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U.S. ATOMIC ENERGY COMMISSION

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OFFICE OF SALINE WATER

EVAPORATOR COMPONENT DEVELOPMENT PROGRAM

EVALUATION OF LONG TUBES FOR EVAPORATORS

B. E. Mitchell

J. A. Smith

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OFFICE OF SALINE WATER
Evaporator Component Development Program

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Final Report

MARCH 1968

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I. SUMMARY

The concept of utilizing long (to 360-ft) condenser tubes to achieve economies of construction and operation in large multistage flash evaporators appears feasible. Tests where long tubes were installed under simulated field conditions have shown that long tubes can be successfully inserted with annular clearances between the tubes and the tube sheets as low as 0.0015 in. and that long tubes can be successfully installed by a combination of power feeding and automatic alignment of the tube with the tube sheet hole.

On the basis of information from tubing suppliers, long tubes should be priced competitively with standard tube lengths by 1970.

Our economic analysis indicates a 3% reduction in plant capital costs if long tubes are used in large MSF plants (250 Mgd). The savings in water cost over plants with 60-ft tubes are about 0.2¢/1000 gallons.

II. CONCLUSIONS

The studies and tests reported here indicate that the use of long tubes is feasible and that such designs should be considered for future large plants and modules.

While additional experience and development are required to prove their reliability, long tubes appear to have a number of advantages for large plants which outweigh the disadvantages.

The advantages of long tubes include the following:

1. A cost advantage of 3% reduction in capital cost and 0.2¢/1000-gallon reduction in water cost. Though this appears to be a firm cost differential, it is within a range which can be influenced by competitive factors for a given plant.
2. Energy losses in the intermediate water boxes are avoided.
3. There are fewer and shorter outages for leakage. Leaking tubes may be more rapidly located and plugged since the end water boxes are readily accessible.

The advantages of shorter tube bundles include the following:

1. They are existing practice.
2. Less surface is lost when a leaking tube is plugged.
3. Thermal expansion problems are less severe.
4. The plant is better protected against major losses in the event of multiple tube failures in one or more adjacent stages.

The field tests we conducted indicate the following:

1. Long tubes can be successfully inserted through a series of tube sheets with annular clearances as low as 0.0015 in.
2. Good alignment between adjacent tube sheets is required; parallel alignment is more critical than vertical or horizontal alignment.

III. INTRODUCTION

Early Oak Ridge design studies of large multistage flash evaporators for use in desalination service indicated that long, continuous tubing for the heat recovery and the heat reject condenser surfaces could provide significant economy in plant construction costs. It appeared that bundles using long tubes would be cheaper to build than other alternatives. Their use would permit simplification of the evaporator structure, reduction of building volume, elimination of intermediate water boxes and expansion joints, and lower tube entrance and exit losses. Further studies at Oak Ridge and by other plant designers continue to indicate that the use of long tubes offers important advantages for decreasing capital cost.

In view of the attractive potential of long tubes, the Office of Saline Water has sponsored work at Oak Ridge with the objective of preparing criteria by which any proposed design incorporating long tubes can be evaluated. Included in the scope of this work were the following aspects:

1. Structural considerations--length between supports, provisions for differential expansion rates between tube and vessel, and methods of tubing and retubing in the field.
2. Fabrication and handling--shop versus on-site fabrication, practical mill lengths, wall thicknesses required for stability in handling, and shipping problems.
3. Heat transfer and hydrodynamics--literature search for information on high L/D ratios on thermal conductance and friction.
4. Cost factors--mill extras for various lengths, possible effect on base price and mill extras of large orders optimally spaced, tube sheet drilling costs, tube support plate drilling costs, tube rolling or end welding costs, and related economic considerations.
5. Overall economic and operational comparison between evaporators using long tubes and conventional shorter bundles.

This document is a final report on the Oak Ridge study and outlines the accomplishments and conclusions to date.

IV. THERMAL STRESS

A major consideration in the utilization of long tubes in large multi-stage flash evaporators is the tube stresses which will be induced when the plant is heated to operating temperature levels. It is important that any proposed method of installation be analyzed to determine the likelihood of tube failure from overstress.

Provisions are required for tube expansion in the long, continuous tube design concept because of difference in overall thermal expansion of the tubes and of the evaporator shell in which the tubes and water boxes are mounted. The differences in thermal expansion are caused by the following:

1. Difference in heating and cooling rates for the relatively massive evaporator shell and the thin tubes at the time of evaporator start-up or shutdown. This can be a large effect unless start-up or shutdown is very slow.
2. Difference in steady-state operating temperature between the evaporator shell and tubes. The tubes will be at a few degrees higher temperature than the shell at each point in the plant.
3. Difference in thermal expansion coefficient of the evaporator shell material and tubes. For example, the expansion coefficient for 70-30 cupronickel tubes is $9.0 \times 10^{-6}/^{\circ}\text{F}$; for steel, 6.5×10^{-6} ; and for concrete, 7.9×10^{-6} .

In addition to the above three factors, changes in overall length between the shell and the tubes can be caused by the provision of expansion joints in the evaporator shell. If shell structural and foundation problems are provided for by shell expansion joints at right angles to the tubes, the ends of the shell will remain in a fixed position and the effect will be as though the thermal expansion of the shell were zero. This will give the greatest relative motion between the freely expanding tubes and the shell. A containment shell which has no expansion joints but has one end fixed with the other allowed to move would have the effect of reducing tube stress where both end tube sheets are fixed or of reducing the bellows expansion where one is fixed and the other is attached to the building with a bellows.

Since the most straightforward method of providing for the tube expansion is for all tube supports to be fixed with the tubes fastened to the end sheets and sliding through the intermediate supports, we made an investigation to determine the feasibility of this method. Tubes installed horizontally in this manner (Figure 1) would have an initial deflection Y_1 , resulting from the weight of the water and the tube. As each tube is heated, it tries to expand; however, its expansion is restricted by the end tube sheets, and a thrust load (S) is produced. The initial deflection will be distributed equally among the stages, since the tubes are free to slide through the intermediate

AMBIENT TEMPERATURE @ INSTALLATION

"S" = THRUST LOAD DEVELOPED BY THERMAL EXPANSION OF CONDENSER TUBE.

y_1 = INITIAL DEFLECTION (WT. OF H_2O & TUBE), ASSUMING SLOPE OF TUBE IS ZERO AT TUBE SHEETS, AND THRUST LOAD IS ZERO.

AS THERMAL EXPANSION OF TUBE OCCURS & THRUST LOAD "S" INCREASES

Figure 1

TUBING THERMAL EXPANSION MODEL

tube sheets. The distance along the deflection curve will also increase until some distance ℓ_2 is reached such that $\ell_2 - \ell_1$ is equal to the average stage thermal expansion ($\Delta L/N$). Assuming that close fitting holes through the intermediate tube supports are required to minimize interstage leakage, we conclude the slope of the tube must be zero where it passes through each support. This situation is then equivalent to a uniformly loaded beam with lateral end loads and fixed ends as shown by Figure 1. With these assumptions, expressions were derived for the deflection at the center of the span and for the maximum moments which occur at the ends. A Fortran computer program (Appendix A) was prepared for calculating deflection, end moments, length of deflection curve, and maximum stress for any given tube, span distance, and end load. Another program was prepared for calculating the stage and cumulative thermal expansion of any tube. Results of the calculations for various alternative tubes are tabulated in Table I. It can be seen that tubes 3, 5, and 7 are stressed beyond their tensile strength, that tubes 1, 3, 4, 5, and 7 are stressed beyond the yield point, and that the stresses in all tubes far exceed the ASME code allowable, which eliminates this installation method as a solution.

Analyses have been made of several methods of reducing tube stresses induced by thermal expansion. Investigation of the alternative methods indicated that the floating tube sheet is the most practical method.

1. Slotted Tube Sheet. One method of stress reduction is to allow the tube to assume its natural slope where it passes through the intermediate tube supports. The points of inflection then occur in the span between the tube supports as shown in Figure 2. This method has the effect of increasing the distance between peaks of inflection by a factor of two which is illustrated by comparing tubes 3 and 8 and 4 and 9 (Table I) where the only difference is the span length. By this method, the maximum stress is reduced by more than 50%, but it is still above the allowable. To accommodate the change in slope, we would have to use contoured interstage seals, which would add to the cost and to the complexity.
2. Expansion Rods. Another method considered is shown in Figure 3. The tube sheet at the brine inlet is rigidly mounted, and all others are allowed to float. Expansion rods attached to each tube sheet, and riding on bearings, expand at the same rate as the tubes to prevent relative motion between the tube sheets and the tubes. Plastic inserts in the holes seal around the tubes, and sheet metal seals around the circumference of the tube sheets complete the stage separation. The only stresses and deflections in the tubes result from the weight of the tubes and of the contained water. The maximum stress for tube 6, for example, is 2696 psi with .035-in. maximum deflection. The main

Table I
THERMAL STRESSES IN LONG TUBES

Tube Number	Tube Temp. Inlet (°F.)	Tube Temp. Outlet (°F.)	Stage Length (in.)	No. Stages	Total Thermal Expansion (in.)	Ave. Thermal Exp./stage	Y ₂	Deflection (in) Stress (lb/in ²) Bending + End Load	End Load (lbs.)	Tensile Strength (psi)	Yield Strength (psi)	ASME Code Allowable (psi)
1	88.0	226.0	101.0	40	3.60	.090	1.91	37,806	1037	50,000	18,000	12,000
2	88.0	226.0	101.0	40	2.12	.053	1.49	31,849	355	58,000	40,000	14,500*
3	88.0	226.0	71.0	40	2.56	.064	1.35	58,356	2115	50,000	18,000	12,000
4	88.0	226.0	71.0	40	1.48	.037	1.03	46,491	757	58,000	40,000	14,500*
5	88.0	226.0	71.0	40	2.36	.059	1.30	42,965	695	38,000	15,000	9,000
6	71.4	225.2	71.3	40	1.52	.038	1.03	32,549	296	58,000	40,000	14,500*
7	71.4	225.2	71.3	40	2.40	.060	1.30	42,965	695	38,000	15,000	9,000
8	88.0	226.0	140.0	20	2.56	.128	2.69	26,489	485	50,000	18,000	12,000
9	88.0	226.0	140.0	20	1.48	.074	2.11	22,309	160	58,000	40,000	14,500*

Tube No.Description

1	1.0 in. O.D. x .049 in. wall x 338.9 ft. Aluminum-Brass
2	1.0 in. O.D. x .016 in. wall x 338.9 ft. Titanium
3	1.0 in. O.D. x .049 in. wall x 236.7 ft. Aluminum-Brass
4	1.0 in. O.D. x .016 in. wall x 236.7 ft. Titanium
5	0.75 in. O.D. x .035 in. wall x 236.7 ft. 10% Cupronickel
6	0.75 in. O.D. x .016 in. wall x 271 ft. Titanium
7	0.75 in. O.D. x .035 in. wall x 271 ft. 10% Cupronickel
8	1.0 in. O.D. x .049 in. wall x 236.7 ft. Aluminum-Brass
9	1.0 in. O.D. x .016 in. wall x 236.7 ft. Titanium

SLOTTED TUBE SHEETS

INTERSTAGE SEAL TO ACCOMMODATE NATURAL SLOPE

Figure 2
TUBE STRESS REDUCTION

Figure 3
EXPANSION RODS

disadvantage of this method is the relatively high cost of fabrication and installation of the rods, bearings, and seals around the circumference of the tube sheets.

