



Calhoun: The NPS Institutional Archive
DSpace Repository

Theses and Dissertations

1. Thesis and Dissertation Collection, all items

1983-12

Marine steam condenser design optimization

Buckingham, Thomas M.

Monterey, California. Naval Postgraduate School

<https://hdl.handle.net/10945/19876>

Downloaded from NPS Archive: Calhoun



Calhoun is the Naval Postgraduate School's public access digital repository for research materials and institutional publications created by the NPS community. Calhoun is named for Professor of Mathematics Guy K. Calhoun, NPS's first appointed -- and published -- scholarly author.

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

<http://www.nps.edu/library>

DUDLEY K...
NAVAL DE...
MONTEREY, CALIFORNIA 93943

NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

MARINE STEAM CONDENSER
DESIGN OPTIMIZATION

by

Thomas M. Buckingham

December 1983

Thesis Advisor:

R. H. Nunn

Approved for public release; distribution unlimited.

T214364

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Marine Steam Condenser Design Optimization		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; December 1983
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Thomas M. Buckingham		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943		12. REPORT DATE December 1983
		13. NUMBER OF PAGES 224
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Condenser Optimization CONDIP ORCON1 Condenser Computer Program		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A surface-condenser analysis code was coupled with a constrained function minimization code to produce an automated marine condenser design and optimization package. The program, CONDIP, was based on the principles developed in ORCON1, a sophisticated computer code produced by the Oak Ridge National Laboratory. CONMIN, the optimization program, was developed at the Ames Research Center.		

CONDIP is an extremely versatile design tool, incorporating a detailed analysis of the complex steam-side thermodynamic processes occurring at each row in the condenser. The additional capability of tube enhancement is also included. However, in coupling CONDIP with CONMIN numerous problems had to be overcome in order to make CONDIP capable of completing an analysis even when thermodynamic conditions in the condenser became infeasible. This had to be accomplished while ensuring continuity in all constraint and objective function evaluations. A series of test cases were conducted to evaluate and compare the importance of various objective functions and design criteria.

Approved for public release; distribution unlimited.

Marine Steam Condenser
Design Optimization

by

Thomas M. Buckingham
Lieutenant, United States Navy
B.A., College of the Holy Cross, 1977

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
December 1983

ABSTRACT

A surface-condenser analysis code was coupled with a constrained function minimization code to produce an automated marine condenser design and optimization package. The program, CONDIP, was based on the principles developed in ORCON1, a sophisticated computer code produced by the Oak Ridge National Laboratory. CONMIN, the optimization program, was developed at the Ames Research Center.

CONDIP is an extremely versatile design tool, incorporating a detailed analysis of the complex steam-side thermodynamic processes occurring at each row in the condenser. The additional capability of tube enhancement is also included. However, in coupling CONDIP with CONMIN numerous problems had to be overcome in order to make CONDIP capable of completing an analysis even when thermodynamic conditions in the condenser became infeasible. This had to be accomplished while ensuring continuity in all constraint and objective function evaluations. A series of test cases were conducted to evaluate and compare the importance of various objective functions and design criteria.

TABLE OF CONTENTS

I.	INTRODUCTION	10
	A. BACKGROUND	10
	B. METHODOLOGY	10
	C. OBJECTIVE	13
II.	NUMERICAL OPTIMIZATION	14
	A. BACKGROUND	14
	B. CONSTRAINED FUNCTION MINIMIZATION (CONMIN)	15
	C. CONTROL PROGRAM FOR ENGINEERING SYNTHESIS (COPEX)	19
III.	CONDENSER DESIGN IMPROVEMENT PROGRAM (CONDIP)	21
	A. BACKGROUND	21
	B. CODE DEVELOPMENT	26
	1. Steam Flow Effects	29
	2. Steam Pressure and Temperature Effects	33
	C. LIMITATIONS	37
IV.	DESCRIPTION OF THE MAIN AND SUPPORTING SUBROUTINES	42
	A. MAJOR SUBROUTINES	42
	1. ANALIZ	42
	2. INPUT	42
	3. OUT3	43
	4. ORCON	43
	5. SECALC	44
	6. HETTRN	46
	7. COOLEX	47
	8. OUT2	48

