First VTE Pilot Plant Report

July 1, 1967

United States Department of the Interior

Office of Saline Water • Research and Development Progress Report No. 367

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First VTE Pilot Plant Report
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By Oak Ridge National Laboratory, Oak Ridge, Tennessee, R. P. Hammond, Program Director for the Office of Saline Water, J. A. Hunter, Director; Everett N. Sieder, Chief, Distillation Division; Paul G. Tomalin, Project Engineer

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FOREWORD

This is one of a continuing series of reports designed to present accounts of progress in saline water conversion and the economics of its application. Such data are expected to contribute to the long-range development of economical processes applicable to low-cost demineralization of sea and other saline water.

Except for minor editing, the data herein are as contained in a report submitted by the contractor. The data and conclusions given in the report are essentially those of the contractor and are not necessarily endorsed by the Department of the Interior.

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VTE PILOT PLANT ANNUAL REPORT FOR THE PERIOD ENDING JULY 1, 1967

John W. Hill

ABSTRACT

A pilot plant consisting of five vertical-tube evaporator effects with auxiliary equipment has been constructed and tested by the Oak Ridge National Laboratory (ORNL) under contract to the Department of the Interior, Office of Saline Water, Distillation Division.

The plant, which could evaporate a maximum of 20,000 gallons of water per day under optimum conditions, has been tested in both the rising-film and falling-film modes of operation using fresh water and sodium chloride solutions over the range of process conditions of interest in seawater evaporators.

Improved heat transfer coefficients have been achieved using evaporator tubes having enhanced (fluted or grooved) surfaces, and operability of the train of effects has been satisfactory. The plant has been disassembled and sent to the Office of Saline Water East Coast Engineering and Development Test Station, Wrightsville Beach, North Carolina, where tests using seawater will be carried out by the Stearns-Roger Corporation under subcontract to ORNL. The plant equipment, test results, and the proposed test program are described. A photograph of the pilot plant is shown in Fig. 1

INTRODUCTION

Background

Earlier research, experimental, and demonstration work done by OSW contractors had indicated that significant improvements in heat transfer coefficients are obtainable in the condensing to boiling regime typical of the vertical tube evaporator.

Tests on single tubes had indicated the most promising surface modifications for enhancing heat transfer.[1,2]

Further study of these surfaces required a flexible test facility in which operating conditions simulating those of a large distillation plant could be attained and in which tests with actual seawater could be performed. The VTE Pilot Plant provides a wide range of test conditions for study of evaporator tube performance.

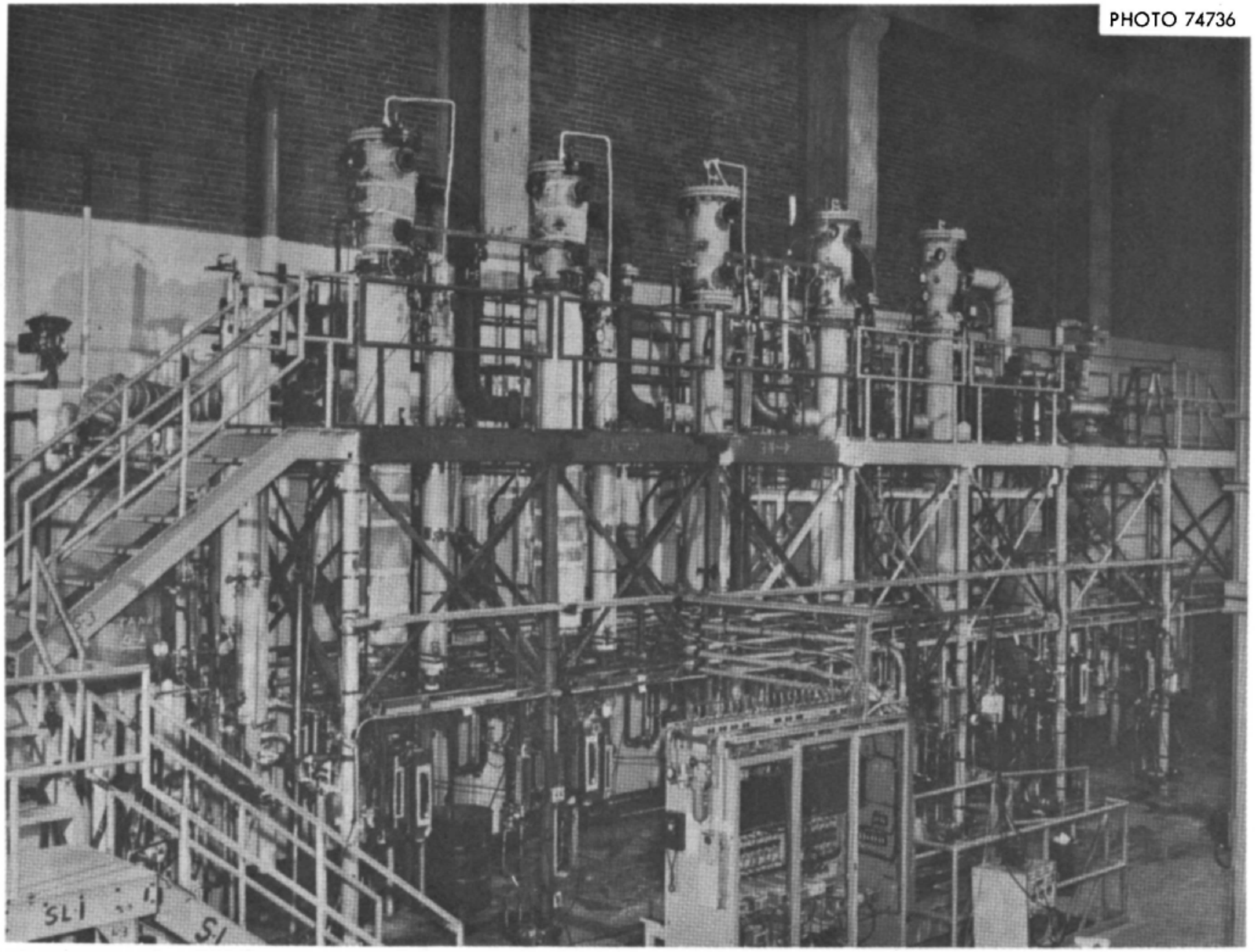


PHOTO 74736

Fig. 1. The Five-Effect Vertical-Tube Evaporator Pilot Plant at ORNL. In this photograph the five effects are piped for upflow operation. Tests were also conducted with three effects in upflow plus two in downflow.

Purpose

The Vertical Tube Evaporator Pilot Plant was designed to be used for the study and definition of operating conditions and processes which can exploit the potential advantages of high performance heat transfer surfaces.

OSW's stated objectives for the pilot plant tests were as follows:

a. To test various proposed multieffect configurations in upflow, downflow, or combination, and/or various feed flow sequences.

b. To develop and test methods of control and regulation of the multieffect process.

c. To test methods of distributing flow to parallel tubes and removing and separating liquid and vapor.

d. To develop process information for design of VTE plants and modules.

DESCRIPTION

Design Basis

The VTE Pilot Plant was designed for testing a variable number of effects, up to five, at operating conditions representative of the high temperature or low temperature ends of a multiple effect evaporator plant.

Each evaporator effect can have up to seven tubes. The tubes are easily removable, and tube sheets can be changed to accommodate tubes of different diameter.

The equipment was designed to permit operation with all effects in upflow or downflow, or operation with a combination of upflow and downflow effects. Changes from one mode of operation to another can be accomplished by interchanging the effect water boxes and piping.

In the initial installation, operating temperature can be varied from 260°F to 120°F, and brine flow rates up to 30 gpm can be accommodated. There will normally be a ΔT of 50 to 75°F across five effects. The evaporator bodies can be operated with brine inlet temperatures to 325°F, but some of the auxiliary equipment (salvaged tanks and condensers) would have to be replaced and an additional brine heater and feed pump would be needed to operate at a 325°F temperature.

Provision was made in the design to permit bypassing up to 5 gpm of feed around an effect. Cooling surface was provided as a part of each steam chest to permit condensation of 100 to 150 lb per hr of water per effect if desired.

Feed brine heating was provided in four shell and tube heat exchangers shown in Fig. 1, 2 and 3 as the final condenser, after-condenser, brine preheater, and final brine heater.

The seawater feed will be treated with sulfuric acid and deaerated to prevent alkaline scale.

The vacuum deaerator was designed to operate at a temperature of 125°F with an inlet flow rate up to 30 gpm.

Auxiliary equipment was sized to handle flow rates as follows:

Brine flow to 15,000 lb/hr (30 gpm)
Brine bypass to 2500 lb/hr (5 gpm) per effect
Tube condensate - 750-3000 lb/hr (1.5-6 gpm)

The instruments are standard, commercially available models. Pressure taps were provided at appropriate points to permit precise pressure measurements by means of absolute and differential pressure manometers. Chromel-alumel thermocouples were used for temperature measurements. Provisions were made for temperatures to be recorded; and connections were provided for reading each thermocouple using a potentiometer.

Level controllers were provided for each effect, the source tank, the mix tank, and the deaerator. The brine inlet temperature and flow rate were also automatically controlled.

The flow diagram for the upflow pilot plant is shown on Fig. 2, 3, and 4 (Drawings EPA44913E, F and G). Equipment layout is shown on Fig. 5, 6, and 7 (Drawings EPA44913H, J and K). An evaporator effect is shown in Fig. 8 and the deaerator is shown in Fig. 9. Typical heat and material balance data are shown in Fig. 10.

Process Description

Upflow Operation

Inlet seawater is preheated, acidified with sulfuric acid, deaerated, and heated to the desired temperature in the feed treatment circuit described

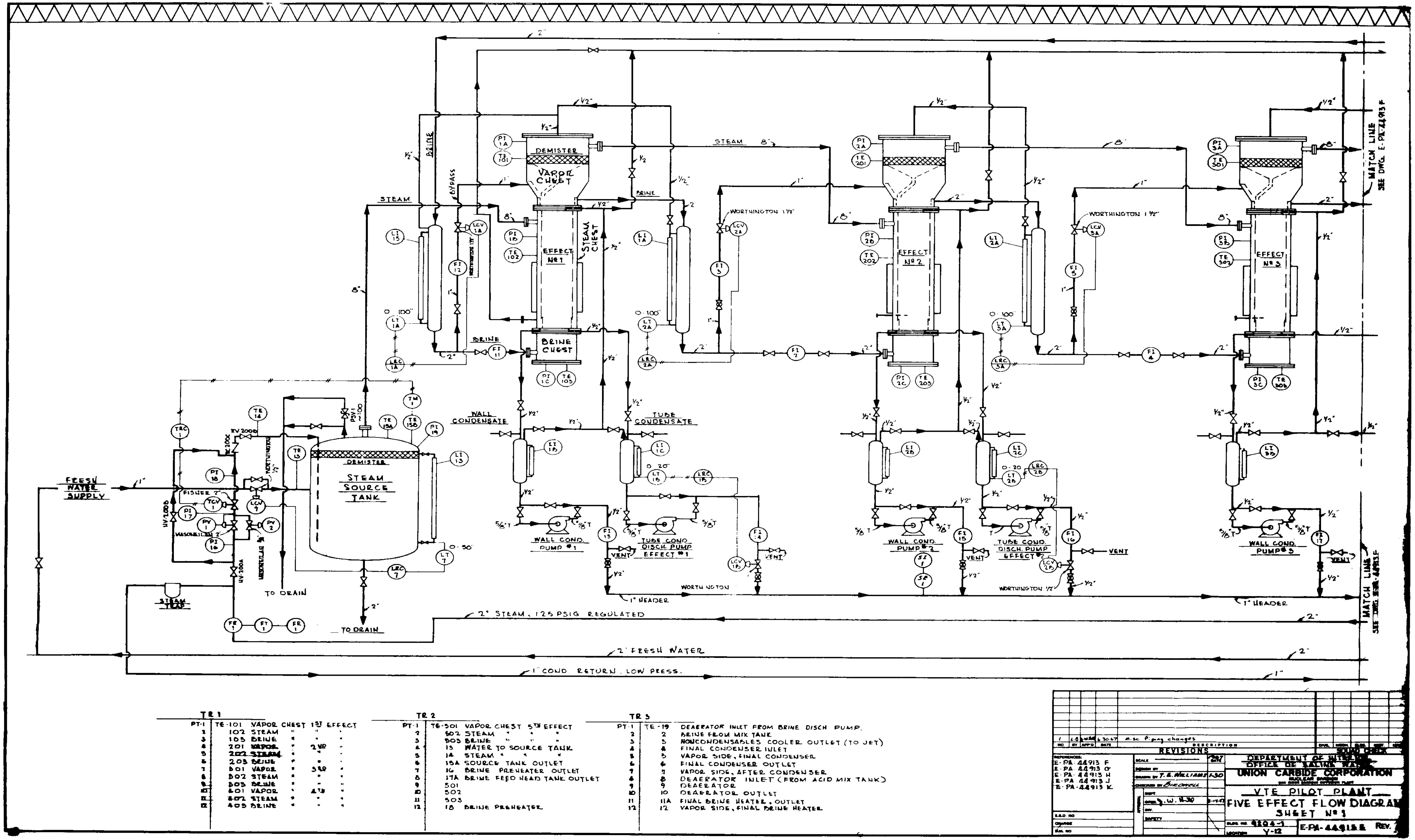


Fig. 2. Five Effect Flow Diagram - Sheet No. 1.

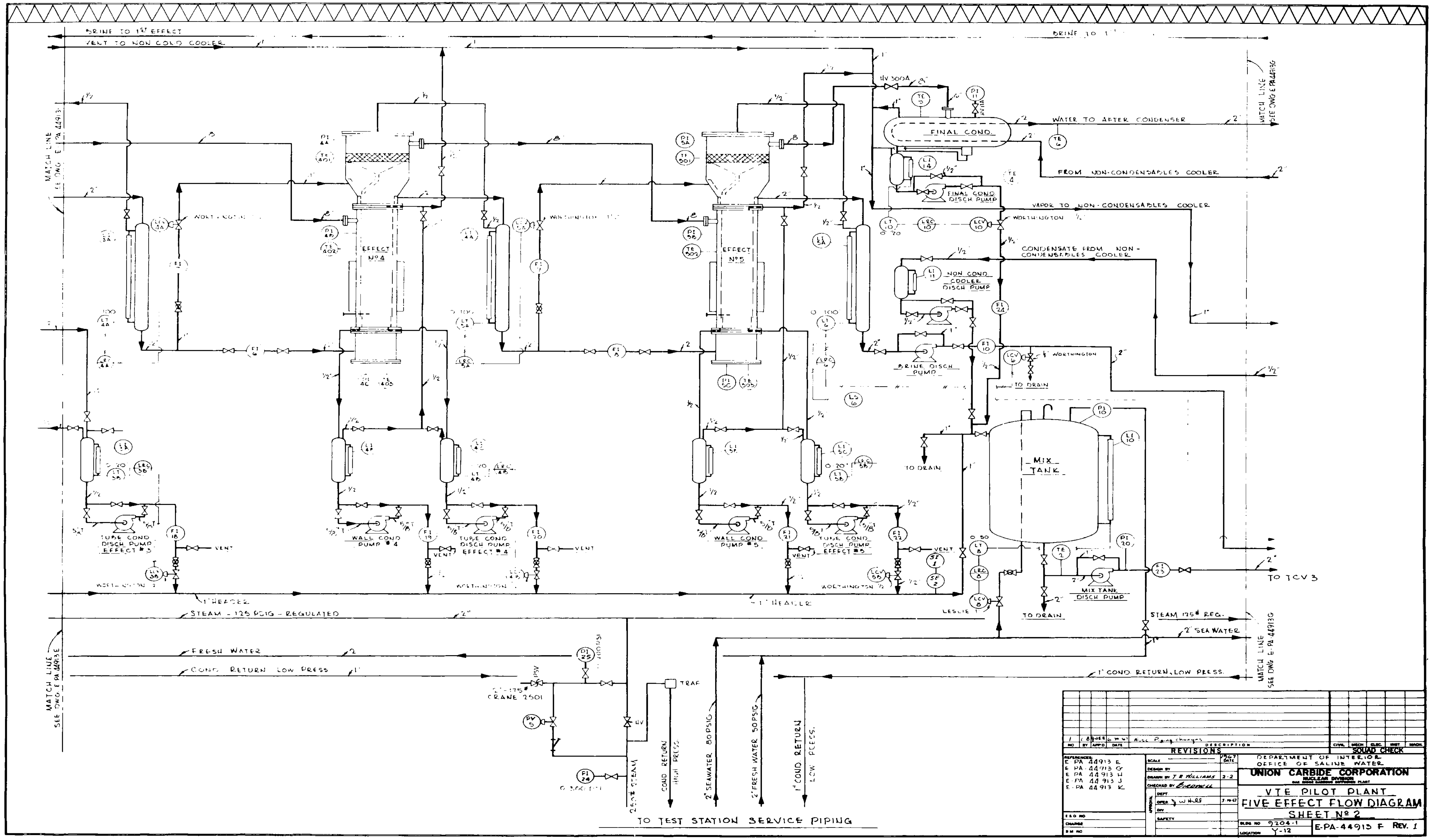


Fig. 3. Five Effect Flow Diagram - Sheet No. 2.

