Vacuum-Freezing Vapor-Compression Process: Evaluation on Brackish Water

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Vacuum-Freezing Vapor-Compression Process: Evaluation on Brackish Water

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Contract No. 14–01–0001–967

UNITED STATES DEPARTMENT OF THE INTERIOR • Walter J. Hickel, Secretary
Carl L. Klein, Assistant Secretary for Water Quality and Research

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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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ABSTRACT

The Vacuum-Freezing Vapor-Compression (VFVC) Process was evaluated on high salinity brackish water during the period from February 1968 through December 1969 by Colt Industries Inc, under O.S.W. Contract No. 14-01-0001-967 at Roswell, New Mexico.

The 15,000 gpd VFVC test plant is mounted on a mobile trailer which was built by Colt Industries Inc. in their factory at Beloit, Wisconsin. Prior to operation at Roswell, the plant was operated at Wrightsville Beach, North Carolina to check out the system and to operate the trailer on sea water.

The system was checked out and the unit was operated successfully on sea water.

In Roswell, tests were conducted to determine the effects of precipitation and scaling on the VFVC Process. A number of tests were carried out with yields of 20% to 80%, and the effluent brine concentration ranging from 2.13% to 8.0%. In the entire range, no significant evidence of precipitation or scaling was noticed. No difficulty was encountered in making 500 ppm potable water. The fresh water had a very natural taste.

I BACKGROUND

Colt Industries, through its subsidiary Fairbanks Morse Inc, has been developing a Vacuum-Freezing Vapor-Compression Process for the desalting of sea water since 1960.

The development work began with the study of the basic process and techniques for freezing ice crystals, compressing water vapor, cleaning ice crystals of residual brine, and melting ice crystals with compressed water vapor. Equipment was designed at Beloit, Wisconsin at the Research Center of Fairbanks Morse Inc, and a test unit was built. The test unit, having a designed capacity of 60,000 gallons per day, was erected in the Fairbanks Morse factory at Beloit, Wisconsin in December, 1960 and tests were conducted from that time until February, 1965.

A solution of sodium chloride and water was used throughout the testing since Beloit, Wisconsin has no sea or brackish water sources. The unit underwent constant modification throughout the test period in order to improve the performance of all components. The tests and modifications encompassed every part of the process and each piece of equipment necessary to make the plant operative.

In February of 1965, Colt Industries and the Office of Saline Water concluded a contract for transfer of the VFVC pilot plant at Beloit Wisconsin to the O.S.W. Test Facility at Wrightsville Beach, North Carolina. The purpose of this contract was to evaluate the VFVC Process in an actual sea water environment.

Under this contract and subsequent amendments, the output of the plant was increased to 125,000 gpd, and unattended automatic operation of the plant was demonstrated. In June of 1968 the plant was rebuilt with a simplified process in which the melting and washing processes are combined in the same chamber and all of the conversion process occurs in one process vessel rather than two vessels.

In April of 1967, Colt Industries and the Office of Saline Water concluded a contract to design and construct a mobile Vacuum-Freezing Vapor-Compression desalting unit for evaluation on various brackish waters, and a separate supporting office-laboratory trailer. Construction of the mobile unit was completed in July of 1968 (Figure 1) and an amendment to the contract was obtained for operation of the plant. The following were to be accomplished under this amendment:

"1. Establish the operating characteristics of the mobile trailer desalting unit on sea water at Wrightsville Beach, North Carolina.

"2. Operate the unit at Roswell, New Mexico, and two additional sites as selected by O.S.W. to demonstrate the capability of using the VFVC process on brackish water.

"3. Determine the effects of precipitation of mineral compounds from the feed, and the ability to operate without serious problems caused by scale formation on any of the process components.

"4. Perform on a regular basis analysis of all of the feed and effluent streams, as well as any deposits obtained within the equipment by use of a supporting laboratory trailer.

"5. Determine the maximum feasible degree of concentration of feed by the VFVC process on various types of brackish water."

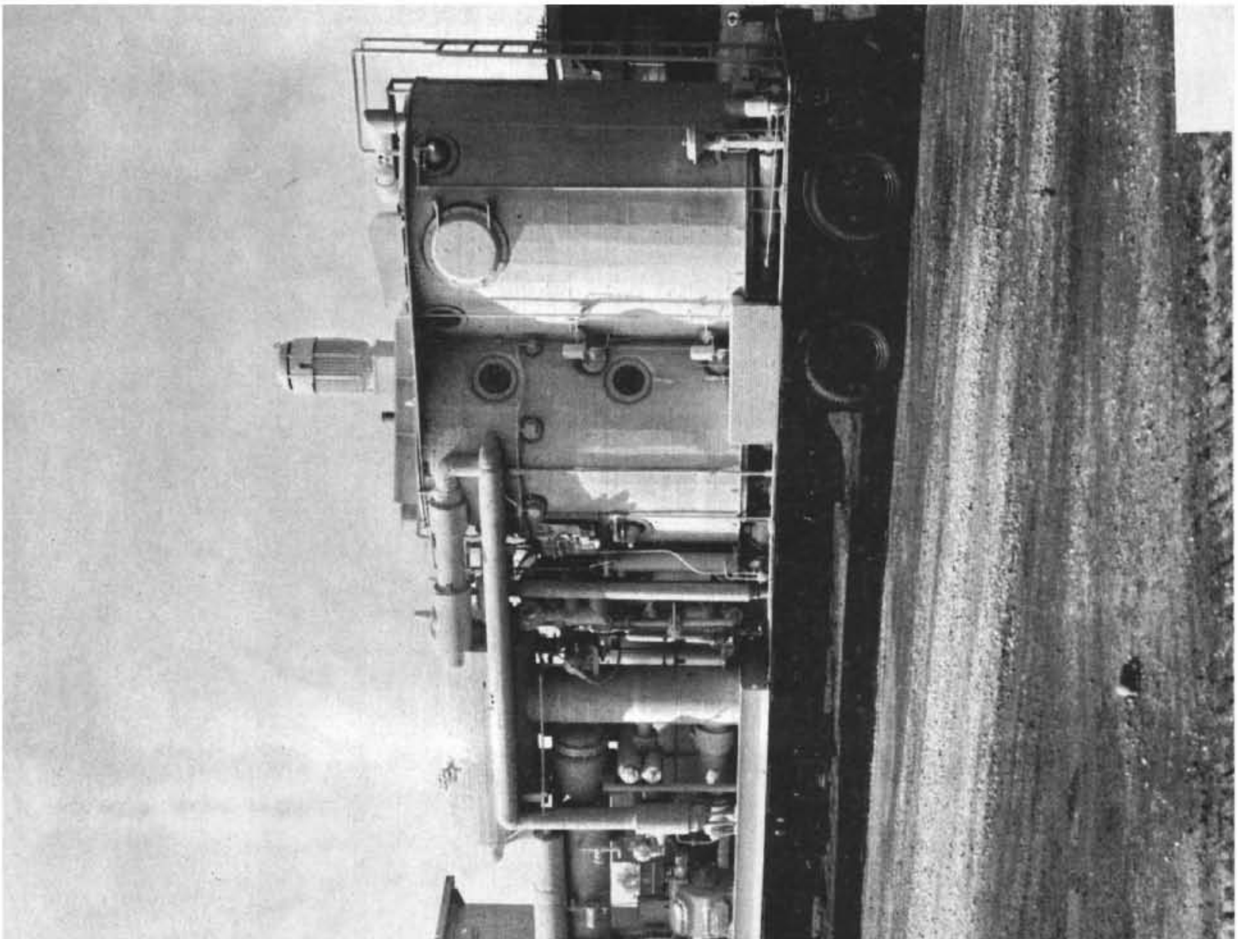


FIGURE 1

II THEORY AND PROCESS DESCRIPTION

A. Theory

The principles involved for converting sea and brackish water to fresh water in the VFVC Process are rather well known in physical chemistry. They are summarized below:

1. When sea or brackish water is boiled, the vapor that is produced is pure water vapor; the salts are concentrated in the remaining brine.

2. When sea or brackish water is frozen, the individual ice crystals consist of pure water; the salts are concentrated in the remaining brine. However, each ice crystal is coated with a layer of concentrated brine that adheres to the surface of the crystal and this layer must be removed by washing.

3. When a non-volatile substance is dissolved in a liquid, the vapor pressure is lowered. This lowering of the vapor pressure by a solute also brings about other changes: the freezing point is lowered, and the boiling point is raised. The freezing point of typical sea water is 28.6°F.

4. The boiling point of sea water varies drastically with pressure. By reducing pressure to 3.9 mm of mercury absolute, the boiling point temperature of sea water is reduced to 28.6°F, which is the same as the freezing point. In other words, the triple point of sea water is at 28.6°F and 3.9 mm of mercury absolute where liquid, gas, and solid phases coexist.

5. Thermodynamically at 32°F, to convert one pound of fresh water into vapor, about 1070 BTU must be removed. To convert one pound of fresh water into ice, 144 BTU must be removed. The ratio of the heat that is added in producing one pound of vapor to the heat that is removed in producing one pound of ice is about 7.5 to 1.0.

6. The melting point of pure ice is 32°F and the vapor pressure of ice is the same as that of pure water at the same temperature. The equilibrium pressure of pure water at 32°F is 4.58 mm of mercury absolute.

7. The same principles discussed above are applied to brackish water desalting. However, the triple point varies with types of brackish water; e.g, with 1.6% T.D.S. the triple point is 30.5°F and 4.27 mm mercury absolute.

B. Process Description

A simplified diagram, Figure 2, shows both the essential components of the process and flow paths of the various streams in the system. Typical heat and mass balances are shown on Figures 3 and 4.

Feed water is pumped at ambient temperature from the sea, from wells, or some other source through a filter to remove entrained solids. At this point, the feed water would normally pass through a vacuum deaerator to remove any dissolved gases. However, since the feed water rate on the Mobile Trailer is relatively small, this item was omitted and the air removal system enlarged to compensate for the dissolved gases in the feed water.

The feed water flows into the system through heat exchangers where the sea water is cooled by heat exchange with the cold brine and the cold product water flowing separately out of the system. This feed water, now cooled almost to its freezing point, is then pumped into the freezer.

Under the influence of the low pressure in the freezer, (about 3.4 mm of mercury) the sea water boils so that part flashes into vapor. In so doing, the vapor extracts its heat of vaporization from the rest of the sea water since no external heat is supplied to cause the boiling. But the bulk of the sea water is already at its freezing point. Therefore, the removal of additional heat from this cold sea water causes a portion of it to freeze, and to give up its heat of crystallization. About 7.5 pounds of ice are formed for each pound of vapor.

Between 30% and 90% of the feed water is converted into pure ice and vapor. Because the salts in this converted portion of the feed water are left behind, the remaining feed water becomes more and more concentrated until it contains 5 to 7% of salts.