3. Floating Water Box. The tubes are attached at each end to tube sheets rigidly attached to the inlet and outlet water boxes (Figure 4). There are unbalanced forces on the boxes from the hydraulic pressure due to the reduced reaction area on the side where the tubes penetrate the water box. If the outlet water box is allowed to move in the direction of this force as shown in Figure 4, the unbalanced pressure force will put an initial tensile force of approximately 3 pounds on each of the 18,416 tubes (with a water box pressure of 43 psig).
4. Floating Tube Sheet. This is the most practical method investigated. This is a modified floating water box with the water box fixed and an expansion joint between the tube sheet and the water box (Figure 5). Each tube experiences an end load of about 9 pounds to move the tube sheet 3.5 in. against the expansion joint (with 43-psig water and a bellows stiffness of 45 pounds per inch of perimeter). Resultant tube stresses and deflections approximate those of the floating water box design.
5. Independently Floating Tubes. This is a method whereby the tubes are fastened only at the inlet tube sheet with slip fit seals for each tube in the intermediate tube supports and in the tube sheet side of the outlet water box (Figure 6). Each tube is allowed to expand independently so that any differential expansion that might occur would not produce any additional tube stress. A leakage shield could be provided as shown to collect any leakage from the seals in the tube sheet. This method has the advantages of requiring no moving parts or expansion joints and of producing lower tube stresses than any of the other methods discussed. Since there would be a 40-psi pressure differential across the tube-to-tube-sheet seals in the water box, development and testing would be required to assure that these seals would prevent any high velocity leak that would erode the tube, the seal, or the tube sheet.

V. POSSIBLE METHODS FOR INSTALLING LONG TUBES

Several alternative methods for inserting tubes into the evaporator shell were analyzed. They were applied to a 250-Mgd representative multilevel flash evaporator¹, but they are also applicable to single-level plants; the only difference is that the height of the insertion points for the multilevel plant varies, and thus considerable scaffolding is required. The costs of two methods were compared on a preliminary basis, as presented in this section. On the basis of this comparison, "powered drive roll-automatic guide" was selected as the preferred method. The costs of this method were worked out in greater detail for Section IX.

Figure 4
FLOATING WATER BOX

Figure 5
FLOATING TUBE SHEET

All Tube Sheets Rigid - Condenser Tubes Fixed One End Only.

Figure 6
FLOATING TUBE BUNDLE DESIGN

The 250-Mgd flash evaporator plant has banks of condenser tubes arranged alongside the flashing brine trays. These tubes are continuous from end to end of each effect and pass through intermediate, supporting tube sheets which also separate the flashing stages. Condenser tubes of the heat recovery section of the single-effect plant pass through 40 stages and are approximately 275 ft long from water box to water box. The tubes are arranged in 16 separate tube bundles per 50-Mgd module. These tube bundles are stacked 8 high on each side of the brine trays. Each tube bundle consists of 2,352 3/4-in. O.D. tubes on 1.00-in. triangular spacing. The overall size of the bundle is 3.5-ft wide x 4.0-ft high. The intermediate tube supports are about 4-ft wide x 4.5-ft high x 3/4-in. thick.

Powered Drive Rolls, Automatic Guides

For a highly automated approach, guiding devices requiring no human attention at the stages can be used. These devices are shown on Figure 7. Tubes are inserted one horizontal row at a time, preferably by driving all the tubes in the row simultaneously. As soon as a complete horizontal row has passed through a stage, as indicated by microswitches, the guide tray is lowered to accept the next horizontal row of tubes. If a reliable tube driving device that will positively drive all tubes in a row uniformly is developed, the tubes can be inserted as fast as they are fed to the tube sheet.

It is estimated that the automatic tube guides can be built for \$7,500 each. To drive tubes through the evaporator, a set of drive rolls (\$20,000) will feed tubes into a pushing device shown on Figure 8. The pushing device is estimated to cost \$30,000. If a conservative figure of 600 tubes per hour can be installed by this method using a crew of 8 men, labor cost is $\$9.00 \times 8/600 = \0.12 per tube.

$$\text{Capital Cost: } \frac{7500 \times 42 + 20,000 + 30,000}{188,160} = \$1.94 \text{ per tube.}$$

$$\text{Total Cost: } 0.12 + 1.94 = \$2.06 \text{ per tube.}$$

Note: Two spare tube guides are included in the above capital cost.

In-Place Bundle Assembly

Figure 9 shows a concept in which the bundle is assembled inside the evaporator shell. The dollies are drawn into the far end water box and must be removed. They can be made so that they can be disassembled for easy removal.

Following is an estimate of labor and capital costs for this method:

END VIEW

ELEVATION TYPICAL STAGE

- NOTES:
- 1- ONE ASSEMBLY REQUIRED PER EVAPORATOR STAGE.
 - 2- TRAY LOWERS TO NEXT HORIZONTAL ROW AS SOON AS LAST TUBE IS INSERTED IN ANY HORIZONTAL ROW.

Figure 7
AUTOMATIC TUBE GUIDE

Figure 8

INSERTION OF FULL LENGTH TUBES IN
EVAPORATOR-HYDRAULIC TUBE PUSHER

Figure 9
COIL TO SHELL INSTALLATION

Capital Equipment:

Track	\$20,000
Bundle dollies - 10 at \$2,500	25,000
Tube sheet dolly	7,500
Pull dolly	10,000
Pull expanders - 2,352 at \$15	35,280
Miscellaneous cable, etc.	<u>2,500</u>

\$100,280

$$100,280/188,160 = \$0.53 \text{ per tube capital cost.}$$

Installation:

Lay track	40 hours
Put hoist in place	4
Set dollies on track	6
Load tube sheets on dollies	2
Push expanders through tube sheets	2
Actuate expanders into tube sheets	16
Pull bundle in shell and secure	40
tube sheets - 40 sheets at 1 hr/sheet	
Remove equipment and track	<u>32</u>

142 hours

$$142 \times 9.00/2,352 = \$0.54 \text{ per tube.}$$

Total cost per tube, equipment plus installation = $0.53 + 0.54 = \$1.07$.

VI. LONG TUBE INSERTION TESTS

A series of tests were performed at Oak Ridge to evaluate the long tube concept. The tests were performed on the long tube test facility as shown on Figures 13, 14, 15, 16, 17, and 18.

The test system consisted of a stand with simulated condenser tube sheets at 7-ft intervals across a span of 357 ft, a tube pusher mechanism for installing the long tubes, a dynamometer for measuring the pushing force, and several 365-ft tubes which were fabricated from 50-ft, 0.049-in. wall, 3/4-in. O.D., 90-10 cupronickel tubes spliced together. The semi-circular tube sheets contained ten 0.760-in. (TEMA standard fit) diameter holes for tubes without interstage seals and ten 0.875-in. diameter holes for tubes with interstage seals. These holes were beveled on each side of the tube sheet. All the tube sheets were aligned to within 0.036 in. on the horizontal and vertical axes, with respect to the center line of the tube sheet housing and were parallel to each other. A surveyor's transit and a tube sheet fixture were used to attain this alignment.

Figure 10
LONG TUBE TEST SYSTEM

PHOTO NO. PH-66-960

Figure 11
TUEE PUSHER

Figure 12
TUBE SUPPORT PLATE

ITEM	QTY.	DWG. NO.	P. NO.	MATERIAL & DESCRIPTION
1	48	EM-22915B2	1	TUBE SHEET-INTERMEDIATE
2	1	EM-22915B1		- SHELL
3	26	EM-22915B2		- SUPPORT STAND
4	48	TH13		- SCEL 2" 3CM 40 PIPE 18" X 18" 60 R22 X 4 L
5	2	EM-22915B2	2	TUBE SHEET- END
6	140	TH13		- CUPRNICHEL TUBE 400 X 0.035 WALL 80" LENGTH
7	80	TH13		- CUPRNICHEL TUBE 400 X 0.06 WALL

Figure 13
LONG TUBE INSTALLATION TEST FIXTURE ASSEMBLY

Figure 14
DETAILS - TEST FIXTURE

Figure 15
DETAILS - TEST FIXTURE

ITEM	QTY.	DWG. NO.	PT. NO.	MATERIAL & DESCRIPTION
1	2	THIS	1	STEEL
2	1	THIS	-	SUPPORT BEAM
3	2	THIS	2	STEEL
4	1	THIS	-	STEEL 1/2\"/>

Figure 16
TUBE SHEET FIXTURE

FRAME WELDMENT

SCALE $\frac{1}{8}'' = 1''$

PT. NO.	QTY.	MATERIAL & DESCRIPTION
1	2	I BEAM 6 x 6 M20 STL
2	2	I BEAM 6 x 6 M20 STL
3	2	BRKT WELDMENT (THIS DWG) STL
4	2	ANGLE 2 x 2 x 3/16 STL

BRACKET WELDMENT

SCALE $\frac{1}{8}'' = 1''$

PT. NO.	QTY.	MATERIAL & DESCRIPTION
10	1	STL A151 C 1010 - 1020
11	2	
12	2	

ITEM	QTY.	DWG. NO.	PT. NO.	MATERIAL & DESCRIPTION
1	1	E-M-29915 J1	—	BASE WELDMENT SUB ASSY
2	4		20	CASTER (MODIFIED)
3	16	THIS	—	1/2-13 NC x 1 1/2 LG HEX HD CAP SCR
4	1		—	FRAME WELDMENT SUB ASSY
5	1	E-M-29915 J1	—	ANCHOR STAND SUB ASSY
6	4	THIS	—	3/8-10 NC x 1 1/2 LG HEX HD CAP SCR
7	4		—	3/8-10 NC CINCH ANCHOR

SIDE VIEW

SCALE $\frac{1}{8}'' = 1''$

SECTION "A-A"

SCALE $\frac{1}{8}'' = 1''$

Figure 17
O.S.W. - LONG TUBE INSERTION TESTS

BASE WELDMENTSCALE $\frac{1}{8}" = 1"$

PT. NO.	Q'TY	MATERIAL & DESCRIPTION
1	2	STL A151 C 1010-1020
2	2	
3	2	
4	2

PT. NO.	Q'TY	MATERIAL & DESCRIPTION
10	1	STL A151 C 1010-1020
11	1	
12	4	

SLOT BOLT HOLES TO
OUTSIDE EDGES
AS SHOWN PART 20SCALE $\frac{1}{4}" = 1"$

MAT'L: V-GROOVED CASTER ASSY
CAT NO. 804-BV
FAULTLESS CASTER CORR
EVANSVILLE, IND.