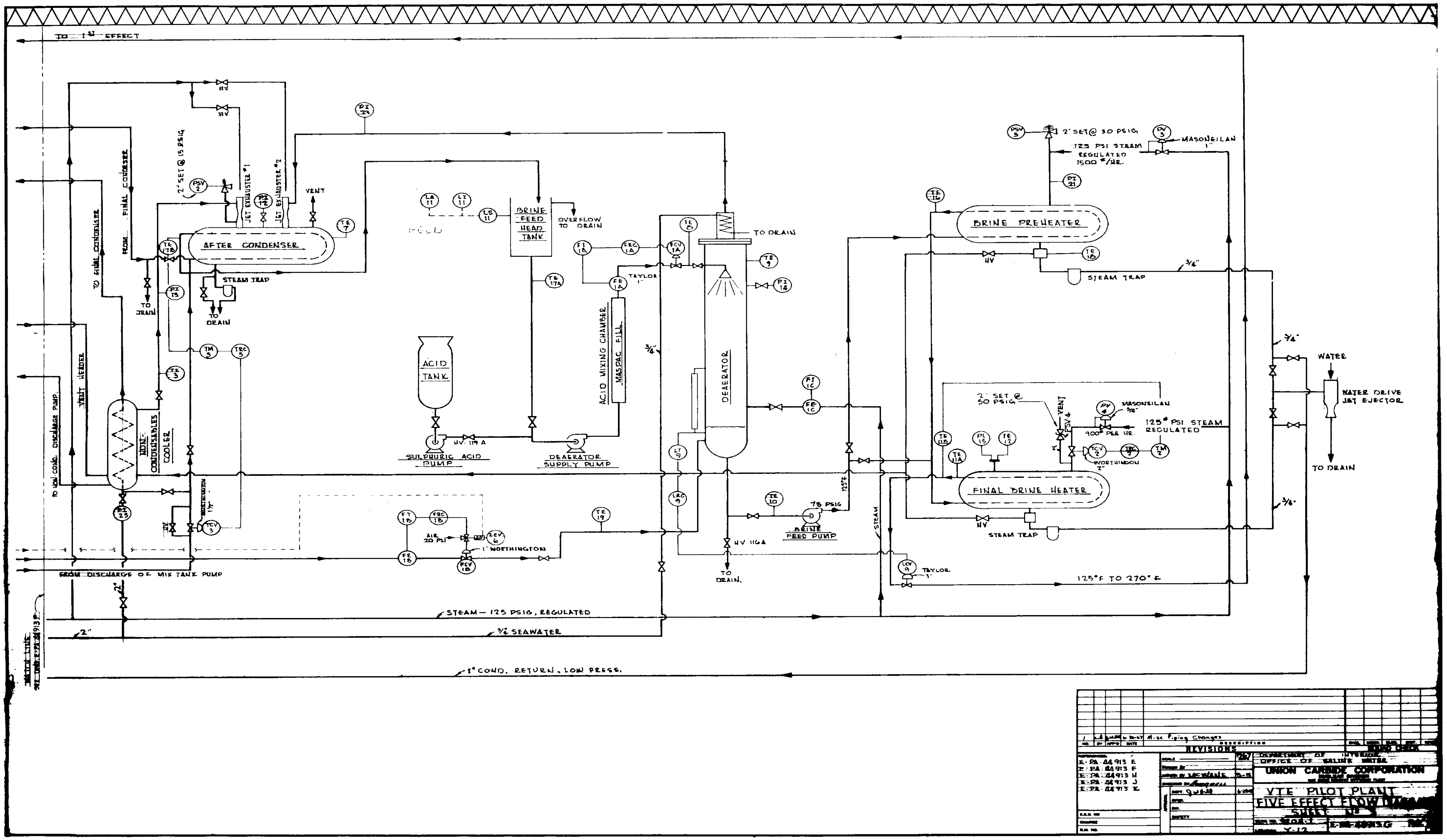


Fig. 4. Five Effect Flow Diagram - Sheet No. 3.

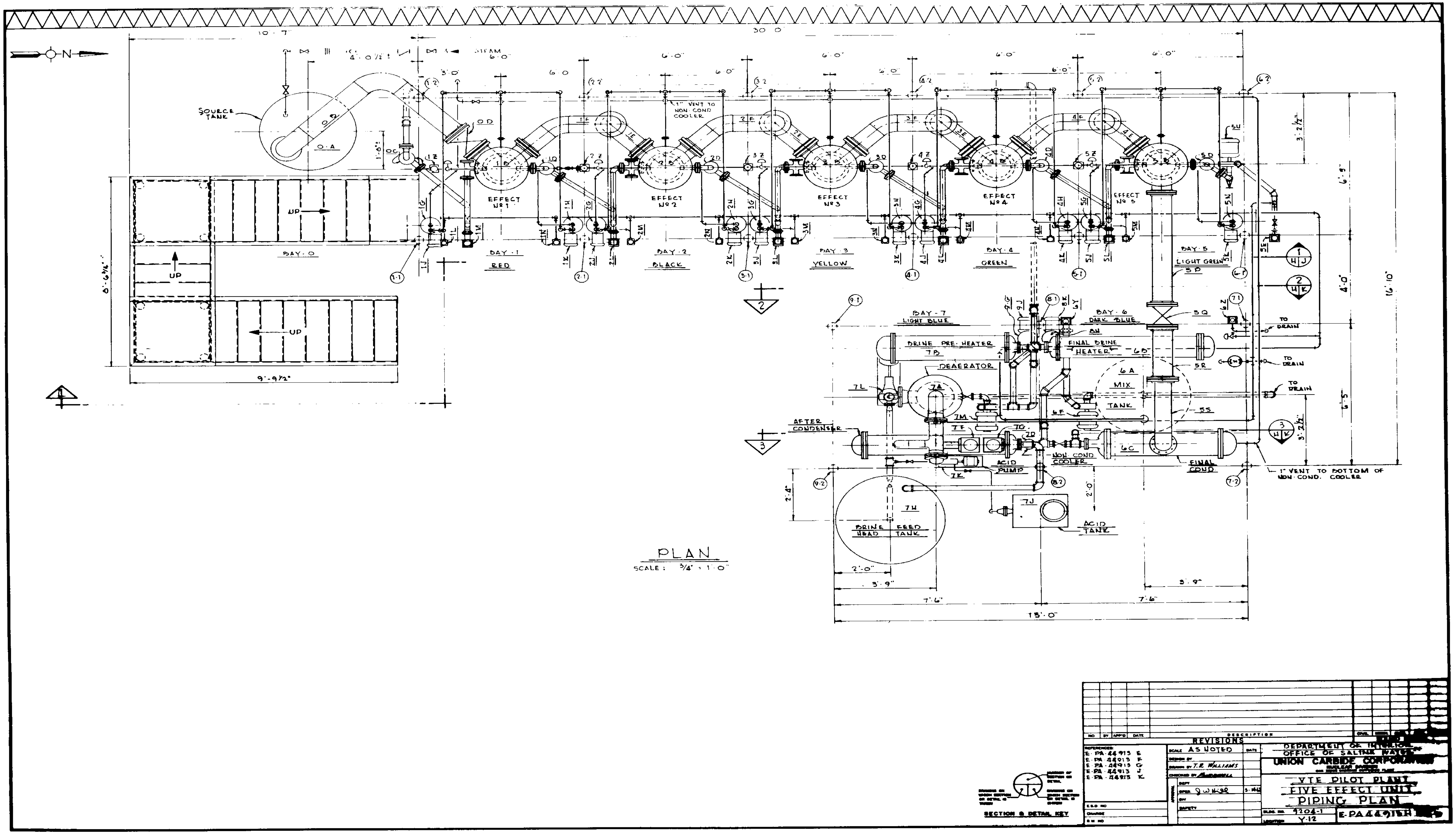


Fig. 5. Five Effect Unit Piping Plan.

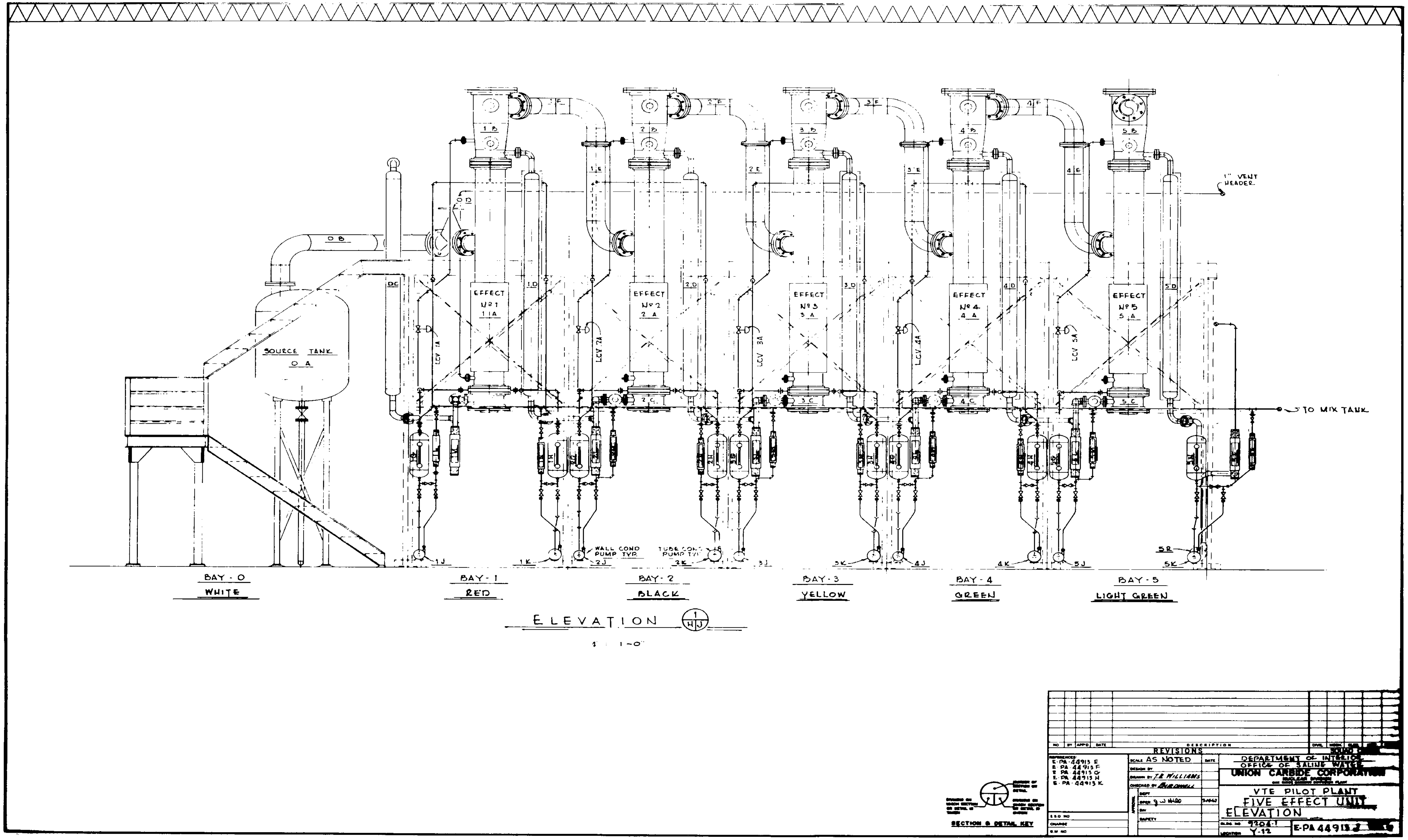


Fig. 6. Five Effect Unit Elevation.

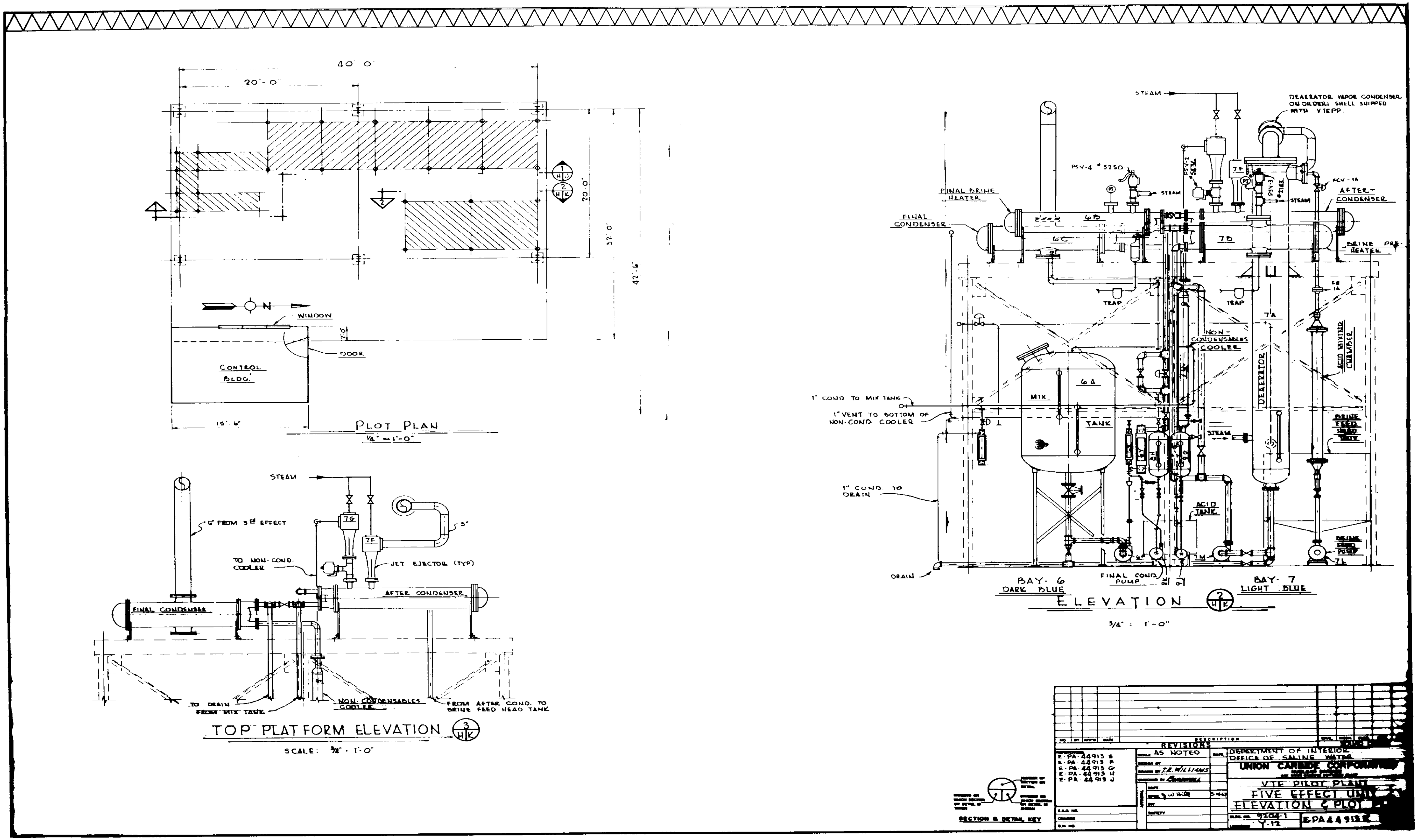


Fig. 7. Five Effect Unit Elevation & Plot Plan.