The slurry, or mixture of brine and ice crystals, is removed continuously from the freezer and is pumped into the counter-washer. Here the ice crystals are propelled counter-currently to the stream of wash water distributed on the top of the ice pack, and the ice crystals are washed free of all adhering brine solution. The washed ice, now free of salts, is scraped into the melter.

The water vapor produced in the freezer by the simultaneous boiling-freezing process is removed from the freezer by the vapor compressor. It is compressed to an absolute pressure of 4.8 mm of mercury and discharged into the melter. At a pressure of 4.8 mm of mercury, the vapor condenses when

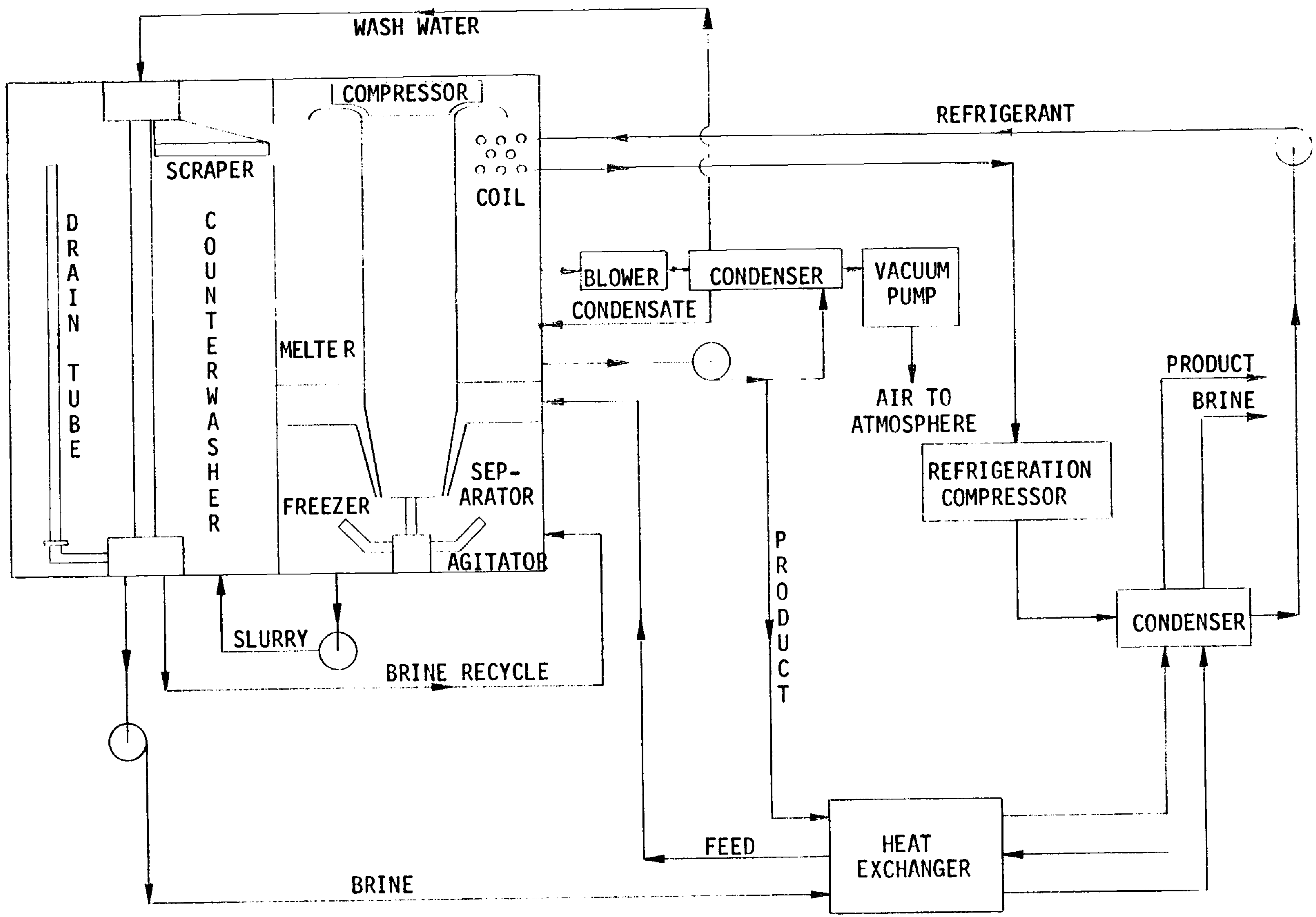


Figure 2

COLT INDUSTRIES VFVC BRACKISH WATER DESALINATION PROCESS brought into contact with the washed ice. As the vapor condenses, it gives up its heat of vaporization and this heat is absorbed by the ice in melting. The condensed vapor and melted ice form cold product water.

The heat transfer in the freezer during the formation of the ice and vapor takes place at the surface of the sea water; and in the melter as the vapor condenses and the ice melts, it takes place at the surface of the ice.

The cold product water from the melter and the cold brine effluent from the counterwasher are discharged through the heat exchangers to cool the incoming sea water. However, some heat still enters the system with the feed water. Also, the energy of the pumps and compressors utilized in the process shows up as heat and some heat enters the system through the insulation. To maintain thermodynamic balance, a refrigerated coil in the melter is used to condense the excess vapor resulting from the loss of ice due to this heat input.

Because the operating pressure is well below atmospheric, some air inevitably enters the system. This air is removed continuously by a combination blower-condenser-vacuum pump system.

Figure 3

MATERIAL AND HEAT BALANCE FOR MOBILE VFVC PROCESS
FOR LOW SALINITY BRACKISH WATER
(Based on Feed Salinity of 0.5% or 5,000 ppm)

		MATERIAL BALANCE		HEAT BALANCE	
		IN lbs/hr	OUT lbs/hr	IN BTU/hr	OUT BTU/hr
Heat Exchanger					
Feed Water		6,390	6,390	1,557,700	1,313,500
Product Water		5,892	5,892	1,190,200	1,412,600
Brine		498	498	99,600	121,400
	TOTAL	12,780	12,780	2,847,500	2,847,500
Freezer					
Feed		6,390	---	1,313,500	---
Recycle		41,307	---	8,112,700	---
Slurry		---	46,920	---	8,438,600
Vapor		---	777	---	987,600
	TOTAL	47,697	47,697	9,426,200	9,426,200
Counterwasher					
Slurry		46,920	---	8,438,600	---
Brine		---	498	---	99,600
Recycle		---	41,307	---	8,112,700
Ice		---	5,427	---	289,300
Wash		312	---	63,000	---
	TOTAL	47,232	47,232	8,501,600	8,501,600

	MATERIAL BALANCE		HEAT BALANCE	
	IN lbs/hr	OUT lbs/hr	IN BTU/hr	OUT BTU/hr
Melter				
Ice	5,427	---	289,300	---
Vapor	777	---	991,300	---
Product	---	6,204	---	1,240,800
Heat Losses	---	---	200,200	---
Heat Removal	---	---	---	240,000
TOTAL	6,204	6,204	1,480,800	1,480,800

Figure 4

MATERIAL AND HEAT BALANCE FOR MOBILE VFVC PROCESS
FOR HIGH SALINITY BRACKISH WATER
(Based on Feed Salinity of 1.7% or 17,000 ppm)

		MATERIAL BALANCE		HEAT BALANCE	
		IN lbs/hr	OUT lbs/hr	IN BTU/hr	OUT BTU/hr
Heat Exchanger					
Feed Water		8,490	8,490	2,058,000	1,726,000
Product Water		5,892	5,892	1,190,200	1,415,600
Brine		2,598	2,598	510,300	616,900
	TOTAL	16,980	16,980	3,758,500	3,758,500
Freezer					
Feed Water		8,490	---	1,726,000	---
Recycle		39,207	---	7,700,300	---
Vapor		---	777	---	987,500
Slurry		---	46,920	---	8,438,800
	TOTAL	47,697	47,697	9,426,300	9,426,300
Counterwasher					
Slurry		46,920	---	8,438,800	---
Brine		---	2,598	---	510,300
Recycle		---	39,207	---	7,700,300
Ice		---	5,427	---	291,200
Wash		312	---	63,000	---
	TOTAL	47,232	47,232	8,501,800	8,501,800

	MATERIAL BALANCE		HEAT BALANCE	
	IN lbs/hr	OUT lbs/hr	IN BTU/hr	OUT BTU/hr
Melter				
Ice	5,427	---	291,200	---
Vapor	777	---	991,300	---
Product	---	6,204	---	1,240,800
Heat Leakage (in the system)	---	---	198,300	---
Heat Removal	---	---	---	240,000
TOTAL	6,204	6,204	1,480,800	1,480,800

III PLANT DESCRIPTION

A. Hydroconverter

The hydroconverter is a cylindrical vacuum vessel fabricated from mild steel. It is 6 1/2 feet in diameter by approximately 8 1/4 feet high, and is composed of four major elements: freezer, carryover separator, melter, and the flexblade compressor. These elements are builtogether as the function of each of these elements depends on the others.

1. Freezer

The lower section of the hydroconverter is used as a freezer. It has an agitator in its center which is belt driven through the bottom of the vessel. The agitator has two arms at 180° apart, and at the end of these arms two pipes are attached in a scoop type fashion. While the agitator is rotating, they scoop water from the freezer pool and throw it on the freezer wall. This creates the effective evaporation surface area required and keeps the ice and brine in a homogeneous mixture. There are four baffles at 90° apart which are attached to the walls and the bottom deck of the freezer. These baffles dampen the vortex effect formed by the rotation of the agitator. At the bottom deck, there is a four inch opening to remove the slurry.

2. Carryover Separator

The vapor produced in the freezer is ducted by a tube extending from the top of the freezer through the center of the melter, which is located above the freezer, to the inlet of the compressor. At the inlet of this tube, extending below it into the freezer, is the carryover separator. This element which reduces the amount of entrained droplets to an acceptable value consists of a multiplicity of flattened aluminum tubes arranged in a conical pattern around the inlet tube and extending downward into the freezer. These tubes are canted at an angle to the periphery of the inlet tube in such a way as to produce a rotational flow of the vapor within the inlet tube. The rotational flow within the inlet tube causes the entrained droplets to impact against the walls of the inlet tube. The sea water or brackish feed water, after precooling in the heat exchanger, flows through the flattened aluminum tubes (separator louvers) internally and is discharged into the freezer through the orifices at the bottom of each louver. The sensible heat in the precooled sea water provides a temperature slightly above the freezing point temperature of the brine in the freezer, and prevents any ice accumulation on the louvers of the separator.

3. Vapor Compressor

The vapor compressor is of the radial type located at the top of the vessel immediately beneath the hydroconverter tankhead, Figure 5. The underside of the tankhead serves as the upper shroud for the compressor. The inlet tube extends from the freezer up through the melter to the compressor. The lower shroud is made of fiberglass and is connected directly to the inlet tube. A diffuser ducts the vapor directly to the melter. Since the compressor is located above the melter, the vapor discharges from the diffuser into the melter at all points around the circumference of the diffuser and, therefore, no scroll is required.