Figure 18
O.S.W. - LONG TUBE INSERTION TESTS

Two-hole brackets were later fabricated and attached to the original tube sheets in order to conduct tube insertion tests on tube sheet hole sizes between 0.752 in. and 0.760 in. These holes were not beveled as were the larger holes; more tube binding and tube scratching resulted under these conditions.

All of the following tube insertion tests were conducted with tubes which measured 0.751 in. to 0.752 in. in outside diameter.

The initial test consisted of manually installing a 365-ft-long tube through tube sheets with 0.760-in. holes. With one man guiding the tube through the tube sheets, one man supporting the end of the long tube, and one man providing a pushing force, the tube was installed with ease. Concurrently, tests were being conducted in a second test facility to determine the amount of interstage leakage that would be experienced with a 0.752-in. O.D. tube and a 0.760-in. tube sheet hole without seals. This leakage was excessive as detailed in a separate report.² Accordingly, we attempted to determine the minimum clearance between the tube and the tube sheet that could be achieved and still successfully insert the long tube.

We then fabricated two-hole brackets which were attached to the intermediate tube supports to obtain a range of tube hole sizes between 0.752 in. and 0.760 in. As was anticipated, we found that the 0.752-in. O.D. tube could not be inserted through tube sheets with 0.752-in. holes. The tube could be inserted through tube sheets with 0.754-in. holes, but with a degree of difficulty which was beyond the realm of being practical. The tube could be inserted through tube sheets with 0.755-in. (TEMA special close fit) holes with difficulty but within a practical range. Thus, we determined that the minimum differential diameter size between the tube and the tube sheet hole was 0.003 in. or an annular clearance of 0.0015 in. and that this differential was dependent upon close alignment of all tube sheets. Tubes of 0.752-in. O.D. can be installed through tube sheets with hole sizes from 0.756 in. to 0.760 in. with relative ease.

Tube vibration occurs as the tubes are inserted through close fitting tube sheet holes. When this occurs, the required driving forces increase sharply to a point where the drive rolls slip, stopping the forward motion of the tube. In such instances, it was necessary to interrupt tube insertion to allow the tube vibration to cease. This problem was less pronounced as the tube sheet holes were increased in size. The tube vibration increased the time of tube insertion from approximately 330 seconds for 0.760-in. tube sheet holes to approximately 860 seconds for 0.755-in. holes. Vibration also occurred when the tube was removed but was not as pronounced. The tube pusher provided the driving force in both directions--pushing for inserting and pulling for removing. The results of these tests are summarized in Table II.

We also demonstrated that the concept of power feeding in conjunction with automatic alignment of the tube with the tube sheet holes is feasible and practical. "V" shaped tube guide brackets which were

TABLE II

TESTS WITH PROPERLY ALIGNED TUBE SHEETS

The data below represent the results of tube insertion tests with all tube sheets properly aligned on the horizontal and vertical axes, with respect to the center line of the tube sheet housing, and with all tube sheets parallel to each other.

Test No.	Tube Size O.D., inches	Tube Sheet Hole Size, inches	Annular Clearance, inches	Dynamometer Reading, pounds	Insertion Speed, ft/minute
1	0.752	0.760	0.004	30-40	66.4
2	0.752	0.754	0.001	*	12.2
3	0.752	0.755	0.0015	80-250	25.5
4	0.752	0.756	0.002	50-250	
5	0.752	0.753(seal)	0.0005	80-100	57.3
6	0.752	0.760(auto- alignment)	0.004	80-100	

* The tube pusher as originally installed did not have sufficient driving force to insert the tube. The power of the drive mechanism was increased later, but power drive tests on this size tube sheet hole were not repeated since the tube bracket holes were reamed to larger sizes. However, the tube was successfully installed through the combined efforts of ten men who were guiding, pulling, and pushing in conjunction with the under-powered tube pusher. Therefore, the effort required was not accurately measured by the dynamometer.

fabricated from 1-in. x 1-in. x 1/8-in. angle-iron were positioned atop and between two adjacent tubes which were already in place. The V-shaped bracket was thus in position to accept a bullet-nose-equipped tube and to guide the tube into the proper tube sheet hole (Figure 19). Fifteen such brackets were used and a tube was power fed and automatically aligned over a total distance of 105 ft. This test was conducted using 0.760-in. tube sheet holes. The results of this test are also summarized in Table II.

We also conducted successful tests on inserting tubes through tube sheets equipped with polypropylene seals. The seals were installed in the 0.875-in. tube sheet holes and had an opening measuring 0.753 in. in diameter. Thus, the annular clearance between the tube and the seal was 0.0005 in. The results of this test are also summarized in Table II.

We conducted tests to simulate the effect of tube sheet misalignment caused by settling of the evaporator building. This misalignment could cause concern if it becomes necessary to remove old tubes and install new ones. This condition was simulated by raising the 1/4 and 3/4 supporting points of the testing rig 1/4 in. and by lowering the 1/2 support point 1/4 in. Tube insertion tests with three misaligned plates demonstrated that a tube could be installed through tube sheets with 0.760-in. holes, but could not be installed through tube sheets with 0.755-in. and 0.756-in. holes. We then misaligned seven plates similarly and successfully inserted a tube through 0.760-in. holes. The results of these tests are summarized in Table III.

We also conducted tests to determine the effect of tube sheets which were not parallel to each other. This was accomplished by rotating two tube sheets 2.4° in opposite directions. With this condition, we could not insert tubes through even the largest size (0.760-in.) holes. Parallel misalignment has a greater effect on tube insertion efforts than either vertical or horizontal misalignment. The results of these tests are summarized in Table IV.

VII. TUBE FABRICATION AND HANDLING METHODS

The following outlines the current thinking of some manufacturers for the fabrication of long tubes:

1. Company A. The large amounts of tubing required for an MSF plant will probably require on-site tube fabrication. Two or three concepts are being studied. One concept would be redrawing of coils on large high-speed bull blocks as is normally done with copper tubing; subsequent straightening and rounding would be required with this concept. Another concept would be the roll-forming of strip material and seam welding it into tubes of the desired lengths.

BREAK ALL SHARP EDGES & CORNERS
ON $\frac{1}{32} \times 45^\circ$ CHAMFER UNLESS NOTED.

TUBE GUIDE BRACKET

MATL: AS NOTED

50 REQD.

SCALE $\frac{3}{4}'' = 1''$

TUBE GUIDE

MATL: AS NOTED

50 REQD.

SCALE $\frac{3}{4}'' = 1''$

Figure 19
DETAILS - TEST FIXTURE

TABLE III

TESTS WITH MISALIGNED TUBE SHEETS

Outlined below are data from tube insertion tests showing the effect of tube sheet vertical misalignment. The effect of horizontal misalignment would be similar and was not simulated since it was more difficult to achieve with our test system.

Three tube sheets misaligned--the 1/4 and the 3/4 supporting points were raised 1/4 in.; the 1/2 supporting point was lowered 1/4 in.

Test No.	Tube Size O.D., inches	Tube Sheet Hole Size, inches	Annular Clearance, inches	Dynamometer Reading, pounds	Insertion Speed ft/minute
1	0.752	0.755	0.0015	80-250	*
2	0.752	0.756	0.002	50-250	**
3	0.752	0.760	0.004	30-40	60.4

* Could install only 8 ft past first misaligned sheet.

** Could install only 28 ft past second misaligned sheet.

Seven tube sheets misaligned; the 1/8, 3/8, 5/8, and 7/8 supporting points were raised 1/4 in.; the 1/4, 1/2, and 3/4 supporting points were lowered 1/4 in.

Test No.	Tube Size O.D., inches	Tube Sheet Hole Size, inches	Annular Clearance, inches	Dynamometer Reading, pounds	Insertion Speed ft/minute
1	0.752	0.755	0.0015	80-250	*
2	0.752	0.756	0.002	50-250	**
3	0.752	0.760	0.004	30-40	66.4

* Same as above.

** Same as above.

TABLE IV
TESTS WITH TUBE SHEETS NOT PARALLEL

Presented below are data from tube insertion tests showing the effect of the tube sheets not being parallel to each other. This condition was simulated by misalignment of one tube sheet by rotating it 2.4° in a clockwise direction and a second tube sheet a similar amount in a counterclockwise direction. The second tube sheet was located 21 ft from the first sheet.

<u>Test No.</u>	<u>Tube Size O.D., inches</u>	<u>Tube Sheet Hole Size, inches</u>	<u>Annular Clearance, inches</u>	<u>Dynamometer Reading, pounds</u>	<u>Insertion Speed, ft/minute</u>
1	0.752	0.755	0.0015	80-250	*
2	0.752	0.756	0.002	50-250	**
3	0.752	0.760	0.004	30-250	***

* Could install only 2 ft past first misaligned sheet.

** Could install only 9 ft past first misaligned sheet.

*** Could install only 15 ft past second misaligned sheet.

2. Company B. The rearrangement of manufacturing facilities to make long tube lengths in the shop is being investigated, and they expect to have this work accomplished within twelve to eighteen months. Apparently, the long tube lengths (360 ft) would be shipped to the site on special rail cars, coupled together.
3. Company C. They are unable to produce tube lengths over 80 ft at this time. They are investigating the possibility of producing tubes up to 400-ft lengths in coils in the shop and expect to be able to produce these within about two years.
4. Company D. They plan to make thick-wall shells in the shop, with the tubes drawn to size in an on-site tube mill.
5. Company E. Some production work has been done to determine the problems encountered in the production of long tube lengths. They have found that the aluminum brass cannot be drawn into long lengths, but 90-10 cupronickel can be fabricated into 360-ft lengths. They presently can produce lengths up to 120 ft, and their approach is to shop fabricate the long tubes and coil them for shipment. Straightening would be required at the site.

