REC-OCE-70-16

HYDRAULIC MODEL STUDIES OF INTERSTAGE MODULE PIPING IN THE 2.5 MGD UNIVERSAL DESALINATION PLANT - OFFICE OF SALINE WATER

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Bureau of Reclamation

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16. Abstract

A 1:2.33 scale model was used to determine the head loss for 118 deg F (47.77 deg C) salt water brine flowing through the interstage piping between 2 of the modules in the 2.5 MGD Universal Desalination Plant. Head loss coefficient curves for the system with and without a control valve were established for Reynolds numbers ranging from 170,000 to 1,200,000. Total head loss in the prototype system was 0.53 ft (16.15 cm) without a control valve in the system and 0.56 ft (17.07 cm) with a butterfly control valve 100% open at the downstream end of the system.

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by
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May 1970

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Denver, Colorado

UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION
Walter J. Hickel, Secretary
Ellis L. Armstrong, Commissioner

ACKNOWLEDGMENT

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CONTENTS

	Page
Purpose	1
Conclusions	1
Applications	1
Introduction	1
The Model	1
The Investigation	2
Without Control Valve	2
With Control Valve	2
Appendix A	3

LIST OF FIGURES

Figure		
1	Plant Schematic and Tabulation Sheet	5
2	Module Assembly—Heat Recovery Below 180° F	6
3	Module End—RH—Heat Recovery Below 180° F	7
4	Module End—LH—Below 180° F	8
5	Model Layout of Intermodule Piping	9
6	Model Views	10
7	Head Loss Between Modules M6-M7	11
8	Flow Conditions at Entrance and Exit Plenums	12
9	Butterfly Valve Installation	13
	Conversion Factors—British to Metric Units of Measurement	

PURPOSE

The purpose of the study was to determine the head losses incurred with the discharge of a given quantity of 118° F (47.77° C) 5 percent salt-saturated brine through the most critical of the interstage module piping.

CONCLUSIONS

1. Head loss coefficient curves for the system with or without the control valve were determined for Reynolds numbers ranging from 170,000 to 1,200,000, Figure 7.

2. The total head losses for the required flow with and without a control valve were 0.53 and 0.56 feet (16.15 and 17.07 cm), respectively. Thus, the differential head between modules must be increased to provide the desired flow.

APPLICATIONS

This study was conducted primarily on a Reynolds number model relationship to determine the head loss incurred by 118° F (47.77° C) 5 percent salt-saturated brine flowing between modules in a desalination plant. The results can be compared with two methods of computing the losses shown in the appendix and thus the best method for computing the losses in installations of similar design can be determined.

INTRODUCTION

The Office of Saline Water requested the Chief Engineer's Office of the Bureau of Reclamation to design, construct, and test a model of the interstage piping between modules at the most critical location with respect to driving force (or head) required and the driving force available in the 2.5 MGD (9.46×10^6 L/D) Universal Desalination Plant, Figures 1, 2, 3, and 4. The outside pipeline between the last two modules, M6 and M7, provided the most critical flow conditions. The available driving force between these two modules will be the minimum in the system, and the outside line will offer more resistance to the flow than the shorter inside line.

The flashing brine in these last two modules will be 5 percent salt saturated at 118° F (47.77° C) flowing at a rate of nearly 5,965,000 pounds (2,705,724 kg) per hour. The brine is assumed to be equally divided between the inside and outside passages, each of which has an inside diameter of 2.33 feet (71.1 cm). For these considerations, the brine will have a density of 63.7 lbs/ft^3 (1,020.39 kg/m^3), and a dynamic viscosity of 4.06×10^{-4} lbs/ft sec (0.56 kg/m sec) from which the Reynolds number was computed to be approximately 1.17×10^6.

The available driving force between M6 and M7 was computed to be approximately 0.25 foot (7.74 cm) of water with the two modules at the same elevation. Head losses computed for the design flow by the velocity head loss method and the equivalent length loss method (Appendix A) were determined to be approximately 0.5 and 0.4 foot (15 and 20 cm) of water, respectively, for the design configuration. Thus, some adjustment in relative elevation of the modules is necessary based on these computations. Because of limitations on the elevation of the modules, the hydraulic model study was undertaken to more accurately determine the losses. In addition, there was a need to determine the added loss created when using an interstage control valve in the line to match the pressure drop to the driving force for appropriate brine levels in the stages adjacent to the ends of the modules.

THE MODEL

The configuration of the outside pipeline to convey the brine from Module M6 to M7, including the entrance and exit from and into the pipeline, Figures 1, 3, and 4, was modeled to a scale of 1 to 2.33, Figures 5 and 6. An open box represented each of the two modules. The left side of each module was represented so that the right side of each box is on the centerline of the module. The reverse is true in the prototype layout in Figure 1.

The 28-inch- (71.12-cm-) inside-diameter steel pipe in the prototype was represented with a 12-inch (30.48-cm) steel pipe in the model. The roughness coefficient "f" in the model was estimated at 0.013 for the Reynolds number at which the prototype is expected to operate. This roughness coefficient compares favorably with estimates for the prototype pipe. Water at 67.5° F (19.72° C) represented the 118° F (47.77° C) brine in the prototype.

In the second phase of the investigation, a butterfly valve in the full-open position was installed in the pipeline to represent the control valve. For Reynolds number similarity, the model was operated such that the prototype discharge of 2,982,500 pounds (1,352,862 kg) per hour per pipe [13.4 cfs (0.38 cms)] was represented by approximately 9.00 cfs (0.255 cms) in the model. The prototype velocity of approximately 3.05 feet (0.91 m) per second in the pipe was represented by a velocity of about 11.50 feet (3.51 m) per second in the model. A prototype head loss of 0.4 foot (0.12 m) would be represented by approximately 5.5 feet (1.68 m) of water in the model.

For Froude number similarity, the model was operated such that the prototype discharge of 13.4 cfs (0.38 cms) was represented by 1.56 cfs (0.04 cms) in the model, and the pipeline velocity was approximately 2.0 feet (0.66 m) per second in the model.

THE INVESTIGATION

In the first phase of the investigation, the overall head loss between Modules M6 and M7 of the 2.5 MGD (9.46×10^6 L/D) Universal Desalination Plant, Figures 1 through 4, was determined for a range of Reynolds numbers up to and including 1.117×10^6 without a control valve.