The compressor rotor consists of a slotted hub in which thin flexible stainless steel blades are attached. The flexible blades have epoxy plugs which fit into the slots. When the compressor rotates, the centrifugal force causes the blades to assume radial position. Attached to the bottom of the rotor is a separate inducer for guiding the vapor into the main rotor. The inducer itself is constructed of thin flexible stainless steel blades so located on the periphery of the inducer hub that under the action of centrifugal force, the inducer blades assume the proper inlet angle.

4. Melter

The melter, located in the upper portion of the hydroconverter, surrounds the compressor inlet tube. Ice from the counterwasher is delivered into the volume of the melter by a scraper which scrapes the ice off the top of the counterwasher and dumps the ice through an opening between the counterwasher and the melter into the melter. Ice is distributed around the vapor tube by a melter distributor. The melter distributor has a central bearing mounting and has two rotating arms. Attached to each of the arms is an agricultural type plow which distributes the ice around the vapor inlet tube and creates a large surface area for the condensation. Product water is pumped out of the lower portion of the melter.

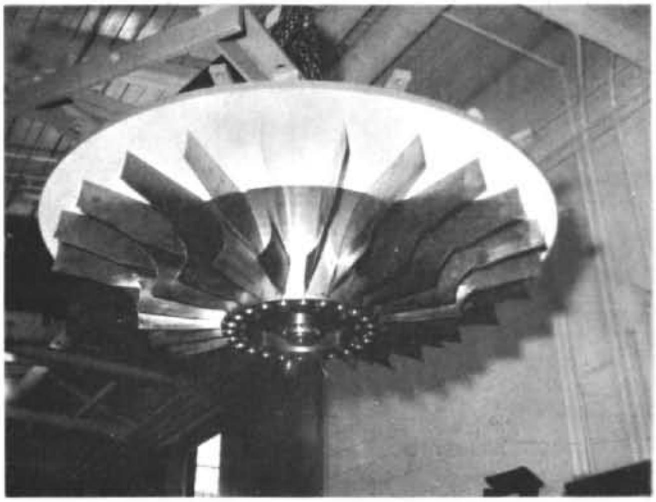


Figure 5

Vapor Compressor

(lower shroud removed)

B. Counterwasher

The counterwasher is a cylindrical vacuum vessel 6 feet in diameter by 8 1/4 feet high.

Slurry is distributed in the counterwasher through an eight outlet, equal path header system which is arranged on the bottom of the counterwasher with the outlets spaced on the mean diameter between the brine storage tank and the outer walls.

The brine drainage system consists of a series of six PVC pipes, four inches in diameter, extending from the bottom of the counterwasher column and up to within a few inches of the top of the ice pack. These drain tubes contain a drainage screen consisting of 1/8" and 1/16" diameter drilled holes to provide adequate drainage area. These screens are located approximately halfway up the column.

The wash header and the counterwasher scraper arms assembly are supported by a four inch steel pipe which extends the length of the vessel. The counterwasher scraper has two arms. Each arm has a set of cutter blades which scrape half the area of the counterwasher. The washer water pipes are located on the back of each arm.

Ice is harvested by each of the scraper arms and distributed to the outside of the counterwasher where, in turn, it is dumped through the opening between the counterwasher and the melter.

C. Heat Exchanger

The sea water or the brackish water required for the process is cooled by a dimpled plate, three fluid, aluminum heat exchanger. The process feed water is cooled by the effluent brine and the product water simultaneously. The plates are 9 3/4 inches wide by 82 1/2 inches long, with distribution ports at each end. The three fluids are ducted through the plates to their respective passages. The passage height is 3/16". The height of the passage is controlled by the dimples embossed on the plate surface. There are three passages for the product, and four passages for the brine. The heat exchanger is designed for 94% effectiveness; i.e, 94% of the heat in the feed water is transferred to the effluent streams.

D. Heat Removal System

Thermodynamic balance of the process is maintained by a heat removal system which consists of a bundle of refrigerated tubes located in the melter just below the main vapor compressor and above the surface of plowed ice in the melter. This coil consists of approximately 247 square feet of 7/8" diameter copper tubes. The coil is cooled by Freon 22. Evaporated F-22 is compressed by a reciprocating compressor and condensed in a shell and tube condenser, cooled by the outgoing product and brine streams. Refrigerant is pumped to the coil where it evaporates. The refrigerant, Freon 22, is in a sealed loop and is isolated from the rest of the system.

E. Air Removal System

The non-condensible gases which enter the system are removed from the melter by a blower, shell and tube condenser, and vacuum pump air removal sub-system. The blower evacuates approximately 2200 cfm of water vapor and air mixture from the melter and discharges it at a pressure of approximately 13 mm Hg to a shell and tube condenser. This condenser is supplied with cold product water from the melter. The bulk of the water vapor condenses and the concentrated air is drawn from the opposite end of the condenser by a vacuum pump and is discharged to atmospheric pressure. The blower is a Roots Connersville type and the vacuum pump is a Stokes.

F. Controls

The control system is designed for full automatic operation of the plant, Figure 6. All the control valves, level controllers, flow controllers, and recorders are pneumatically operated. An air compressor supplies dry air for the controls. A rate controller monitors the feed flow to the process. The slurry flow out of the freezer is fixed by a positive displacement pump. Recirculation of the brine to the freezer maintains the level in the freezer and the ice fraction is controlled by the freezer level controller in such a way as to maintain the recirculation flow equal to the difference between the slurry flow and the feed flow. The slurry flow is always higher than the feed flow in order to maintain a workable ice fraction in the freezer. The flow of brine and product out of the system is regulated through the use of level controls on the counterwasher and melter respectively.

The wash flow to control product salinity can be regulated manually or automatically. A control valve is operated by a sensor that senses the product salinity and fixes the amount of wash water.

The rate of heat removal is controlled by monitoring the amount of ice in the melter. For this purpose, electrical probes are inserted through the peripheral walls of the melter at intervals. They sense the quantity of the ice in the melter and directly control the cylinder cut-outs on the refrigeration machine.

An alarm system is provided for the following: high compressor vibration, low lube oil pressure in any equipment, high or low feed pressure, low product or brine flow, any motor stops, low pressure or high temperature in the closed loop cooling system, high absolute pressure, and low suction or high discharge pressure on the refrigeration compressor.

The alarm system can be operated in either the manual or automatic mode. In the manual mode, an alarm sounds, requiring operator acknowledgement and remedy. Electrical interlocks are provided so that any equipment directly affected by the alarm is shut down and protected. In the automatic mode in the event of any alarm, the entire plant is shut down and isolated to maintain a vacuum on the system. This mode allows for unattended operation with little risk of damage to any equipment. A control schematic is shown in Figure 6.

G. Pumps and Piping

All pumps used in the system have cast iron housings and impellers except the feed pump, which has a stainless steel impeller. The slurry pump is a positive displacement type with stainless steel shaft and cast iron impellers. It discharges a constant slurry flow of 85 gpm to the counterwasher. The product and feed pumps are low NPSH centrifugal pumps, while the brine pumps are of the peripheral type. Two brine pumps are used to accommodate a wide range of brine flows. The refrigerant recirculation pump is of a totally enclosed canned motor type to minimize the possibility of refrigerant leakage.

All the piping in the system is of welded steel construction except the brine drainage tubes and wash pipes, which are of PVC. All the process piping is well insulated.