One approach to low-cost long tubes is to use as-welded* cupronickel tubes. It appears that an as-welded tube of this type can be produced as much as 15% cheaper than the cost of the current practice in manufacturing seamless tubes. A machine for fabricating this tubing by high-frequency welding costs approximately \$300,000

Consideration has been given to several methods for splicing tubes. In general, the methods discussed with the tube manufacturers were upset welded joints, brazed sleeve joints, butt-welded joints with filler metal, and butt-welded joints by fusion welding.

Fabrication, Testing, and Handling of Tubes

Tubing can be produced in existing mills, shipped to the evaporator site in standard lengths, and then welded into the required length; it can be shipped full length on several railroad cars or possibly

* An "as-welded" tube is defined as a tube which has undergone no special handling following manufacture. However, this does not rule out such operations as eddy-current testing, weld dressing, or sizing that may be performed automatically in sequence with the manufacturing operation, but does eliminate such procedures as hydrostatic testing and complete visual examinations.

shipped in coils for straightening at the site. A promising approach may be to ship semi-finished material such as rolled strip or thick-walled tube shells to the evaporator site and fabricate the tubes there.

Inspection of the tubes will be influenced by the fabrication method. All material will be checked for chemical and physical properties. Tube diameter, straightness, wall thickness, and outside finish will be determined. These items can be adequately controlled by statistical quality control inspection similar to that used in tubing production plants. Statistical control methods can also be used for inspection of tubing surface for cracks, laps, and finish defects which are visually detectable.

Tubing will be inspected by either ultrasonic or eddy-current methods to discover hidden flaws. This is particularly important for welded tubes and will preferably be done simultaneously with the welding so that defective joints can be immediately detected.

Tubes will be stacked and stored after testing and inspection. The tubes are rather fragile and difficult to handle; for example, a 3/4-in. x .035-in. wall 90-10 cupronickel tube 275 ft long weighs about 85 pounds, must be supported every 25 ft to avoid damage from its own weight, and can be bent on 14-ft radius without taking a permanent set. They must be stored carefully with adequate support to avoid bending, crushing, or denting. When the tubes are to be inserted in the evaporator, they will be loaded on a train of cars on tracks running from the storage point to the evaporator (Figure 20). The carts preferably will be loaded with correct number of tubes for one complete tube bundle and arranged in the proper number of horizontal and vertical rows on spacer-supports on the carts. The tube supports on the carts will be designed as frictionless rollers so that the tubes can be easily pulled longitudinally from the carts.

When the train is loaded, any special tube preparation such as swaging bullet noses on the tubes to facilitate insertion will be done using portable tools. The train will then be pulled along the tracks to scaffolding at the evaporator in line with the opening where the tubes will be inserted. It is not necessary to provide clearance in line with the evaporator for straight-in insertion of the tubes since they can be brought around a fairly tight curve without damage to the tubes. Where the train is brought around a curve, it may be necessary to use radius rods on the carts to prevent derailment because of side forces required to bend the tubes.

VIII. OPERATION AND MAINTENANCE

Methods of Removing or Replacing Tubes

The long tubes can be removed, if necessary, by using a rotary cutter to cut the inside of the tube behind the tube sheet at both ends, removing the rolled ends, inserting an expansion rod device into both tube ends,

Figure 20
INSERTION OF FULL LENGTH TUBES IN EVAPORATOR

and withdrawing the tube by applying a pulling force with a winch. A pulling rod or cable should be pulled in from the opposite end as the tube is pulled out. A short section of the tube or the entire tube could be replaced and reinstalled by this method. It is possible that impingement erosion near the water box might require replacing a short section of each tube. This can be done by pulling out a section of each tube as described above, replacing the faulty section, pulling the tube back into place, and rolling the tube ends into the end tube sheets. In a similar manner, the entire tube can be replaced, if desired. Dummy support plates approximately six inches from each end tube sheet may be required on the original installation to hold the tube in position after the ends were cut, and good access to the end tube sheets would be required to successfully remove and replace the tubes.

Plugging of Tubes

Tubes will be plugged as leaks develop. In accordance with power station practice, an evaporator might be shut down for replacing all the tubing after 10 to 15% have been plugged. In the case of 90-10 copper-nickel tubes, it would be expected that retubing would not be necessary until after at least fifteen years of operation; with 70-30 copper-nickel tubes, retubing would probably not be required within thirty years.

With 360-ft-long tubes, plugging would be simple since the tube ends are easily accessible. With shorter tube lengths and intermediate water boxes, tube plugging would be more difficult since access would be required to the interior of all water boxes for testing and plugging.

Tube Vibration

Vibration can rapidly destroy condenser tube bundles by fatiguing the tubes at points of maximum stress if the vibrations are of sufficient amplitude. Such vibration, which has been encountered in central station condensers, is thought to be due to the Von Karman vortex effect.

Tubes in the long tube design will be supported at least at every stage wall where tubes pass through an intermediate tube support. If more frequent support is required, one or more additional supports can be provided within each stage. For a large plant, support may be provided by an additional intermediate tube support in each stage since the tooling will be available for drilling it along with the stage separator supports. Several tube lacing or bar separator schemes are in use which can be installed after the tubes have already been inserted. Two examples of such supports, designed for desalination service, are shown in Figure 21.

The standard practice for support spacing in steam surface condensers is at intervals of 50 to 60 tube diameters. For the long tube evaporator design, which warrants a high premium for maximum protection of the tubes,

Figure 21
INTERMEDIATE COIL SUPPORTS

supports at the 50-60 diameter spacing might be assumed in the absence of contrary data.

Tube Leakage

Product water will be contaminated by any leakage from condenser tubes. A completely ruptured tube in the 250-Mgd plant design would increase the salt content of the product by about 5 ppm. Possibly five leaks of this magnitude could be tolerated out of 188,160 long tubes before part of the evaporator need be shut down for repair.

For purposes of planning interim replacements, it is assumed that 70-30 copper-nickel tubes will have a thirty-year life. This is interpreted to mean that after thirty years it would be more economical to replace the tubes than to continue to operate the original set. Of the 188,160 tubes in a 250-Mgd plant, possibly 10% would be plugged. The pattern of failure after the initial shakedown period is likely to be infrequent for the first twenty years with rising frequency thereafter. Shutdowns of a portion of the plant for tube plugging are probably not required for many years; such repairs could be carried out during plant outages.

Failures will occur as the result of the following:

1. Corrosion

- a. Impingement erosion, particularly at entrances.
- b. Pitting attack.
- c. Pitting underneath deposits.

2. Stress Concentration

- a. Rolled joints.
- b. Thermal or mechanical load at supports.

The plant containing 60-ft tubes is likely to experience two to three times as many failures as the 360-ft tubed plant because many failures are associated with inlet turbulence. The fraction of surface lost after thirty years is likely to be less than half as much, however, because one-sixth as much tubing is lost per casualty.

The long tube design offers an advantage in making rapid repairs when tube leaks occur. The water boxes are at the ends of the evaporator heat recovery and heat reject sections and are fairly accessible. Short bundles have the water boxes buried inside the evaporator, and discovering a leaking tube or tubes could be a slow process. Leaking tubes could be located more rapidly in the long tube design. First, with the module shut down, tubes would be plugged temporarily (for example, rubber stoppers) at one end. Then, a slight positive air pressure in the evaporator would cause air flow in any leaking tube; this flow could be detected by a simple test, such as a soap bubble check at the unplugged tube end. Tests of this nature have proved to be a simple and reliable leak detection method.

There are some service disadvantages to long tubes. Each long tube must withstand the full range of service conditions, while the short bundles can have tubes of different thicknesses and materials adapted to the exact condition. In the event some condition of temperature, pressure, or noncondensables causes accelerated attack on tubes in only a few stages, repair of the short tube design would be easier than for the long tube design.

To recapitulate, a long-tubed plant would have perhaps two to three times as much surface out of service at a given time relative to a short-tubed plant. More downtime and much more maintenance labor is required for leak-hunting and tube-plugging in the short-tubed plant. Most of these casualties would occur after twenty years in a 70-30 copper-nickel system.

In the absence of real service data, it is difficult to predict a significant difference between long- and short-tubed plants in leakage costs.

IX. SHOP-ASSEMBLED TUBE BUNDLES

As an alternate construction (for cost comparison purposes) to the continuous long-tube evaporator bundle, the bundles can be built in shorter lengths connected by water boxes. The shorter bundles can be shop-assembled in lengths up to an estimated 60 ft, transported to the evaporator shell, inserted in the shell, and connected water box to water box. Figure 22 shows the tube bundle in place, and Figure 23 shows the water box construction. The longitudinal section shows a method equalizing the length of tube and the brine flashing length by longitudinal offset of the stage walls. It is not certain that this refinement is necessary or economical, in which case the stages at the water box support point would have a longer flashing length.

The tube bundles would be shop-fabricated using suitable spacing and aligning fixtures for the water boxes and intermediate tube supports. The completed bundle would have a water box half on each end; these would be blanked off and the bundle leak tested. It would then be ready for transport to the evaporator. Temporary longitudinal members would be required to stiffen the bundle for transportation and to stabilize the intermediate tube sheets, which may be loose on the tubes. We provided two 2-in. x 6-in. rectangular tubes under the bundle as part of the longitudinal stiffeners and for inserting the bundle into the evaporator.

The bundle would be placed on scaffolding at the correct elevation to be inserted lengthwise into the evaporator. A winch would be provided to pull the bundle into the evaporator. Temporary rollers would be secured to each stage wall to support the bundle on the two 2-in. x 6-in. tubes beneath the bundle. The bundle would then be drawn through the evaporator to its permanent position. At this position the water

ELEVATION
PREFABRICATED 60 FT TUBE BUNDLE

Figure 22
SINGLE LEVEL EVAPORATOR, 60-FT. TUBES - ELEVATION

Figure 23
INTERMEDIATE WATER BOX

boxes and intermediate tube sheets would be jacked clear of the rollers, and the channels and rollers would be removed. The bundle would then be bolted in place, using filler plates between the tube sheets and the openings in the stage walls. The remaining bundles would be installed consecutively in the same way. The water boxes would be bolted end to end after the bundles were inserted.