9.	OUT2C	48
10.	OUT3	48
B.	SUPPORTING SUBROUTINES	49
V.	RESULTS	64
A.	CONDIP VERIFICATION	64
B.	EXPLANATION OF THE CASE STUDIES	69
1.	Constraint Framework for CONDIP	71
2.	Design Variable Framework for CONDIP	73
C.	CASE STUDIES USING CONDIP	75
1.	Case One	75
2.	Case Two	76
3.	Case Three	77
4.	Case Four	79
5.	Case Five	80
VI.	CONCLUSIONS	89
VII.	RECOMMENDATIONS	91
	APPENDIX A: GLOSSARY	93
	APPENDIX B: USERS MANUAL FOR CONDIP	97
	APPENDIX C: CONDIP LISTING	132
	LIST OF REFERENCES	224
	INITIAL DISTRIBUTION LIST	226

LIST OF TABLES

I.	Input Design Data	82
II.	CCNDIP Verification Results	83
III.	Volume Minimization	84
IV.	Power Minimization	85
V.	Power Minimization With Volume Constant	86
VI.	Volume Minimization With Power Constant	87
VII.	Volume Minimization With Linear Variations	88

LIST OF FIGURES

2.1	Flow Diagram For ANALIZ and COPES/CONMIN	19
4.1	Flow Diagram for the ANALIZ Subroutine	51
4.2	Flow Diagram for the INPUT Subroutine	52
4.3	Flow Diagram for the ORCON Subroutine	53
4.4	Flow Diagram for the SECALC Subroutine	54
4.5	Flow Diagram for the HETTRN Subroutine	60
4.6	Flow Diagram for the COOLEX Subroutine	61
B.1	Sample Data Input	131

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Professor Robert Nunn and Professor Gary Vanderplaats for their advice and guidance during the development of this project. Without their encouragement and valuable assistance this thesis could never have been completed.

Many thanks and appreciation are due my wife, Susan, for her understanding, encouragement and participation in this endeavor.

Finally, this thesis is dedicated to Louis Perra, a close friend, whose pride and faith in my goals and ability inspired me to do the best job possible.

I. INTRODUCTION

A. BACKGROUND

For many years the steam plant was unchallenged in its role as the primary type of marine propulsion systems. But recently gas turbines have become a desirable alternative despite the fact that they are less efficient than comparable steam plants. The primary advantage of gas turbines is their light weight and compact size. Thus, in order for the marine steam plant to survive, it is imperative that lighter, more compact and efficient steam plants be developed.

While there are numerous advanced concepts in all areas of steam propulsion which can be explored, one simple way to streamline the steam plant is the elimination of overdesign. Most overdesign is due to unnecessary safety factors used to offset lack of detailed knowledge about the thermal processes in the plant. Identification of the minimum safe design could significantly reduce unnecessary overdesign and result in the development of a smaller, more compact power plant.

B. METHODOLOGY

In the United States the most prevalent criterion for the design and specification of surface condensers is based on the "square-root of V" relationship, as developed by the Heat Exchange Institute (HEI) [Ref. 1]. The HEI method was adopted by the Department of the Navy Bureau of Ships (now Naval Sea System Command) for specification of U.S. Naval condensers.

The HEI method is very simple in its approach, calculating the overall heat transfer coefficient as a function of cooling water velocity through the tubes, inlet coolant temperature, tube wall thickness and material, and fouling. The limitations of this method are apparent. Designs based on HEI are insensitive to shell-side conditions. Saturation steam pressure, temperature and enthalpy are assumed to be constant as steam passes through the bundle, whereas in reality there is a continual pressure drop as steam flow passes over the rows of tubes, with a corresponding decrease in saturation temperature. There is also no provision for any effects of condensate film, external tube enhancement, etc. on the shell-side of the bundle. In addition, the HEI method does not account for the presence and effect of non-condensable gases that inevitably contaminate a condenser.