In the second phase, the head loss measurements were to be repeated but with a butterfly control valve 100 percent open placed near the downstream end of the intermodule piping.

Phase I Without Control Valve

The inverts of the two boxes representing Modules M6 and M7 were set at the same elevation. The water surface piezometers shown in Figure 5 were used to measure the depth of flow for model discharges ranging from 1.5 to over 9 cfs (0.042 to 0.255 cms). The head loss in the system between the two modules was the difference in flow depths plus the velocity head differential. This head loss was then related to the interstage pipeline velocity head to obtain the loss coefficient K shown plotted versus Reynolds number in Figure 7. By applying the total head loss coefficient of 3.65 at the anticipated Reynolds number of 1.117×10^6 in Figure 7 to the prototype velocity head in the pipeline between modules, the head loss is determined to be 0.53 foot (16.15 cm). This corresponds closely with the maximum computed head loss (see Appendix).

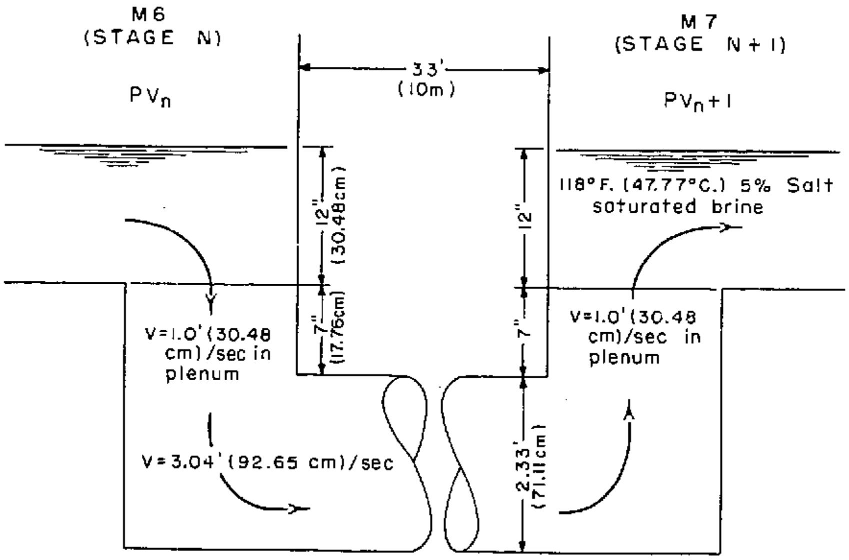
To observe the plenum entrance and exit flow conditions which were drowned out by the large model depths necessary for a Reynolds number relationship, the model was operated on a Froudian relationship. Vortices appeared in the entrance plenum and a considerable turbulence was present in the exit plenum, Figure 8. However, due to the lack of model similarity in representing the 118° F (47.77° C) brine in the prototype, it was not clear as to how these flow conditions using the Froudian relationship represented the prototype.

Phase II With Control Valve

A butterfly valve was installed near the downstream end of the interstage piping, Figures 5 and 9, to determine its effect on the head loss when the valve is fully open. The same tests performed without the valve were repeated and the results plotted in Figure 7. The head loss coefficient was increased to about 3.86 at the anticipated prototype Reynolds number of 1.117×10^6, equivalent to a total head loss to about 0.56 foot (17.07 cm).

APPENDIX A

HEAD LOSS CALCULATIONS BETWEEN VESSELS M6 TO M7



Flow rate per pipe is 2,982,500 pounds (1,352,862 kg) per hour

Velocity Head Loss Method

Entrance and Exit Losses

Entrance loss from Stage n to plenum	K = 0.5
Exit loss from plenum to Stage n+1	K = 1.0
Total	K = 1.5

$h_L = K\frac{V^2}{2g}$ where V = 1.00 ft/sec (30.48 cm/sec)

= 0.023 foot (0.70 cm) of H_2O

Entrance loss from plenum to pipe	K = 0.5
Exit loss from pipe to plenum	K = 1.0
Total	K = 1.5

$h_L = K\frac{V^2}{2g}$ where V = 3.05 ft/sec (92.96 cm/sec)

= 0.217 foot (6.61 cm) of H_2O

Bend Losses

Four 45^0 miter bends — K = 0.45 per bend

$h_L = K\frac{V^2}{2g}$ where V = 3.05 ft/sec (92.96 cm/sec)

= 0.260 foot (7.92 cm) of H_2O

Pipe Loss

Reynolds Number "R_e" $= \frac{VD\rho}{\mu}$ where D = 2.33 feet (71.02 cm)

V = 3.05 ft/sec (92.96 cm/sec)

ρ = 63.7 lb/ft^3 (1,020.38 kg/m^3)

μ = 4.06 x 10^{-4} lb/ft sec (0.60 centipoise)

(Reference: "Saline Water Conservation Data Book"—OSW 12.90)

R_e = 1.117 x 10^6

then f = 0.013 (Reference: Crane T.P. No. 409, page 6)

$h_L = f \frac{L}{D} \frac{V^2}{2g}$ where L = 33 feet (10.06 m) = 0.026 foot (0.79 cm) of H_2O

Total losses, H_L = 0.023 + 0.217 + 0.260 + 0.026 = 0.526 foot (16.03 cm) of H_2O

Equivalent Length Loss Method

Entrance and Exit Losses

Same as for Velocity Head Loss Method.

Bend and Pipe Losses

L (for 45° miter) = 15 $\frac{L}{D}$ (per bend)

Total equivalent L = 33 + (4 x 15 x 2.33) = 173 feet (52.73 m)

$$h_L = f \frac{L}{D} \frac{V^2}{2g} = 0.013 \times \frac{173}{2.33} \times \frac{3.05^2}{2g}$$

= 0.139 foot (4.24 cm) of H_2O

Total losses H_L = 0.023 + 0.217 + 0.139 = 0.379 foot (11.55 cm) of H_2O

AVAILABLE DRIVING FORCE

Vapor pressure in M6 (PV_n) – vapor pressure in M7 (PV_{n+1}) = 0.25 feet (7.74 cm) of H_2O