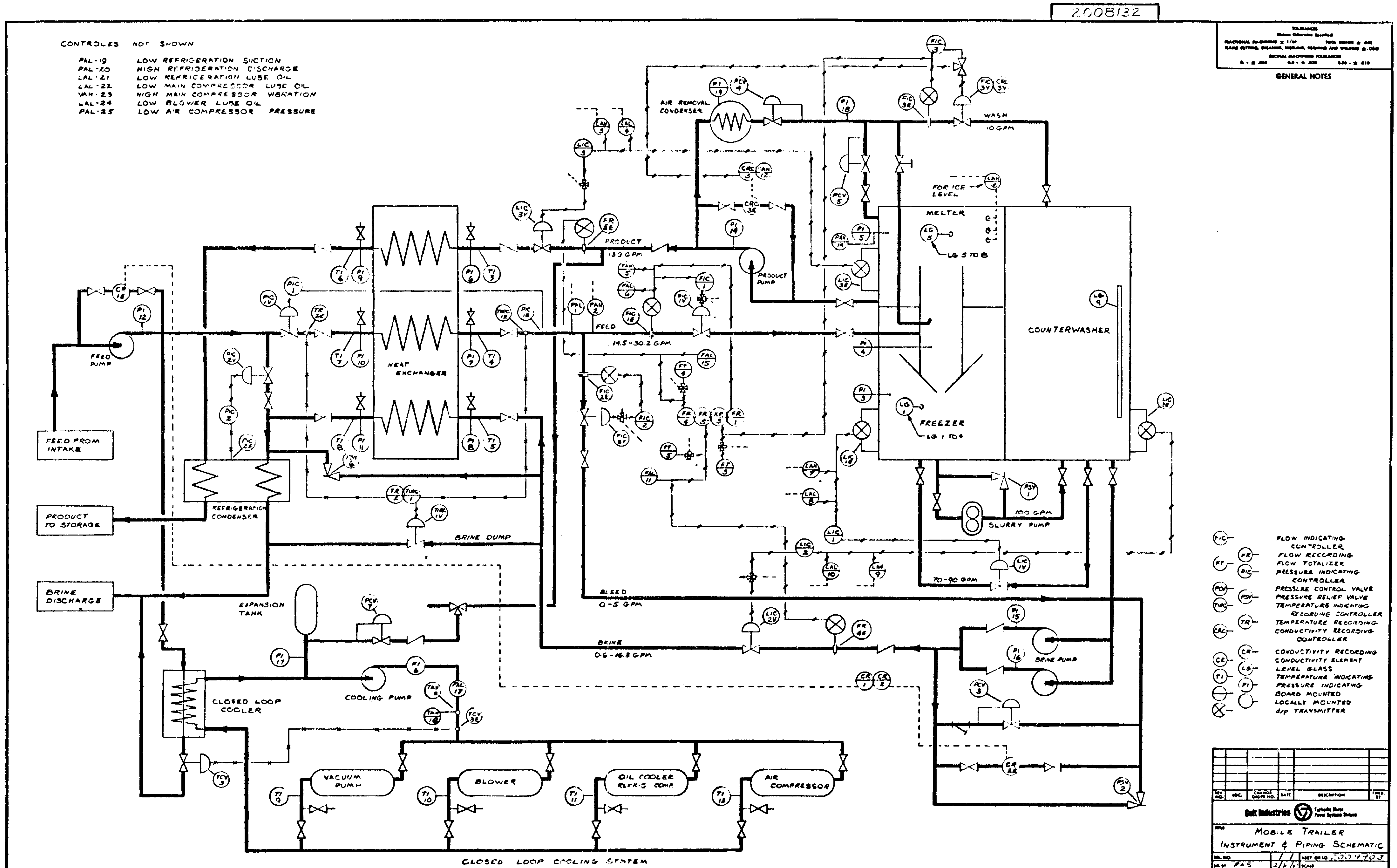


Figure 6 FLOW AND CONTROL SCHEMATIC

H. Closed Loop Cooling System

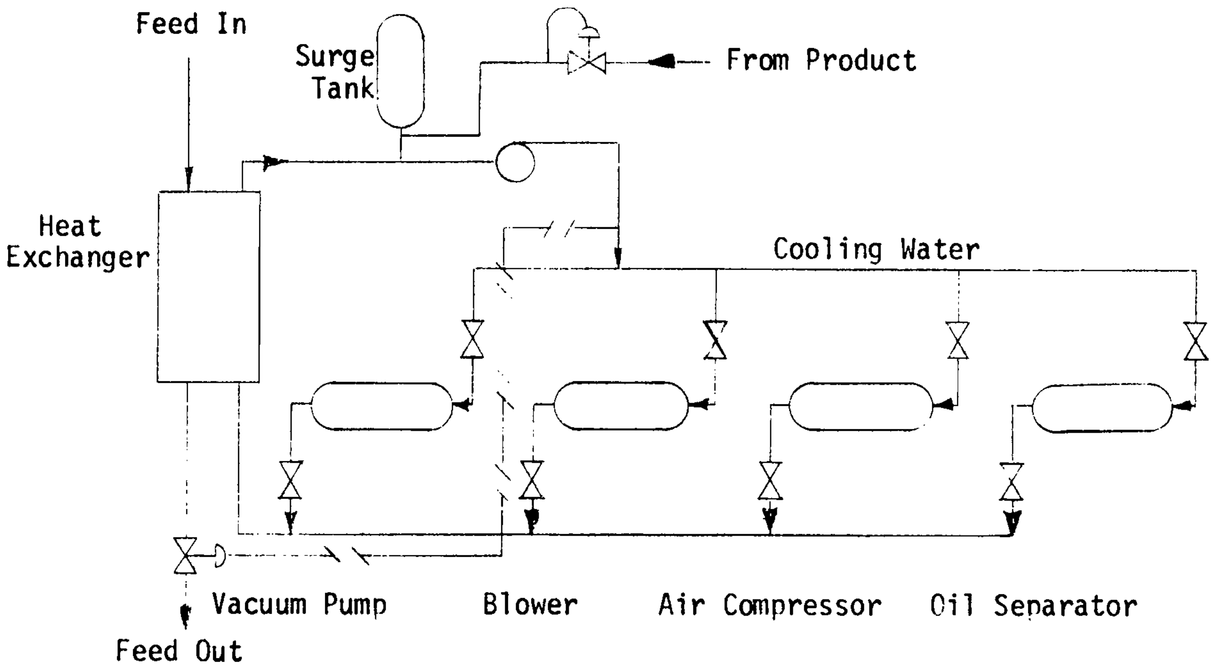


Figure 7

Closed Loop Cooling System

It is necessary to control the temperature of the lube oils in the vacuum pump, air removal blower, and compressor for the control system, and the oil separator in the refrigeration system. A closed loop cooling system is designed to control these temperatures.

The closed loop cooling system consists of a small shell and tube heat exchanger, a small builtogether pump, a temperature control valve, and a pressure control valve. The piping is similar to that shown in the above schematic. The closed loop system is charged with water which circulates through the cooling systems of the above components. Heated water is then introduced into a small heat exchanger which is cooled by part of the incoming feed water. This heated feed is discharged with effluent brine. A temperature control valve maintains a fixed temperature of the cooled closed loop fluid. A pressure control valve automatically adds product water to the system if the pressure drops.

IV MONTHLY SUMMARIES

June 1968

Installation of process vessels and piping were completed. The vessels, refrigeration coil in the melter, and the heat exchanger were tested for leaks. Small leaks were discovered and were fixed. The main vapor compressor was assembled.

July 1968

Manufacture and factory checkout of the Mobile Trailer were completed and an air leak rate of less than 4 liters per minute was obtained. A leak in the refrigeration coil was found and repaired. The main compressor was balanced at 3600 rpm, and was spun at the desired speed of 7800 rpm.

August 1968

After a road test, the unit was shipped to Wrightsville Beach for initial checkout of the system.

The unit arrived in generally good condition on August 12, 1968, although there was some minor shipping damage which was repaired.

Sea water and electrical connections were completed, and preliminary checkouts made. Controls were zeroed and calibrated. Electrical connections and motor rotations were checked out.

September 1968

Operational checkout of the unit began on September 5. The refrigeration system was charged, flows were established, and minor pump problems were corrected. The main compressor was started on September 13, but the driving cog belt slipped. The belt was tightened, and the compressor was started. The lower bearing in the compressor failed as the compressor approached peak speed of 7800 rpm. This failure was caused by misalignment of the compressor drive shaft because of over-tightening the belt to prevent slippage. Considerable damage was caused to some of the inducer blades, main blades, shroud, tankhead, and oil slinger. A three-bearing compressor drive shaft was designed to take the increased bending load. Two idlers were also used to increase the belt contact area in order to reduce tension requirements. Temperature and salinity indicator controllers were checked out, and the insulation on the unit was coated with fiberglass cloth and resin.

October 1968

The main compressor drive rework was completed. The main compressor was then operated at 3600 very smoothly, but at 7800 rpm before reaching full speed, two blades pulled out of their mounting and sheared off the next two blades. Four 1/8" diameter pins were installed in the plug of each compressor blade to prevent blade pull-out, Figure 10. Two blades were tested at 7800 rpm first, and then the rest. Balancing of the compressor was begun.

November 1968

During November, the Mobile Trailer was operated for a total of 17.5 hours. Production rates from the unit reached about 10,000 gpd with acceptable product water. The first part of the month was devoted to solving the problems in the compressor drive and balancing the compressor. During the operation in the later part of the month, the brine drainage screen section in the counterwasher was found to be frozen, and a steady brine level in the counterwasher could not be maintained; hence, continuous operation was not possible.

December 1968

The unit operated over 70 hours during December at its rated capacity of 15,000 gpd. Extended operation of the unit was not possible due to freeze up of the brine drainage screen section in the counterwasher. Several tests were conducted to determine if this problem could be eliminated by an operational procedure. The results of the tests were negative. On December 20, the plant was shut down to modify the brine drainage section.

January 1969

The plant continued to be plagued by freeze up problems in the counterwasher. Five significant tests were conducted during the month of January 1969. The untt was operating at 120% of its rated capacity on all occasions. At the end of these tests, it was concluded that freezing of fresh water to inner column of the counterwasher was still the major problem. This was caused by the adverse thermal gradients existing in the column. These gradients resulted from the temperature differential between the brine in the bottom of the column and the washed ice at the top. The freezing was caused by conduction through the metal drainage section. Operation of the unit was stopped on January 22 to install six PVC brine drainage tubes and to prepare the unit for shipment to Roswell, New Mexico.

February 1969

During February, the unit was transferred to Roswell, New Mexico. The water analysis laboratory was also shipped to Roswell at the same time so that it could be utilized in conjunction with the test unit. Both units arrived in good shape. All the utilities were connected to the units. Preliminary checkouts were completed and the controls were re-calibrated.

March 1969

Operation of the unit during March was limited to checking out the unit. Initial tests indicated a capacity of 19 to 22,000 gpd at a yield of 65%. The newly installed brine tubes performed well, and no freeze up in the counterwasher or difficulty in washing was encountered.

As the unit was operated on a high feed rate, some freeze up of the carryover separator was observed. Investigation revealed that at a flow rate of 18 gpm or higher, there was no flow through the separator or the cone. An overflow loop is built into the feed line to the separator, and when the flow was increased above 18 gpm, water was siphoned through this loop causing most of the feed to bypass the separator and allow it to freeze. A valve was installed in the overflow line to eliminate this flow from the system.

April 1969

The test unit operated for 90 hours during April. Production rates from the unit were in excess of 15,000 gpd on all occasions with rates above 20,000 gpd achieved during several of the tests. A total of six test runs were completed, the longest being 25.8 hours. The plant was operated on automatic mode on several occasions. No problems with this system were encountered. No evidence of scaling, precipitation, or corrosion were observed.

During this period, a problem of ice pack cracking and slurry channeling through it was observed. Observations revealed that the slurry nozzle nearest to the place the ice pack was cracking was causing some turbulence when the ice pack was forming at the point where the slurry flow impinged on the counterwasher wall. The slurry nozzles were turned so that they were tangential, and this turbulence was eliminated.

May 1969

The plant operated for 116.6 hours during May producing 50,584 gallons of fresh water for an average production rate of 10,390 gallons per day. Ice pack split and slurry pump problems hampered the continuous operation of the unit. However, during the period from 5/20 through 5/23, the plant operated for 77.75 hours with only short shutdowns. The exact cause of a noise emanating from the slurry distribution system was checked out for blockages. No blockage was observed.

June 1969

The test unit was operated for 109 hours during June producing 26,030 gallons. Sustained operation was not possible as attempts were made to eliminate the recurring noises in the slurry pump and ice pack split in the counterwasher by varying process conditions. The slurry pump was taken apart and inspected. Nothing could be found to explain its noisy operation, and the slurry pump was lowered by 12 inches. Steps were taken to reduce the splashing in the freezer in order to lower the separator loading by increasing the agitator diameter, lowering its speed, and reducing the size of the baffles in the freezer.

July 1969

Only 51 hours of operation were possible during the month of July. No operation was possible until July 16 due to the lack of feed water from the station and maintenance required on the air removal blower. Continuous operation could not be sustained due to severe cavitation of the slurry pump. Inspection of the counterwasher and freezer showed a considerable amount of sand and silt which was attributed to the new feed booster pump which the station had installed. In the last week of the month, the timing belt on the compressor drive was replaced by four V-belts. These belts allowed longer periods of operation and eliminated the high pitch noise emanating from the timing belt.

August 1969

The test unit was operated for 156.2 hours during August producing 17,977 gallons. The design capacity could not be achieved due to severe cavitation of the slurry pump. A number of modifications were tried which resulted in removing the slurry inlet nozzle from the freezer. As the approach temperature was quite high on the heat exchanger, the heat exchanger was disassembled and inspected. A considerable amount of sand and silt was found in the sheets. This was caused by the addition of a booster feed pump by the Roswell Test Station to augment the feed supply. Analysis of the sample revealed no sign of corrosion, scaling, or precipitation. However, colonies of anaerobic bacterias which were very active during the down time of the unit were found on the sheets. A simple detergent washing removed them.

September 1969

The test unit operated for 162.6 hours during September. The first ten days of the month were utilized in completing the counterwasher modification in which the two-foot diameter center column was replaced by a four-inch steel pipe, assembly of new wash lines, and cleaning of the internal flow passages of the droplet separator which was partially plugged with sand and silt.