X. COST ESTIMATES

Cost Comparison of 60-ft Versus 360-ft Tubes

The economic advantages of full length condenser tubes for MSF plants have been examined through cost analyses of 60-ft prefabricated and 60- and 360-ft field-fabricated tube bundles. A major difference in evaporator design introduced by the utilization of full length condenser tubes is the elimination of interconnecting water boxes (Figure 23). Thus, the longer tubes avoid the incorporation of costly components and also permit a reduction in structure size. Other design features in these analyses were assumed to be unchanged between plants with different condenser tube lengths. A cost comparison between 60- and 360-ft tubes in a single-level 250-Mgd MSF evaporator plant is presented below.

1. The 60-ft prefabricated bundles are shop fabricated and installed in the plant as completely assembled bundles.
2. For the field-erected bundles, both the 60-ft and the 360-ft tubes would be installed in the plant after the tube sheets are permanently positioned at the plant site.
3. The tube costs are based on a recent price estimate for 3/4-in. O.D., 0.042-in. wall, welded, 70-30 copper-nickel tubes. It is assumed that the shop purchases tubes from a nearby mill, but that tubing for installation in the field is fabricated in an on-site mill.
4. Tube sheet hole costs are based on a cost estimate of \$0.035/hole in 3/4-in.-thick steel plate and \$0.087/hole in 2-in.-thick steel plate for 3/4-in.-diameter holes by the trepanning method.
5. Calculations were made to evaluate the production losses due to leaks and the maintenance labor required for plugging these leaks under varying assumptions of leakage. This analysis indicates that the economic loss due to tube leaks under the worst conceivable conditions has no appreciable effect in the annual cost comparison between 60- and 360-ft tube bundles. Accordingly, this item has been left out of the annual cost comparison.

6. Entrance and exit losses are calculated with resistance coefficients of 0.5 at the entrance and 1.0 at the exit; a brine flow of 15,100 gpm through the box; a brine velocity of 5.65 ft/sec; and a power cost of 2.0 mills/Kwh. These amount to \$40.20/box/yr. There are 400 intermediate water boxes in a 250-Mgd plant, for a total power loss of \$16,100/yr.
7. Shop labor is assumed to be \$10/hr; field labor, \$6.50/hr.
8. Jigs and fixtures and on-site tube mills are written off over the one job.

Capital Cost Breakdown for Those Items that Change

	Prefabricated	Field-Fabricated Bundle	
	Bundle 60-ft	60-ft	360-ft
Evaporator structure	\$19,883,850	\$19,883,850	\$19,229,970
Tubes	26,905,375 ^a	26,905,375 ^a	26,905,375 ^b
On-site mill			600,000
Tube sheet - end	168,507	175,557	175,557
Tube sheet - intermediate	817,719	887,120	992,730
Intermediate water boxes	1,664,160	1,664,160	
Tube pushers, fixtures, etc., material	94,930	94,930	167,250
Tube pushers, fixtures, etc., labor	459,845	600,470	611,135
Tube rolling, fixtures, etc., material	300,000	300,000	300,000
Tube rolling, fixtures, etc., labor	92,544	94,850	19,970
Fixtures for bundle alignment, material	145,200		
Fixtures for bundle alignment, labor	144,200		
Freight allowance	946,700 ^c	567,000 ^d	378,000 ^e
Extra handling at job site	46,200		
Total	\$51,669,230	\$51,173,312	\$49,379,987
Differential costs of 60-ft tubes over 360-ft tubes	\$ 2,289,243	\$ 1,793,325	

^aF.O.B. at tubing plant

^bDelivered at the desalting plant

^cBundle from Newark, New Jersey, to San Diego, California

^dTubing from Newark, New Jersey, to San Diego, California

^eStrip copper from East Alton, Illinois, to San Diego, California

Annual Cost Breakdown for Those Items that Change

	<u>\$/yr</u>		
	<u>Prefabricated</u>	<u>Field-Fabricated Bundle</u>	
	<u>Bundle</u> <u>60-ft</u>	<u>60-ft</u>	<u>360-ft</u>
<u>Fixed Costs</u>			
Amortization @ 5.185%	\$2,679,050	\$2,653,336	\$2,560,352
Insurance @ 0.25%	129,173	127,933	123,450
Interim replacement @ 0.35%	<u>180,842</u>	<u>179,106</u>	<u>172,830</u>
Total Fixed Costs	\$2,989,065	\$2,960,375	\$2,856,632
<u>Operating Costs</u>			
Power losses			
Water boxes @ \$40.20/ box/yr	<u>16,100</u>	<u>16,100</u>	
Total Operating Costs	\$ 16,100	\$ 16,100	
Total Annual Costs	\$3,005,165	\$2,976,475	\$2,856,632
Differential costs of 60-ft tubes over 360-ft tubes	\$ 148,533	\$ 119,843	
Differential cost (¢/1000 gallons)	0.181	0.146	

Tube Costs

The largest component of the total cost in a large MSF evaporator plant is for tubing, which represents approximately 30% of the total capital cost. Thus, considerable savings can be realized if tubing costs can be lowered.

Six of the major fabricators of copper-base alloy tubes were asked to supply cost estimates on 50-, 100-, and 360-ft seamless tubes and also to estimate what the costs would be in 1970. Also, we requested them to consider both shop and on-site fabrication in the development of 360-ft tube costs. These manufacturers have to date supplied only current 50-ft and 100-ft cost data for 60,000-ft quantities (Table V) with no cost-scaling allowances for larger amounts. Two manufacturers predicted that 360-ft tubes in 1970 (Table VI) would be at the same unit cost as current 100-ft tubes. Unpredictable copper prices and low profit margins were cited as reasons for the reluctance to predict

Table V
CURRENT CONDENSER TUBE COSTS FOR LARGE MSF PLANTS

Material	O.D., in.	Wall, in.	Company A	Company B	Company C	Company D		Company E	
			\$/ft (100 ft)	\$/ft (100 ft)	\$/ft (100 ft)	\$/ft (50 ft)	\$/ft (100 ft)	\$/ft (50 ft)	\$/ft (100 ft)
Aluminum, brass	5/8	.049	0.288	0.288	0.288	0.241	0.279	0.261	0.289
	3/4	.049	0.351	0.351	0.351	0.296	0.347	0.316	0.352
	1	.049	0.472	0.472	0.472	0.396	0.456	0.361	0.472
	1 1/4	.049	0.698	0.579	0.622	0.502	0.569	0.503	0.579
90-10 cupronickel	5/8	.042	0.315	0.314	0.314	0.267	0.305	0.287	0.315
	3/4	.042	0.378	0.377	0.377	0.322	0.366	0.342	0.378
	1	.042	0.501	0.501	0.501	0.426	0.485	0.379	0.502
	1 1/4	.042	0.720	0.613	0.613	0.536	0.602	-	0.614
	5/8	.035	0.310	0.274	-	0.227	0.275	0.226	-
	3/4	.035	0.369	0.329	-	0.273	0.329	0.247	-
	1	.035	0.477	0.435	-	0.359	0.435	0.359	-
	1 1/4	.035	-	-	-	0.451	0.536	0.451	-

Quotations are current prices for 50- and 100-ft seamless tubes in 60,000-ft quantities. Quotations were requested for 47-million-ft (1 1/4-in. OD) to 94-million-ft (5/8-in. OD) quantities.

Table VI
PROJECTED (1970) TUBE COSTS FOR LARGE MSF PLANTS

Material	O.D., in.	Wall, in.	Company D \$/ft	Company E \$/ft
Aluminum brass	5/8	.049	0.279	0.289
	3/4	.049	0.347	0.352
	1	.049	0.456	0.472
	1 1/4	.049	0.569	0.579
90-10 cupronickel	5/8	.042	0.305	0.315
	3/4	.042	0.366	0.378
	1	.042	0.485	0.502
	1 1/4	.042	0.602	0.614
	5/8	.035	0.275	
	3/4	.035	0.329	
	1	.035	0.435	
	1 1/4	.035	0.536	

Estimates are for 360-ft seamless tubes in 60,000-ft quantities. Quantities were requested for 47-million-ft (1 1/4-in. OD) to 94-million-ft (5/8-in. OD) quantities. Projections for 360-ft tubes are based on current prices of 100-ft seamless tube lengths and assuming maximum utilization of scrap.

An as-welded tube can be obtained for 10 to 15% less than a seamless tube according to one manufacturer.

prices and for the absence of further cost scaling. Also, they pointed out that the projected 360-ft tube costs were based on the assumption that tube splicing would be permitted to minimize scrap losses. Without this assumption, one company felt that prices could possibly be 50% greater on the 360-ft lengths.

After lengthy discussions with responsible management in the industry, some ground rules were established which should result in more reasonable cost projections.

1. Limited splicing of shorter tube lengths will be accepted to minimize scrap losses. Also, some tubes not long enough for the heat recovery section will be shortened for use in the heat reject section.
2. Tubes will be produced in cold worked temper to avoid the cost of annealing. The cold worked temper will facilitate handling for the long-tube concept and reduce the amount of denting.
3. Tubing specifications will be, in general, less stringent than present specifications for steam surface condenser tubing. A little more latitude would be allowed in surface blemishes.
4. To produce low-cost, reliable tubing, we must establish methods to maintain tube quality.

As related to the potential lower cost of welded tubing, some tube producers have indicated they have been unable to obtain suitable equipment for reliable 100% on-line monitoring for discontinuities at tube-fabricating speeds of 200-500 ft/min. The customary rotating of the tube in conjunction with a stationary ultrasonic probe is not feasible, and the only commercially available ultrasonic tester featuring a rotating probe can test at tube speeds no greater than 150 ft/min. Moreover, the makers of ultrasonic tube testers have stated that they are reluctant to recommend their instruments for testing welded-type tubing because of serious interfering back reflections caused by the residual weld flash left after scarfing.

Eddy-current tube testers have the capability of testing at high speeds, but characteristically are unable to detect lengthy discontinuities such as long cracks in the seam weld or weld faults resulting from either overheat or underheat conditions.

A state-of-the-art survey of tube testing devices has disclosed two advanced eddy-current instruments which are claimed to have the full capability for reliable high-speed testing of long welded tubes. These instruments provide not only a differential output signal to reflect pinholes, inclusions, and short hairline cracks but also an absolute output signal to reflect long cracks or open seam welds. At tube speeds of several hundred feet per minute, the instruments are

able to resolve two No. 80 drilled holes spaced 0.1 in. apart. For long cracks, or open weld seams, these instruments not only sense the discontinuity but also provide a recording of the full length to distinguish it from the response resulting from two widely spaced holes.

The difference in tubing costs for optimally spaced orders or for orders placed with one or several companies has been investigated. The tube manufacturers have stated that the tubing costs for a large order will be the same regardless of whether the order is placed with one or three companies. They have further declared that a large order of, say, 95 million ft of 5/8-in. O.D., cupronickel tubing (MWD plant) can be produced within two years with present industry capacity if the order is split between three major tube producers. Industry has ample capacity for producing large quantities of the primary thick-wall shells, but they would be short on draw bench facilities for drawing tubes into finished sizes.