FIGURE 1

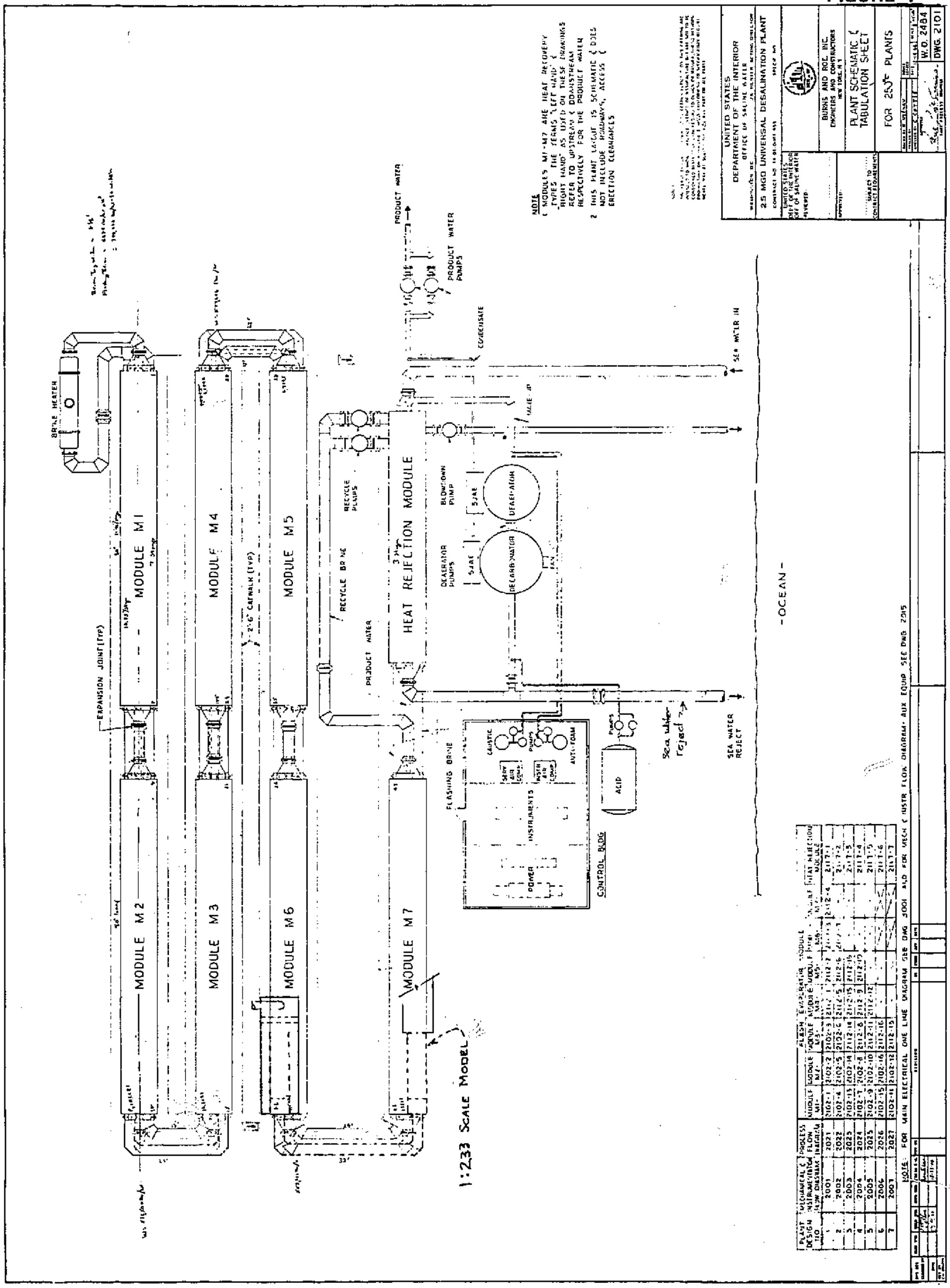
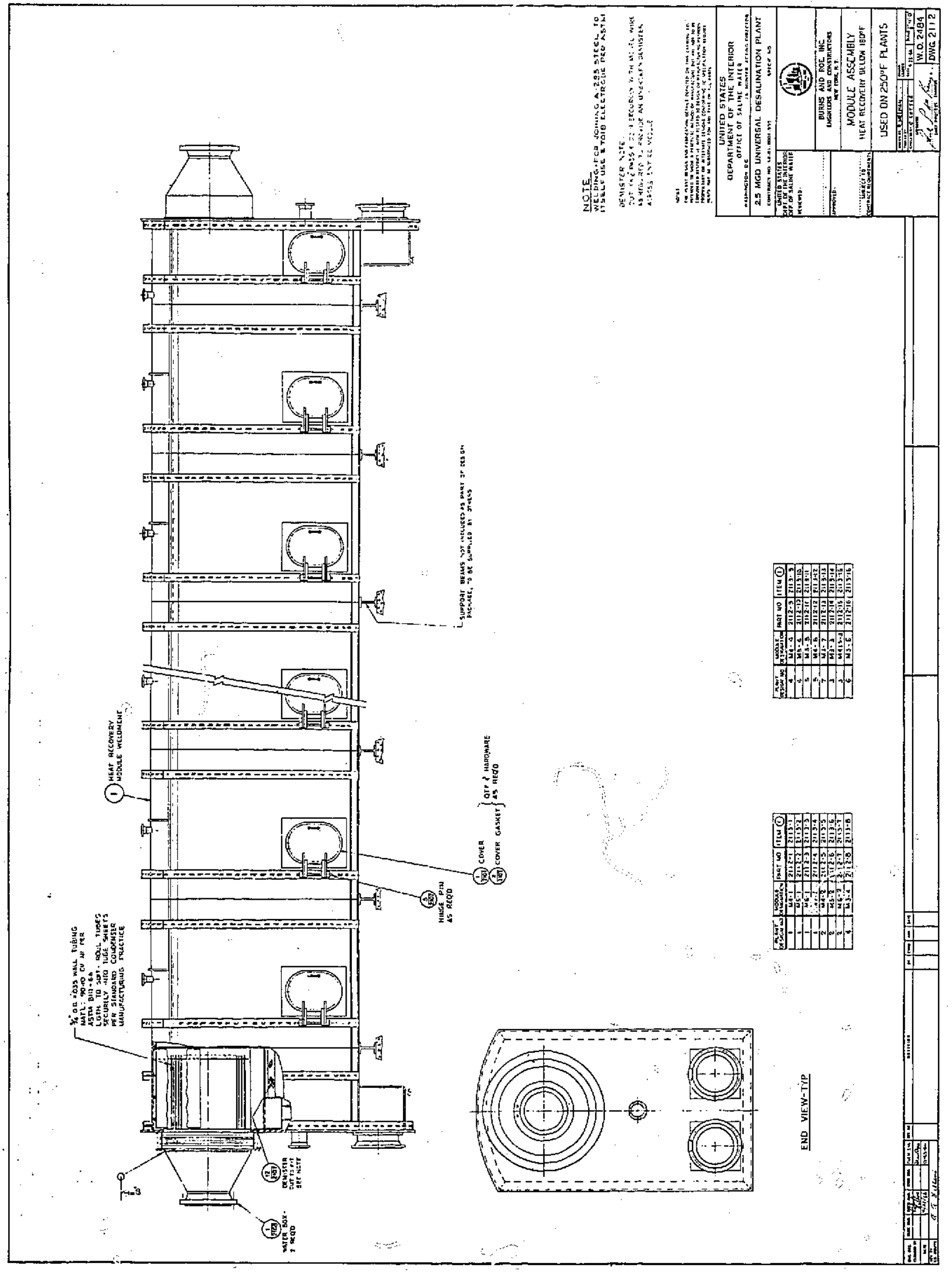