Four long operations were achieved between 30 and 55 hours. During one of the operations, grinding noises could be heard emanating from the main compressor drive. Disassembly of the compressor showed the plastic cage of one of the bearings was cracked. The blades were in good condition. The bearings were replaced and the compressor was reassembled. Agitator tests were made during the down time and revealed a heavy splashing of the agitator liquid in the freezer through the separator louvers. This splashing was reduced by lowering the liquid level in the freezer. Removal of the two-foot diameter center column in the counterwasher and lowering the liquid level in the freezer eliminated the ice pack split and freezing of carry-over separator respectively.

October 1969

The unit operated for 161.7 hours during the month of October, producing 44,700 gallons of potable water. Until October 16, no operation was possible as the unit was moved to a different location on the Roswell Test Site at the Station's request, and the utilities were not restored to the unit until the 15th. Short tests were carried out with a low feed rate of 8 gpm. Samples of the brine effluent were collected, and the brine concentration was measured from 7.5 to 8.0%, giving a 70 to 80% process yield.

The sheaves on the main compressor motor were changed to reduce the compressor speed from 7800 rpm to 7300 rpm. Ice-sensing probes in the melter for the refrigeration machine unloaders were installed at 40% and 70% of the melter capacity rather than 70% and 85%. Both of these changes resulted in increased stability of the unit. Unattended automatic operation of the unit was demonstrated at the end of the month.

November 1969

Successful unattended automatic operation was achieved for nearly three days during November. The total operation of the unit during November was 105.7 hours, producing 36,047 gallons of fresh water. Due to extremely cold weather conditions during the second half of the month, operation of the unit was not possible. Most of the water had to be drained from the unit to prevent freeze damage to system components. The Mobile Trailer was not equipped to operate at ambient temperatures below the freezing point. Operation was, therefore, terminated and the unit was secured. A post-trial inspection was conducted which revealed no evidence of precipitation or scale in major system components.

A production summary follows.

PRODUCTION SUMMARY

MONTH	MONTHLY PRODUCTION (gallons)	CUMULATIVE PRODUCTION (gallons)	OPERATING TIME (hours)
August 1968			
September 1968			
October 1968			
November 1968	11,728	11,728	17.45
December 1968	12,158	23,886	72.15
January 1969	18,093	41,979	57.41
February 1969	---	41,979	---
March 1969	19,116	61,095	50.55
April 1969	37,793	98,888	90.97
May 1969	50,484	149,372	116.6
June 1969	26,030	175,402	109.0
July 1969	6,766	182,168	51.0
August 1969	17,977	200,145	156.2
September 1969	26,754	226,899	162.61
October 1969	44,700	271,599	161.7
November 1969	36,047	307,646	105.7
December 1969	---	307,646	---

V DISCUSSION OF OPERATION

A. Wrightsville Beach, North Carolina

The overall operation of the unit can be divided into two different operations. The first was more mechanically oriented. The unit was shipped to Wrightsville Beach, N. C. for initial checkout of the system and components, and to operate on sea water to checkout the process. The checkout of the system began after connecting the utilities to the unit. Motor rotation and pumps were checked out. Two pumps developed leaks, which were repaired. The controls were recalibrated as much of the tubing had come loose and the controller recorders were damaged during the shipment from Beloit, Wisconsin to Wrightsville Beach. The refrigeration system was charged with F-22. The system was thoroughly checked for air leaks and an air leak rate of 4 liters per minute was obtained. The unit was ready for the initial check of the process components.

After cooling down the system, the main compressor was started. Before the compressor could reach the peak speed of 7800 rpm, the lower bearing of the compressor drive failed, resulting in considerable damage to the main and inducer blades, tankhead, shroud, and oil slinger. A thorough investigation revealed that the compressor drive was misaligned because of the need to over tighten the belt to prevent slippage. A new compressor drive with three bearings was designed to take the bending load that resulted from over tightening. Two idlers were installed on the drive to increase the belt contact area and reduce the tension.

Following this modification, the compressor operated very smoothly at 3600 rpm; however, at 7800 rpm under some high stresses, two main blades pulled out of their plugs and damaged the following two. To strengthen the plug, four 1/8" diameter pins were installed in the plug of each compressor blade. The compressor drive problems were solved and balancing was completed.

The unit was operated and its rated capacity of 15,000 gallons per day was achieved; however, continuous operation could not be achieved due to freezing of fresh wash water on the central brine extraction column. Minor modifications were made to the brine extraction system, but the results were negative. Six PVC brine drainage tubes were installed in the counter-washer which had proven to be an effective method of brine extraction on our experimental plant in Wrightsville Beach.

B. Roswell, New Mexico

Brackish water found in the grounds of New Mexico has a high calcium sulphate content and the salinity of the water is about 1.6%. The salt concentration of this water is one of the highest in the nation.

The Roswell operation was mostly process operation. No difficulties whatsoever were encountered in achieving the design capacity of 15,000 gallons per day. Capacities over 20,000 gallons per day were achieved. The unit was operated with different process conditions by varying the feed flow, approach temperature to the hydroconverter, and controlling the heat removal system. The yield of the unit ranged between 2% and 8%. From time to time, the unit components were opened to observe any evidence of the precipitation, scaling, or corrosion. No evidence of any scale or precipitation was found.

A continuous three-day unattended and automatic operation of the unit was attained in November with 57% yield from the unit. During the period from March to October, 1969, some mechanical problems were encountered. In the beginning, the slurry pump developed cavitation after several hours of operation. A thorough check and inspection of the slurry suction and discharge and distribution did not reveal anything which would lead to cavitation. However, after removing the inlet slurry suction nozzle, cavitation was eliminated. Another problem was ice pack splits in the counterwasher. After a careful study of slurry distribution and ice rise rate, the central brine extraction tank was removed and replaced by a 4" steel post which supports the scraper and wash distribution system.

No ice pack split problems were encountered since then. Some maintenance work was required on the air removal blower and main compressor. The position of the ice sensing probes was moved to a different location to give more stable operation. The main compressor was slowed down from 7800 rpm to 7300 rpm to reduce the capacity closer to the design value of 15,000 gpd and to promote greater mechanical reliability.

No pretreatment of the feed water was required, contrary to other processes operating on this water. The feed water was pumped directly from the well through a strainer into the process. Problems with calcium sulphate scale which plague other processes are eliminated in the VFVC Process because of its low temperature operation and the use of direct contact heat transfer which eliminates scale collecting heat transfer surfaces.

VI COMPONENT EVALUATION

A. Vapor Compressor

The vapor compressor on the Mobile Trailer unit was designed and manufactured in Beloit, Wisconsin. The nominal capacity of the compressor is 50,000 cfm. Over 1150 hours of compressor operation were logged during January 1969 through November 1969. The vapor compressor has performed satisfactorily during 1969. A number of extended and short-term tests were carried out at different capacities and yields by varying the feed water temperature and flow rate. The production range varied between 10,000 gallons per day to 22,000 gallons per day. During the down time, the compressor blades were checked for evidence of salt deposits. The procedure of washing the compressor blades was eliminated as no salt deposits were observed on the blades.

Initial operation of the vapor compressor was hampered due to slippage of the drive cog belt, misalignment of the compressor drive shaft, main blade failures, and vibration due to unbalance.

The cog belt on the compressor drive needed excessive tightening in order not to slip during its acceleration. This over tightening of the belt caused misalignment of the compressor drive shaft. During compressor acceleration, the lower bearing in the compressor failed. The compressor shaft was cocked and caused damage to the inducer blades, compressor blades, shroud, tankhead, and oil slinger. Figure 8 shows a picture of the damage.

A new drive was designed which reduced belt tension. It consisted of three bearing compressor drive shaft to take the bending load, two idlers to increase the belt contact area to reduce the tension requirement. Figure 9 shows the new drive system.

The new drive was installed and the compressor was operated. This time in its accelerating period, two main blades pulled out of their mounting and sheared off the next two blades. However, no damage was done to the other parts of the compressor. Four 1/8" diameter pins were installed in the plug of each compressor blade, Figure 10.

During the balancing period of the compressor, it was found that the hemisphere on the compressor rotor was cocked and inducer blades were rubbing against the main rotor blades causing some removal of metal from the compressor blades.

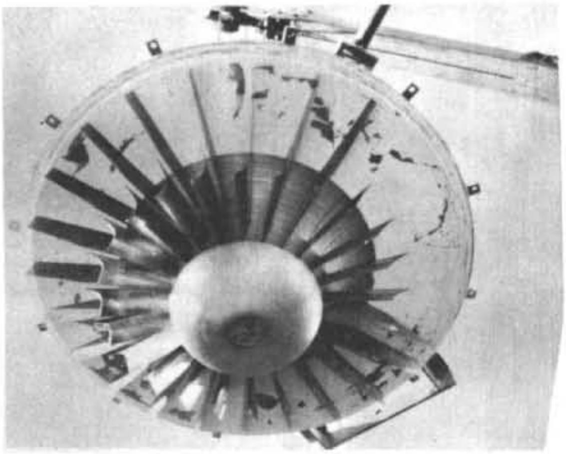


Figure 8

Damaged compressor after blade failure. Note missing blades on right side of compressor

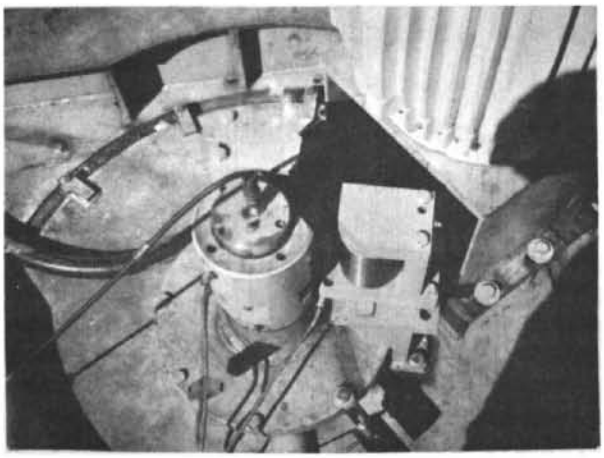


Figure 9

Compressor drive system with third bearing and idlers installed

Figure 10

Compressor blades with pins installed in epoxy plugs

Inducer blades and the hemisphere were removed. The compressor was operated without the inducer blades.

Periodic maintenance on the compressor drive was required. The timing cog belt showed an excessive amount of wear. This timing belt was replaced by four V-belts. The change of belts allowed longer periods of operation and eliminated the need for idlers.

B. Counterwasher

The counterwasher plays a very important part in the VFVC Process. The ice is extracted and washed in this column. The original counterwasher consists of a six foot diameter vessel with a 24 inch diameter center column. This column had 24 inch high brine screen section in the middle made of perforated PVC sheet while the rest of the column was of steel.

After a few initial tests, it was evident that the brine level in the counterwasher could not be controlled. Brine drainage column modifications were made by changing the size of perforated holes on the brine screen and lowering the brine screen section. In both cases, the result was flooding brine out of the counterwasher. Considerable evidence of hard ice build up on the brine screen section was found, Figure 11. The problem was traced to adverse thermal gradients between the brine near the center of the column and washed ice at the top. Even though the drainage screen section was made of PVC, the rest of the column was of steel and allowed conduction to cause freezing of wash water on the column.