With the capabilities of high speed computers now available, more comprehensive methods have been developed to account for the deficiencies of the HEI method. In particular, a radial flow computer code was developed to calculate the local heat transfer and thermodynamic properties on a row by row basis. Known as ORCON1, this code was developed by Oak Ridge National Laboratory (ORNL) under contract to the Office of Saline Water during the period from 1968-1970 [Ref. 2]. The program was based, in part, on the work performed by Eissenberg [Ref. 3]. Eissenberg's experimental results led to correction factors on the basic Nusselt equation to account for condensate inundation effects on tubes within a condenser bundle. Basically, ORCON1 divides the condenser into sectors and performs a row by row analysis within each sector, determining local heat transfer coefficients, heat flux, steam characteristics, the effect of condensate inundation and numerous other parameters at each row. ORCON1 is also capable of incorporating the effects of both tube-side and steam-side enhancement factors. Since

ORCON1 represented a much more comprehensive and detailed analysis of the condenser than the less exact HEI method, its results could be expected to be more precise.

Some work has been done at the Naval Postgraduate School to improve the capabilities of ORCON1. In his development of OPCODE2, Johnson [Ref. 5] added subroutines to ORCON1 which calculated tube-side pressure drops, corresponding pumping power and condenser volume. Nunn and Marto [Ref. 14] have incorporated the effects of vapor shear in an amended version of ORCON1 called MORCON. MORCON includes the correlations developed by Fujii [Ref. 4] to determine the effect of vapor velocity on the thermal resistance of the condensate film on the condenser tubes. In general, vapor shear effects tend to enhance the condenser heat transfer on the steam-side of the tube while condensate inundation tends to inhibit it.

The ability to represent numerically the actual thermodynamic processes occurring within the condenser has improved dramatically. However, the capability to couple these increasingly comprehensive and complex condenser design programs with an optimizing procedure has not made comparable progress. Optimization is a powerful tool which can help in reducing overdesign and achieving the goal of a safe compact condenser design.

There are currently numerous computer optimization programs available which can be coupled with general design programs of all types to numerically improve and ultimately determine the best design. The key is to properly write the design program so that it is compatible with the optimizer. Johnson [Ref. 5] developed a computer program called OPCODE1, based on the HEI method of condenser design, and was able to couple it with one such numerical optimizer. The results of OPCODE1 demonstrated how condenser designs can indeed be safely improved upon. It also revealed the

versatility of condenser design optimization as a powerful design tool. However, Johnson was unsuccessful in coupling OPCODE2 (his derivative of ORCON1) with an optimizer. This failure does not alter the fact that in order to fully appreciate more sophisticated condenser design analyses, such as that used in ORCON1, it is imperative that computer programs be developed which will be compatible with current numerical optimizers.

C. OBJECTIVE

There were two primary objectives of this thesis. The first objective was to develop a computer code which incorporates the basic condenser analysis of ORCON1 and the subsequent improvements made in MORCON and OPCODE2, but which will be capable of being coupled with a numerical optimizer to yield a complete, detailed design package. This design package can then be used as a tool in obtaining a much more reasonable conceptual design and for use in comparison studies. It would provide the naval architect the ability to optimize weight, volume, cost or any other potential design objective of the marine plant.

The second objective was to make this design package capable of determining the single best design rather than simply an improvement over the initial design. The key was to construct the program in such a way so the optimizer does not stop at some relative optimum, but continues the analysis until no further improvement can be realized. It is most desirable to be able to reach this single true optimum design regardless of initial design variable values.

II. NUMERICAL OPTIMIZATION

A. BACKGROUND

Nearly all design problems require either the minimization or maximization of a parameter. This parameter will be called the problem's objective function or design objective [Ref. 6]. For a given design to be feasible or acceptable, it must satisfy a set of design constraints which are either maximum or minimum limiting values for a pre-determined set of parameters or functions of parameters. For example, in any condenser design the outer diameter of a condenser tube can never be less than zero and there is normally some practical upper limit which also cannot be exceeded. These limits are design constraints on the tube outer diameter. In the design problem there is also a set of design variables which are parameters whose values can be changed within specified limits in order to minimize or maximize the design objective. For example, in minimizing the condenser volume an engineer may want to vary tube inner diameter, tube wall thickness and tube length. These three parameters would thus be examples of typical design variables.

For such complex design problems as the treatment of the condenser design in ORCON1, it is necessary to choose an optimization scheme which can handle the problem and provide a rational, rapid approach to design automation and optimization. An optimization program based on direct methods for solution of constrained problems [Ref. 11] was chosen for this research work.