UNITED STATES
DEPARTMENT OF THE INTERIOR
OFFICE OF SALINE WATER
2.5 MGD UNIVERSAL DESALINATION PLANT
BURNS AND ROE, INC.
ENGINEERS AND CONSTRUCTORS
PLANT SCHEMATIC & TABULATION SHEET
FOR 2.5 MGD PLANTS
W.O. 2484
DWG. 2101
MODULE M1
MODULE M2
MODULE M3
MODULE M4
MODULE M5
MODULE M6
MODULE M7
HEAT REJECTION MODULE
BRINE HEATER
EXPANSION JOINT (TYP)
2'-6" CATWALK (TYP)
RECYCLE BRINE
RECYCLE PUMPS
PRODUCT WATER
PRODUCT WATER PUMPS
CONDENSATE
SEA WATER IN
SEA WATER REJECT
BLOWDOWN PUMP
DEAERATOR PUMPS
DEAERATOR
DECARBONATOR
FLASHING BRINE
CAUSTIC
PUMPS
ANTI-FOAM
INSTRUMENTS
POWER
CONTROL BLDG
ACID
-OCEAN-
1:233 Scale Model
Sea water reject

FIGURE 2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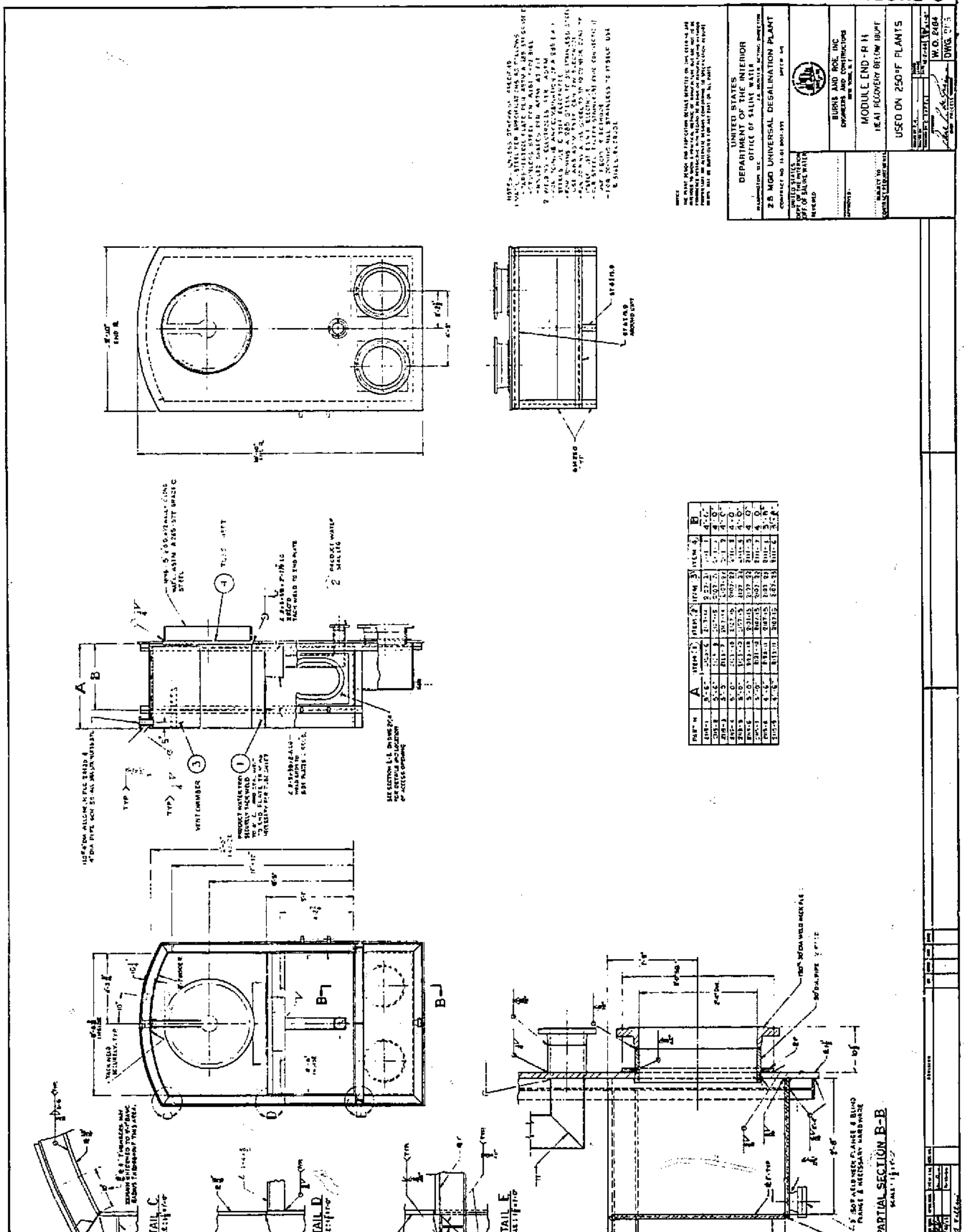
2.5 MGD UNIVERSAL DESALINATION PLANT
BURNS AND ROE, INC.
ENGINEERS AND CONSTRUCTORS
NEW YORK, N.Y.
MODULE ASSEMBLY
HEAT RECOVERY BELOW 180°F
USED ON 250°F PLANTS
W.O. 2484
DWG. 2112
END VIEW-TYP
HEAT RECOVERY MODULE WELDMENT
COVER
COVER GASKET
HINGE PIN AS REQ'D
DEMISTER
WATER BOX