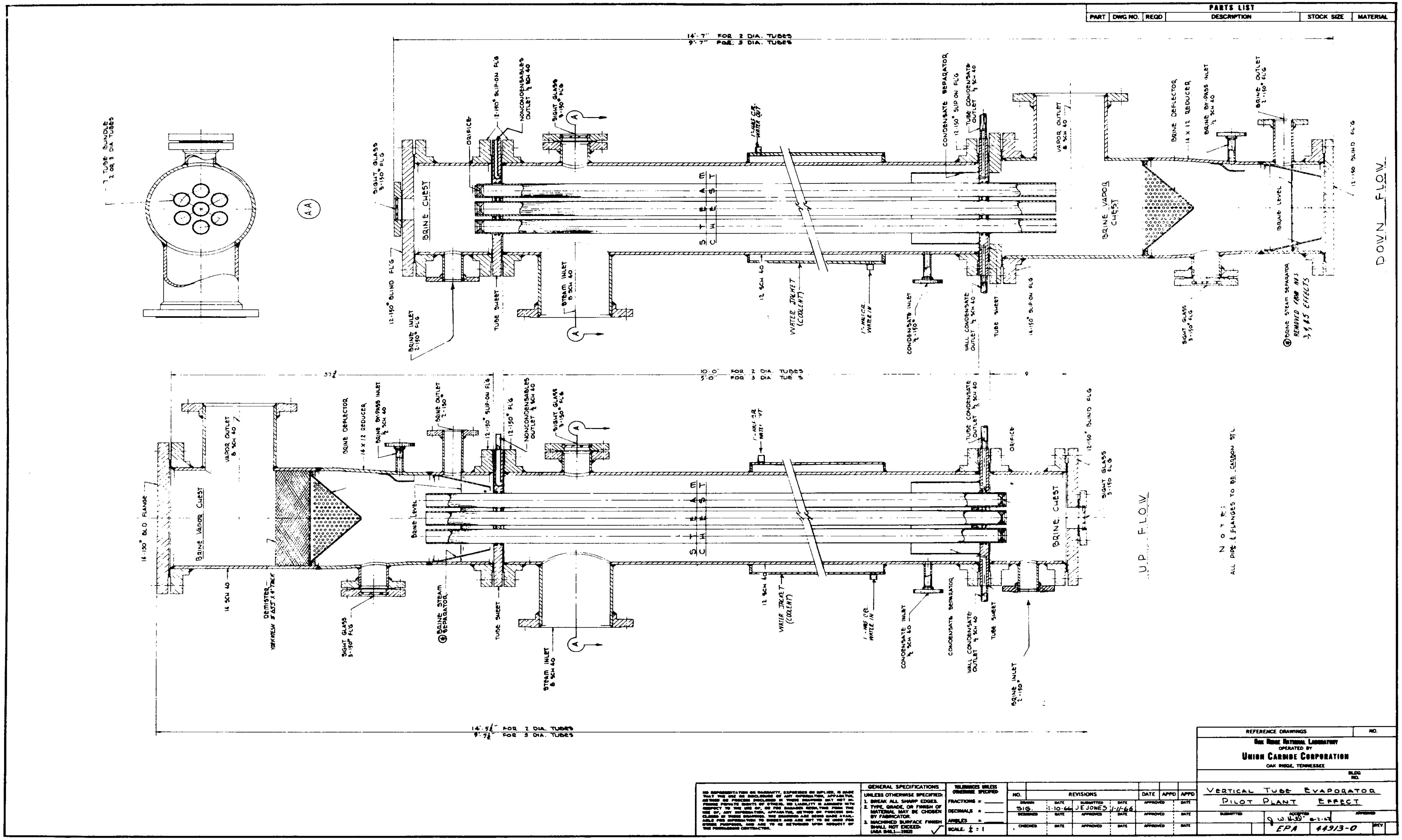


Fig. 8. Vertical Tube Evaporator Pilot Plant Effect.

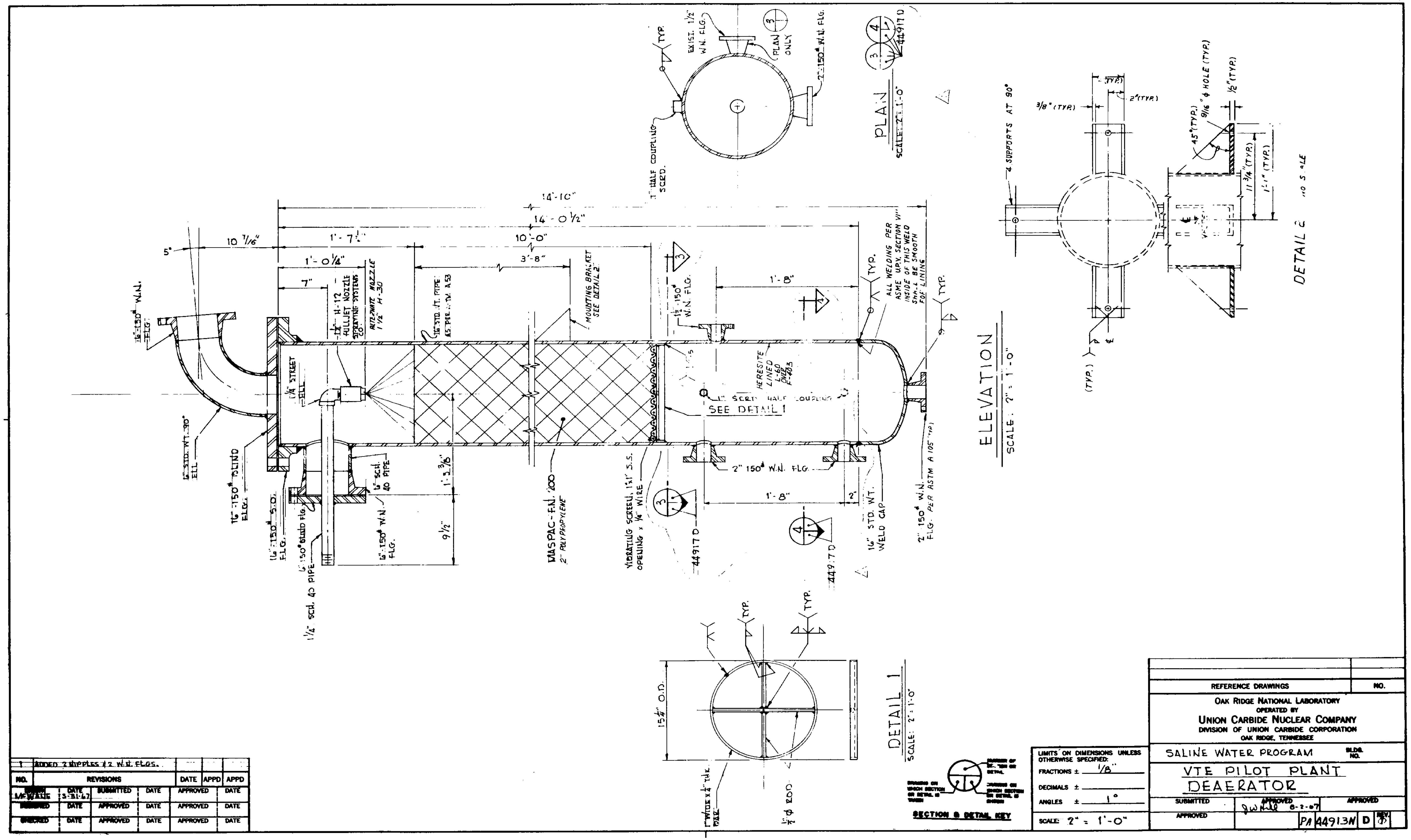


Fig. 9. VTE Pilot Plant Deaerator.

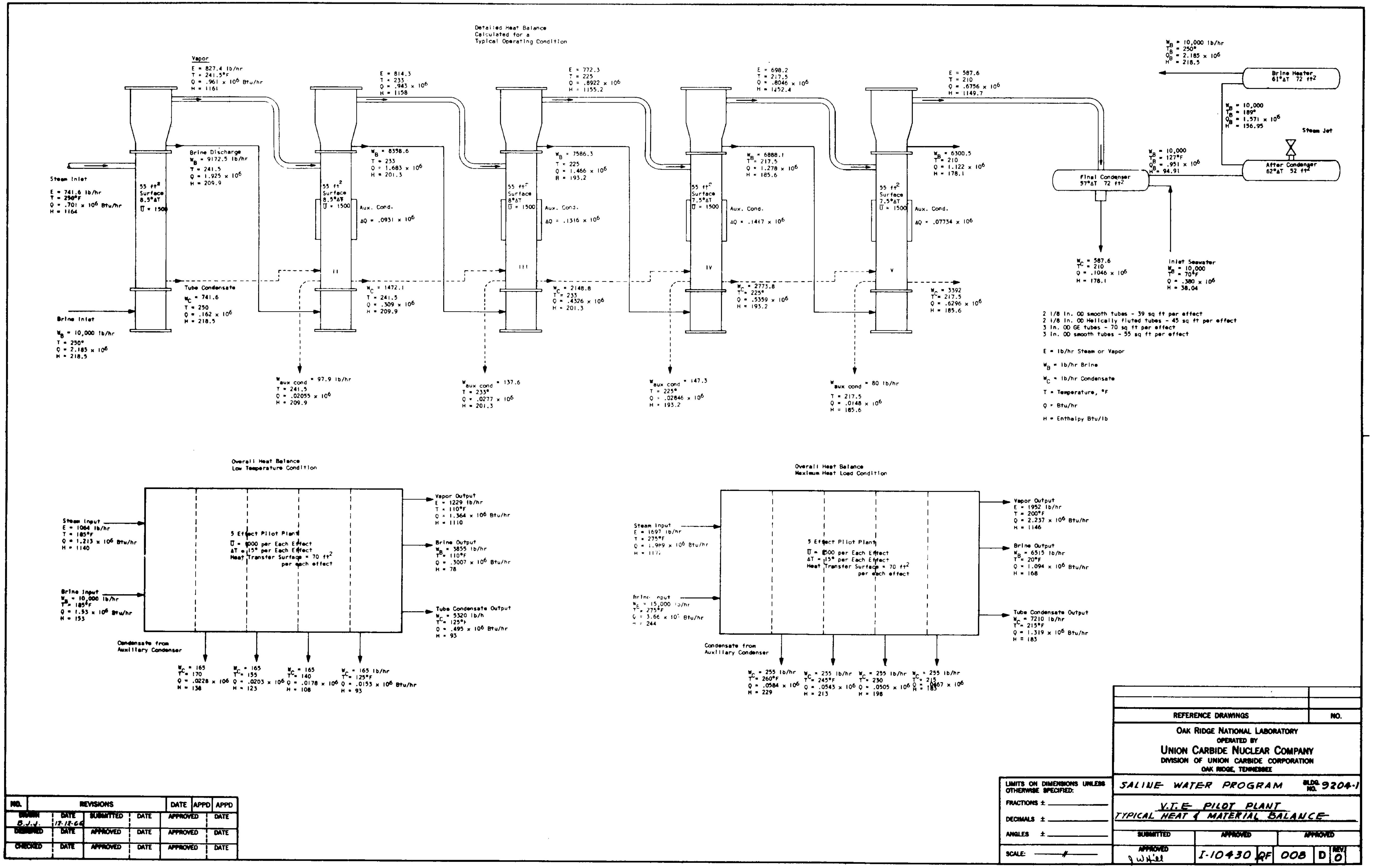


Fig. 10. Typical Heat & Material Balance.

below. Treated brine is fed to the first evaporator brine chest (Fig. 8) at the rate desired for the test. Bypass brine is fed to the vapor chest permitting regulation of the flow rate for succeeding effects.

Steam is provided to the first effect from the test station steam supply through the source tank which serves as a desuperheater.

Brine is fed to the inlet orifice at the bottom of each tube and vapor is generated by heat transfer from steam condensing on the outside of the tube walls. When the feed is superheated, additional vapor forms due to flashing in the inlet orifice. The vapor and brine leaving the evaporator tubes are separated in the vapor chest with the vapor going to the steam chest of the succeeding effect and the brine going to the brine chest of the succeeding effect. A vertical standpipe, equipped with sight glasses permits observation of the brine level preceeding each effect. A liquid level controller is provided for each standpipe to regulate the bypass brine flow automatically. A deflector and a wire mesh demister are mounted above the tubes in each effect. Deflectors of various types can be used at the upper ends of individual tubes to prevent discharge brine from falling back into the tubes.

In each effect, condensate from the outer surfaces of the evaporator tubes drains into a small tank which is equipped with a sight glass and can be used for short-term measurement of the condensate collection rate. Normally, a level controller maintains a constant level in the tank by throttling a control valve at the discharge of the condensate pump for the effect. A rotometer is provided in the condensate pump discharge line for measurement of the flowrate.

The condensate piping is arranged to permit diversion of the pump output through a cooler to a tank for more accurate determination of the collection rate.

Wall condensate resulting from heat lost through the evaporator shell can be collected separately and measured.

Product condensate can be sent to the test station supply tank or discarded to drain.

Each steam chest is vented to the suction of jet No. 1.

Steam from the last effect is condensed in the final condenser. Condensate is collected and measured in equipment identical to that provided for the tube condensate.

Noncondensable gases from the final condenser or individual effects pass through the noncondensable cooler to the suction of jet No. 1.

Downflow Operation

To change to falling film evaporation, the evaporator effects are rearranged as shown in Fig. 8 and the steam and brine pipes are changed accordingly. A pump is provided for each effect to transfer brine to the succeeding effect. The liquid level in each brine chest is controlled automatically using a throttling valve in the discharge line from the pump.

Feed Treatment Circuit

(Reference Flow Diagrams 1, 2, 3 - Figures 2, 3, 4). Brine is taken from the plant supply line into the mix tank which serves to separate the pilot plant from the station system and act as a head tank.

Brine is pumped from the mix tank to the noncondensable cooler, the final condenser, and the after-condenser for preheating, and is then discharged into the brine feed head tank. Flow is controlled by a temperature control valve (TCV-3).

A bypass is provided around the noncondensable cooler and the final condenser, so that these units can be cooled by a separate water system if desirable.

Brine from the feed head tank is acidified with sulfuric acid and pumped through a mixing chamber to the deaerator.

Two interchangeable spray nozzles are furnished for use in the deaerator to permit varying the flow from 30 gpm to 10 gpm without excessive pressure drop.

Brine flow rate to the deaerator is controlled using flow control valve FCV-1A. Brine is pumped from the deaerator through the brine preheater and the final brine heater to the first evaporator effect. Flow to the first effect is controlled with the deaerator level control valve (LCV-9) and the rate should correspond to that set by FCV-1A. A bypass is provided around the preheater. If needed, caustic can be added to the feed stream to adjust the pH.

Steam from the station supply is used in the shells of the heaters to heat the brine. The temperature of the brine leaving the final brine heater is controlled by a temperature control valve (TCV-2) in the steam line to the heater shell. Steam to the brine preheater is controlled with a manual pressure regulator.

If the shells of these heaters are operating at sufficient pressure, condensate is trapped to the test station condensate return line. When the shells are at lower pressures, a water driven ejector is provided to remove the condensate to drain.

Recycle of Brine

The system is arranged to permit recycle of blowdown brine for tests at higher brine concentrations when the five effects are operating as the low temperature portion of a multiple effect plant.

Blowdown brine from the last effect is returned to the deaerator thru flow meter FE1B and flow control valve FCV1B. Excess brine is dumped to drain through level control valve LCV-6 which maintains the level in the vertical stand pipe upstream of the brine discharge pump. The desired amount of fresh makeup brine will be added through the normal path using FDV-1A as control.

In this mode of operation the excess brine required to properly cool the after condenser overflows to drain from the brine feed head tank.

Evaporator Effects.

(Reference Dwg. Figure 8). Each evaporator effect consists of an inlet brine chest, evaporator tubes, a steam chest surrounding the tubes, and a vapor chest for separating product steam from unevaporated brine. All evaporator parts and connections are of carbon steel and are flanged to permit rearrangement into different operating modes. Tubes are sealed to the tube sheets using double rubber "O" ring seals.

Hose clamps (not shown) were installed on each tube (one above the top tube sheet and one below the bottom tube sheet) to insure that the tubes could not slip vertically.

The various evaporator tube and "O" ring sizes used are tabulated on Fig. 11 which shows the hole and ring groove dimensions involved.

The conical deflector is provided to insure that only small amounts of entrained liquid reach the stainless steel (Yorkmesh) demister.

When the pilot plant is piped for upflow operation, the brine inlet pipe to each effect serves as a surge tank. The expanded section of pipe is equipped with a level controller which controls the bypass valve for the effect.

The connection labeled "condensate inlet" was provided to permit flashing of condensate from effect to effect, but it has not been piped for that use. The connections are available for use as additional vent points if desired.

The steam chest are provided with jackets that could be used, if desired, for removal of small amounts of heat such as would be available from flashing condensate. The jackets have not been piped for use in the initial installation, however.

Cylindrical shrouds were provided around the evaporator tubes in the first two effects to distribute the steam. When 3-in.-diam tubes are used, clearances are too small to permit use of the shrouds.