The Oak Ridge National Laboratory expects to enter into OSW-sponsored subcontracts with tubing manufacturers to develop more economical fabrication procedures and more accurate tubing cost predictions.

XI. BIBLIOGRAPHY

¹"Conceptual Design Study of a 250-Million-Gallons-Per-Day Multistage Flash Distillation Plant," OSW Research and Development Report No. 214 (February, 1966), prepared for the Office of Saline Water at the Oak Ridge National Laboratory.

²Mitchell, B. E., and J. A. Smith, "Interstage Vapor Leakage in MSF Plants," ORNL-TM-1770, Oak Ridge National Laboratory, April, 1967.

APPENDIX A
LONG TUBE STUDY FORTRAN PROGRAMS

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APPENDIX A

LONG TUBE STUDY FORTRAN PROGRAMS

In order to evaluate the fixed inlet and outlet tube sheet method of providing for the thermal expansion of long tubes, it was necessary to determine the tube stresses and deflections that would be produced by taking up the thermal expansion in the deflection curve.

Attached are derivations of the expressions for the deflection, end moments, and maximum fibre stress for a uniformly loaded tube with fixed ends and end loading. This represents a section of condenser tube between any two adjacent tube sheets. Since other methods of providing for the thermal expansion result in tensile end loads, expressions were also derived for this situation.

Also attached are discussions and copies of the Fortran programs which were prepared to facilitate the computation of tubes of various diameters, materials, wall thickness, and span length.

The Tube Deflection and Stress Program computes and tabulates the deflection, length of deflection curve, end moment, and maximum fibre stress for end loads, beginning at the largest compressive load that is within the accuracy range of the derived expressions⁽¹⁾ and reducing in increments to any preselected value.

The thermal expansion program computes the thermal expansion of each stage and the cumulative expansion of the tubes for any desired combination of tube length, material, inlet and outlet temperatures.

These programs are useful not only for the purpose stated originally but also for obtaining the deflection and stress values produced by other methods of providing for the thermal expansion as well as from loads produced on the tube during installation.

(1) The load which will produce a deflection at the center of the span not greater than 20% of the span length.

CONDENSER TUBE UNIFORMLY LOADED
WITH FIXED ENDS AND END LOADS

Derivation of Deflection, End
Moment, and Maximum Stress Equations

$M_0 = M_\ell$ = end moments - in.-lb (negative as shown)

$V_0 = V_\ell$ = vertical shear - lb

S = lateral load - lb

E = modulus of elasticity - lb/in.²

I = moment of inertia - in.⁴

y = deflection - in.

w = uniform load - lb/in.

ϵ = unit strain - in./in.

ℓ = length of span - in.

L = length of deflection curve - in.

Compressive End Load (S Positive)

For y positive downward, the differential equation for the deflection curve is:

$$EI \frac{d^2 y}{dx^2} = -M$$

$$M = -M_o + \frac{w\ell x}{2} - \frac{wx^2}{2} + Sy$$

$$EI \frac{d^2 y}{dx^2} = -Sy + M_o - \frac{w\ell x}{2} + \frac{wx^2}{2}$$

$$\frac{EI}{S} \frac{d^2 y}{dx^2} = -y + \frac{M_o}{S} - \frac{w\ell x}{2S} + \frac{wx^2}{2S}$$

Let $p^2 = \frac{S}{EI}$

then

$$\frac{d^2 y}{dx^2} = -p^2 y + \frac{p^2 M_o}{S} - \frac{p^2 w\ell x}{2S} + \frac{p^2 wx^2}{2S}$$

Solution of this equation $y = Y_c + Y_p$

$$(D^2 + p^2)y = \frac{p^2 M_o}{S} - \frac{p^2 w\ell x}{2S} + \frac{p^2 wx^2}{2S}$$

$$Y_c = C_1 \cos px + C_2 \sin px \quad Y_p = Ax^2 + Bx + C$$

$$(D^2 + p^2)(Ax^2 + Bx + C) = 2A + p^2 Ax^2 + p^2 Bx + p^2 C$$

$$= -\frac{p^2 M_o}{S} - \frac{p^2 w\ell x}{2S} + \frac{p^2 wx^2}{2S}$$

Equating like powers of x

$$p^2 A = \frac{p^2 w}{S} \quad A = \frac{w}{S} \quad p^2 B = -\frac{p^2 w\ell}{2S} \quad B = -\frac{w\ell}{2S}$$

$$2A + p^2 C = \frac{p^2 M_o}{S} \quad C = \frac{M_o p^2 - w}{S p^2} \quad Y_p = \frac{wx^2}{2S} - \frac{w\ell x}{2S} + \frac{M_o p^2 - w}{S p^2}$$

General solution is:

$$y = C_1 \cos px + C_2 \sin px + \frac{wx^2}{2S} - \frac{w\ell x}{2S} + \frac{M_O p^2 - w}{Sp^2}$$

Solve for C_1 and C_2

At $x = 0$ $y = 0$

$$0 = C_1 \cos 0 + C_2 \sin 0 + \frac{M_O p^2 - w}{Sp^2}$$

$$C_1 = - \left(\frac{M_O p^2 - w}{Sp^2} \right)$$

At $x = \ell$ $y = 0$

$$0 = - \left(\frac{M_O p^2 - w}{Sp^2} \right) \cos p\ell + C_2 \sin p\ell + \frac{w\ell^2}{2S} - \frac{w\ell^2}{2S} + \frac{M_O p^2 - w}{Sp^2}$$

$$C_2 = \frac{\left(\frac{M_O p^2 - w}{Sp^2} \right) (\cos p\ell - 1)}{\sin p\ell}$$

$$y = - \left(\frac{M_O p^2 - w}{Sp^2} \right) \cos px + \frac{\left(\frac{M_O p^2 - w}{Sp^2} \right) (\cos p\ell - 1)}{\sin p\ell} \sin px + \frac{wx^2}{2S} - \frac{w\ell x}{2S} + \frac{M_O p^2 - w}{Sp^2}$$

$$y = \left(\frac{M_O p^2 - w}{Sp^2} \right) \left[1 - \cos px - \left(\tan \frac{p\ell}{2} \right) \sin px \right] + \frac{wx^2}{2S} - \frac{w\ell x}{2S}$$

$$\frac{dy}{dx} = \left(\frac{M_O p^2 - w}{Sp^2} \right) \left[p \sin px - p \left(\tan \frac{p\ell}{2} \right) \cos px \right] + \frac{wx}{S} - \frac{w\ell}{2S}$$

M_o must cause the slope to be 0 at ends

$$\frac{dy}{dx} = \left[\frac{M_o p^2 - w}{Sp^2} \right] \left[p \sin px - p \tan \frac{pl}{2} \cos px \right] + \frac{wx}{S} - \frac{wl}{2S} = 0$$

At $x = 0$

$$\frac{M_o p^2 - w}{Sp^2} \left[0 - p \tan \frac{pl}{2} \right] - \frac{wl}{2S} = 0$$

$$\left(\frac{M_o p^2 - w}{p} \right) \tan \frac{pl}{2} = - \frac{wl}{2}$$

$$M_o p^2 = - \frac{wlp}{2 \tan \frac{pl}{2}} + w$$

$$M_o = - \frac{wl}{2 p \tan \frac{pl}{2}} + \frac{w}{p^2}$$

$$M_o = \frac{w}{p^2} \left[1 - \frac{p l}{2 \tan \frac{pl}{2}} \right]$$

$$M_o = \frac{w}{p^2} \left[1 - \frac{pl}{2} \cot \frac{pl}{2} \right]$$

Substituting this value for M_o and simplifying

$$y = \frac{w l}{2Sp} \left[\sin px - \cot \frac{pl}{2} (1 - \cos px) \right] - \frac{wx}{2S} (l - x)$$

$$\text{At } x = \frac{l}{2}$$

$$y = \frac{wl}{2Sp} \left[\tan \frac{pl}{4} - \frac{pl}{4} \right]$$

Maximum stress = δ

$$\delta = \frac{M_o D}{2I} + \frac{S}{A} \quad A = \frac{\pi}{4} \left[D^2 - (D-2T)^2 \right]$$

$$\alpha = \frac{M_o D}{2I} + \frac{4S}{\pi(D^2 - (D-2T)^2)}$$

These expressions when the end load is tensile are determined in the same manner to be:

$$\alpha = \sqrt{\frac{S}{EI}}$$

$$y = \frac{wl}{2S\alpha} \left[\frac{\sinh(\alpha x) + \sinh(\alpha(l-x)) - \sinh(\alpha l)}{\cosh(\alpha l) - 1} \right] + \frac{wx}{2S} (l-x)$$

$$\text{when } x = \frac{l}{2}$$

$$y = \frac{wl^2}{8S} - \frac{wl}{\alpha S} \sinh\left(\alpha \frac{l}{2}\right) \left[\frac{\cosh\left(\alpha \frac{l}{2}\right) - 1}{\cosh(\alpha l) - 1} \right]$$

$$M_o = \frac{wl}{2\alpha} \left[\frac{\sinh(\alpha l)}{\cosh(\alpha l) - 1} \right] - \frac{w}{\alpha^2}$$

when $S = 0$

$$y = \frac{w}{24EI} x^2 (l-x)^2$$

$$M_o = \frac{wl^2}{12}$$

FORTRAN PROGRAM FOR COMPUTATION OF DEFLECTION,
LENGTH, END MOMENT, AND MAXIMUM FIBRE STRESS

1. The following data are entered on a data card for each tube to be calculated:
 - a. Modulus of elasticity (lb/in.^2)
 - b. Moment of inertia (in.^4)
 - c. Length of span (in.)
 - d. Outside diameter (in.)
 - e. Wall thickness (in.)
 - f. Uniform load (lb/in.)
 - g. Minimum end load (lb)
 - h. Smaller decrement of load (lb)
 - i. Larger decrement of load (lb)
 - j. Tube material
2. The maximum compressive end load which is the critical column load for the tube is calculated. This is used as the starting point.
3. This end load is then used in the proper equation to calculate the deflection at the center of the span.
4. This value of the deflection is checked and if it is greater than 20% of the span, the end load is reduced by the smaller decrement of the load (5.0 lb was used in all runs made to date) because the accuracy of the equations drop off rapidly for large deflections.
5. When the load has been reduced sufficiently to pass the above test, the end moments, maximum fibre stress, and length of deflection curve are calculated.
6. The length of the deflection curve is calculated by taking increments of .005 times the span, computing the deflection over this increment, and solving for the hypotenuse of these triangles which approximate the curve. These values are summed from one end to the center of the span and multiplied by 2 to obtain the complete length. The values of end load, deflection, length of curve, end moment, and maximum stress are printed out.
7. The end load is then reduced by the small decrement and the process repeated until the end load has been reduced to the point where the length of the deflection curve is not appreciably greater (.010 in.) than the span.
8. The end load is then reduced each time by the larger decrement (20 lb in all runs to date), and the length of the curve is set to the span length before it is printed out.