FIGURE 3



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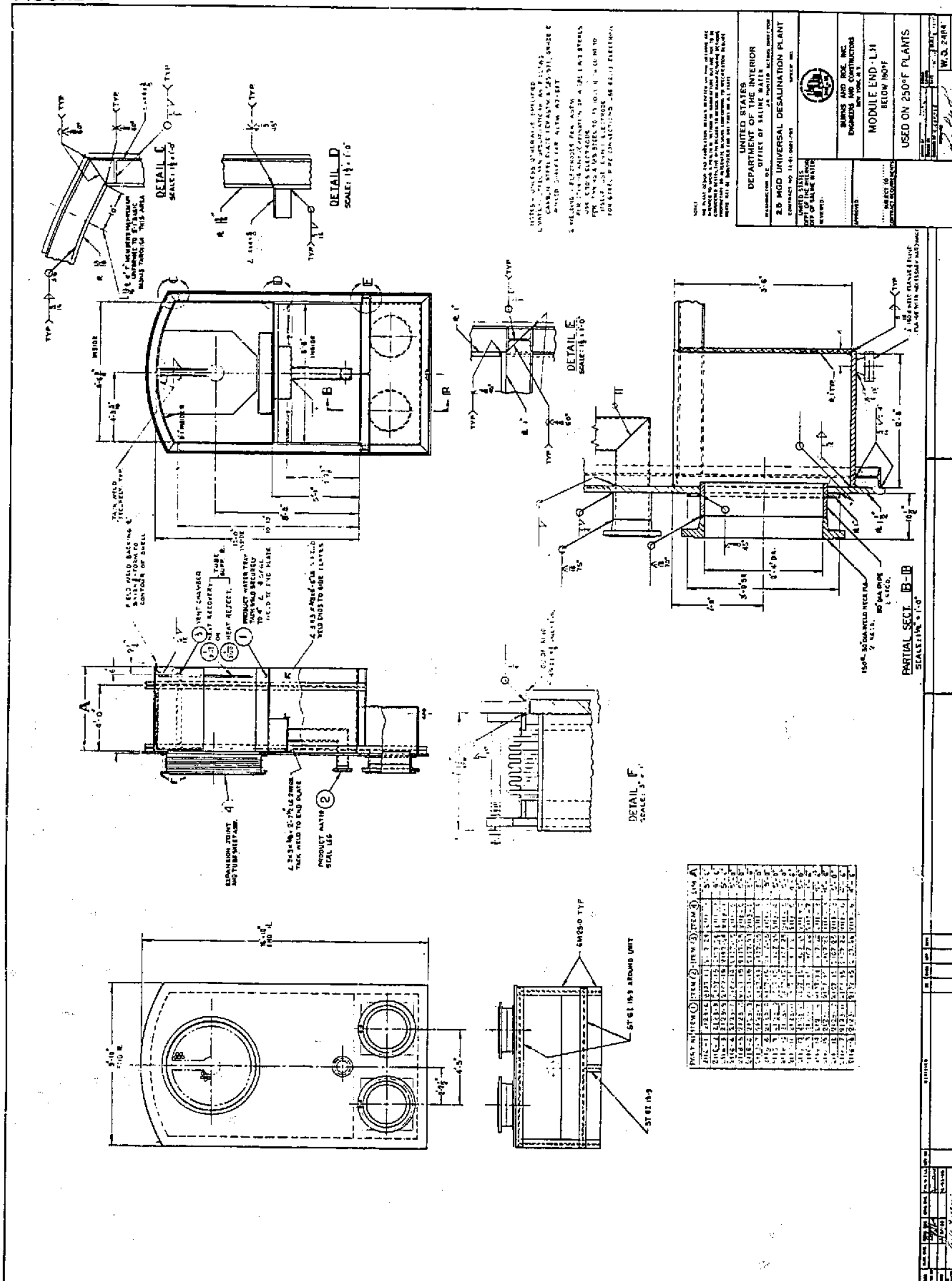
2.5 MGD UNIVERSAL DESALINATION PLANT
BURNS AND ROE, INC.
MODULE END-R.H.
HEAT RECOVERY BELOW 180°F
USED ON 250°F PLANTS
DETAIL C
DETAIL D
DETAIL E
PARTIAL SECTION B-B