Six all PVC drainage tubes were installed in the counterwasher equidistant from the inner and outer columns of the counterwasher. The low thermal conductivity of PVC has prevented any significant conduction of heat from brine to the washed ice.

Another problem encountered with the counterwasher was ice pack splits after several hours of operation. The original counterwasher was designed for 15,000 gallons per day capacity with affixed ice rise rate of 183.5 lbs/hr. ft^2. However, in Roswell, New Mexico where feed water salinity ranges between 1.6 and 1.7%, the capacity of the unit was exceeding well over 15,000 gallons per day and the ice pack rise rate was calculated to be 245 lbs/hr. ft^2. The pack rise rate exceeded 30% of the designed capacity. Removing of the center brine drainage column which was not being used helped to stabilize the ice pack. The center column was replaced by a 4" diameter post. Ice pack rise rate with this configuration was calculated to be 217 lbs/hr. ft^2. No ice pack split problems were encountered after this modification, and the counterwasher and brine drainage system performed effectively.

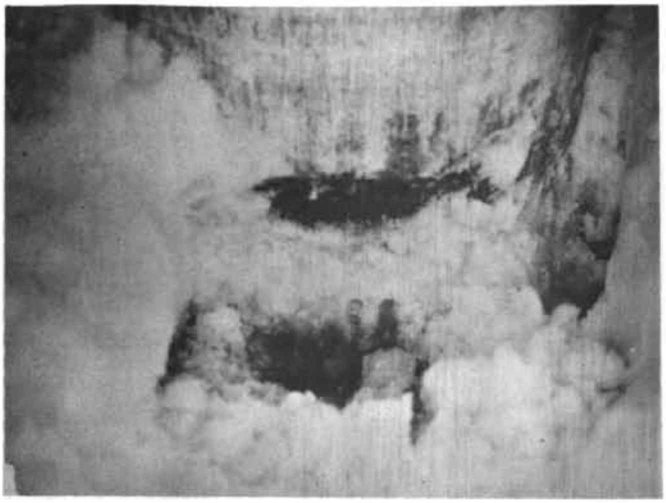


Figure 11

Frozen screen section in counterwasher.

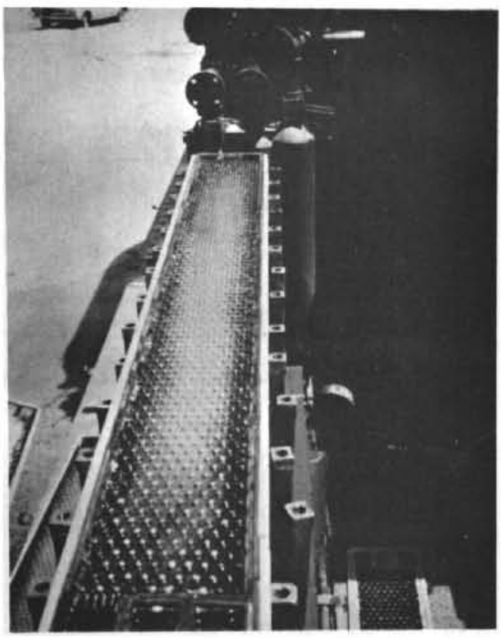


Figure 12

Feed heat exchanger before cleaning.

C. Heat Exchanger

The three-fluid heat exchanger on the mobile VFVC unit is a dimpled plate type, manufactured by Colt Industries Inc. This heat exchanger has 14 passes and 10 sections. Each section consists of 15 dimpled sheets. It is so arranged and stacked that the feed water flows through 7 passes, and the brine and product through 4 and 3 passes, respectively. The effective heat transfer area per plate is 3.31 ft^2. From the thermodynamic point of view, the heat exchanger has performed very satisfactorily. Approach temperatures of about 1°F on the hot end, and 4°F on the cold end were possible. However, process conditions required the feed temperature at the inlet to the hydroconverter at 40°F or above on brackish water and, therefore, the heat exchanger was not fully used. Either effluent brine or product was bypassed. Exact evaluation of the heat exchanger performance has not been possible due to normal flow fluctuation and the process conditions which led to bypassing the product and brine. Because of the high design effectiveness of the heat exchanger (about 94%), extremely accurate measurements of the flow and temperature would be required for an exact analysis. However, since the feed temperature could be controlled at any temperature required, the effectiveness of the heat exchanger was always satisfactory.

During the entire 17 months of operation, the heat exchanger was taken apart three times: 12/11/68 at Wrightsville Beach, and 3/17/69 and 8/14/69 in Roswell. On the first two occasions, there was absolutely no evidence of any scale or precipitation on the sheets. However, on the first occasion in Wrightsville Beach, a fine film of sand and silt was observed which was washed down. On the first occasion in Roswell, the heat exchanger was taken apart to clean the plugged port holes on the product side. Disassembly revealed that the product side of the heat exchanger was plugged with debris from modifications which were carried to the top of the ice pack, from there they went to the melter with the ice, and then to the product side of the heat exchanger. No trace or any sign of any precipitation or scale was observed.

After a long period of shutdown in the months of July and August 1969 for modification, the unit was restarted again, but this time the feed temperature could not be controlled as desired and it was evident that effectiveness of the heat exchanger had dropped considerably. The heat exchanger was taken apart. On disassembly, the heat exchanger sheets were found to be covered with black, brown, and white patches. These patches were arranged in a definite pattern. Black patches were seen along the rubber gasket, brown patches were in the middle area, and the white patches were dispersed very thinly. The thickness of these patches was less than one milimeter. A sample of these patches was collected for thorough laboratory analysis. The following paragraph is taken from the laboratory analysis done by the station chemist at the O.S.W. Roswell, New Mexico Test Facility.

> Date of Sample Collected: 8/14/69
> Source: Colt Industries Heat Exchanger
> Date of Analysis Reported: 9/2/69
>
> 'Bacteria cultures taken from the heat exchanger of the Colt Industries desalination unit revealed the presence of 1,000 to 10,000 colonies of anaerobic bacteria per cubic centimeter and less than ten colonies of aerobic bacteria per cubic centimeter. The generally good condition of the plates from the heat exchanger after cleaning tends to indicate that the problem is one of bacteriological fouling by the anaerobic bacteria rather than one of corrosion or scaling.'
>
> 'Anaerobic bacteria would be particularly active during down time when the water in the heat exchanger becomes stagnant. It was recommended that the heat exchanger be either drained or that water be continuously circulated through it when the unit is not operating.'

A simple detergent washing of the plates with a broom removed most of the bacteriological colonies, Figure 12. Following this cleaning, the heat exchanger was operated over 500 hours further. No difficulty was encountered in controlling the feed inlet temperature to the hydroconverter.

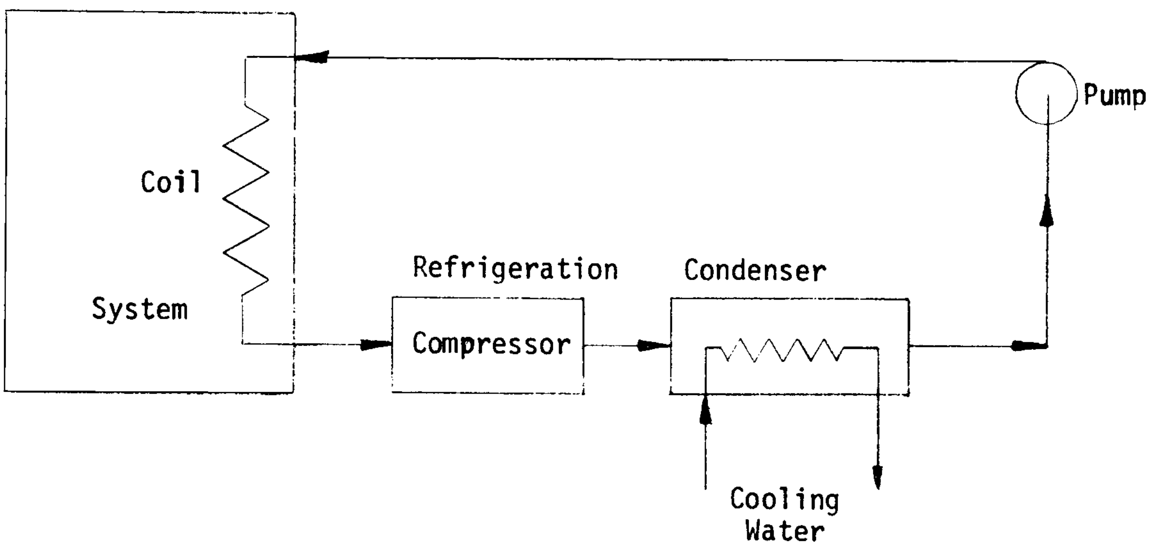
D. <u>Refrigeration System</u> (Heat Removal Unit)

Since the VFVC Process operates below ambient temperatures, all of the work put into the system is converted into heat which must be removed to maintain the thermodynamic balance of the system. This is done by means of a refrigeration system.

The heat removal system consists of a reciprocating multi-cylinder compressor, a refrigerant pump, condenser, oil separator, and evaporating coil where the refrigerant is evaporated. A schematic of the refrigeration system is shown on the next page.

Figure 13

Heat Removal Control System
Schematic



Refrigerant F-22 is used in the system. The refrigeration compressor can be operated at 100%, 66%, or 33% of its capacity, depending upon the quantity of ice in the melter. Ice sensing probes are installed in the melter at two different locations which automatically unload or load the cylinders of the compressor when they come in contact with the ice. The entire refrigeration system has operated very efficiently and satisfactorily.

The only preventive maintenance required for this system is checking and preventing any F-22 refrigerant leakages at the flanges, valves, and fittings.

E. Pumps

No difficulty or problem was encountered with any pumps except the slurry pump. A general pump inspection revealed all the pumps are in good condition. During the operational checkout period in Wrightsville Beach, N. C. the slurry pump had cavitated under vacuum. To eliminate this problem, the inlet suction nozzle of the slurry pump was increased from 3" diameter to 4" diameter, and the original speed was reduced by 20%. Under different process conditions in Roswell, severe cavitation developed after several hours of operation. This cavitating noise could be stopped by adding hot feed to the freezer. This suggested that there was some kind of ice stratification in the freezer. To improve the suction head, the pump was lowered by 12". This did not improve the cavitation. Several changes were made to the freezer baffle configuration and the suction inlet nozzle of the slurry pump. These changes did not improve the performance of the pump. Cavitation still recurred after several hours of operation. As a drastic measure, the suction inlet slurry nozzle was removed from the freezer, which improved the performance of the slurry pump considerably. Cavitation of the pump was eliminated, but stratification of the ice in the freezer still existed. This problem was eliminated by increasing the pump speed to the original, thereby increasing the recycle flow and, hence, reducing the slurry ice fraction in the freezer. No further problems were encountered.