B. CONSTRAINED FUNCTION MINIMIZATION (CONMIN)

Vanderplaats [Ref. 7] developed an optimization program, CONMIN, capable of optimizing a very wide class of engineering problems. CONMIN is a fortran program, in subprogram form, that optimizes a multi-variable function subject to a set of inequality constraints.

It is practical at this point to introduce three basic definitions and their respective conditions [Ref. 8].

DESIGN VARIABLES: Those parameters which the optimization program is permitted to change in order to improve the design. Design variables appear only on the right side of an equation, are continuous, and have continuous first derivatives.

DESIGN CONSTRAINTS: Any parameter which must not exceed ~~specified bounds~~ for the design to be acceptable. Design constraints may be linear or nonlinear, implicit or explicit, but they must be functions of the design variables. Design constraints appear only on the left side of equations.

OBJECTIVE FUNCTION: The parameter which is going to be minimized or maximized during the optimization process. The objective function may also be either linear or nonlinear, implicit or explicit, and must be a function of the design variables. The objective function usually appears on the left side of an equation. The only exception is if the objective function is also a design variable.

Assuming that the optimization process requires the minimization of a particular objective function the general optimization problem can be stated as:

Find the vector of design variables, \underline{X} ,
To minimize the objective function, $F(\underline{X})$,
Subject to the constraints:

$$G_j(\underline{X}) \leq 0.0 \quad j = 1, NCON \quad (\text{eqn 2.1})$$

$$VLB_i \leq \underline{X} \leq VUB_i \quad i = 1, NDV \quad (\text{eqn 2.2})$$

In the general problem, $G_j(\underline{X})$ are the constraint functions; there are NCON constraints and NDV design

variables; VLB_i and VUB_i are the lower bounds and upper bounds of the i -th design variable. If the equality condition is met, ($G_j(\underline{X})=0.$), the constraint is active. If the inequality is met, ($G_j(\underline{X})<0.$), the constraint is inactive. Finally, if the inequality of equation 2.1 is violated, ($G_j(\underline{X})>0.$), that constraint is said to be violated. Because of numerical inaccuracies representing exact zero on the computer, the equality condition is represented by a band around the value $G_j(\underline{X})=(0.\pm CT)$ where CT is the constraint thickness.

Any design which satisfies the inequalities of equations 2.1 and 2.2, thus having no violated constraints, is said to be feasible. If the design violates any of these constraints it is said to be an infeasible design. The design which best minimizes the objective function while still remaining feasible is said to be optimal.

CONMIN requires an initial set of values for the design variables \underline{X} to obtain an initial design which is either feasible or infeasible. If the initial design is feasible, CONMIN moves in a direction which will minimize the objective function. If the initial design is infeasible, CONMIN moves toward a feasible solution with minimal increase in the object function.

The optimization process proceeds in an iterative fashion. Johnson [Ref. 5] presents in greater detail the procedures utilized in CONMIN to search for the minimum objective value. In general, the methods used by CONMIN to determine search direction include the method of steepest descent, the method of conjugate direction, and the method of feasible directions. For further background concerning CONMIN and the numerical techniques utilized in optimization, consult Vanderplaats [Ref. 7], Fletcher and Reeves [Ref. 9], Zoutendijk [Ref. 10], and Vanderplaats and Moses [Ref. 12]. However, it is necessary to stress a few pertinent points which will aid in understanding how the program was developed in this thesis.

The optimization process begins by calculating the gradient of the objective function using a finite difference technique. A perturbation is applied to each of the design variables in a single forward step and the gradient vector is determined.

$$\Delta F(\underline{X}) = \begin{bmatrix} \frac{\partial F(\underline{X})}{\partial X} \\ \frac{\partial F(\underline{X})}{\partial X} \end{bmatrix}$$

The search direction is then calculated and is a function of this gradient and any active or violated constraints resulting from the applied perturbation. Subsequent search directions are a function of previous search directions, as well as current gradient information and any appropriate constraint factors. Obviously, the size of the perturbation and the size of the bandwidth about an active constraint will have a great deal of effect on the search direction and ultimate optimization process. This detail will be recalled later-on during the code development.