FIGURE 4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DEPARTMENT OF THE INTERIOR
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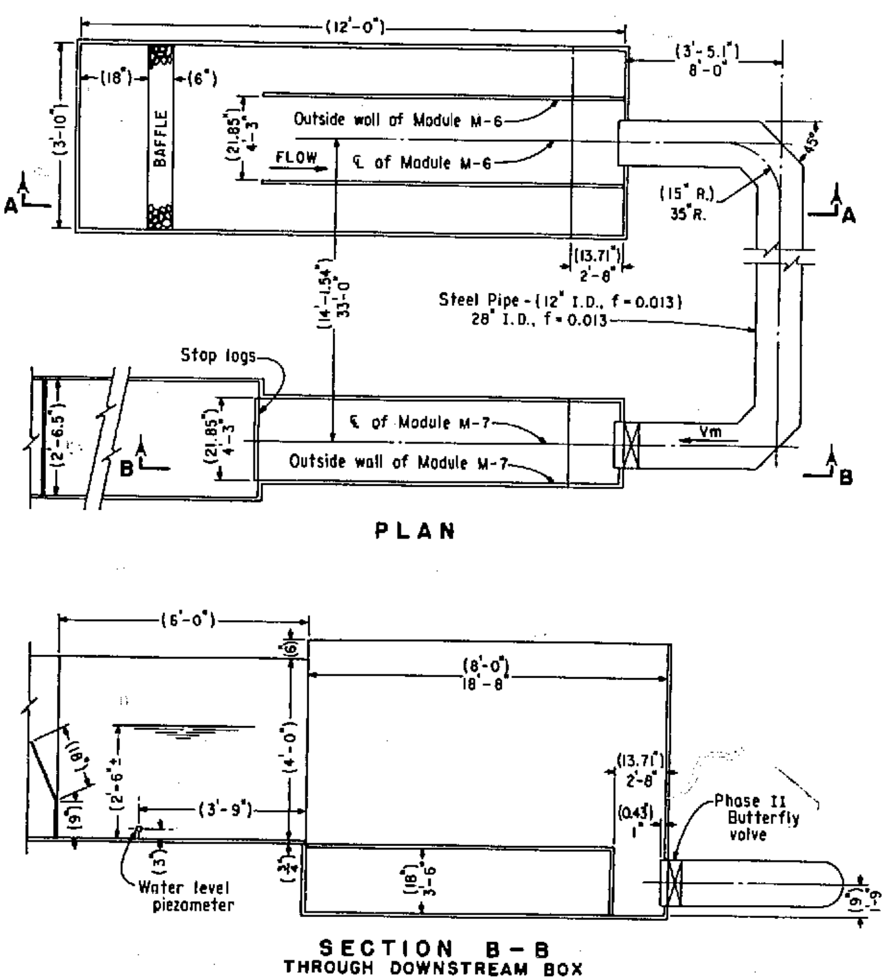
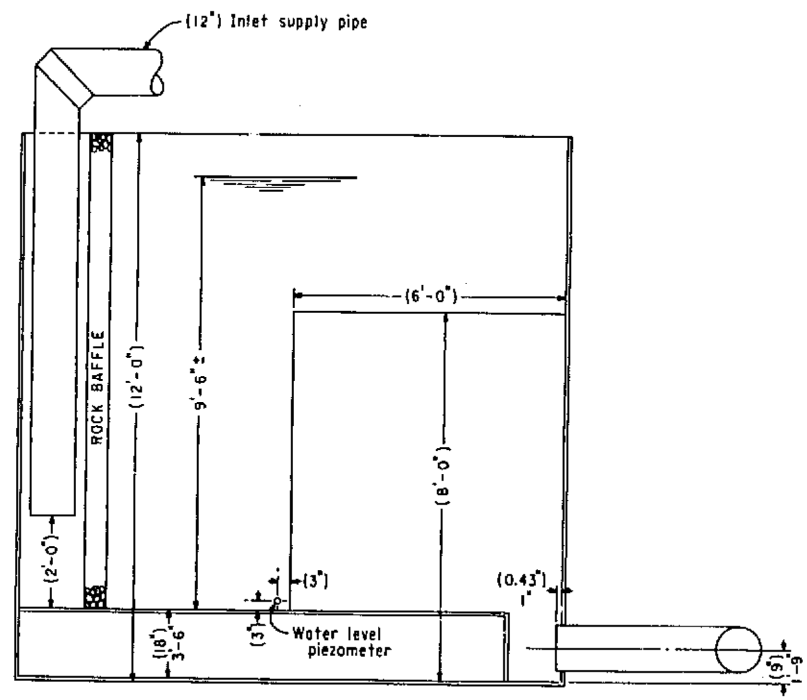
2.5 MGD UNIVERSAL DESALINATION PLANT
BURNS AND ROE, INC.
ENGINEERS AND CONSTRUCTORS
NEW YORK, N.Y.
MODULE END - L11
BELOW 180°F
USED ON 250°F PLANTS
W.O. 2484
DWG 211G
DETAIL C
DETAIL D
DETAIL E
DETAIL F
PARTIAL SECT. B-B

FIGURE 5





SECTION A - A
THROUGH UPSTREAM BOX

NOTES

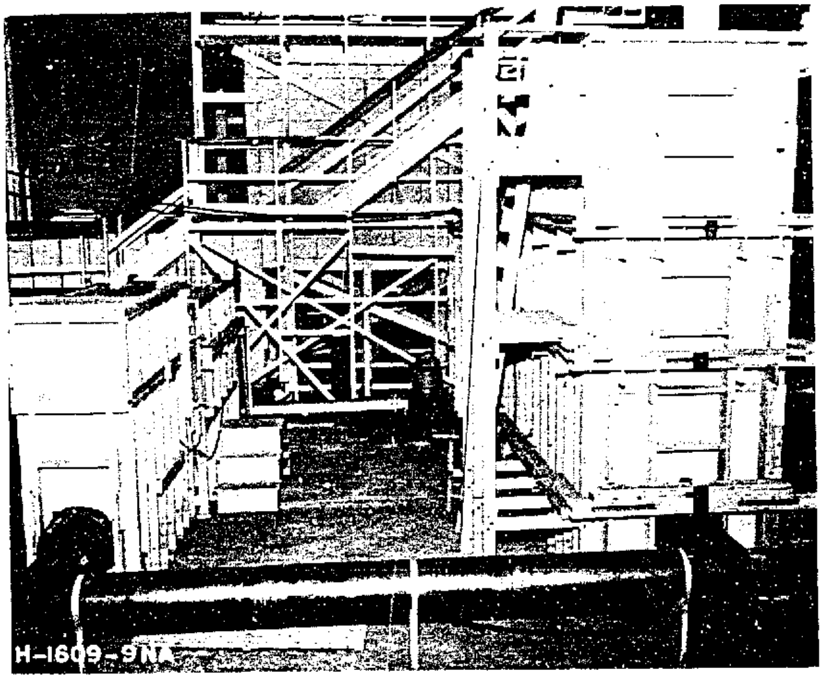
Dimensions in parenthesis are model. Others are prototype.
For $R_e = 1.117 \times 10^6$:
$Q_p = 13.0$ cfs
$Q_m = 8.96$ cfs
$V_p = 3.05$ ft./sec.
$V_m = 11.48$ ft./sec.
Where "p" is a prototype value and "m" is a model value.
Prototype fluid is 5% salt saturated brine at 118°F. Model fluid is water at 70°F.