F. Controls

The control system on the Mobile Trailer unit is designed for complete automatic, unattended operation. Once the steady state is reached, the plant can be operated on automatic mode. Since all the controls are a function of each other, they vary in their given range. All the pertinent information is recorded on charts. The control system consists of:

1. Feed flow rate
2. Freezer level
3. Counterwasher level
4. Melter level
5. Wash flow rate controller
6. Feed temperature to hydroconverter controller
7. Product salinity controller
8. Refrigeration controller

The first five controllers are controlled by sensing a differential pressure with a conventional pneumatic force balance d/p cell which is used in association with a pneumatic controller and control valve to control the desired variable. No specific problems were encountered with any of these controllers except a periodic maintenance and cleaning.

The feed temperature controller controls the temperature of the feed going to the hydroconverter for various process yields. A thermal bulb senses the temperature of the cold feed after the heat exchanger, a recorder records it, and the controller converts it into an output signal which controls the brine dump valve. If the temperature of the feed is below the set point, the brine dump valve opens proportionately and cold brine is bypassed around the heat exchanger, raising the feed temperature. This thermal bulb was damaged in shipment to Wrightsville Beach. After repairs, this controller performed satisfactorily.

The product salinity controller consists of a conductivity cell, an automatic temperature compensator, recorder, and controller. Corrected conductivity is recorded directly in ppm of Total Dissolved Solids. The controller output signal operates the wash control valve. The product salinity controller can be operated in manual or automatic mode. This system has been very useful for automatic operation.

The refrigeration controller system consists of two pairs of electrodes, Figure 14.

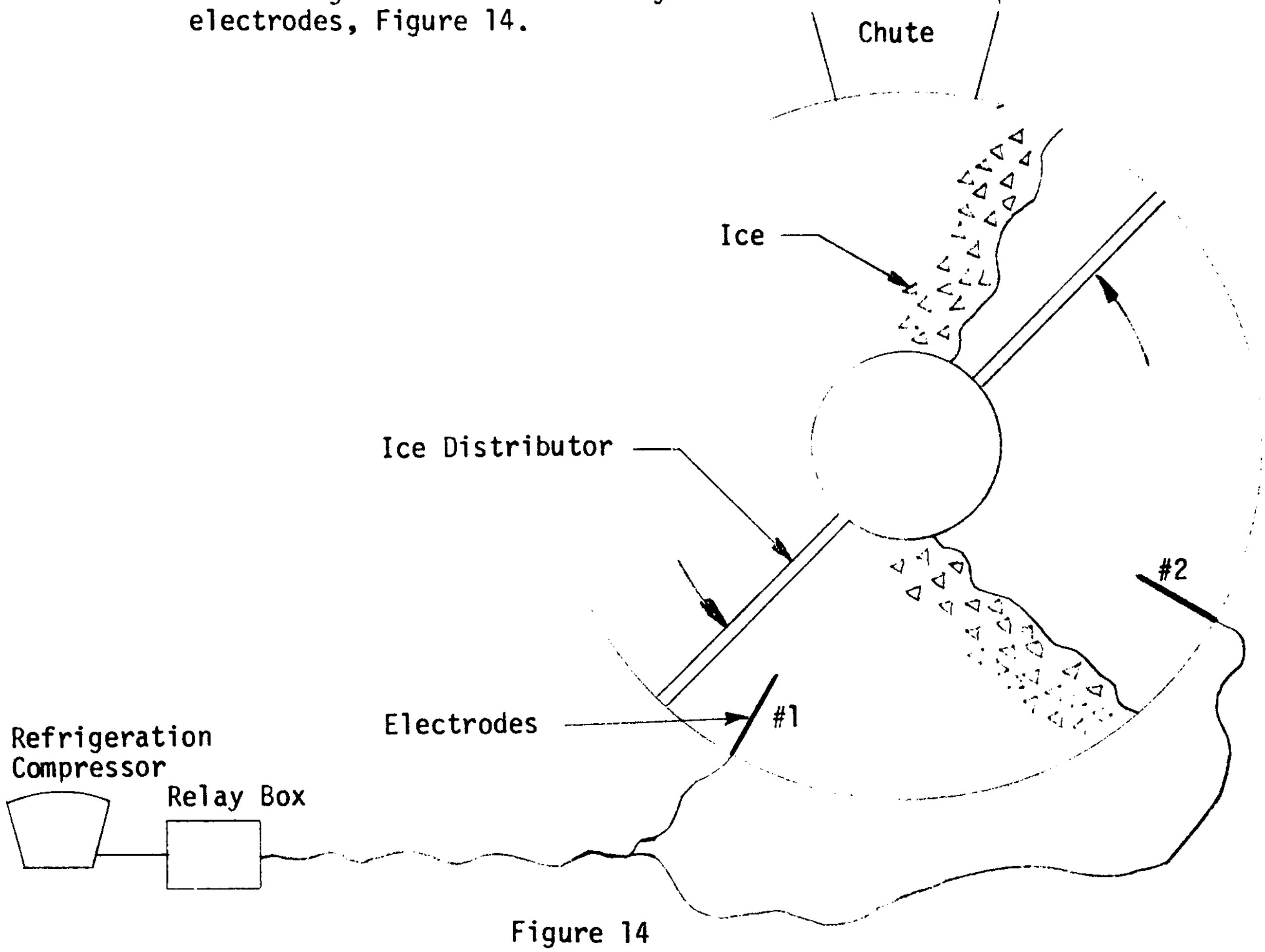


Figure 14
Refrigeration Controller

Ice fills the melter in a counterclockwise manner. The refrigeration system operates at 100% capacity. When ice makes contact with the first pair of electrodes, through a relay one cylinder on the refrigeration compressor is unloaded and the refrigeration system capacity drops to 66.66%. As ice continues to fill the melter, it makes contact with the second pair of electrodes, and again the refrigeration system capacity drops by 33.33%. The procedure is reversed when the ice is not in contact with the electrodes.

This system of controlling ice in the melter has operated well.

Melter probes were located at 70 and 85% of the melter capacitance. Due to small capacitance of the melter, the location of the probes was changed to 40 and 70% capacitance to give a more stable operation.

G. Freezer

Based on performance and the geometry of a freezer employed on a larger VFVC Process, a scaled-down freezer was designed for the Mobile VFVC Process. Tip speed of the agitator was designed at 26 feet per second at 233 rpm with an expected design heat transfer coefficient of 30,000 BTU/hr ft^2 °F. Results were extremely satisfactory. Heat transfer coefficients were measured 33% higher than the design point. However, due to extremely agitated pool, a tremendous amount of splashing on the carryover separator was observed. This resulted in increased heat loading on the carryover separator and caused it to freeze. After a few tests, the tip speed of the agitator was reduced to 20 feet per second at 150 rpm. This, and a lower liquid level in the freezer, reduced the heat load on the separator. The resulting heat transfer coefficient was calculated at 29,500 BTU/hr ft^2 °F, which was still close to the design value.

H. Melter

No experiments were conducted to evaluate the performance of the melter. The heat transfer coefficient calculated ranged between 7,000 and 10,000 BTU/hr ft^2 °F.

I. Carryover Separator

The carryover separator used on the Mobile Trailer is of the centrifugal type and consists of hollow guide vanes. These guide vanes induce a swirling motion in the vapor flow, and cause the entrained droplets to impact against the wall of the inlet tube. The carryover separator was very effective.

There was absolutely no evidence of any salt build up on the compressor blades or the rotor. However, a problem of freezing of louvers was encountered. This problem was traced to the heavy splashing of the agitated liquid on the vanes. After reducing the speed of the agitator and lowering the level in the freezer, this problem was eliminated.

J. Air Removal System

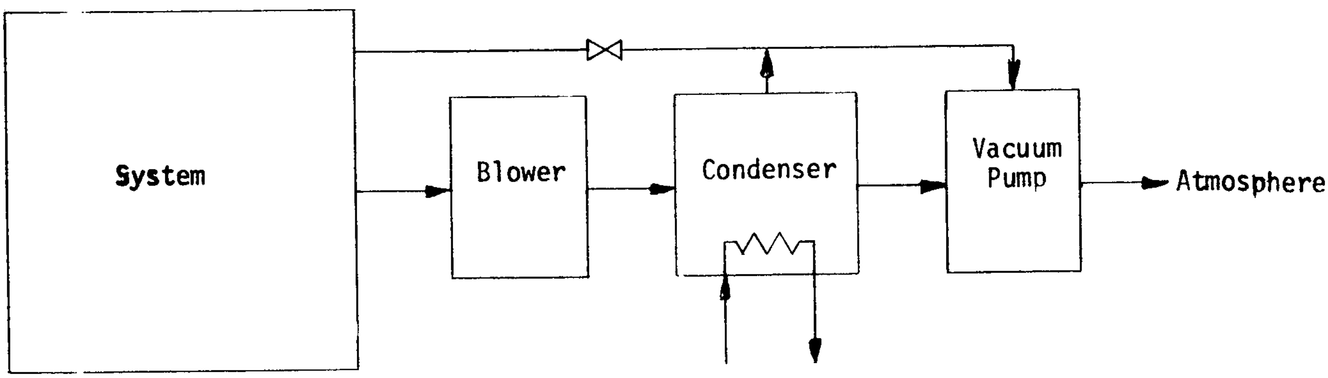


Figure 15

Air Removal System

It is desirable to maintain low air partial pressure in the melter because high air partial pressure reduces the system capacity. In the case of high air partial pressure, there is a gas layer at the ice vapor interface, and the water vapor must diffuse through this layer in order to condense on and melt the ice. When the air concentration increases, the diffusion resistance increases. Thus, the bulk vapor partial pressure increases to compensate for the added resistance. The resultant, higher melter pressure throttles the compressor and reduces the system capacity.

There are two sources of non-condensibles in the system: gases dissolved in the feed water, and air leaks in the system through the flanges, valves, seals, and inevitable other leaks.

The air removal system consists of three main components and piping. A schematic is shown above. These components are: blower, vacuum pump, and condenser. All of these items are furnished by vendors.

1. Blower

A 2400 cfm blower is a positive displacement type unit furnished by Roots Connersville Company. This unit is self-lubricated throughout by a completely self-contained circulating oil system. The oil system consists of an oil sump and the oil pump, which is flange mounted to the gear housing and direct driven from the upper impeller shaft. Its suction line is protected by a mesh type strainer. Discharged oil is cooled by an external sump mounted oil cooler.

This blower has been a reliable piece of equipment on the trailer unit. Its large volume capacity has eliminated the necessity of a deaerator.

At no time were problems with a high air partial pressure encountered. The lobes are made of ductile iron and have an average clearance of 0.005 inches. Since the blower is handling water vapor and non-condensible gases, care must be taken that the blower lobes do not seize when a long period of shutdown is anticipated.