There are some limitations to CONMIN. The number of design variables (NDV) directly affects the computational time required to reach an optimum. Since the calculation of the gradient information required for each design variable at the beginning of each design iteration is found by using a single forward finite difference step, requiring a complete pass through the analysis portion of the program, there is an increase in CPU time as NDV increases. Also, as NDV increases, there is the corresponding rise in machine related numerical innacuracy. Vanderplaats [Ref. 6] recommends no more than twenty as a practical limit for the number of design variables.

It is quite possible that while design improvement may be obtained, the single best design optimum or true optimum

may not be reached. This is not an uncommon occurrence and there are several possible explanations. For example, the design problem may not be formulated properly or the analysis may be extremely complex and non-linear. However, a more common reason is that there are "relative optimums" between the initial design and the single true optimum. This concept of relative vs true optimum design can be better explained through an analogy. The search for the best optimum design can be likened to a blind man climbing to the top of a mountain. The blind man knows he is proceeding up the mountain by sensing the direction of ascent. However, the paths he takes may be limited by barriers or fences which will restrict the directions he can go. These fences represent constraints in the optimization problem. During the journey he may also encounter small crests and valleys. If the available paths lead the blind man up to one of these crests prior to reaching the mountain top, he will be confronted with a situation where he will sense no further rate of ascent and he will stop his journey. So although he has made progress from his initial starting point, the man did not achieve his ultimate goal of climbing the mountain.

During optimization, the search for a true optimum may proceed along a path on which the objective function assumes such relative optimum values. If the optimizer can not be made to "look beyond" these relative peaks, then the optimization will cease - at a design which may be an improvement over the initial one but short of the true optimum. This problem may be overcome by starting the design with several different initial design vectors, \underline{x} , until the same optimal design is repeated. Another alternative may be to increase the size of the finite difference so that the optimizer uses larger perturbations of \underline{x} thus looking beyond any small increases in the objective function which could stand in the way of further design progress. This second

alternative will be specifically addressed during the discussion of the code development.

C. CONTROL PROGRAM FOR ENGINEERING SYNTHESIS (COPES)

The optimizer, CONMIN, was written in subroutine form. Vanderplaats [Ref. 13] has developed a main program to simplify the use of CONMIN and aid in the design optimization process.

The user must supply an analysis subroutine called ANALIZ, which consists of three segments: input, analysis and output. COPES acts as an interface between ANALIZ and the optimizer CONMIN. Based on a flag from COPES (ICALC=1,2,3) ANALIZ performs the proper function. Figure 2.1 offers a simplified illustration of the interrelationship between COPES, ANALIZ and CONMIN.

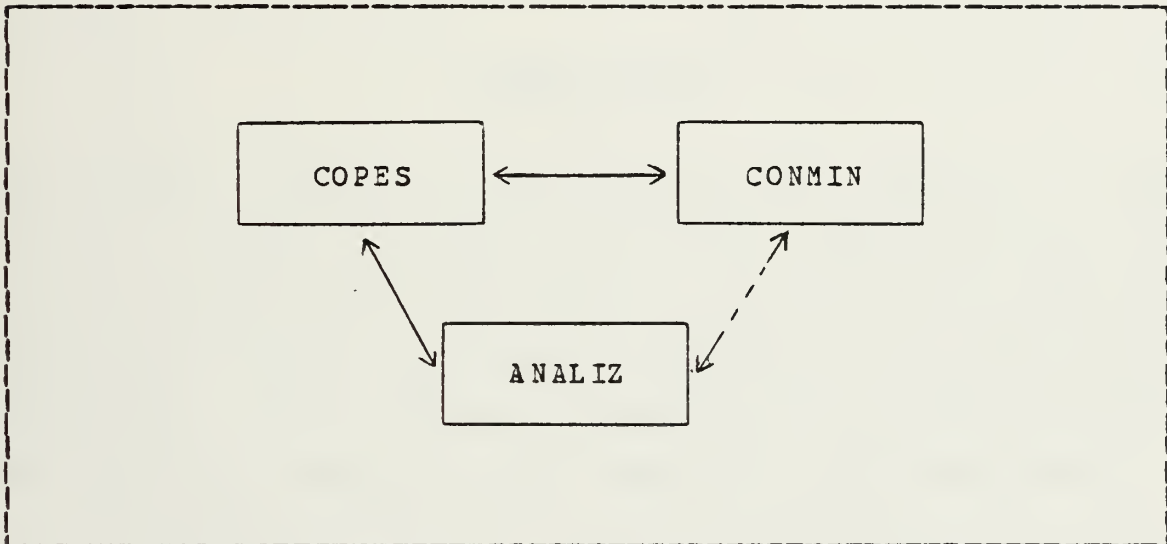


Figure 2.1 Flow Diagram For ANALIZ and COPES/CONMIN.