2.5 MGD UNIVERSAL DESALINATION PLANT

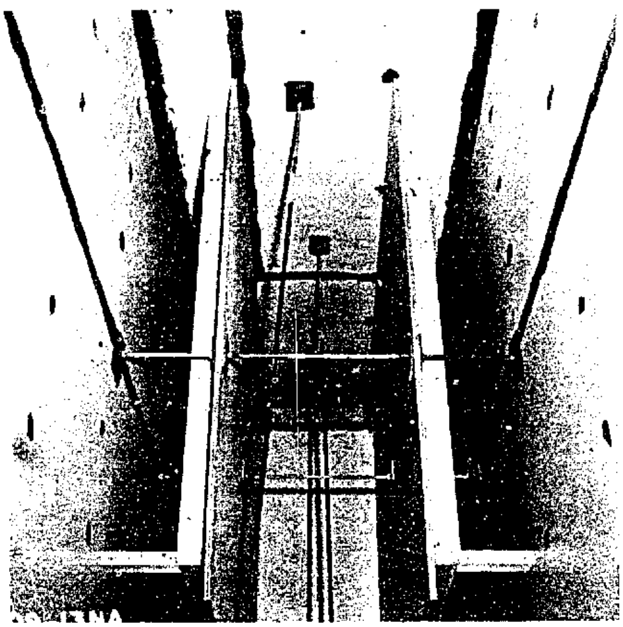
MODEL LAYOUT OF INTERMODULE PIPING

1:2.33 SCALE MODEL

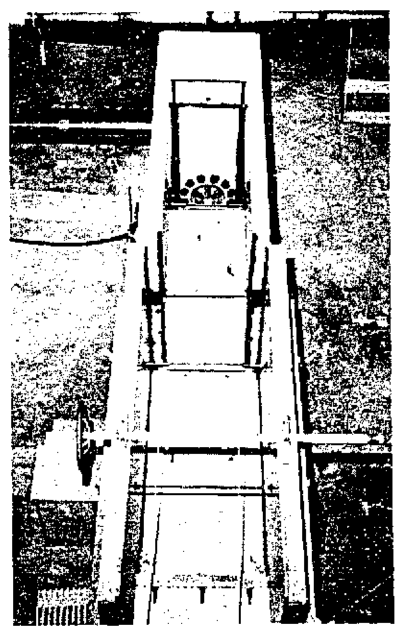
FIGURE 6



A. Interstage pipeline from module M6 on the right to module M7 on the left. Photo P800-D-66407



B. Plenum entrance to pipeline in M6. Photo P800-D-66408



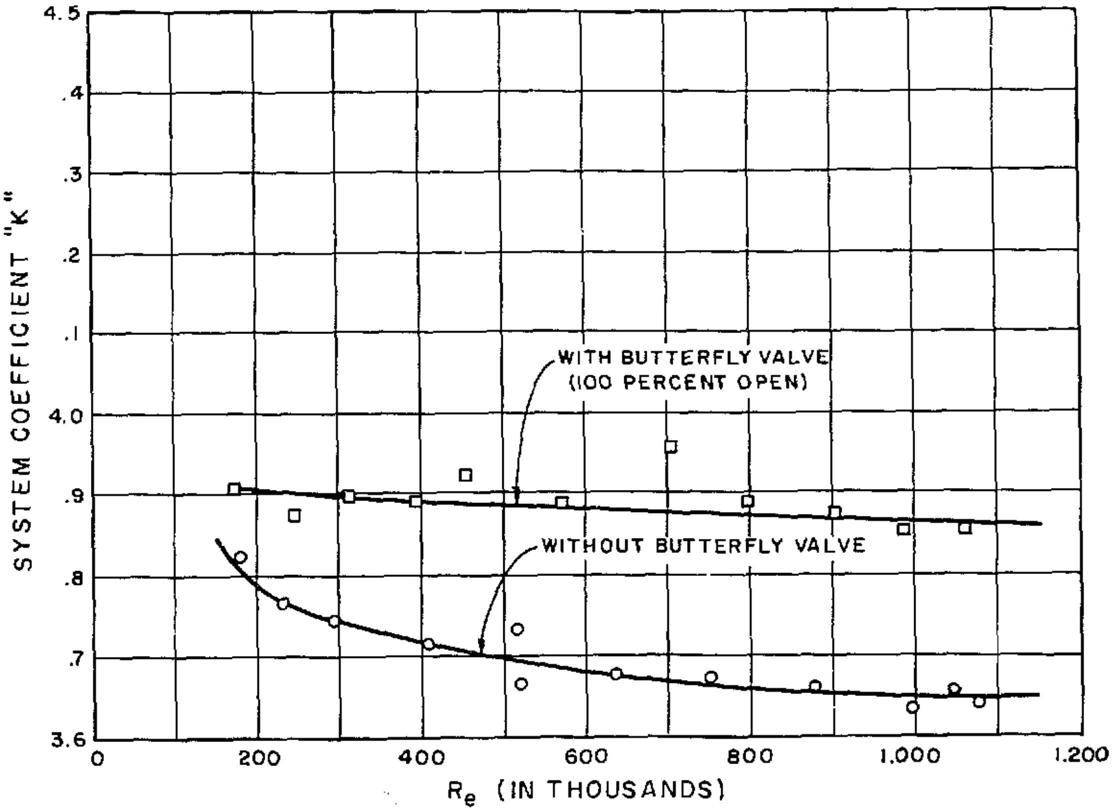
C. Plenum exit from pipeline into M7. Photo P800-D-66409

2.5 MGD UNIVERSAL DESALINATION PLANT

INTERSTAGE PIPING MODEL

1:2.33 SCALE MODEL

FIGURE 7



$K = 2g\,(H_L/V^2)$ and $R_e = VD/\nu$

Where:

H_L = Total Head Loss between modules.

V = Velocity in the Pipe between modules.

D = Inside diameter of Pipe.