Tubes

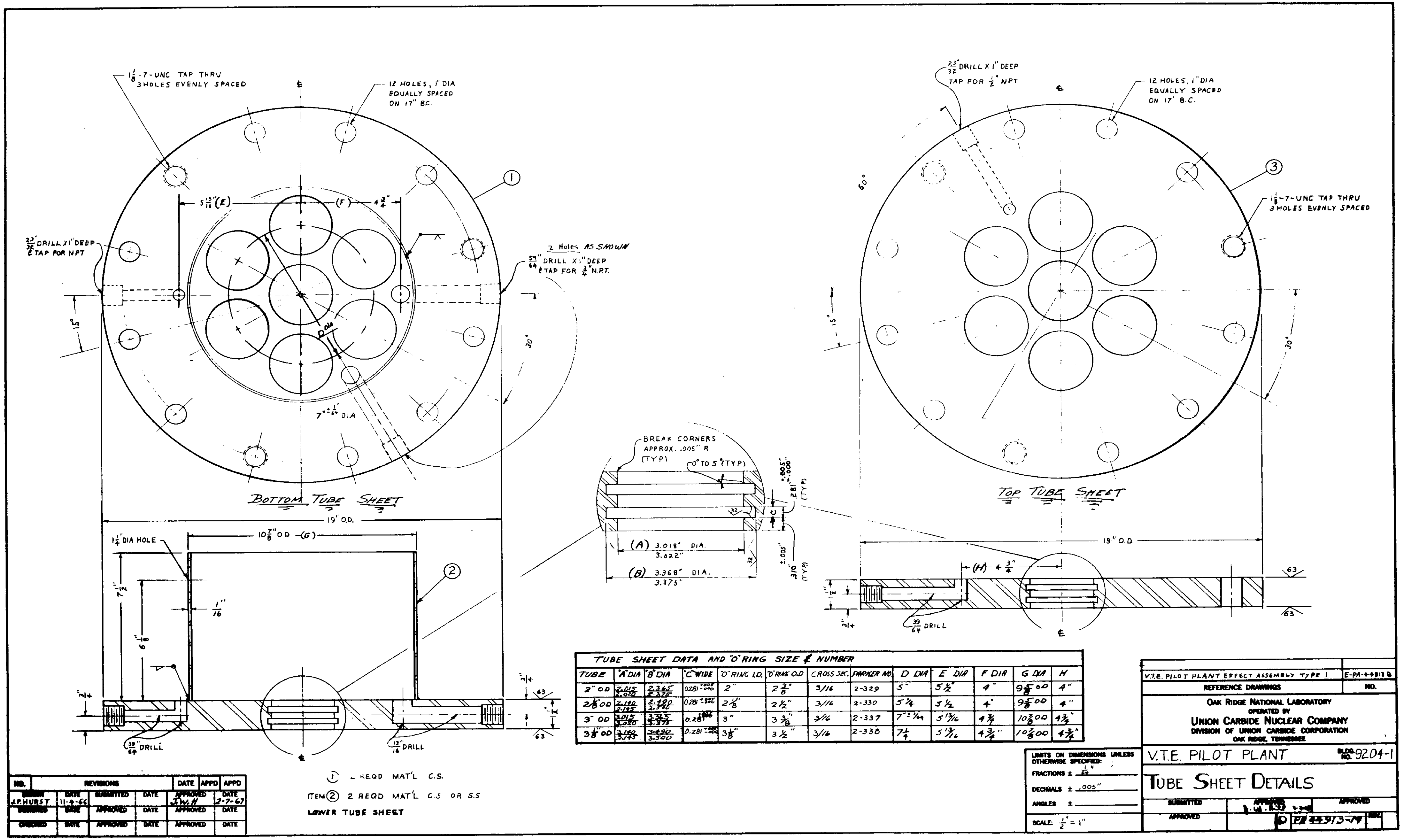
The following types of evaporator tubes were tested at ORNL. All tubes were 11-ft 1-in. in overall length with 4-1/2-in. of smooth wall at one end and 10-1/2-in. of smooth wall at the other end.

1. Smooth walled copper tubes, 2-1/8-in. OD, Type M, with a 0.050-in. wall thickness.
2. Spirally grooved copper tubes, 2-1/8-in. OD, having 24 grooves with an 11-in. lead, and a 0.040-in. wall thickness.
3. GE doubly fluted copper tubes, 3-in. OD, Profile No. 9 with 0.062-in. base wall thickness.

Figure 12 (ORNL Photo 74773) shows sections cut from the above tubes.

The following tubes are being procured for future tests:

1. 90-10 Cu-Ni 2-in. OD; 0.030-in. wall. These tubes are to be spirally grooved.



TUBE SHEET DATA AND "O" RING SIZE & NUMBER												
TUBE	"A" DIA	"B" DIA	"C" WIDE	"O" RING I.D.	"O" RING O.D	CROSS SEC.	PARKER NO	D DIA	E DIA	F DIA	G DIA	H
2" OD	2.015 2.020	2.365 2.375	0.281 +.005 −.000	2"	2⅜"	3/16	2-329	5"	5½"	4"	9⅝ OD	4"
2⅛ OD	2.140 2.145	2.490 2.500	0.281 +.005 −.000	2⅛"	2½"	3/16	2-330	5¼	5½	4"	9⅝ OD	4"
3" OD	3.015 3.020	3.365 3.375	0.281 +.005 −.000	3"	3⅜"	3/16	2-337	7" ± 1/64	5 13/16	4¾	10⅞ OD	4¾"
3⅛" OD	3.140 3.145	3.490 3.500	0.281 +.005 −.000	3⅛"	3½"	3/16	2-338	7¼	5 13/16	4¾"	10⅞ OD	4¾"

NO.	REVISIONS	DATE	APPD	APPD
DRAWN J.P. HURST	DATE 11-4-66	SUBMITTED	DATE	APPROVED J.W.H. DATE 2-7-67
TRACED	DATE	APPROVED	DATE	APPROVED DATE
CHECKED	DATE	APPROVED	DATE	APPROVED DATE

V.T.E. PILOT PLANT EFFECT ASSEMBLY TYPE 1 — E-PA-44913 B

REFERENCE DRAWINGS — NO.

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE NUCLEAR COMPANY
DIVISION OF UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED:
FRACTIONS ± 1/64"
DECIMALS ± .005"
ANGLES ±
SCALE: ½" = 1"

V.T.E. PILOT PLANT — BLDG. NO. 9204-1

TUBE SHEET DETAILS

SUBMITTED — APPROVED — APPROVED
APPROVED
D PE 44913-14 REV.

Fig. 11. Tube Sheet Details.

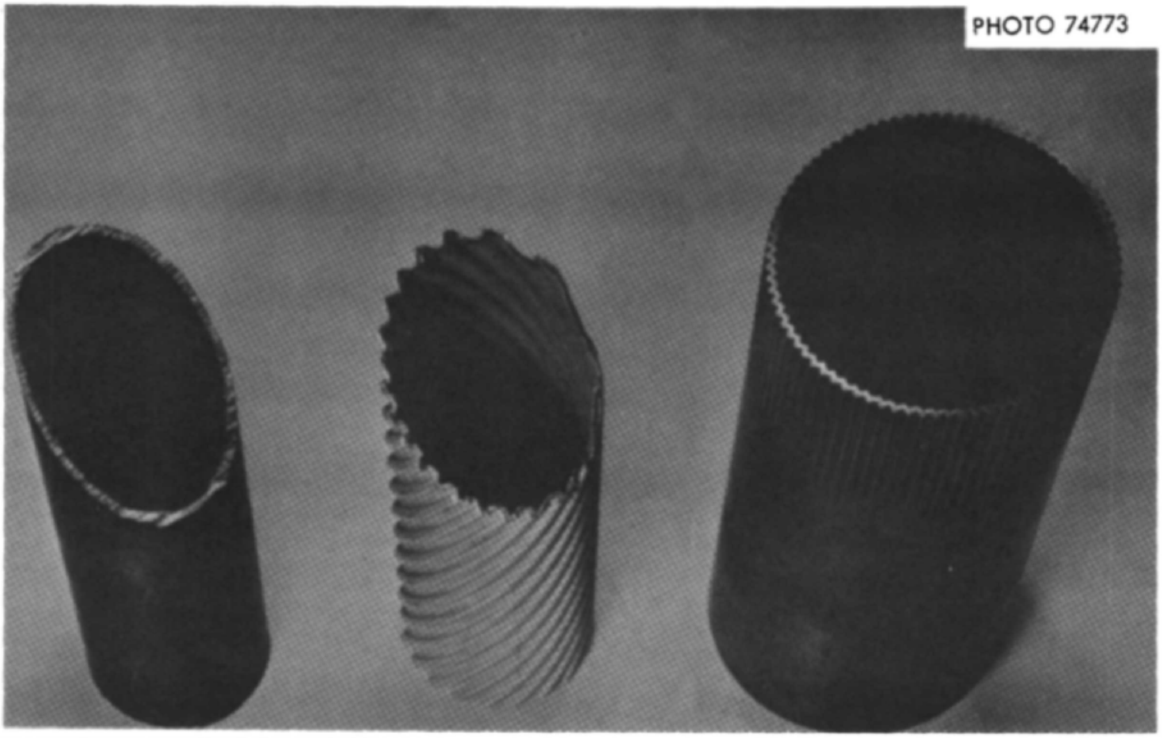


Fig. 12. Sections of Three Evaporator Tubes Tested at ORNL.

2. GE doubly fluted tubes, 3-1/8-in. OD; 0.046-in. wall, made of CDA-194 alloy (base wall thickness - 0.065-in.).

3. Linde tubes - 2-in. OD, 0.050-in. wall, 90-10 Cu-Ni. One tube gold plated on the outside surface and 3 tubes coated with Parylene on the outside surfaces.

Nozzles

Inlet nozzles were used in all tubes in both upflow and downflow operation. In upflow the nozzles provided pressure drop for flashing inlet liquid to steam to assist in establishing a stable flow up the tube, and in some cases the nozzles imparted a swirl to the flowing liquid. Deflectors (90° ells) were attached to the upper ends of some of the tubes to insure that liquid did not fall directly back into the tubes. The combination of spray nozzle and spiral diffuser shown in Fig. 13 was developed in single tube tests by E. C. Hise. A well defined annular flow pattern was generated with liquid spiraling up the fluted wall of the tube. The direction of the inlet swirl of the Sprayco BD 25 nozzle was reversed in order to match the flutes in the tube.

In order to investigate the influence of the inlet flow pattern, the Sprayco nozzles were tested without the spiral diffusers, and also without modification, that is, without reversal of the inlet holes. No deflectors were used at the upper ends of the tubes in these tests.

Simple flat plate orifices were used in further tests of the spiral grooved tubing.

Nozzles used in downflow tests were Schutte-Koerting hollow cone spray (model 1/2 SK 622f), and porcelain spray nozzles (Fig. 13).

Weir-type distributors provided by Stearns-Roger, will be used in tests at Wrightsville Beach.

The Schutte-Koerting and porcelain nozzles have also been used in upflow experiments, and will be tested in the first seawater runs.

Pressure drop vs flow data for the procelain nozzles are given in Fig. 14.

Results from tests using seawater will indicate the tubing and nozzle combinations which give good performance without scale formation and will provide direction for future nozzle choices.

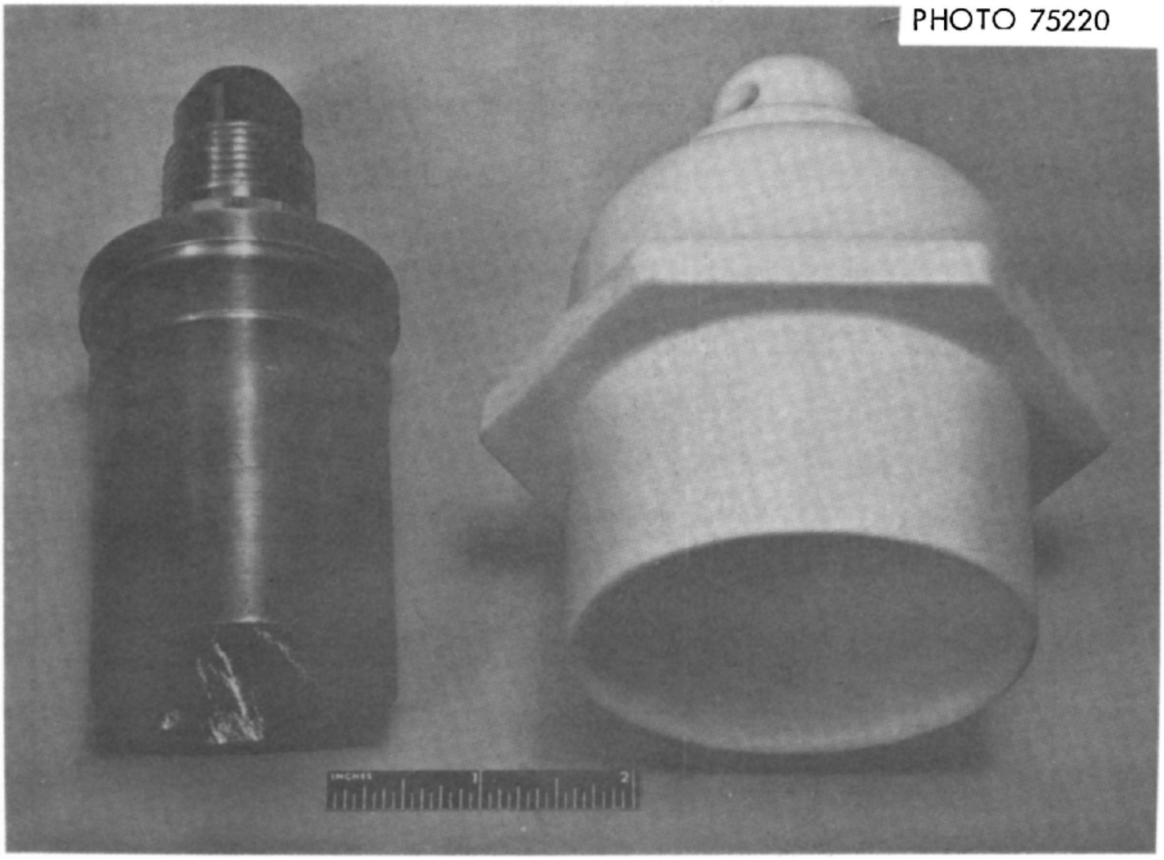


Fig. 13. Spray Nozzle and Spiral Diffuser Developed in Single Tube Tests - at left. Porcelain Spray Nozzle at right.

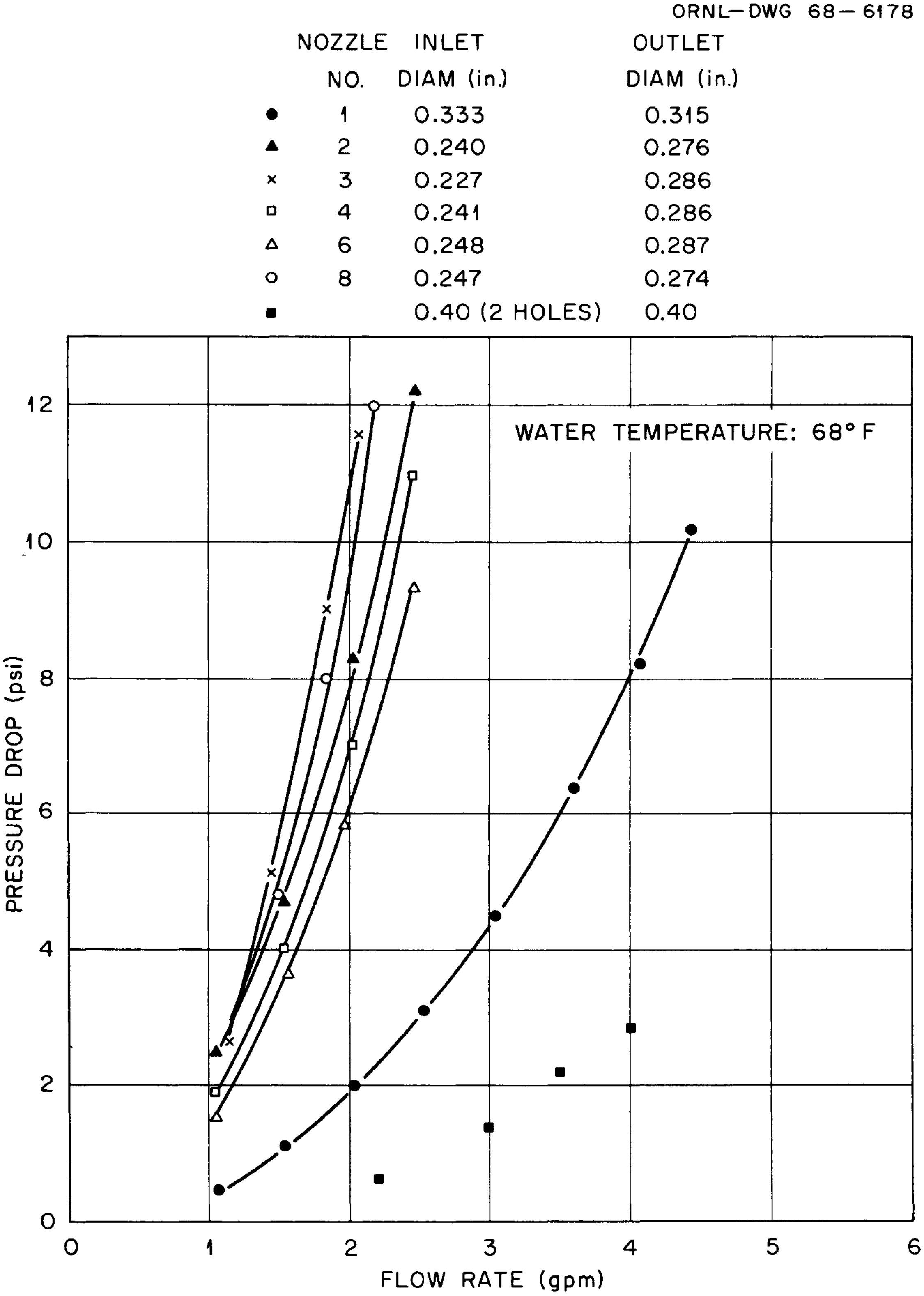


Fig. 14. Pressure Drop vs Flow Rate-Water thru Porcelain Nozzles.