9. As the end load is reduced, different equations are required for zero load and negative (tensile) load. The program provides for the selection of the applicable equation.
10. When the minimum end load is reached (250-lb tensile in all runs to date), the calculations are complete for that tube and the data card is read to begin the computation for the next tube.

TUBE STRESS CALCULATIONS

TUBES - EFN SOURCE STATEMENT - IFN(S) -

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C COMPUTATION OF SAG, LENGTH, AND MAX FIBRE STRESS OF A
C CONDENSER TUBE WITH ENE LOADING.
E IS THE MODULUS OF ELASTICITY (LB PER SQ IN)
I IS THE MOMENT OF INERTIA (INCHES FOURTH)
L IS THE LENGTH OF SPAN (IN INCHES)
D IS THE CUTSIDE DIAMETER (INCHES)
T IS THE WALL THICKNESS (INCHES)
W IS THE UNIFORM LOAD DENSITY (LB PER INCH)
SPIN IS THE MINIMUM ENCL LOAD (LB)
DELSL IS THE SMALLER OCCURENCE OF LOAD (LB)
DELSL IS THE LARGER OCCURENCE OF LOAD (LB)
MATJ1,MATL2 IS THE MATERIAL OF THE TUBE.
REAL I,L,MU
INTEGER SPIN,DELSL,DSO
C
C SIN(X)=0.5*(EXP(X)-EXP(-X))
PI(Y)=0.5*(EXP(Y)+EXP(-Y))-1.0
C
C10 READ(7,11E,1),L,C,T,W,XMIN,XSLSS,DELSL,NATL1,MATL2
C 1 FORMAT(6E10.0,I4,2I3,2A5)
C
C WRITE(6,2) NATL1,MATL2
C 2 FORMAT(1H1,'X26PCCONSUMER TUBES W/END LOAD/HMC,7X9HHMATERIAL,2A5)
C
C WRITE(6,3) E,I,L,C,T,W
C 3 FCMPAT11HD,7XZHEIE15.0,6XZHI1E12.0,6XZHL1E13.0/H,7XZHDI1E13.0,6X
C 12H1E13.0,6XZPMWE13.0)
C
C WRITE(6,4)
C 4 FCMPAT11HD,1XKHENC LOAC,3XIDHCPEFLCTCN,7XOHLEVGMH,EXICHMENT MOME
C 2T,1XIDHPAX STRESS/H,1XDHMFOUNDS,1XBHM INCHEIS,8XRIINCHEIS),
C 37X1XDHM INCHES,8XSHPS11)
C
C COMPUTE PAX ENCL LOAD
SBI(L,D)=(3.14159+2)*E*I/(L*L)/FLOAT(DESSL)
SD = I *F(I*15)/DESSL
KFI=
GC TC 110
C12 SD + SD-DESSL
GC TC 110
C19 SD + SD-DESSL
I16 IF(SD.LT.SPIN)GC TO I10
I16 IF(SD)113:I10:I10
C
C END LOAD IS NEGATIVE - COMPUTE SAG.
C1 SCFFLEP(LAU)
PSC = SCF(E*I)
PR SCRT(PSC)
DEFW=L/L1/(2.35+C*PI)*(1+(SINO(.25*PI-L)/COS(C.25*PI)))-(C.25*PI))
L1=L-C*.25*PI
C
C DEFN NUT EXCESSIVE - COMPUTE ENCL MOMENT AND MAX STRESS
C14 MU=(PW/F50)/(C*(D-.5)*L)/(COSE(D+.5*PI))/SINE(C+.5*PI)
STRAP=ENDL*.5*SD/C*(1+(1+.35*C)/2).14159+(D+.2-D-.2*C+.7+23))
GC C10D-I10)
C
C COMPUTE LENGTH
```

2 3

6 7

15

16

17

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TUBES - EFN SOURCE STATEMENT - IFN(S) -

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C5 YL#D.0
DELX # 0.005*L
F#D.0
ESS #D.0
DC I22 J#1,I00
XR #CELEX
YR#(1+X)/(2.0*SC+P1)+(SINH(P*X)-(COS(0.5*P*L)/SINH(.5*P*L))+
4.1*(.3-C5(P*X)))-(W*X+(-L-X)/(2.0*CS))
DESS # SCRT((1YR-YL)*+2)*CELEX*+2)
ESS # ESS + DESS

120 YL # YR
DESS #2.0*ESS
112 IF 11E55-L1.G1.U.31) GO TO 107
K#2
1C6 ESS#L
GC TR 107

END LCAD IS ZERO - COMPUTE SAC, END MOMENT, AND MAX STRESS.
110 DEF# #((W/10.0*2N.D+E1))*(L*#4)
P#D W*L/12.0
A#D.0
STRPAX# 0.5*P0-C/1
IF (K1-21111,106,106)
COMPUTE LENGTH
111 YL#D.0
DELX #D.005*L
X#D.0
ESS #D.0
DC I21 K#1,I00
XR#CELEX
YR # (1/24.D+C*1)*X+(L-X)*(L-X)
DESS # SCRT((1YR-YL)*+2)*(CELEX*+21)
ESS #ESS+DESS
121 Y#YR
ESS #2.0*ESS
GO TC 112

END LCAD IS NEGATIVE - COMPUTE SAC, END MOMENT, AND MAX STRESS
113 S2 # F(CATISO1)
ST # AES(S2)
X#L,SC(1E+11)
DEF# ((W*L)/(0.D+ST))-(W*L/(AL*ST1)+SINH(.5*AL*E1)-(PHI(E1*
S1/P#1)*(AL*11))
P#D W*L/12.SINH(P*L)/(2.0*D*AL*P#1*(AL*11))-(W/(AL*+2))
A#D.0
STRPAX # (D.5*P0+C/1)*(ST/3.14159*(C-T)+T)
IF (K1-21111,106,106)
COMPUTE LENGTH
114 YL#D.0
DELX #D.005*L
X#D.0
ESS #D.0
DC I22 A#1,I00
XR#CELEX
YR # (1+X)/(2.0*ST+AL1)+(SINH(AL*X)+S1*W*(L-X))-SINH(AL*11)
7 PHI (AL*12.0) -(W*(L-X)/(2.0*ST))

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TUBES - EFN SOURCE STATEMENT - 1FN(S) -

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DESS # SCRT((IYR-YL)*.2)+(CELY*.2))
ESS #ESS +DESS
122 YL#YR
ESS #2.0*ESS
GC TC 112
107 WRITE(6,5)SU,CEFL,ESS,MQ,STRMAX
5 FORMAT(1HC,17,4E16.6)
IF(11-21102,109,109
END

```

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SAMPLE TUBE STRESS PRINTOUT

CONDENSER TUBES W/END LOAD

MATERIAL, TITANIUM

E) 0.160000E 08
D) 0.100000E 01I) 0.600000E-02
T) 0.160000E-01L) 0.100000E 03
W) 0.353370E-01

END LOAD (PCUNDS)	DEFLECTION (INCHES)	LENGTH (INCHES)	END MOMENT (LB INCHES)	MAX STRESS (PSI)
* 375	0.896863E 01	0.101955E 03	0.171263E 04	0.150301E 06
* 370	0.398292E 01	0.100390E 03	0.767828E 03	0.714663E 05
* 365	0.256027E 01	0.100161E 03	0.498209E 03	0.488969E 05
* 360	0.188666E 01	0.100088E 03	0.370532E 03	0.381561E 05
* 355	0.149380E 01	0.100055E 03	0.296057E 03	0.318488E 05
* 350	0.123645E 01	0.100038E 03	0.247259E 03	0.276812E 05
* 345	0.105480E 01	0.100027E 03	0.212808E 03	0.247091E 05
* 340	0.919740E 00	0.100021E 03	0.187184E 03	0.224727E 05
* 335	0.815377E 00	0.100016E 03	0.167378E 03	0.207212E 05
* 330	0.732316E 00	0.100013E 03	0.151609E 03	0.193060E 05
* 325	0.664639E 00	0.100011E 03	0.138755E 03	0.181337E 05
* 320	0.608433E 00	0.100000E 03	0.128076E 03	0.171427E 05
* 300	0.454760E 00	0.100000E 03	0.988417E 02	0.143022E 05
* 280	0.363178E 00	0.100000E 03	0.813771E 02	0.124424E 05
* 260	0.302379E 00	0.100000E 03	0.697488E 02	0.110690E 05
* 240	0.259075E 00	0.100000E 03	0.614306E 02	0.997217E 04
* 220	0.226663E 00	0.100000E 03	0.551953E 02	0.904754E 04
* 200	0.201493E 00	0.100000E 03	0.503270E 02	0.823749E 04
* 180	0.181380E 00	0.100000E 03	0.464196E 02	0.750752E 04
* 160	0.164940E 00	0.100000E 03	0.432106E 02	0.683574E 04
* 140	0.151251E 00	0.100000E 03	0.405251E 02	0.620759E 04
* 120	0.139674E 00	0.100000E 03	0.382423E 02	0.561300E 04
* 100	0.129756E 00	0.100000E 03	0.362760E 02	0.504479E 04
* 80	0.121164E 00	0.100000E 03	0.345631E 02	0.449769E 04
* 60	0.113649E 00	0.100000E 03	0.330561E 02	0.396775E 04
* 40	0.107020E 00	0.100000E 03	0.317190E 02	0.345196E 04
* 20	0.101128E 00	0.100000E 03	0.305235E 02	0.294798E 04
* 0	0.958577E-01	0.100000E 03	0.294475E 02	0.245396E 04
* -20	0.911152E-01	0.100000E 03	0.284732E 02	0.277713E 04
* -40	0.868246E-01	0.100000E 03	0.275863E 02	0.310757E 04
* -60	0.829245E-01	0.100000E 03	0.267749E 02	0.344432E 04
* -80	0.793637E-01	0.100000E 03	0.260294E 02	0.378654E 04
* -100	0.760998E-01	0.100000E 03	0.253416E 02	0.413359E 04
* -120	0.730971E-01	0.100000E 03	0.247047E 02	0.448487E 04
* -140	0.703253E-01	0.100000E 03	0.241130E 02	0.483992E 04
* -160	0.677588E-01	0.100000E 03	0.235615E 02	0.519832E 04
* -180	0.653755E-01	0.100000E 03	0.230460E 02	0.555972E 04
* -200	0.631566E-01	0.100000E 03	0.225629E 02	0.592382E 04
* -220	0.610854E-01	0.100000E 03	0.221090E 02	0.629035E 04
* -240	0.591477E-01	0.100000E 03	0.216816E 02	0.665909E 04

FORTRAN PROGRAM FOR COMPUTATION
OF TUBE THERMAL EXPANSION

1. The following data are entered on a data card for each tube to be calculated.
 - a. Coefficient of thermal expansion (in./in./°F)
 - b. Length of tube (in.)
 - c. Number of stages
 - d. Temperature of tube at seawater inlet (°F)
 - e. Temperature of tube at seawater outlet (°F)
 - f. Initial temperature of tube at installation (°F)
2. The ΔT per stage is calculated from the inlet and outlet temperatures and the number of stages.
3. The length of each stage is computed using the tube length and the number of stages.
4. The expansion of the first stage is computed, then the second stage, etc., until all stages have been completed. As the expansion of each stage is obtained, it is added to the summation of the stages already calculated and both values are tabulated.