2. Air Removal Condenser

This is a shell and tube heat exchanger with one pass on the shell side and four passes on the tube side. The tube side surface area is 62 ft^2. Discharged water vapor and non-condensible gases from the blower are introduced in this heat exchanger. The water vapor condenses on the tubes and condensate is removed from the bottom and returned to the melter. Non-condensed gases are introduced to the suction of the vacuum pump from where they are discharged to the atmosphere. Whenever a shutdown is anticipated, care must be taken to drain the heat exchanger.

3. Vacuum Pump

The 80 cfm Stokes hot pump was furnished by Pennsalt Chemical Company. The hot pump consists of an insulated "microvac" pump and an oil temperature control unit. As the oil in the vacuum pump runs hot at the temperature above the boiling point of water, water vapor is exhausted to the atmosphere as steam not condensed in the lubricant. When the pump is in operation, lubrication of the internal parts is completely automatic. The oil temperature control unit consists of a thermal switch (set at 225°F) that senses the pump discharge temperature. The oil then passes from the thermal switch, through a circulating pump, to a diversion valve that directs the oil to either the cooling unit or heating unit.

This hot pump has operated very satisfactorily handling water vapor. To insure its efficient performance, oil was changed every six months and the thermal switch was cleaned every two months. This preventive maintenance is easy to perform and is not time consuming.

K. Motors

All the motors on the trailer unit have either encapsulated or moisture proof windings. No problem with any of the motors was encountered except the product pump motor which had a bearing failure. This failure was caused by an obvious misalignment of the pump.

L. Piping

All the process piping on the unit is of steel and PVC. PVC piping is used only on brain drainage and slurry discharge. The rest of the piping is steel and is insulated. No problems were encountered with the piping.

VII CHEMICAL ANALYSIS

A. Equipment Description

Along with the mobile VFVC process plant, a 36 ft. x 8 ft. mobile chemical laboratory was furnished as part of this contract. The laboratory is well equipped for chemical analysis of the feed and effluent streams, precipitates, and scales. It provided storage room for chemicals, experimental equipment, and spare parts for the process plant. It also served as an office for the operating crew of the plant.

The mobile chemical laboratory has centralized heating and air-conditioning; a refrigerator; chemical-proof sink and drain, equipped with hot and cold running water; and fume exhaust hood. All cabinets and cupboards are equipped with chemical-proof working surfaces.

The experimental equipment purchased for the mobile chemical laboratory under this contract include:

1. Sartorius balance
2. Precision oven
3. Furnace
4. Barnstead distillation unit
5. Beckman O_2 analyzer
6. Beckman conductivity meter
7. Fisher titrimeter
8. Infra-red lamp
9. Hellige turbidimeter
10. Taylor chlorine test kit
11. Thermolyne hot plate
12. Bausch and Lamb spectrophotometer (Spectronik 20)
13. Ohaus balance
14. Miscellaneous glassware
15. Miscellaneous chemicals

B. Brackish Water Analysis

Brackish water of the type found in the ground waters in New Mexico contains a considerable amount of scale-forming minerals; namely, calcium, magnesium, and silicates. Total Dissolved Solids contents of this type of brackish water range from 15,500 ppm to 16,500 ppm. This brackish water is considered one of the most corrosive and scale-forming waters in the nation. Brackish water can be categorized in two forms: high salinity brackish water, and low salinity brackish water. In low brackish water, Total Dissolved Solids range between 1000 ppm to 5000 ppm; while in high brackish water, it ranges from 5000 ppm to 18,000 ppm.

A chemical analysis of Roswell, New Mexico brackish water feed is very useful in reviewing possible combinations of scale materials. A typical feed water analysis is given below:

CHEMICAL ANALYSIS

Elements (constituents)	ppm
Calcium as Ca++	545
Magnesium as Mg++	156
Sodium as Na+	5,187
Barium as Ba++	0
Sulphates as SO_4--	1,475
Chlorine as Cl-	8,224
Iron total	0.2
Bicarbonate as HCO_3-	213
Total Dissolved Solids (TDS)	15,799
Total hardness as $CaCO_3$	2,000
Total alkalinity as $CaCo_3$	174

Physical properties	Ph - 7.137
Sp. Gr.	1.01 @ 21°C
Conductivity	20k @ 21°C

(Ref. Mar. 5, 1969)

C. Scaling and Precipitates

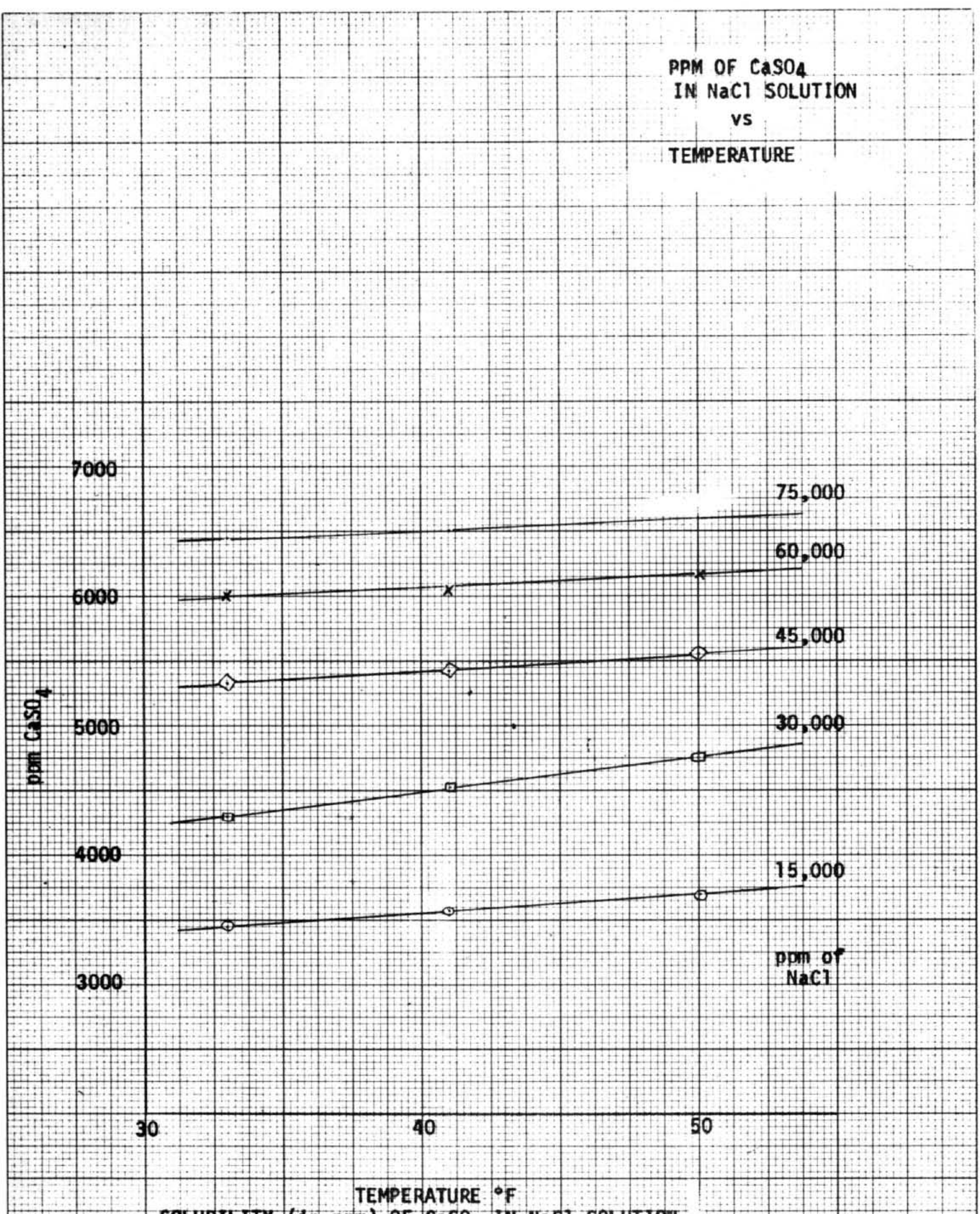
Calcium and sulphate ions combine to form calcium sulphate and precipitate as calcium sulphate scale. Calcium sulphate forms a tenacious scale and greatly reduces the overall heat transfer coefficient. This calcium sulphate also has an ability to cement particles of suspended matter, such as rust.

Calcium sulphate may precipitate as scale in three forms: $CaSO_4$ (anhydrite), $CaSO_4$ x 1/2 H_2O (hemihydrite), and $CaSO_4$ x $2H_2O$ (gypsum). The solubility of each of these forms of calcium sulphate is different.

Most of the inorganic salts behave in a particular manner. Their solubility increases with an increase in the temperature; however, calcium sulphate has an inverse solubility curve. That is, solubility of calcium sulphate increases with decrease in the temperature. In the temperature range of interest (26°F to 30°F), $CaSO_4$ x 2 H_2O is the least soluble, and $CaSO_4$ x 1/2 H_2O is more soluble. However, the solubility of calcium sulphate is also affected by the other salt contents in the solution; namely, sodium chloride, Figure 16. As the concentration of sodium chloride increases, the solubility of caldium sulphate decreases; so it was possible that when the feed was concentrated, the resulting brine would be super-saturated with calcium sulphate which could precipitate.

The unit was operated between 20 and 80% yield; i.e. 20 to 80% of the feed water was converted into fresh water. Brine effluent concentration was measured between 2 and 8%. Samples of brine effluent taken from time to time showed absolutely no evidence of any insoluble or suspended particles which indicated that all the calcium sulphate was soluble in concentrated brine and was removed with the brine effluent.

During the down time of the unit, some fouling problems in the heat exchanger were observed. After taking samples and analyzing them, it was found that the fouling was due to the presence of colonies of anaerobic bacterias rather than precipitations or scales. Further analysis revealed that this type of bacteria is active during down time of the unit when water is in a stagnant condition. Simple detergent washing cleaned the plates of the heat exchanger.



SOLUBILITY (in ppm) OF $CaSO_4$ IN NaCl SOLUTION
VARIOUS TEMPERATURES

Figure 16

VIII CONCLUSIONS

Based on the performance of the Mobile Brackish Water VFVC Test Plant, the following conclusions can be made:

1. The plant operated at its design capacity on both sea and brackish water.

2. Scaling and/or precipitation were not observed and, therefore, did not affect the operation of the plant.

3. The test plant was designed to demonstrate the feasibility of the VFVC Process to process brackish water at high concentration ratios. The plant demonstrated that this is feasible. This minimizes the brine disposal problem encountered with other processes operating on brackish water. VFVC Process plants converting 80% of the Roswell feed water to fresh water are feasible. On lower salinity feed water, up to 95% of the feed can be converted.

4. No problems were encountered in maintaining the product salinity below 500 ppm.

5. The unit operated successfully in t he automated unattended mode, thus minimizing the labor requirements for the process.

6. Based on the above, it is concluded that larger, economical VFVC plants can be built which would operate on brackish water at high concentration ratios.

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