ORNL TEST PROGRAM AND RESULTS

The testing program at ORNL was carried out in four runs each of whic involved a different combination of evaporator effects and tubes as indicated below.

Run 1 – Operation of only two effects using smooth walled copper tubes (2-1/8-in. OD) in upflow configuration.

Run 2 – Operation of two effects using GE doubly fluted copper tubes (3-in. OD) in downflow configuration.

Run 3 – Operation of five effects. Three effects equipped with spirally grooved copper tubes (2-1/8-in. OD) in upflow configuration, and two effects equipped with GE doubly fluted copper tubes (3-in. OD) in downflow configuration.

Run 4 – Operation of five effects. Same as Run 3 except that the two effects containing doubly fluted tubes were repiped to upflow configuration.and only four GE tubes were used per effect.

Purposes for the runs were to shakedown equipment, observe operation of the upflow system, and measure heat-transfer coefficients to insure adequacy of equipment and instruments.

Potable water was used for makeup. Sodium sulfite was added to the water to minimize oxidation of the system since the deaerator and other feed treatment equipment were not installed at ORNL. The feedwater and heating steam for the first effect were mixed together in the source tank to generate saturated steam and provide feedwater at the same temperature. Water discharged from the lowest effect was recycled to the source tank. The O_2 concentration in the feed liquid ranged from 0.5 to 1.0 ppm.

A few tests were run using sodium chloride solutions.

Operating conditions were varied to cover the range of interest, but many times only a single observation was made at a given condition. There was not time to repeat all operating conditions even when plant conditions (inleakage, etc.) were less than optimum.

Brine inlet temperatures ranged from 260°F to 100°F and flow rates up to 20 gpm (total for seven tube units).

With a given set of nozzles in an upflow effect, the brine flow rate was regulated at values which could flow through the effect without excessive level in the brine line from the previous effect.

The temperature difference across the plant was varied by regulating the final condensing temperature and the inlet steam conditions.

The heat-transfer capabilities of the effects determined the temperature differences across individual effects.

Following determination of satisfactory operation for a given set of tubes, measurements were made of the following:

a. brine inlet temperature,

b. steam and vapor temperatures (vapor temperature same as brine temperature at point measured),

c. brine and condensate flow rates,

Overall heat-transfer coefficients were then calculated, based on the steam chest to vapor chest (exit brine) ΔT measured using calibrated thermocouples and the heat-transfer rate derived from the measured condensing rate on the tubes.

A typical test series covered the range of operating variables indicated below.

Brine Inlet Temperature	Brine Flow Rate	Steam Chest to Steam Chest ΔT
260°F	1-2 gpm/tube	6-12°F
200°F	1-3 gpm	6-12°F
150°F	1-3 gpm	10-18°F
120°F	1-3 gpm	10-18°F

In all cases the brine was flashed thru the inlet orifice to the evaporating temperature. There was no intereffect cooling.

It should be noted that the plant was manned on only one shift per day during operating periods. The system was brought to operating conditions, data was taken and the plant was shut down during an 8-hr shift.

The importance of reducing air inleakage was evident in each run. Poor performance was noted for heat transfer surfaces and pumps when air was leaking into the system. It was necessary to tighten flanges and other connectors several times since test runs involved daily thermal cycling.

Run 1

Two effects were used with the piping arranged for upflow operation. Operation with this arrangement began November 30, 1966 and was completed December 22, 1966.

Each effect was equipped with seven smooth copper tubes (2-1/8 in. OD, 0.058-in. wall thickness, Type M) with 10 ft of heated length. The tubes in the second effect were plated on the outside with a 0.0003-in. thickness of nickel-phosphorus. Copper tubes were used because of availability and the promising results obtained in single tube tests when operating with dropwise condensation on the tubes.

Inlet orifices for the tubes in both effects were flat plates with 0.187-in. diam holes for flow rates above ~ 1.3 gpm per tube. An orifice hole size of 0.128-in. diam was used for flow rates below 1.3 gpm per tube. All tests in this series were made using plain water.

For Effect 1, feed rates were between 0.7 and 2.1 gpm per tube, and temperature differences varied from 8.5 to 15.5°F. For Effect 2, feed rates varied from 1.0 to 2.0 gpm per tube, and temperature differences varied from 8 to 22°F. In all cases, overall heat-transfer coefficients were based on steam chest to vapor chest temperature differences measured using calibrated thermocouples.

The data points recorded are presented in Fig. 15 as apparent overall heat-transfer coefficients versus evaporating brine temperature. The wide spread of points reflects the varied combinations of flow, inlet temperature, and temperature difference observed during the run. The primary purpose of the run was to demonstrate operability of equipment and time was not available to take sufficient data to separate the effects of the different variables.

The four highest values shown in Fig. 15 were observed after a solution of montan wax in carbon tetrachloride was added to the steam chest of the first effect in an effort to promote dropwise condensation on the tubes.

The nickel-phosphorus coating did not provide any lasting enhancement of dropwise condensation.

All operation was under manual control.

Run 2

Two effects were used with the piping arranged for downflow operation.

Operation in this mode extended from January 10, 1967 to February 22, 1967.

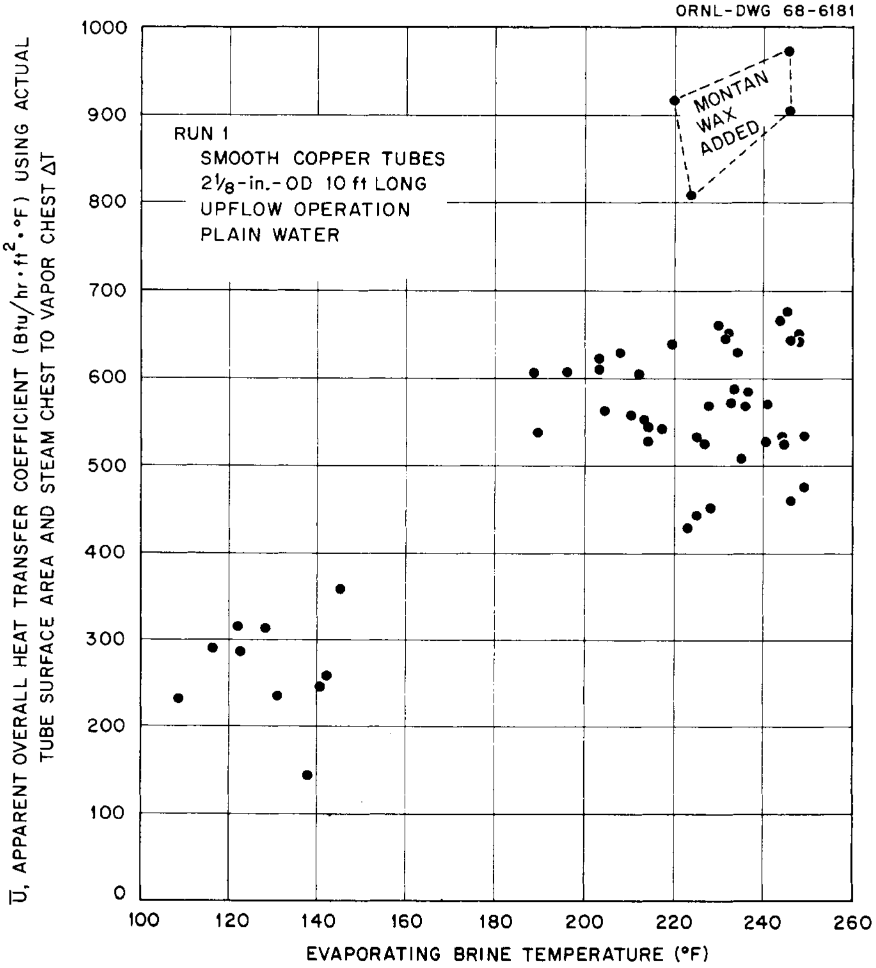


Fig. 15. VTE Pilot Plant Heat Transfer Data.

Each effect was equipped with seven GE doubly fluted tubes made of copper, Profile No. 9, 3-in. OD, 0.062-in. base wall thickness, and a heated length of 10 ft.

Inlet nozzles for the tubes were Schutte-Koerting, Model 1/2SK622F, made of stainless steel.

All tests in this run were made using plain water. Flow rates were varied from 1.3-2.4 gpm per tube with steam chest to vapor chest ΔT of 5.5 to 14°F. All temperatures were measured using calibrated chromel-alumel thermocouples and the results obtained are combined with GE tube data from Runs 3 and 4 and shown in Fig. 16.

These data are tabulated in the Appendix.

Again, all operation was under manual control.

It is not possible to operate the effects satisfactorily at low temperatures during this run due to excessive pressure drop in the steam chests. The shrouds around the tubes were too close to the chest wall. These shrouds were removed from the effects.

Run 3

Five evaporator effects were used during this run with the first three effects in upflow operation and the last two effects in downflow. Operation began April 3, 1967 and continued to May 4, 1967.

The evaporator tubes and nozzles used are described below:

> Effect 1 contained seven spirally grooved tubes, 2-1/8-in. OD, 10 ft long, made of copper having 0.040-in. wall thickness. These tubes have 24 spiral grooves with a lead of 11-in. Spray nozzles (Sprayco BD-25) with spiral diffusers were soldered to the tubes and deflectors were attached to the tops of the tubes.
>
> Effect 2 contained seven spirally grooved copper tubes with the same nozzles as above, except that no spiral diffusers were used.
>
> Effect 3 contained seven spirally grooved copper tubes fitted with flat-plate-inlet orifices at the lower ends of the tubes and deflectors at the upper ends. The orifice hole size was 0.187 inches in diameter.

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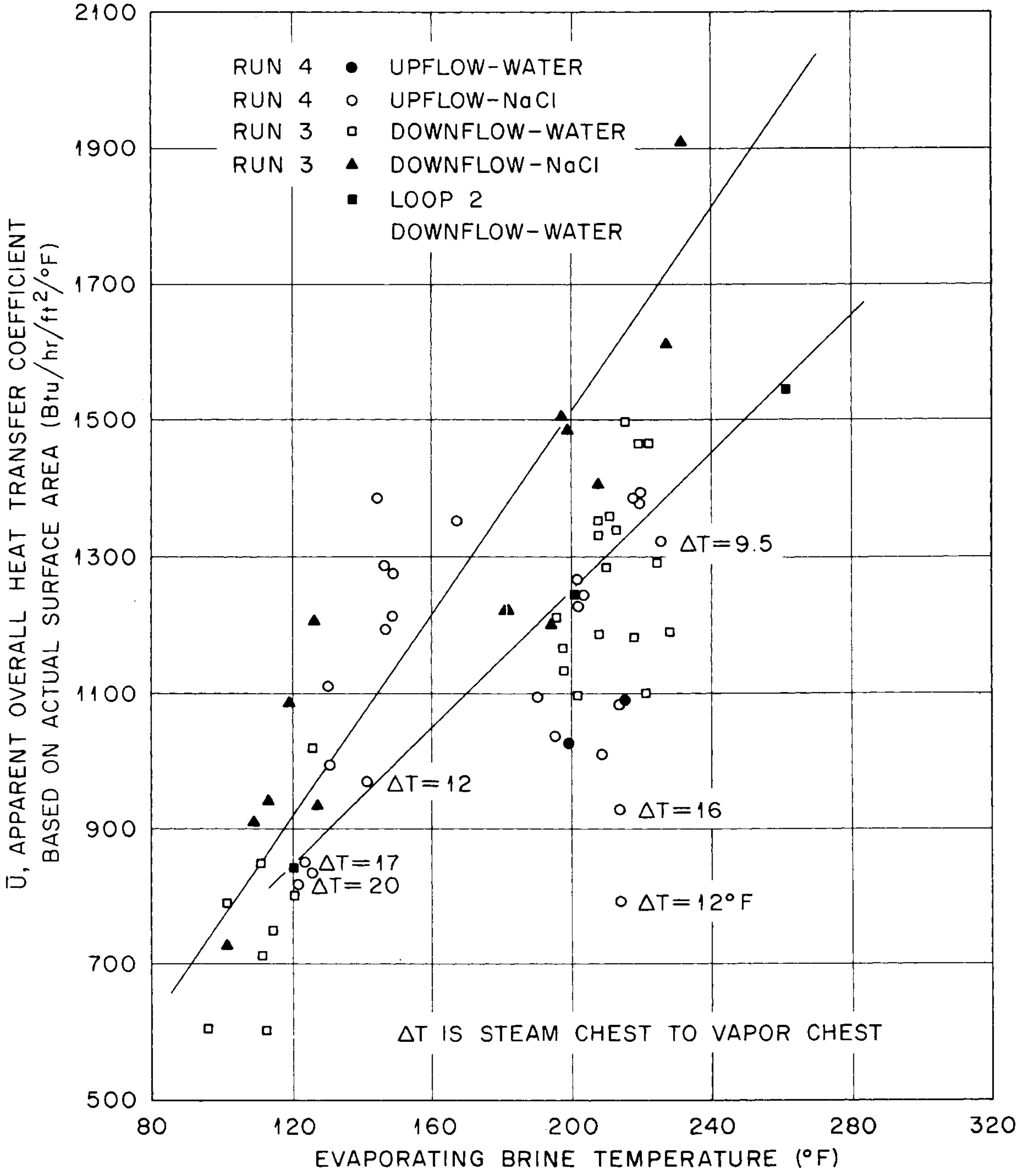

Fig. 16. VTE Pilot Plant - GE doubly fluted tubes.

Effect 4, for runs 3-1 thru 3-16, contained seven GE doubly fluted tubes made of copper, with GE Profile No. 9 fluting. The tubes were 3-in. OD, with a 0.062-in. base wall thickness, and a heated length of 10 ft. Schutte-Koerting nozzles, Model 1/2SK622F, made of stainless steel, were used.

Effect 4, for runs 3-17 thru 3-21, contained four GE doubly-fluted tubes of the type described above, and used porcelain nozzles (ref. Knox Porcelain Dwg. M33647) having 0.25-in. diam inlet holes.

Effect 5 contained seven GE doubly fluted tubes made of copper, shaped according to GE Profile No. 9. The tubes were 3-in. OD, with a 0.062-in. base wall thickness, and a heated length of 10 ft.

Schutte-Koerting nozzles, Model 1/2SK622F, made of stainless steel, were used.

Level controllers were placed in service for the source tank, mix tank and each evaporator effect during this run.

Data from spirally grooved tubes tested in Runs 3 and 4 were combined and are presented in Fig. 17.

Data from GE fluted tubes in Runs 2, 3, and 4 are presented in Fig. 16. All of the data are tabulated in Appendix I.

Run 4

The evaporator tubes and nozzles in Effects 1 and 2 were the same ones listed for Run 3. Effect 3 had the same seven spirally corrugated tubes but the nozzles were Sprayco BD-25. Effects 4 and 5 each had four GE doubly fluted tubes (3-in. OD). Effect four was equipped with porcelain nozzles and Effect 5 was equipped with SK1/2622F nozzles. All five effects were piped for upflow. The porcelain nozzles used in Effect 4 were removed during part of the run so that the inlet holes could be enlarged from 0.25-in. diam to 0.4-in. diam. A second tangential inlet hole was added at the same time. Heat transfer data are presented in Figs. 16 and 17. All of the data are tabulated in the Appendix.

CONCLUSIONS

It has been demonstrated that the plant can be operated stably in both upflow and downflow modes to acquire adequate heat transfer data for evaluation of evaporator tubes and nozzles for vertical tube evaporators.