THERMAL EXPANSION PRINTOUT

CALC2
 EXTERNAL FORMULA NUMBER - SOURCE STATEMENT - INTERNAL FORMULA NUMBER(S)

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C THERMAL EXPANSION OF CONDENSER TUBE
C COEFFICIENT OF THERMAL EXPANSION (DATA CCF)
C LENGTH OF TUBE (IN.) (DATA S)
C NUMBER OF STAGES (DATA N)
C TEMP OF TUBE AT INLET (DATA TI)
C TEMP OF TUBE AT OUTLET (DATA TO)
C INITIAL TEMP OF TUBE (DATA TA)
100 READ(S,1)COF,S,N,TI,TO,TA
1 FORMAT(2E13.6,13,F7.2)
WRITE(6,2)COF,S,N,TI,TO,TA
2 FORMAT(5HDATA/1HD,12HCOEFFICIENT1E13.6,5X7HLENGTH1E13.6,5X2HN)
1 13/ 2X 5H11F7.2,5X 5H101F7.2,5X 5H1A1F7.2)
WRITE(6,7)
NN=N-1
DT=((TO-TI)/FLOAT(N))
T=DT
SDX=DT,C
T=TI+DT
J=0
DO 5 I=1,N
T=TI+DT
C K IS STAGE EXPANSION
C J IS STAGE NUMBER
J=J+1
X=TS/FLOAT(N)
DX=COF*X*(T-TA)
C SDX IS TOTAL EXPANSION OF TUBE
SDX=SDX+DX
5 WRITE(6,11)J,1,DX,SDX
7 FORMAT(1HD,5HSTAGE,5X11HTEMPERATURE,5X8HSTAGE DL,5X
1 15HACCUMULATIVE DL)
8 FORMAT(1HD,15,9X F7.2,4X E13.6,5X E15.6)
GO TO 100
END

```

DATA 338.9 FT. TITANIUM
 COEFFICIENT) 0.60000E-05 LENGTH) 0.406680E 04 N) 40
 TI) 88.00 TO) 226.00 TA) 70.00

STAGE	TEMPERATURE	STAGE DL	ACCUMULATIVE DL
1	226.00	0.951631E-01	0.951631E-01
2	222.46	0.930046E-01	0.188168E-00
3	218.92	0.908461E-01	0.279014E-00
4	215.38	0.886875E-01	0.367701E-00
5	211.85	0.865290E-01	0.454230E-00
6	208.31	0.843705E-01	0.538601E-00
7	204.77	0.822119E-01	0.620811E-00
8	201.23	0.800534E-01	0.700866E-00
9	197.69	0.778949E-01	0.778761E-00
10	194.15	0.757365E-01	0.854497E-00
11	190.62	0.735779E-01	0.928075E-00
12	187.08	0.714195E-01	0.999494E-00
13	183.54	0.692607E-01	0.106879E-01
14	180.00	0.671022E-01	0.113580E-01
15	176.46	0.649437E-01	0.120080E-01
16	172.92	0.627851E-01	0.126359E-01
17	169.38	0.606266E-01	0.132421E-01
18	165.85	0.584681E-01	0.138268E-01
19	162.31	0.563095E-01	0.143899E-01
20	158.77	0.541510E-01	0.149314E-01
21	155.23	0.519925E-01	0.154515E-01

22	151.69	0.498339E-01	0.159497E-01
23	148.15	0.476754E-01	0.164264E-01
24	144.62	0.455169E-01	0.168816E-01
25	141.08	0.433583E-01	0.173152E-01
26	137.54	0.411998E-01	0.177272E-01
27	134.00	0.390413E-01	0.181176E-01
28	130.46	0.368827E-01	0.184864E-01
29	126.92	0.347242E-01	0.188337E-01
30	123.38	0.325657E-01	0.191595E-01
31	119.85	0.304071E-01	0.194634E-01
32	116.31	0.282486E-01	0.197459E-01
33	112.77	0.260901E-01	0.200068E-01
34	109.23	0.239315E-01	0.202461E-01
35	105.69	0.217730E-01	0.204638E-01
36	102.15	0.196145E-01	0.206600E-01
37	98.62	0.174560E-01	0.208345E-01
38	95.08	0.152974E-01	0.209875E-01
39	91.54	0.131389E-01	0.211189E-01
40	88.00	0.109804E-01	0.212287E-01

DATA

APPENDIX B

MINIMUM BENDING RADIUS OF TUBING WITHOUT PERMANENT SET

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APPENDIX B

Minimum Bending Radius of Tubing Without Permanent Set

$dl = R d\alpha$ differential length at neutral axis

$dl_o = (R+r)d\alpha$ differential length at outside surface

$\delta =$ Decimal extension of outside fiber =

$$\frac{(R+r)d\alpha}{Rd\alpha} - 1 = \frac{(R+r)}{R} - 1$$

$S =$ tensile stress, psi $= \delta \times E$, where $E =$ modulus of elasticity

$$S = \left[\frac{(R+r)}{R} - 1 \right] E$$

$$S = \left[\frac{(R + r)}{R} \right] E - E$$

$$R = \frac{rE}{S}$$

For a 90-10 cupronickel light drawn tube with a yield point of 57,000 psi (0.5% ext), a diameter of 3/4 inch, and a modulus of elasticity of 18×10^6 , a safe bending radius which should not leave permanent set would be:

(Assume stress of 40,000 psi maximum)

$$R = \frac{0.375 \times 18 \times 10^6}{40,000}$$

$$R = 169 \text{ inches} = 14+ \text{ feet radius}$$

APPENDIX C

OUTAGES DUE TO TUBE LEAKAGE FOR A 250-MGD REPRESENTATIVE DESIGN

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APPENDIX C

OUTAGES DUE TO TUBE LEAKAGE FOR A 250-MGD REPRESENTATIVE DESIGN

The following conditions and assumptions are used:

Salinity	58,000 ppm
Permitted increase in product water salinity before making repair	25 ppm
"Average leak" (0.020-in.-diameter hole at maximum recycle brine pressure)	50 lb/hr
"Maximum leak" (full tube flow from both broken ends)	6,670 lb/hr
Total number of tubes which will have been plugged in 15 years' operation (10% of 188,160 tubes)	18,816
Turn-around time for a repair period	24 hr
Production loss during repair period (one module)	20 percent

A. For the most favorable case - all "average leaks":

1. Number of failures in a module before a repair period =

$$\frac{\text{Product Rate} \times \text{Permitted Salinity}}{\text{Recycle Salinity} \times \text{Leak Rate}}$$

$$\frac{17.35 \times 10^6 \text{ lb/hr} \times 25 \text{ ppm increase to repair}}{58 \times 10^3 \text{ ppm} \times 50 \text{ lb/hr leak rate}} = 150 \text{ leaks before repair.}$$

2. Number of repair shutdowns in 15 years =

$$\frac{\text{Total Failures}}{\text{Failures before Repair}} = \frac{18,816}{5 \times 150} = 25.1 \text{ repair periods per module.}$$

3. Percent production loss =

$$\frac{\text{Lost Production}}{\text{Total Production}} = \frac{25.1 \text{ days}}{365 \times 15 \text{ yr}} = 0.46\% \text{ production loss}$$

per module = percent production loss for the plant.

B. For the least favorable case - all "maximum leaks":

1. Number of failures per module before a repair period =

$$\frac{17.35 \times 10^6 \times 25}{58 \times 10^3 \times 6670} = 1.121 \text{ leaks.}$$

2. Number of repair shutdowns =

$$\frac{18,816}{5 \times 1.121} = 3,360 \text{ repair periods per module.}$$

3. Percent production loss =

$$\frac{3,360}{365 \times 15} = 61\% \text{ production loss per module = percent}$$

production loss for plant.

If it is assumed that 90% of the failures experienced are of the "average leak" variety and 10% of the "maximum leak" type, the production loss will be $10\% \times 61\% + 90\% \times .46\% = 6.6\%$ production loss for the entire plant.

There is no operating experience for long condenser tubes of this type, so the validity of the above assumptions is not known. Tubes will be tested at the time of scheduled shutdowns for maintenance of pumps and other equipment, and the majority of plugging of tubes with small leaks will be done at these shutdowns. The complete rupture of tubes must be guarded against by minimizing vibration and severe tube stresses.

If it is considered likely that serious production losses will occur from shutdowns, it is possible to provide shutoff valves for each tube bundle or for groups of tube bundles which will permit the module to continue operating at almost full capacity while repairs are made. The shutoff valves will also help to locate the bundle in which leaking tubes have occurred.

APPENDIX D
HEAT TRANSFER IN LONG TUBES

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APPENDIX D

HEAT TRANSFER IN LONG TUBES

The heat transfer coefficient for flow in circular tubes is higher in the thermal entrance region than at the equilibrium condition. Its value is a function of Reynolds number and length to diameter ratio.⁽¹⁾ The local coefficient reaches its asymptotic value at $L/D = 50$, and is 10% higher at $L/D = 10$. There is a negligible effect on overall heat transfer comparing 60-ft and 360-ft tubes.

⁽¹⁾ I. T. Aladyev, NACA TM 1346 (1954).

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