COPES currently provides four specific capabilities, two of which will be applied in this work:

1. Single analysis - just as if COPES/CONMIN were not used.
2. Optimization - minimization or maximization of a multi-variable function with corresponding constraints.

COPES requires certain initial data from the user in order to coordinate the optimization process. Initial values for the design variables as well optimizer control parameters are utilized by CONMIN to conduct its numerical analysis. There are a few optimizer parameters which are particularly important to the treatment of condenser designs. One is the finite difference step used in gradient calculations. Another is the normalization factor used in COPES evaluation of a constraint function. COPES utilizes the following expressions in determining constraint function violations:

$$\frac{BU - CFV}{SCAL1} \leq 0.$$

$$\frac{CFV - BL}{SCAL2} \leq 0.$$

where SCAL1 and SCAL2 are the normalization factors, BU and BL are the upper and lower limits of the constraint, and CFV is the constraint function value. It is intuitive that the normalization factor can play an important role in determining the size of the active region about a given design constraint. Both finite difference and constraint normalization will be recalled later during the code development.

The power of COPES is that it has simplified the procedures involved in using a sophisticated program such as CONMIN. The user is therefore freed from the unwanted role of systems analyst and can concentrate on the design analysis.

III. CONDENSER DESIGN IMPROVEMENT PROGRAM (CONDIP)

A. BACKGROUND

In the late 1960's, engineers at the Oak Ridge National Laboratory developed a sophisticated computer code under contract to the Office of Saline Water. This code, called ORCON1, [Ref. 2] was generated to aid in the analysis and parametric study of large, generally circular condensers. Much of ORCON1 was dependent on Eissenberg's research work [Ref. 3] on the effects of condensate rain on the shell-side convective heat transfer coefficient. Johnson [Ref. 5] took ORCON1 and made a few minor modifications to determine tube side pressure losses and volumetric calculations. Nunn and Marto [Ref. 14] further incorporated the correlations proposed by Fujii [Ref. 4] to determine the effects of shearing forces exerted by high vapor velocities on the condensate film and resulting shell-side heat transfer coefficient.

It was at this point that the development of CONDIP was begun. CONDIP was dependent primarily on the principles detailed in ORCON1 but also incorporated subsequent developments to the basic program. CONDIP was written, however, in such a way as to be compatible with the optimizer, CONMIN.

CONDIP analyzes a single or double pass, circular or semicircular condenser, with steam flowing radially inward on the shell-side of the tubes and variable salinity water flowing on the tube-side. An optional, rectangular air cooler bundle is provided-for as well as shell-side baffles. The circular bundle is normally divided into 30-degree sectors with symmetry about the central axis to reduce computational effort. Unless otherwise specified, tubes are

placed on a 60-degree equilateral, triangular pattern of concentric rows with the rows added from an inner void out to the outermost row. The void serves as a collection header for non-condensable gases prior to passage through an air cooler, if specified. As in ORCON1, CONDIP proceeds sector by sector, row by row through the condenser utilizing an average tube to represent the row segment, and calculates the following quantities in each sector:

- a) Steam pressure losses at the entrance of a sector.
- b) Total pressure of the steam/non-condensable gas mixture entering a row segment.
- c) Saturation pressure of steam entering a row segment.
- d) Saturation temperature of the steam entering a row segment.
- e) Steam flow entering the row segment.
- f) Velocity of the steam/non-condensable gas mixture at the minimum cross-section in the row segment.
- g) The fraction of non-condensable gas in the mixture by weight.
- h) The overall heat transfer coefficient for the average tube in the row segment.
- i) The steam-side condensing coefficient.
- j) The tube-side heat transfer coefficient.
- k) The shell-side film heat transfer coefficient composed of the non-condensable gas film and the condensate film.
- l) The shell-side friction factor.
- m) The shell-side pressure loss as steam passes over the row segment.
- n) The shell-side Reynolds number based on the mass flow at the minimum cross-sectional area in the row segment.
- o) The heat transfer rate per square foot of condenser tube.
- p) The mass flow rate of steam/non-condensable gas mixture at the minimum cross-section in the row segment.