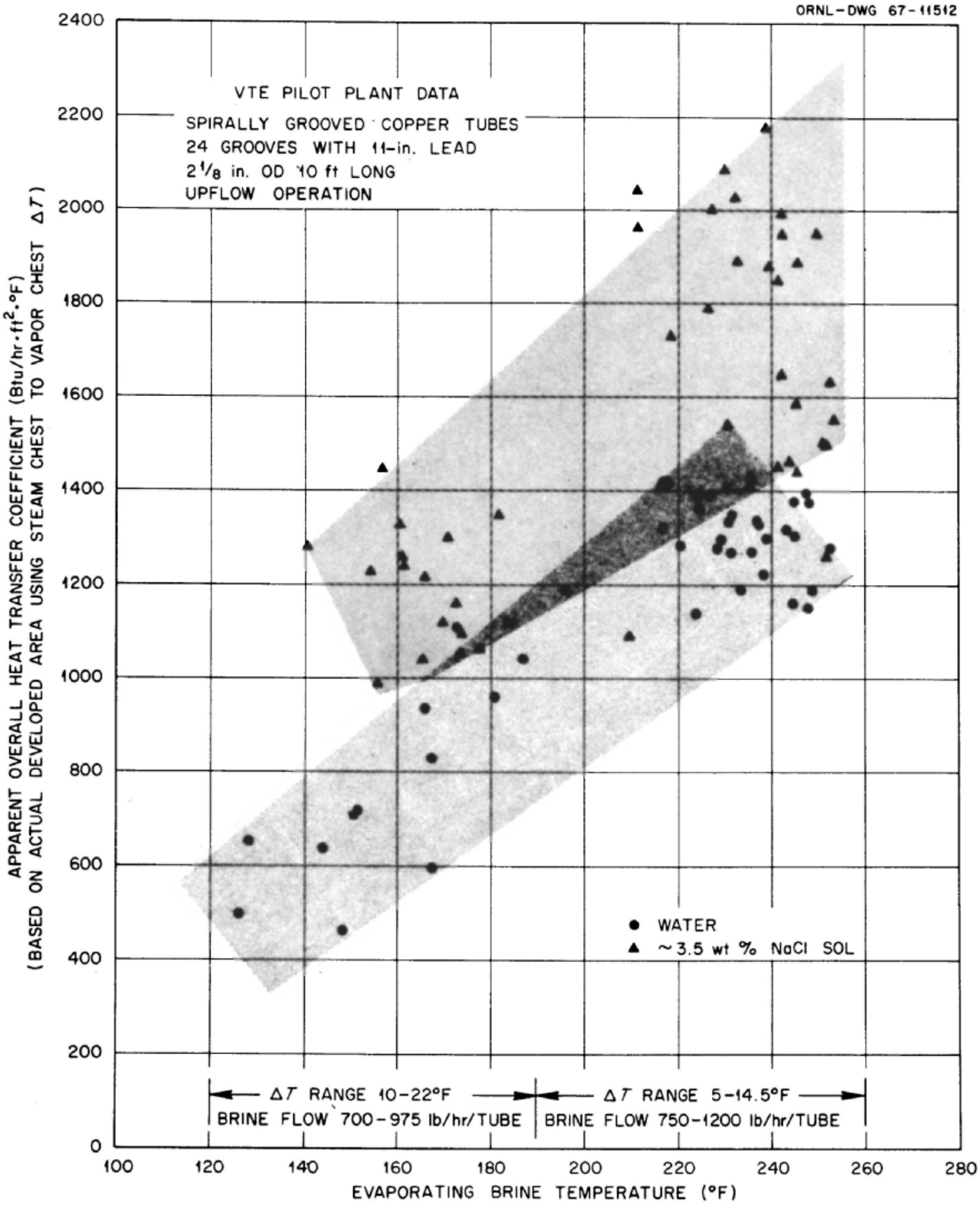

Fig. 17. Runs 3 and 4 - Spirally Grooved Copper Tubes 24 Grooves with 11-in. Lead 2-1/8-in. OD, 10 ft Long Upflow Operation.

With enhanced evaporator tubes, heat transfer coefficients can be attained which are at least two times as high as these previously observed with smooth tubes.

Operation of the plant requires an operator in attendance to monitor controls for the process variables and take data.

Following initial operation using seawater additional instrumentation and controls will be provided as required by program objectives.

TEST PROGRAM FOR WRIGHTSVILLE BEACH

Scope

The primary emphasis will be demonstration of satisfactory operation of the evaporator effects using seawater, and collecting and analyzing operating data to verify improved heat transfer coefficients.

During the first six months of test operation, it is proposed to investigate performance of the five-effect pilot plant in upflow to determine optimum brine flow rates, nozzle types and sizes, and effect temperature differences. It is planned to test at least three tube types: 2-in.-OD apirally-grooved, 3-in.-OD double-fluted (GE), and 2-in.-OD Linde surface tubes treated on the outer surface with Parylene to promote dropwise condensation. The effects will be operated over a range of temperatures so that brine will be evaporated at 260°F maximum, 110°F minimum.

It is expected that operation will be on the basis of three shifts per day, five days per week. Initial operation will require an operator on each shift with assistance on the 8-4 shift in taking data. A goal of the test operation will be to improve the controls to the point that un-attended operation is possible except for data taking.

Following completion of the upflow tests, the plant will be operated in downflow to provide a standard of comparison for the upflow performance. It is planned to use GE doubly-fluted tubes (3-1/8-in. OD, CDA 194) for the standard. Three effects will be repiped to downflow operation and operating conditions will be varied over the range of interest as indicated in the details for upflow runs. Following the tests of the GE tubes, other promising configurations to be proposed by ORNL and approved by OSW, will be tested in downflow.

Run Schedule and Details

Schedule

The installation and shakedown are planned for July 15 to October 15, 1967. The upflow runs are planned for October 15, 1967 to January 30, 1968, followed by downflow runs through June 15, 1968. See Fig. 18.

Installation, Training, and Shakedown Operation

All five effects will be installed for upflow operation. The first three effects are equipped with 2-1/8-in. OD spirally-grooved copper tubes (seven per effect) and the last two effects are equipped with 3-in.-OD doubly-fluted GE copper tubes (four per effect).

During the training and shakedown period, the operability of the system will be reviewed to insure that the controls are adequate. The performance of the preheat circuit including the deaerator will be observed to insure that the equipment is adequate.

Particular emphasis will be given to insuring that the deaerator is satisfactory and that the system is reasonably free of leaks when operated under vacuum.

Runs 1, 2 and 3 (Upflow Data Runs)

Objectives

1. To investigate alternative tube types, nozzle types, feed rates, and operating conditions.
2. To arrive at optimum choices of the above.
3. To provide performance data of sufficient quality to serve for the design of upflow plants.
4. To develop the plant control system in the direction of automated operation.

Run 1. This run will compare a variety of inlet nozzles which have had some preliminary testing and appear to perform well using plain water and sodium chloride solutions.

Effect 1 — Use Sprayco Model BD-25 nozzles with spiral diffuser.

Effect 2 — Use Sprayco Model BD-25 nozzles.

Effect 3 — Use Sprayco Model BD-25 nozzles followed by flat plate orifices.

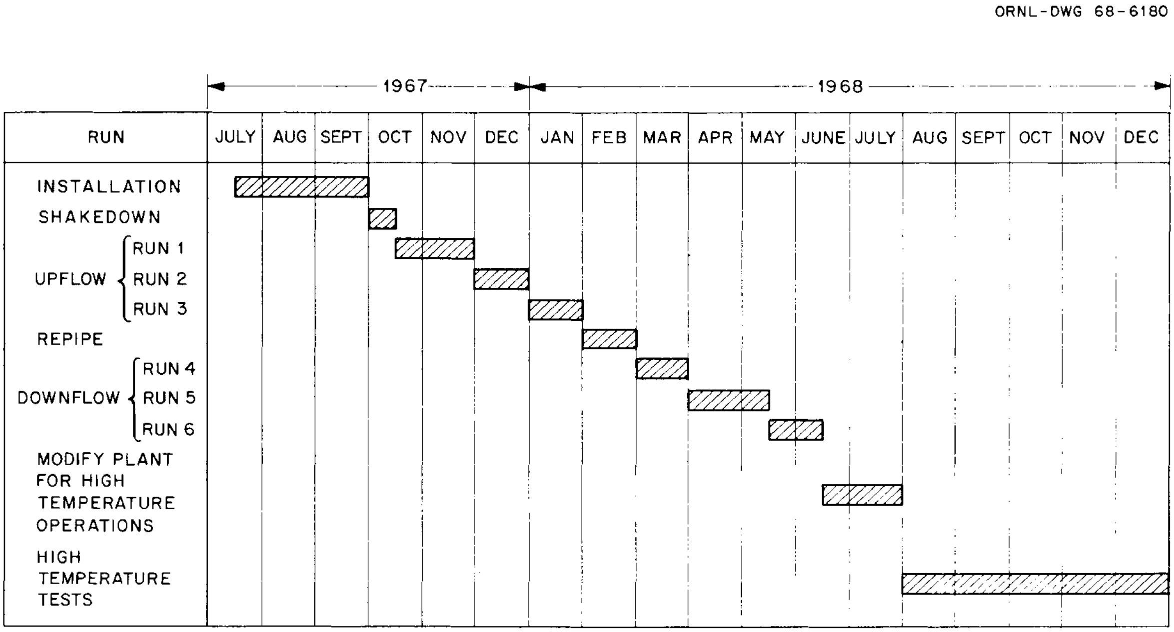

Fig. 18. Pilot Plant Schedule

Effect 4 – Use procelain nozzles (0.40-in. diam holes).

Effect 5 – Use SK 1/2 622F nozzles.

Determine overall heat transfer coefficient as a function of inlet brine temperature, steam chest to vapor chest temperature difference, and inlet brine flow rate. The desired values of these variables are indicated in Table 1. Maintain each condition for 2 days taking temperature, pressure and flow data each day to permit calculation of the overall heat transfer coefficient for each effect and a heat and material balance for each effect. Compare temperatures derived from manometer readings with those from the thermocouples.

Review operability of system to insure that controls are adequate. Specify and procure additional instrumentation and controls as are required and approved by the OSW.

Run 2. Change evaporator tube inlet nozzles as required to provide flow rates listed in Table 2. If flat plate nozzles have been satisfactory in Effect 3, use them in all effects. Repeat observations at operating conditions prescribed in Table 2. Maintain each specified condition for 1 day

Run 3. Install new 90-10 CuNi spirally-grooved tubes in Effect 1; install Linde tubes in Effect 2; install CDA Alloy 194 doubly-fluted tubes in Effect 3; spirally-grooved 90-10 CuNi tubes in Effect 4; and Linde tubes in Effect 5.

Repeat observations at operating conditions prescribed in Table 2. Maintain each specified condition for 1 day.

Calculations and Data Processing. The contractor is expected to calculate flows, heat transfer coefficients, and heat balances using simple hand or computer methods.

Runs 4, 5 and 6 (Downflow Data Runs Using 3 Effects)

Objectives

1. To obtain performance data with double-fluted CDA 194 tubes over a wider range than has been obtained previously with seawater.

Inlet temperature range	260°F – 110°F
ΔT range	8 – 18°F
Brine flow range	1 – 3 gpm
Brine concentration ratio	1 to 3

Table 1. Run 1

Inlet Brine Temperature Effect 1 °F	Steam Temperature to Effect 1 °F	Steam Chest to Vapor Chest ΔT Effect 1 °F	Brine Flow Rate to Effect 1 gpm/tube	Brine Flow Rate to Effects 4&5 gpm/tube	Flowsheet
250	250	8	2.0	3.0	Once-Through
250	250	10	2.0	3.0	Once-Through
250	250	12	2.0	3.0	Once-Through
220	220	10	2.0	3.0	Once-Through
220	220	12	2.0	3.0	Once-Through
220	220	14	2.0	3.0	Once-Through
260	260	7	2.0	3.0	Once-Through
260	260	10	2.0	3.0	Once-Through
260	260	12	2.0	3.0	Once-Through
258	260	10	2.0	3.0	Once-Through
256	260	10	2.0	3.0	Once-Through
180	180	10	2.0	3.0	Recycle,Feed C=2,Blowdown=3
180	180	12	2.0	3.0	Recycle,Feed C=2,Blowdown=3
180	180	14	2.0	3.0	Recycle,Feed C=2,Blowdown=3
178*	180	12	2.0	3.0	Recycle,Feed C=2,Blowdown=3
176*	180	12	2.0	3.0	Recycle,Feed C=2,Blowdown=3

*Subcooled feed.

Table 2. Runs 2 and 3

Inlet Brine Temperature Effect 1 °F	Steam Temperature to Effect 1 °F	Steam Chest to Vapor Chest ΔT Effect 1 °F	Brine Flow Rate to Effect 1 gpm/tube	Brine Flow Rate to Effects 4&5 gpm/tube	Flowsheet
250	250	8	1.5	2.0	Once-Through
250	250	10	1.5	2.0	Once-Through
250	250	12	1.5	2.0	Once-Through
220	220	10	1.5	2.0	Once-Through
220	220	12	1.5	2.0	Once-Through
220	220	14	1.5	2.0	Once-Through
260	260	7	1.5	2.0	Once-Through
260	260	10	1.5	2.0	Once-Through
260	260	12	1.5	2.0	Once-Through
180	180	10	1.5	2.0	Recycle,Feed C=2,Blowdown=3
180	180	12	1.5	2.0	Recycle,Feed C=2,Blowdown=3
180	180	14	1.5	2.0	Recycle,Feed C=2,Blowdown=3

2. Determine scaling limits with double-fluted tubes.
3. Make a run with other promising enhanced downflow systems, for example, Sephton baffles, spiral-fluted tubes, Linde surface and dropwise condensation.

Later Runs. Modify plant for high temperature tests using OSW-approved feed treatment(s). One system which should be considered is CO_2 suppression.

ACKNOWLEDGEMENTS

Design of the pilot plant effects and the test installation at ORNL was done by J. E. Jones with suggestions from E. C. Hise and I. Spiewak. Design of the feed treatment system was done by L. T. Birdwell and R. K. Sood. Test operations and data reduction were carried out first by J. E. Jones and later by R. M. Schilling with J. P. Hurst and G. A. Windle. J. L. Winters and B. Squires provided the instrumentation for the plant. In addition, L. G. Alexander, S. A. Reed, and R. Van Winkle made very helpful suggestions regarding the equipment and the program.

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2. L. G. Alexander, H. W. Hoffman, and P. P. Holz, Improved Heat-Transfer Systems for Evaporators: Studies on Advanced LTV Heat-Transfer Surfaces, Summary Report July 1 - December 31, 1966, USAEC Report ORNL-CF-67-7-22, Oak Ridge National Laboratory, September 1967.

APPENDIX I

Test Data from Operations at ORNL

Table I-1. Run 1
Upflow with Smooth Tubes

Run	Effect No.	Evaporating Brine Temperature °F	Approximate Brine Concentration wt %	Steam Chest to Vapor Chest (Brine Temp.) ΔT, °F	Brine Flow per Tube lb /hr	Apparent Overall Heat Transfer Coefficient Btu/hr·ft^2·°F
1-1	1	204.5	0	12.4	930	560
	2	189.8		14.7	770	540
1-2	1	208.3	0	15.2	930	630
	2	189.0		18.5	870	610
1-3	1	220.0	0	13.8	930	640
	2	203.4		16.8	870	610
1-4	1	212.7	0	13.5	930	610
	2	196.3		16.7	870	610
1-5	1	230.6	0	12.9	960	660
	2	214.5		15.8	890	540
1-6	1	245.7	0	14.3	960	670
	2	228.3		17.5	920	570
1-7	1	235.5	0	9.2	960	510
	2	225.5		8.5	735	570
1-8	1	249.7	0	8.5	960	530
	2	241.6		8.0	735	570
1-9	1	248.2	0	9.7	890	640
	2	237.0		11.0	860	590
1-10	1	246.4	0	11.5	860	640
	2	233.0		13.7	820	570
1-11	1	244.4	0	13.7	1070	670
	2	227.0		19.5	1010	520
1-12	1	245.0	0	10.9	810	520
	2	234.8		10.4	760	630
1-13	1	245.1	0	10.6	785	530
	2	234.0		11.2	760	590
1-14	1	248.8	0	8.7	785	650
	2					
1-15	1	249.4	0	8.6	785	480
	2	241.0		8.5	760	530
1-16	1	246.8	0	10.6	860	460
	2	236.3		10.5	820	570
1-17	1	225.2	0	10.5	840	440
	2	214.7		10.9	810	530
1-18	1	228.4	0	10.0	830	450
	2	217.6		11.0	790	540
1-19	1	223.5	0	11.1	860	430
	2	213.7		10.1	810	550
1-20	1	131.0	0	15.5	620	235
	2	108.8		22.0	520	230

Table I-1. Run 1 (cont'd)

Run	Effect No.	Evaporating Brine Temperature °F	Approximate Brine Concentration wt %	Steam Chest to Vapor Chest (Brine Temp.) ΔT, °F	Brine Flow per Tube lb/hr	Apparent Overall Heat Transfer Coefficient Btu/hr.ft^2·°F
1-21	1	224.2	0	9.5	750	810
	2	210.8		13.3	710	560
1-22*	1	246.3	0	10.0	610	900
	2	232.5		14.0	570	650
1-23	1	246.3	0	9.2	540	970
	2	232.0		14.3	500	650
1-24	1	220.2	0	11.9	550	920
	2	203.8		18.2	480	620
1-25	1	145.0	0	14.0	380	360
	2	128.1		17.9		310
1-26	1	137.5	0	24.5	680	140
	2	116.6		20.9	570	290
1-27	1	142.0	0	15.7	680	260
	2	122.6		18.4	550	290
1-28	1	140.6	0	16.4	650	245
	2	122.1		17.9	540	310

*Before Runs 1-22 new orifices of 0.1285-inches diameter were added to the tubes of both effects 1 and 2.

