Needed for a Batch Cleaning of the Evaporator

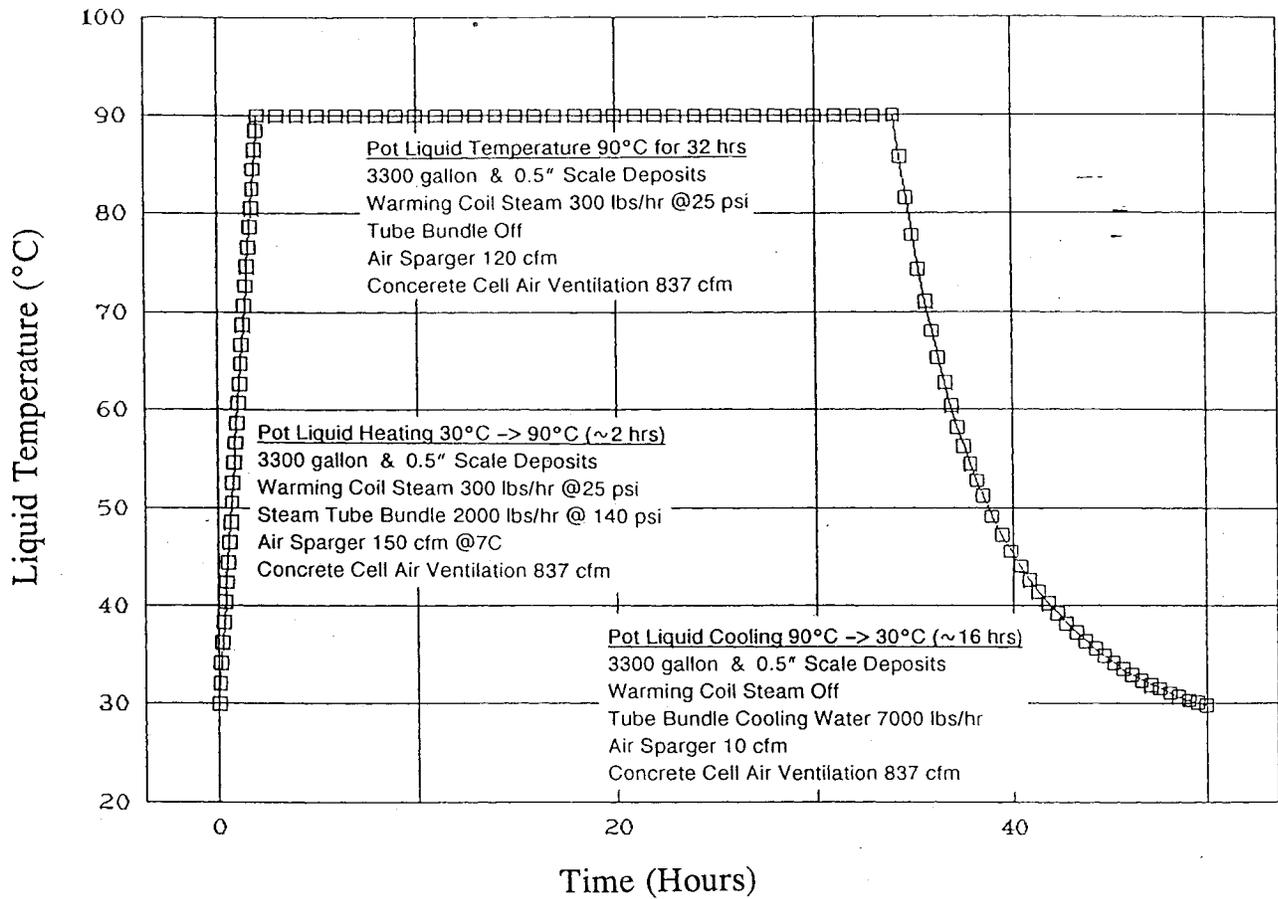


Figure 5
 Evaporator Pot Liquid Temperature Versus Heating & Cooling Time

Table 1

Comparative Heating Analysis and Optimum Heating & Cooling Calculation Results

3000 Gallon Pot Liquid Heating Time from 30C to 90C	
<u>(a) steam heating from tube bundle and warming coil with sparger air</u>	
(Case 1) sparger air, tube bundle steam 2000 lbs/hr -----	2.0 hours (optimum)
(Case 2) sparger air, tube bundle steam 1500 lbs/hr -----	2.5 hours
(Case 3) sparger air, tube bundle steam 1000 lbs/hr -----	3.8 hours
(Case 4) sparger air, tube bundle steam 500 lbs/hr -----	7.2 hours
<u>(b) lance line direct steam injection and warming coil steam heating</u>	
(Case 5) steam lance and warming coil, each 300 lbs/hr -----	9.5 hours
<u>(c) different pressures of warming coil steam heating and air sparger</u>	
(Case 6) sparger air 10 cfm, 140 psig warming coil -----	40.4 hours
(Case 7) sparger air 10 cfm, 85 psig warming coil -----	49.1 hours
(Case 8) sparger air 150 cfm, 140 psig warming coil -----	53.2 hours
(Case 9) sparger air 150 cfm, 85 psig warming coil -----	72.0 hrs
(case 10) sparger air 10 cfm, 25 psig warming coil -----	92.7 hours
(Case 11) sparger air 150 cfm, 25 psig warming coil -----	360 hours
3000 Gallon Pot Liquid Cooling Time from 90C to 30C	
(d) tube bundle cooling water, lance air, ventilation -----	16 hours (optimum)