- q) The mass flow of condensate produced as steam passes over the row segment.
- r) The cooling water temperature at the outlet end of the condenser.
- s) The coolant pressure loss on the tube-side.
- t) The average Reynolds number of the coolant through the tube.
- u) The heat transfer coefficient for the non-condensable gas film.
- v) The internal heat film heat transfer coefficient.
- w) The number of tubes per row segment.
- x) The cross-section area available for steam flow per row segment.
- y) The cumulative shell-side pressure drop.
- z) The LMTD based on inlet and outlet coolant temperatures and saturation temperature at each row segment.

In addition to the above parameters, the area-weighted overall heat transfer coefficients for the condenser, cooler and combined condenser are used to calculate the "back calculated" log mean temperature difference (LMTD). Steam exit-fraction, condenser volume, coolant pumping power and numerous other factors are calculated from the cumulative results of the row and sector analysis.

There are two significant contributions to the external film heat transfer coefficient which have a profound impact on the overall analysis. As mentioned earlier, Eissenberg [Ref. 3] corrected for condensate inundation effects on the external heat transfer coefficient with a series of empirical relations. He created a flooding factor F using the following relation:

$$F_n = .6F_d + (1 - .5647 F_d) n^S \quad (\text{eqn 3.1})$$

where F_d is a constant indicating the effect of tube spacing and orientation on condensate side drainage. With closely packed tubes, significant side drainage can occur in low velocity steam flow. Condensate generated on tubes above may, due to surface tension effects, proceed laterally to adjacent tubes rather than down. Thus F_d tends to approach 1.0 for closely packed, staggered tube bundles and zero for disperse bundle layouts. S is a constant ranging in value from:

$$(.07 < S < .25)$$

If the condensate rain is acting under the influence of gravity alone S approaches 0.25. But the influence of any steam velocity present begins to alter the rate and direction of condensate flow and correspondingly decrease S . Thus S is a function of vapor velocity and direction, as well as bundle geometry.

The condensate film coefficient for the average tube in the n -th vertical row is then calculated from the uncorrected heat transfer coefficient, h_0 , as follows:

$$h_n = [nF_n - (n-1)F_{n-1}] h_0 \quad (\text{eqn 3.2})$$

It is obvious that the determination of a corrected heat transfer coefficient is highly dependent on the choice of S and F_d in equation 3.1. S and F_d are extremely subjective constants and there does not exist a current analytical expression to determine them. Yet the choice of these constants can have profound impact on the condenser design. In CONDIP, as in ORCCN1 [Ref. 2], the following, relatively conservative values for S and F_d were used:

$$S = 0.2$$

$$F_d = 0.5$$

An additional important contribution to the external film coefficient is the effect of velocity shear forces on the condensate film. Fujii [Ref. 4] developed the following experimental correlations to correct the Nusselt number for the effect of velocity shear:

$$[Nu_m / Nu_o] = c_1 Nu_o^{(4a-1)} Re_L^{(.5-2a)} \quad (\text{eqn 3.3})$$

where Nu_m is the mean Nusselt number, Re_L is the two-phase Reynolds number (based on vapor velocity, tube outside diameter and kinematic viscosity of the condensate) and Nu_o is the standard Nusselt number for the zero shear case. The empirical constants c_1 and a lie within the following ranges:

$$1.13 < c_1 < 1.24$$

$$0.196 < a < 0.2$$

depending on how tube thermal conditions are described. In CONDIP the values for c_1 and a were:

$$c_1 = 1.24$$

$$a = 0.2$$

It should be noted that equation 3.3 is only valid in the range:

$$3.3 < (Re_L / Nu_o) < .28.$$

For smaller values of this parameter Fujii recommends the use of a slightly reduced value of the standard Nusselt number:

$$Nu_m = 0.96 Nu_o \quad (\text{eqn 3.4})$$

It is apparent that the vapor velocities commonly encountered in naval condensers can have an impact on the heat transfer coefficient.

B. CODE DEVELOPMENT

Johnson [Ref. 5] attempted to couple OPCODE2 (his version of ORCON1) with the optimizer CONMIN, but with little success. There were several reasons for this.