Table I-2. Run 2
Downflow with Doubly Fluted Tubes

Run	Effect No.	Evaporating Brine Temperature °F	Steam Chest to Vapor Chest (Brine Temp.) ΔT, °F	Brine Flow per Tube lb/hr	Apparent Overall Heat Transfer Coefficient Btu/hr.ft^2·°F
2-20	4	255	8.2	1190	1631
2-12	4	253	5.5	1190	1538
2-20	5	247.6	7.4	1100	1728
2-13	4	258	6.8	1190	1701
2-13	5	251	6.6	1070	1655
2-22	4	245	10.9	1140	1690
2-23	4	252.5	7.7	1150	1566
2-23	5	245	7.3	1070	1565
2-19	4	262	5.6	1150	1647
		251	5.7	1100	1508
2-26	4	195.5	14.0	1200	1110
2-4	4	209.5	7.6	1190	1413
2-4	5	201	6.7	1090	1531
2-5	4	211	12.2	1165	1203
2-27	4	197	9.0	1125	1369
2-5	5	201.5	10.4	1000	1348
2-27	5	187	9.5	1080	1243
2-6	4	212	10.0	1165	1452
2-6	5	201.5	10.4	1010	1347
2-15	4	195	10.5	1150	1213
2-15	5	184	10.2	1035	1231
2-25	4	199	10.5	1125	1327
2-25	5	188	10.9	1070	1246
2-26	5	183	12.6	1070	1228
2-8	4	236	7.3	1165	1487
2-8	5	229	6.9	1060	1471

Table I-2. Run 2 (cont'd)

Run	Effect No.	Evaporating Brine Temperature °F	Steam Chest to Vapor Chest (Brine Temp.) ΔT, °F	Brine Flow per Tube lb/hr	Apparent Overall Heat Transfer Coefficient Btu/hr·ft^2·°F
2-9	4	235	8.4	1190	1527
2-9	5	226	8.3	1050	1484
2-22	5	234	11.2	1000	1548
2-1	4	213.6	11.0	830	1504
2-1	5	200.6	12.9	660	1268
2-2	4	214	11.4	830	1446
2-2	5	200.5	12.5	680	1325
2-14	4	193	8.4	820	1287
2-14	5	183.5	8.4	725	1284
2-10	5	251	5.9	710	1467
2-7	4	239	6.9	830	1633
2-7	5	231	7.3	720	1475
2-18	4	256	6.2	805	1714
2-18	5	251	5.5	730	1751
2-11	5	251	5.5	710	1550
2-21	4	257.8	8.4	830	1664
2-28	4	292	7.7	805	1670
2-28	5	244	7.3	710	1638
2-24	4	202.6	7.8	1190	1409

Table I-3. Run 3
Effects 1, 2, and 3 in Upflow — Effects 4 and 5 in Downflow

Run	Effect No.	Evaporating Brine Temperature °F	Approximate Brine Concentration wt %	Steam Chest to Vapor Chest (Brine Temp.) ΔT, °F	Brine Flow per Tube lb /hr	Apparent Overall Heat Transfer Coefficient Btu/hr·ft^2·°F
3-1	1	239.2	0	10.6	1050	1300
	2	229.6		9.6	890	1290
	3	220.5		9.0	810	1280
	4	215.3		4.5	870	1500
	5	210.1		5.0	845	1290
3-2	1	247.3	0	11.5	1100	1390
	2	235.8		11.6	975	1270
	3	224.6		10.9	920	1360
	4	218.1		5.7	710	1470
	5	211.8		6.1	700	1340
3-3	1	248.1	0	10.4	960	1370
	2	237.3		10.6	990	1330
	3	226.7		10.2	945	1390
	4	220.4		5.6	780	1470
	5	213.4		6.8	730	1080
3-4	1	252.8	0	9.8	1060	1270
	2	243.3		9.4	960	1310
	3	233.5		9.4	930	1190
	4	227.3		5.4	960	1200
	5	220.6		6.5	910	1100
3-5	1	244.8	0	13.3	1045	1160
	2	231.5		13.6	925	1350
	3	217.4		13.7	770	1410
	4	207.9		8.7	760	1360
	5	197.3		10.5	690	1130

Table I-3. Run (cont'd)

Run	Effect No.	Evaporating Brine Temperature °F	Approximate Brine Concentration wt %	Steam Chest to Vapor Chest (Brine Temp.) ΔT, °F	Brine Flow per Tube lb /hr	Apparent Overall Heat Transfer Coefficient $Btu/hr.ft^2.°F$
3-6	1	245.0	0	13.0	1080	1300
	2	231.4		13.5	1075	1270
	3	217.4		13.6	910	1420
	4	208.1		8.6	800	1340
	5	197.2		10.7	690	1170
3-8	1	167.6	0	11.8	890	830
	2	150.7		14.9	700	700
	3	128.2		22.2	660	650
	4	115.2		12.0	540	750
	5	101.8		12.2	470	790
3-9	1	167.4	0	11.1	960	600
	2	148.4		17.5	760	460
	3	126.2		22.0	800	500
	4	112.2		12.8	680	600
	5	95.9		14.7	640	610
3-10	1	248.0	0	9.6	1060	1150
	2	238.2		9.6	940	1220
	3	228.7		9.3	925	1280
	4	222.5		5.6	1000	1290
	5	216.0		6.4	960	1180
3-11	1	245.1	3.5	11.4	1120	1580
	2	232.9		10.9	1030	1890
	3	218.6		12.5	900	1720
	4	207.4		8.8	650	1400
	5	194.2	7.4	11.0	530	1200
3-12	1	241.8	3.4	12.7	1200	1845
	2	226.9		13.6	1120	1780
	3	211.4		13.7	1025	2040
	4	197.5		11.4	960	1500
	5	180.4	6.7	14.9	780	1220
3-13	1	242.3	3.4	12.2	1190	1990
	2	227.2		13.8	1100	1800
	3	211.5		14.5	1000	1960
	4	197.8		11.5	940	1490
	5	180.5		15.1	760	1200
3-14	1	170.0	3.2	10.9	880	1120
	2	156.0		12.2	870	990
	3					
	4	126.4		10.8	630	930
	5	113.6		11.2	580	940

Table I-4. Run 4
All five Effects in Upflow

Run	Effect No.	Evaporating Brine Temperature °F	Approximate Brine Concentration wt %	Steam Chest to Vapor Chest (Brine Temp.) ΔT, °F	Brine Flow per Tube lb/hr	Apparent Overall Heat Transfer Coefficient Btu/hr.ft^2·°F
4-3	1	252.6	3.3	10.3	940	1630
	2	242.6		8.6	900	1950
	3	232.5		8.5	790	2020
	4	219.0		11.5	660	1400
	5	202.2		14.9	810	1230
4-4	1	249.8	3.2	8.8	980	1950
	2	239.7		9.1	900	1880
	3	230.0		8.6	790	2080
	4	217.2		10.8	660	1390
	5	201.5		14.0	830	1270
4-5	1	251.9	3.0	9.1	980	1500
	2	242.3		8.8	1000	1640
	3	230.3		10.7	980	1410
	4	218.5		11.8	970	1380
	5	203.4		13.9	1080	1250
4-6	1	209.8	3.5	11.8	1000	1080
	2	196.2		12.5	960	1180
	3	182.0		12.9	850	1350
	4	165.5		15.0	920	1350
	5	146.6		17.7	930	1200
4-7	1		3.0			
	2					
	3					
	4	144.1		12.1	745	1390
	5	121.9		20.7	775	820
4-8	1	183.9	4.7			
	2	173.5		11.1	790	1050
	3	161.5		10.7	700	1240
	4	147.7		12.0	790	1280
	5	130.3		15.8	780	990
4-9	1	183.9	4.7			
	2	173.7		10.6	790	1090
	3	161.2		10.6	740	1260
	4	147.5		11.8	700	1220
	5	130.1		16.1	740	1110
4-10	1	184.3	3.9	13.3	860	1120
	2	172.6		11.1	840	1160
	3	160.6		11.4	730	1325
	4	146.2		13.4	700	1280
	5	125.0		19.6	620	830
4-11	1	176.0	3.1			
	2	165.6		9.8	835	1040
	3	154.4		9.9	730	1220
	4	141.1		12.0	1340	970
	5	123.3		16.6	820	850
4-12	1	245.5	3.1	8.8	1030	1430
	2	235.5		9.1	950	1430
	3	224.4		10.1	925	1380
	4	207.8		14.9	1600	1010
	5	190.4		16.5	1000	1100
4-13	1	251.1	2.9	8.3	1220	1490
	2	241.3		9.3	1000	1450
	3	230.8		9.4	940	1540
	4	213.3		16.1	1520	930
	5	196.0		16.8	1020	1040
4-14	1	252.0	3.0	8.0	940	1250
	2	244.0		6.8	930	1460
	3	235.5		7.3	910	1410
	4	224.7		9.5	1240	1320
	5	213.5		12.0	900	790

APPENDIX II

Description of Components and Equipment

Tanks

Condensate Tanks

Separate collector tanks, (8-in. diam pipe - 2 ft long) equipped with sight glasses, are provided for wall and evaporator tube condensate from each effect. The tube condensate tanks each have a level controller operating a throttling valve in the discharge line of the condensate pump. Wall condensate is pumped out under manual control as required.

These tanks are vented to the top of the steam chest which in turn is vented to the noncondensables cooler.

All the other tanks used in the pilot plant were taken from surplus stock at Oak Ridge.

Source Tank

This tank, which was used as a feed heater during the tests at Oak Ridge, serves as a desuperheater. It is made of stainless steel, 42-in. diam and 63-in. long, and is fitted with a submerged inlet line for mixing steam into water. An 8-in. diam steam line connects to the first evaporator effect. The tank is equipped with sight glasses and a level controller (LAC-7).

Steam from the test station supply passes thru regulator valves and a throttling valve (TCV-1). Water can be fed into the tank as required and bled out thru a level control valve.

A relief valve (PSV-1) is provided with its relief setting at 50 psig.

Mix Tank

This is a stainless steel tank with the same dimensions as the source tank except that there is a 16-in. diam top opening.

Sight glasses are provided with the tank and a level controller (LRC-8) regulates the brine inlet flow.

Brine Feed Head Tank

The head tank is made of stainless steel, 1/8-in. thick, and is 48-in. in diameter by 36-in. high. The top lid is hinged.

A low level alarm (LA-11) is provided for this tank.

Acid Tank

This is a horizontally mounted stainless steel tank, 18-in. in diameter by 24-in. long.

Deaerator and Vent Condenser

The deaerator is shown in Fig. 9. It is a vacuum deaerator with gases exhausted by Jet No. 2 thru the six-inch pipe connection at the top of the unit.

Brine enters thru the spray nozzle and is distributed uniformly over the packing. Two interchangeable spray nozzles are provided to insure adequite distribution at all expected water flowrates. The Sprayco 1-1/4 H12 unit is sized for flows up to 12 gpm while the 1-1/2 H30 unit is to be used for higher flows (up to 30 gpm). The deaerator packing is Maspac FN200 made of polypropylene. The inside surface of the vessel is coated with Heresite L-66 applied over Heresite P-403 and baked according to the manufacturer's recommendations.

A level controller (LRC-9) regulates the level using a throttling valve (LCV-9) downstream of the final brine heater.

The vent condenser is a U-tube bundle mounted in a flanged section of pipe in the vent line from the top of the deaerator. The bundle has 8 monel U-tubes (bundle length, 2 ft), 5/8-in.

Condensate drains back into the deaerator.

Heat Exchangers

The condensers and feed heaters for the plant were obtained from a surplus Navy evaporator.

Design data are not available, but each unit has been hydrotested to insure that it is adequate for the intended service.

Final Condenser

This unit is a shell and tube heat exchanger of six pass construction with 110 Cu-Ni tubes, 0.049-in. wall thickness, 5/8-in. OD, 4-ft long. Steam is condensed in the shell side. The shell is cupro-nickel approximately 0.1-in. thick and it has been hydrotested (cold water) to 125 psig. A condensate collection tank with level controller and pump are provided as for the tube condensate collection from evaporator effects.

Brine Preheater

This unit is indentical to the final condenser. Its shell has been hydrotested to 40 psig. The relief valve setting is 30 psig.

After-Condenser and Jets

The shell and tube after-condenser is of two pass construction with 75 Cu-Ni tubes (0.049-in. wall thickness, 5/8-in. OD; 4-ft 5-in. long). Steam is condensed in the shell side. The shell is copper (1/8-in. thick) and it has been hydrotested to 125 psig. The relief valve setting (PSV-2) for this unit is 15 psig. Condensate is discharged to the drain.

Each air ejector is designed to remove 40 pounds per hour of dry air, with a vapor temperature of 100°F and a vacuum at the suction side of 26.5 in Hg. Six hundred and twenty pounds per hour of steam at 80 psig are required.

Final Brine Heater

This shell and tube exchanger is the same basic unit as the after-condenser, but is has had the heads (bonnets) modified to make it a four pass unit.

The shell has been hydrotested to 80 psig. The relief valve (PSV-4) setting is 50 psig. Steam flow to the shell passes thru a pressure reducer then thru a temperature control valve (TCV-2) which controls the brine exit temperature.

Non-Condensable Cooler

This cooler is a jacketed section of pipe cooled by inlet brine. A condensate collection tank and pump identical to those provided for wall condensate are provided.

Pumps

Surplus pumps were used for each brine pumping application in upflow. Four new pumps (Peerless, Size 1-1/2 x 16 "O" AA) made of Type 316 stainless steel are supplied for use as replacements for the used pumps and as interstage brine pumps when the plant is operating in downflow. If the plant inlet brine temperature is raised above 260°F, a new brine feed pump will be required to provide a higher feed pressure.

All condensate pumps are two-stage Eastern pumps, Model 2F-34C-1, made of Type 316 stainless steel.

A summary of the data available for each pump is given below:

Mix Tank Discharge Pump

Allis Chalmers Pump
Size 1.25 x 1.25 Type HHP, 60 gpm, 90 ft head,
Impeller diam 5.5-in., Speed 3500 rpm

Allis Chalmers Motor, 60 cycle,
3HP, Type G, Design B, Frame 184, 220/440 volt,
24 hr, 140°C rise, 3500 rpm

Deaerator Supply Pump, Source Tank Pump

Worthington Pump Model 11CN42

Westinghouse Motor - Frame 224, 3HP

Note: 2 ea replacement shafts and Type 316 stainless steel impellers are furnished for this size pump. Two of these pumps are available.

Brine Feed Pump

Allis Chalmers Pump, Size 1.25 x 1.5 x 6.5,
60 gpm, 3500 rpm, serial 36529-1-2

Allis Chalmers Motor, Type APWW, Frame 254, 220/440 volt,
7.5 HP, 3500 rpm

Brine Discharge Pump - Effect 5

Ingersoll Rand Pump, Type 1LRVNL, 3540 rpm, 150 ft head , SR No. 0757-5180.

Diehl Motor, DIF 213-1203-1, Design B Code H, 5 HP, 3450 rpm

Replacement Pumps

Peerless Pump; Size 1-1/2 x 1 x 6 "O" AA, 40 gpm, 85 ft head, 3500 rpm

U. S. Motor, 3 HP, Type 05 TEFC, Frame 182T, 230/460 Volts

Four of these pumps are furnished in Type 316 stainless steel with 5-1/8-in. diam impellers. Two new impellers, 5-1/2-in. diam, are available to furnish an output head of 125 ft at 30 gpm.

Condensate Pumps

Eastern Pump, Model 2F-34C-1, 3 gpm, 25 psia disch-head

Eastern Motor, Model 2F-34C, 1/2 HP, 3450 rpm

Sulfuric Acid Pump

Lapp Pulsafeeder, Model LS-20, 1040 ml/hr capacity, 1000 psig pressure rating

Materials — stainless steel pumping head (Carpenter 20) with
Hastelloy C, ball checks and Kel-F diaphragm

Instruments

Temperature

Thermocouples

All thermocouples are chromel-alumel, sheathed in 1/8-in. OD stainless steel tubing 12-in. long. They are equipped with a male, Thermo-Electric Type PMSS (or equal) connector for connecting to the extension leads.

Twenty-one thermocouples have been calibrated. Fifteen of these are TE 101, 102, 103, 201, 202, 203, 301, 302, 303, 401, 402, 403, 501, 502, 503. The other six are spares. Calibration records for all 21 are supplied.

Four (4) couples are spare and uncalibrated.

The extension lead wires from calibrated thermocouples run first to the jack panel on cubicle #1, then to the TR. This provides the connection for more accurate potentiometer, ice bath etc.

Temperature Recorders

TR-1, TR-2 and TR-3 are Minneapolis-Honeywell, 12 point, 0-300°F recorders for chromel-alumel thercocouples. They are "Electronix" and equipped with battery eliminators.

Thermocouple connections to TR points are given on Dwg EPA-44913E.

EMF to Pneumatic Converter

TM-1, TM-2 and TM-3 are Minneapolis-Honeywell, Model Y-158N31P-X-D for chromel-alumel thermcouples. The range is 0-300°F input and 3-15 psia output.

Level

All level controllers are equipped with 0-100 scales and indicate empty at the 100 end. The instrument application tabulation sheets show the transmitter ranges and output action. The temperature recorder controllers are equipped with 0-300 linear scales since 0-300°F C/A scales were not available from Foxboro.

Recorder - Controller

Twenty Foxboro, Model M-53, instruments incorporating an M-58 controller are used as follows:

Level controllers LRC-1A, 2A, 3A, 4A, 5A, 1B, 2B, 3B, 4B, 6, 7, 8, 9, and 10 (total 14)

Temperature controllers: TRC-1, TRC-2 and TRC-3

Flow controllers: FRC-1A and FRC-1B

Flow recorder: FR-1 (FR-1 is a controller but used as a recorder only).