ν = Kinematic Viscosity.

g = Acceleration of Gravity

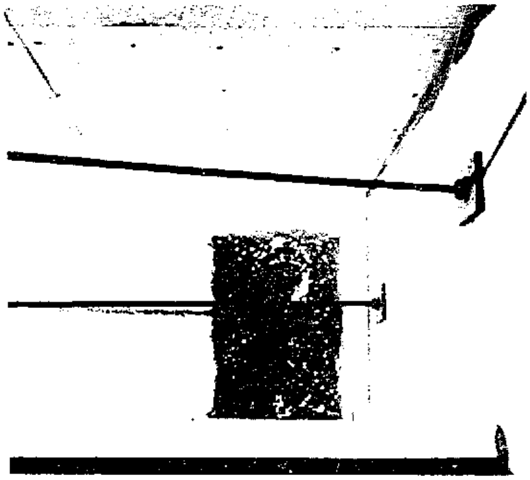
2.5 MGD UNIVERSAL DESALINATION PLANT

HEAD LOSS BETWEEN MODULES M6 AND M7

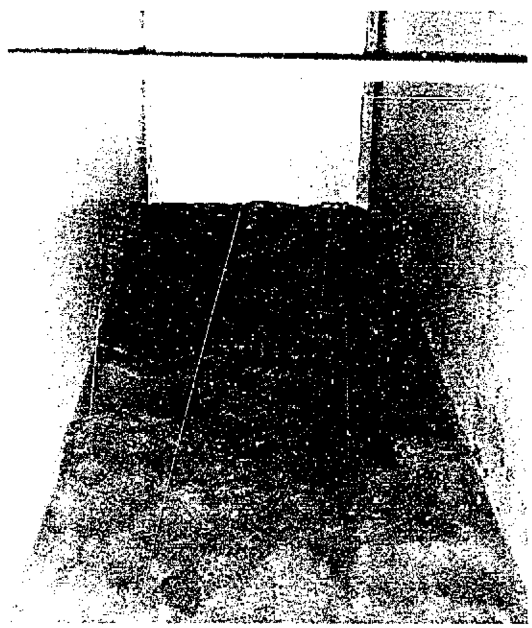
1:2,333 SCALE MODEL

743

FIGURE 8



A. Vortices at plenum entrance in module M6. Photo P800-D-66410

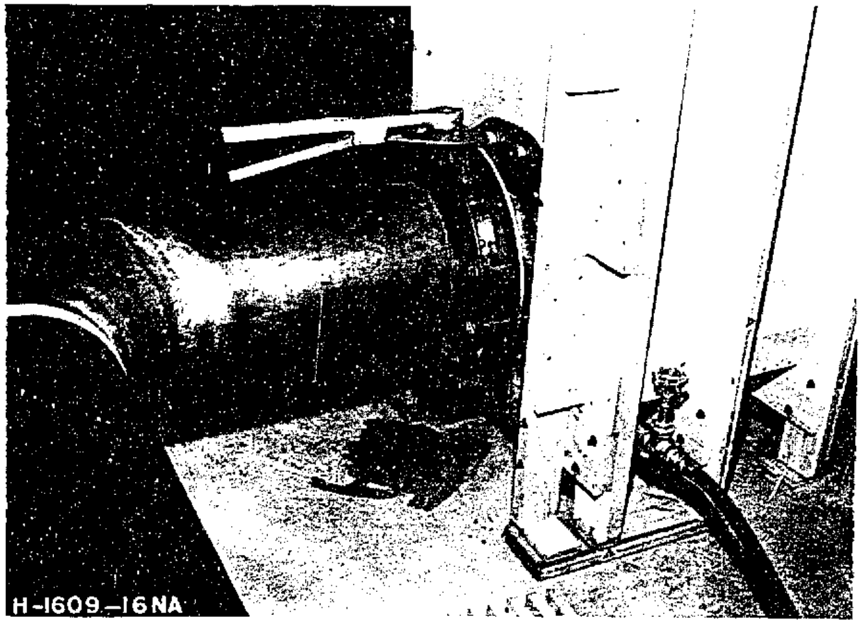


B. Turbulence at plenum exit in module M7. Photo P800-D-66411

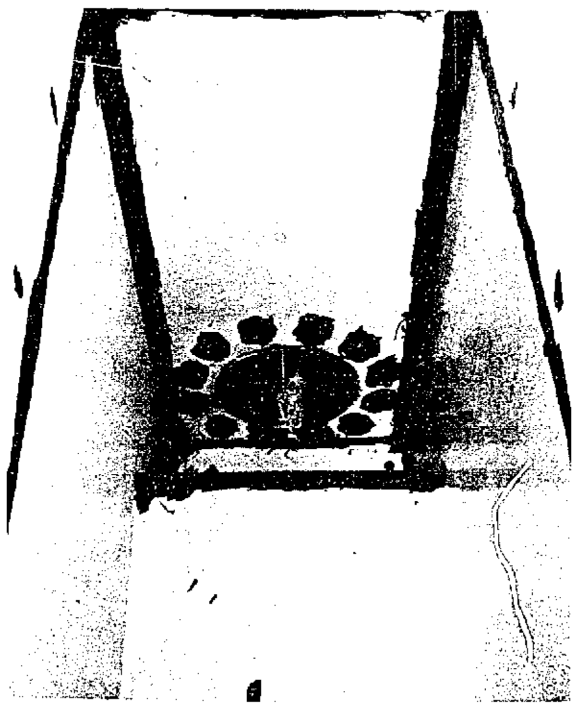
2.5 MGD UNIVERSAL DESALINATION PLANT

FLOW CONDITIONS AT THE ENTRANCE AND EXIT PLENUMS

1:2.33 SCALE MODEL



A. Butterfly valve at entrance to module M6. Photo P800-D-66412



B. Gate leaf in open position. Photo P800-D-66413

2.5 MGD UNIVERSAL DESALINATION PLANT

BUTTERFLY VALVE INSTALLATION

1:2.33 SCALE MODEL

7-1750 (1-70)
Bureau of Reclamation

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03*	Square centimeters
	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	946.358*	Cubic centimeters
	0.946331*	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.092903*	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

GPO 859-301

ABSTRACT

A 1:2.33 scale model was used to determine the head loss for 118 deg F (47.77 deg C) salt water brine flowing through the interstage piping between 2 of the modules in the 2.5 MGD Universal Desalination Plant. Head loss coefficient curves for the system with and without a control valve were established for Reynolds numbers ranging from 170,000 to 1,200,000. Total head loss in the prototype system was 0.53 ft (16.15 cm) without a control valve in the system and 0.56 ft (17.07 cm) with a butterfly control valve 100% open at the downstream end of the system.

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REC-OCE-70-16
Beichley, G L
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Bur Reclam Lab Rep REC—OCE—70—16, Hydraul Br, May 1970. Bureau of Reclamation, Denver, 13 p, 9 fig, 3 tab, append

DESCRIPTORS—/ *Reynolds number/ *Froude number/ *head loss/ turbulence/ vortices/ butterfly valves/ pipelines/ hydraulic models/ density/ piping (mechanical)/ *viscosity/ desalination plants/ brines/ model tests
IDENTIFIERS—/ modules/ salt solutions/ plenum chambers

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