Indicating Controller

A Foxboro Model M-53 instrument is used in only one application, LIC-5B. It was not a required design, but was available.

Transmitters

All level transmitters are Taylor Transaires. Input ranges for the standing leg applications LT-1A, 2A, 3A, 4A, 5A and 6 are 0-100-in. of water. For the source and mix tank levels (LT-7 and LT-8) the range is 0-50-in. of water. All other ranges are 0-20-in. of water. Two Foxboro transmitters (0-20-in. H_2O) are furnished as spares along with one transmitter having 0-200-in. H_2O range.

Flow Recorder and Controllers

The indicating scales on these instruments are square root (0-1), however 0-10 sq root charts are being used. The chart constants shown in the tabulation sheets are based on the 0-10 chart.

Instrument Panel

The panel for the temperature, flow, and level instruments is shown in Fig. 13. An existing electrical breaker panel at Wrightsville Beach provides additional space if needed.

Annunciator

A five channel Tel-Alarm annunciator unit is provided for monitoring plant conditions that the operator feels should be monitored.

PHOTO 75210

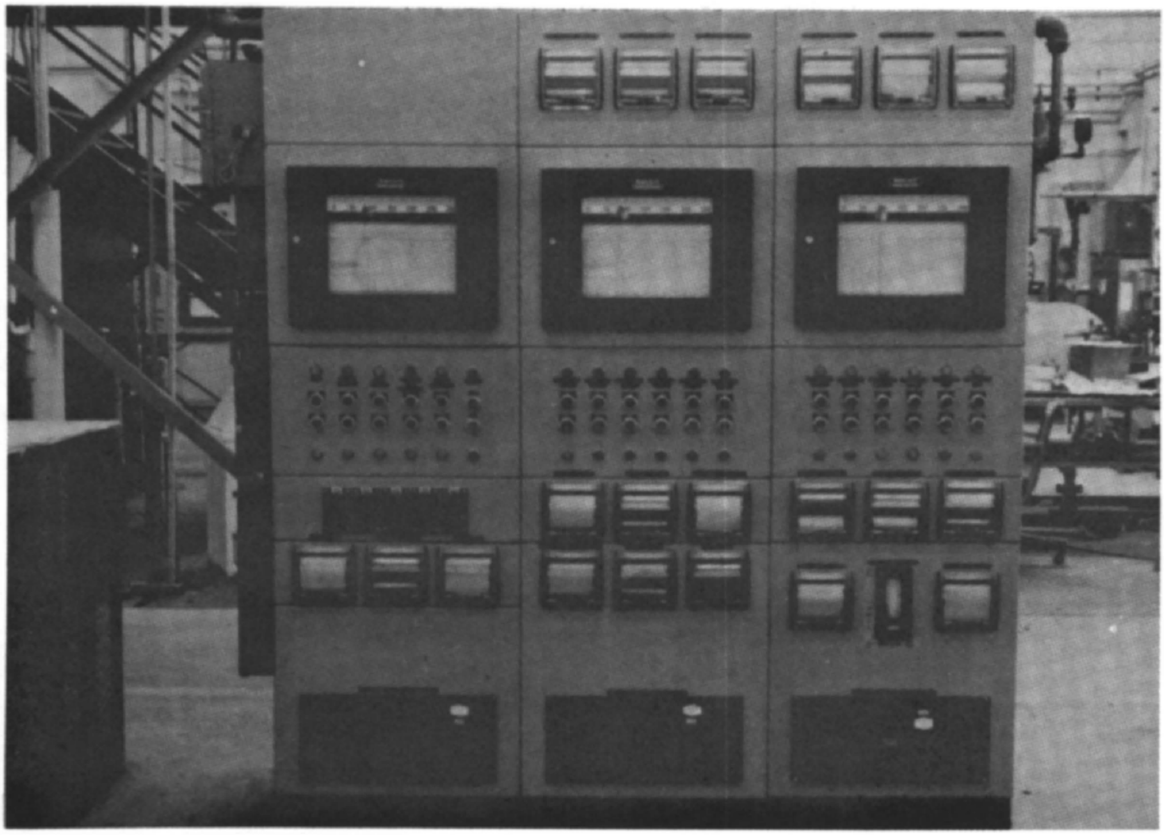

Fig. 13. Instrument Panel for Temperature, Flow and Level Instruments.

APPENDIX III

DATA SHEETS AND SAMPLE CALCULATIONS

VTE PILOT PLANT DATA SHEET

RUN NO. 3-19

DATE 5-10-67 TIME 15^{30} EFFECT NO. 1 TUBE AREA 5.777 ft^2 ea (7 tubes)

TUBE TYPE 2-1/8-in. OD Spirally Grooved Cu NOZZLE Sprayco BD 25 with spiral diffuser

UPFLOW

TEMPERATURES

Variable	Recorder	Millivolt Potentiometer	Temperature from Potentiometer
T 1 – Vapor Out	255.2	5.055	
T 2 – Steam In	263.1	5.212	
T 3 – Brine In	261.0	5.181	
ΔT (T 2 – T 1)			

PRESSURES

	In. HG	psig
P 1 Vapor Chest	34.45	16.8
P 2 Steam Chest	42.90	21.2
P 3 Brine Chest		
P 0 Barometer	29.00	

ΔP

Steam to Vapor	8.45
Steam to Steam	

CONDENSATE FLOW

	Meter No.	%	GPM	Level Change
Steam Chest Wall				
Evaporator Tubes	F1-29	39		
Final Condenser (5th effect only)				

BRINE FLOW

	Meter No.	%	GPM
B 1 Inlet Brine	F1-25		13.7
B 2 Bypass Brine	F1-18		5.4
Brine to Mix Tank (5th effect only)			

VTE PILOT PLANT DATA SHEET

RUN NO. 3-19

DATE 5-10-67 TIME 15^{30} EFFECT NO. 2 TUBE AREA 5.777 ft^2 e (7 tubes)

TUBE TYPE 2-1/8-in. OD Spirally Grooved Cu NOZZLE Sprayco BD-25

UPFLOW

TEMPERATURES

Variable	Recorder	Millivolt Potentiometer	Temperature from Potentiometer
T 1 – Vapor Out	250	4.91	
T 2 – Steam In	254.4	5.031	
T 3 – Brine In	255.4	5.045	
ΔT (T 2 – T 1)			

PRESSURES

	In. HG	psig
P 1 Vapor Chest	26.3	13.6
P 2 Steam Chest	34.45	16.9
P 3 Brine Chest		
P 0 Barometer		

ΔP

Steam to Vapor	8.15	
Steam to Steam		

CONDENSATE FLOW

	Meter No.	%	GPM	Level Change
Steam Chest Wall				
Evaporator Tubes	F1-26	42		
Final Condesner (5th effect only)				

BRINE FLOW

	Meter No.	%	GPM
B 1 Inlet Brine	F1-24		14.5
B 2 Bypass Brine	F1-19		3.7
Brine to Mix tank (5th effect only)			

VTE PILOT PLANT DATA SHEET

RUN NO. 3-19

DATE 5-10-67 TIME 15^{30} EFFECT NO. ____ TUBE AREA 5.777 ft^2/tube (7 tubes)

TUBE TYPE 2-1/8-in. OD Spirally Grooved Cu NOZZLE ____

UPFLOW

TEMPERATURES

Variable	Recorder	Millivolt Potentiometer	Temperature from Potentiometer
T 1 – Vapor Out	240.8	4.72	
T 2 – Steam In	248.2	4.879	
T 3 – Brine In	247.5	4.875	
ΔT (T 2 – T 1)			

PRESSURES

	In. HG	psig
P 1 Vapor Chest	19.75	9.9
P 2 Steam Chest	26.55	13.4
P 3 Brine Chest		16
P 0 Barometer		

ΔP

Steam to Vapor	6.75
Steam to Steam	

CONDENSATE FLOW

	Meter No.	%	GPM	Level Change
Steam Chest Wall				
Evaporator Tubes				
Final Condenser (5th effect only)				

BRINE FLOW

	Meter No.	%	GPM
B 1 Inlet Brine	F1-23		13.5
B 2 Bypass Brine	F1-20		3.7
Brine to Mix Tank (5th effect only)			

VTE PILOT PLANT DATA SHEET

RUN NO. 3-19

DATE 5-10-67 TIME 15^{30} EFFECT NO. 4 TUBE AREA 10 ft^2 each (4 tubes)

TUBE TYPE GE Doubly Fluted - Cu 3-in. OD NOZZLE Porcelain (Knox Porc. Co. Dwg. M33647)

DOWNFLOW

TEMPERATURES

Variable	Recorder	Millivolt Potentiometer	Temperature from Potentiometer
T 1 — Vapor Out	233.9	4.54	
T 2 — Steam In	238.9	4.687	
T 3 — Brine In	239.7	4.684	
ΔT (T 2 — T 1)			

PRESSURE

	In. HG	psig
P 1 Vapor Chest	13.15	6.7
P 2 Steam Chest	19.6	10.2
P 3 Brine Chest		18
P 0 Barometer		

ΔP

Steam to Vapor		
Steam to Steam		

CONDENSATE FLOW

	Meter No.	%	GPM	Level Change
Steam Chest Wall				
Evaporator Tubes	F1-28	40		
Final Condenser (5th effect only)				

BRINE FLOW

	Meter No.	%	GPM
B 1 Inlet Brine	F1-31A	24	
B 2 Bypass Brine			6.7
Brine to Mix Tank (5th effect only)			

VTE PILOT PLANT DATA SHEET

RUN NO. 3-19

DATE ______ TIME ______ EFFECT NO. ______ TUBE AREA 10 ft^3 each (7 tubes)

TUBE TYPE GE Doubly Fluted - Cu 3-in. OD NOZZLE 1/2 SK 622F

DOWNFLOW

TEMPERATURES

Variable	Recorder	Millivolt Potentiometer	Temperature from Potentiometer
T 1 – Vapor Out	226.2	4.419	
T 2 – Steam In	231.8	4.517	
T 3 – Brine In	230.7	4.505	
ΔT (T 2 – T 1)			

PRESSURES

	In. HG	psig
P 1 Vapor Chest	9.25	4.5
P 2 Steam Chest	13.25	6.3
P 3 Brine Chest		
P 0 Barometer	29.00	

ΔP

Steam to Vapor		
Steam to Steam		

CONDENSATE FLOW

	Meter No.	%	GPM	Level Change
Steam Chest Wall				
Evaporator Tubes				
Final Condenser (5th effect only)	F1-21		1.05	

BRINE FLOW

	Meter No.	%	GPM
B 1 Inlet Brine	F1-31B	43	
B 2 Bypass Brine			
Brine to Mix Tank (5th effect only)	F1-16		14.5

SAMPLE CALCULATIONS
(typed from computer printout)

```
Brine In Effect 1 — 3% NaCl
Brine Out Effect 5 — 4.5% NaCl

EFFECT NO = 1

INPUT DATA

R      Ë      A       B1      B2      V1      V2      V3      C1
19     1      5.777   13.7    5.4     5.055   5.212   5.181

C2     F1     F2      B3      B4      C3      C4      F3      F4
0      39     0       14.5    3.7     0       0       42      0

BRINE TEMP T3 = 258.776       T3 — T1 = 5.29082
STEAM TEMP T2 = 260.565       T2 — T1 = 7.0797
VAPOR TEMP T1 = 253.485
U BAR = 1548.87 BTU/HR/FT-2/DEG F
MASS BALANCE = 0.993259
HEAT BALANCE = 1.04078
ENTHALPY IN = 938.373
ENTHALPY OUT = 943.182
BRINE FLOW IN  BRINE BYPASS FLOW IN
  6678.3 LBS/HR  2632.32 LBS/HR
TUBE COND      WALL COND
  472.557 LBS/HR   0 LBS/HR
OTHER CALCULATED DATA
D9, S9, O3, O4, Z9, M9, W3, W4

 58.4335   0.973571   7068.27   1803.63   286.296   473393.0   501.91   0

VAPOR CHEST PRESS 31.1635     TEMP 252.519
STEAM CHEST PRESS 35.3137     TEMP 259.809
```

```
EFFECT NO = 2

INPUT DATA

R      E      A       B1      B2      V1      V2      V3      C1
19     2      5.777   14.5    3.7     4.91    5.031   5.045   0

C2     F1     F2      B3      B4      C3      C4      F3      F4
0      42     0       13.5    3.7     0       0       40.5    0

BRINE TEMP T3 = 252.934       T3 - T1 = 6.62842
STEAM TEMP T2 = 252.51        T2 - T1 = 6.20381
VAPOR TEMP T1 = 246.306
U BAR = 1888.28 BTU/HR/FT-2/DEG F
MASS BALANCE = 0.999331
HEAT BALANCE = 1.1368
ENTHALPY IN = 943.84
ENTHALPY OUT = 948.003
BRINE FLOW IN     BRINE BYPASS FLOW IN
 7080.11 LBS/HR      1806.65 LBS/HR
TUBE COND            WALL COND
 501.91 LBS/HR       0 LBS/HR
OTHER CALCULATED DATA
D9, S9, O3, O4, Z9, M9, W3, W4

  58.6593   0.975202   6591.83   1806.65   250.876   468532.0   494.231   0

VAPOR CHEST PRESS 27.1606      TEMP 244.695

STEAM CHEST PRESS 31.1635      TEMP 252.519
```

```
EFFECT NO = 3
INPUT DATA

R      E      A      B1      B2      V1      V2      V3      C1
19     3      5.777     13.5     3.7     4.72     4.879     4.875

C2     F1     F2     B3     B4     C3     C4     F3     F4
0      40.5    0      24      6.7     0      0      40      0

BRINE TEMP T3 = 245.602      T3 - T1 = 6.38879
STEAM TEMP T2 = 244.555      T2 - T1 = 5.34095
VAPOR TEMP T1 = 239.214
U BAR = 2171.98 BTU/HR/FT-2/DEG F
MASS BLALANCE = 1.12222
HEAT BALANCE = 1.10058
ENTHALPY IN = 949.171
ENTHALPY OUT = 952.713
BRINE FLOW IN      BRINE BYPASS FLOW IN
  6602.4 LBS/HR       1809.55 LBS/HR
TUBE COND          WALL COND
   494.231 LBS/HR     0 LBS/HR
OTHER CALCULATED DATA
D9, S9, O3, O4, Z9, M9, W3, W4

  58.8765    0.976766    3720.4    3276.75    215.983    475070.0    498.65    0

VAPOR CHEST PRESS 23.9436       TEMP 237.691
STEAM CHEST PRESS 27.2834       TEMP 244.949
```

```
EFFECT NO = 4

INPUT DATA

R      E      A      B1      B2      V1      V2      V3      C1
19      4      5.71      24      6.7      4.54      4.687      4.684      0

C2      F1      F2      B3      B4      C3      C4      F3      F4
0      40      0      43      0      0      0      39      0

BRINE TEMP T3 = 237.234        T3 - T1 = 6.26342
STEAM TEMP T2 = 237.179        T2 - T1 = 6.20828
VAPOR TEMP T1 = 230.971
U BAR = 1917.18 BTU/HR/FT-2/DEG F
MASS BALANCE = 0.959088
HEAT BALANCE = 1.12561
ENTHALPY IN = 954.055
ENTHALPY OUT = 958.123
BRINE FLOW IN    BRINE BYPASS FLOW IN
 3725.77 LBS/HR     3281.47 LBS/HR
TUBE COND          WALL COND
  498.65 LBS/HR    0 LBS/HR
OTHER CALCULATED DATA
D9, S9, O3, O4, Z9, M9, W3, W4

  59.0726    0.978174    6824.33    0    248.145    461643.0    481.82    0

VAPOR CHEST PRESS 20.702          TEMP 229.803

STEAM CHEST PRESS 23.8699         TEMP 237.522
```

```
EFFECT NO = 5

INPUT DATA

R      E      A      B1     B2     V1      V2      V3      C1
19     5      10     43     0      4.419   4.517   4.505   0

C2     F1     F2     B3     B4     C3      C4      F3      F4
0      39     0      14.5   0      0       0       1.05    0

BRINE TEMP T3 = 229.579     T3 - T1 = 3.86126
STEAM TEMP T2 = 229.814     T2 - T1 = 4.09696
VAPOR TEMP T1 = 225.717
U BAR = 1610.97 BTU/HR/FT-2/DEG F
MASS BALANCE = 0.894764
HEAT BALANCE = 0.966133
ENTHALPY IN = 958.877
ENTHALPY OUT = 961.537
BRINE FLOW IN   BRINE BYPASS FLOW IN
  6833.87 LBS/HR    0 LBS/HR

TUBE COND          WALL COND
  481.82 LBS/HR      0 LBS/HR
OTHER CALCULATED DATA
D9, S9, O3, O4, Z9, M9, W3, W4

 59.2635   0.979542   7111.88   0   286.787   505513.0   525.735   0

VAPOR CHEST PRESS 18.7865      TEMP 224.651
STEAM CHEST PRESS 20.7511      TEMP 229.93
```

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