ORCON1 uses iterative techniques to solve for such quantities as condensate rate, steam mass flow rate and steam pressure through the sector. If unrealistic values are encountered, such as negative pressures or steam flow, or if the final steam exit-fraction exceeds a predetermined value, ORCON1 stops the analysis, returns to the beginning of the program and changes certain initial input parameters. The analysis begins again and the process is repeated until a satisfactory design is achieved. Thus ORCON1 has a limited capability to make design decisions to obtain a feasible design.

CONMIN, as do most optimizers, requires complete control in determining all iterative design variable values. As explained earlier, it uses perturbation techniques to calculate gradient information for each design variable and active design constraint, which it then uses to determine search directions. A perturbation of the design variable by CONMIN requires a complete, once-through analysis. If ORCON1 is coupled with CONMIN then any adjustment by ORCON1 will yield false gradient information to the optimizer and hinder, if not completely prevent, CONMIN from arriving at the optimum design. During program development it became apparent that the two programs were working independently against each other and that in its present state ORCON1 was incompatible with CONMIN.

In the formulation of CONDIP, it was necessary to locate and neutralize all the places where such design decisions are made. By removing the ability for CONDIP to make any design decisions it became totally passive and dependent on CONMIN for design variable changes.

However, once this was accomplished, another problem area was discovered. In the ORCON1 code and subsequently in CONDIP there are numerous thermal process and properties calculations that use logarithmic functions and other mathematical relationships which could produce singularities if the variables in the arguments approach zero or are negative. For example, saturation steam temperature is calculated from steam pressure using a logarithmic relationship. If, during a design analysis, saturation pressure approaches a negative value, this represents a clear violation of physical realities and of the limits of that property. Yet a computer cannot make that distinction so it tries to calculate the corresponding saturation temperature which, because of the logarithmic relationship, would be undefined. As just explained, ORCON1 with its built-in decision capability simply starts over when this situation is encountered. But CCNDIP, being completely dependent on CONMIN for design decisions, does not have that capability. Remembering that CONMIN requires a complete once-through analysis in order to collect enough information to make a design decision, it was necessary to somehow bypass such mathematical instabilities in order to keep the program operating. Yet the analysis still had to yield reasonable results from the given design in order to obtain meaningful gradients. This prompted the formulation of mathematical relationships to create "penalty" constraints which, if properly written, would indicate to the optimizer that a function or thermal property has violated its physical limits. However, not only would penalty constraints have to be defined, but a "fix up" or "correction" of the violated property or variable would be required in order to allow the analysis to continue. A good physical understanding of the inter-relationship between condenser parameters and the thermal processes resulting from the condenser design is

necessary so that the "fix up" of the violated property would still yield fairly accurate condenser information on which CONMIN could base its search for the optimized design.

For example, a condenser is usually designed around a given steam load. If the condenser has too many tubes, is too long, or coolant flow is too great, then the condenser will be overdesigned. There will be dry tubes within the condenser as all the steam is condensed before steam flow reaches the inner void. In CONDIP this means that zero or negative steam flow will be encountered in the analysis.

If, on the other hand, tube surface area is too small, coolant flow is inadequate or the condenser tube spacing is too tight and is choking the steam flow, then one of two things will happen. Either a quantity of uncondensed steam will make it completely through the condenser, or steam pressure loss in the condenser will cause steam pressure to drop below zero. In addition, there are two reasons why all the steam might not condense. It could be simply due to insufficient heat transfer surface area or it could be because the saturation temperature of the steam has dropped below the coolant inlet temperature. If the latter situation occurs, then there is no driving force for heat to transfer from the steam to the coolant. There is only one way that this situation can occur: if steam saturation pressure drops below some value indirectly determined by the coolant inlet temperature. In any event this condenser is certainly underdesigned and not capable of supporting the required steam load.

As stated earlier, the purpose of optimization is to obtain the best, feasible design. Thus, an understanding of the relationship between the physical characteristics of a given design and the subsequent thermal performances will certainly help in defining the appropriate penalty constraints and their corresponding limits. It will also

aid in the determination of appropriate "corrections" when those limits are violated. It is important to note that with the introduction of these penalty constraints, the definition of a feasible design is revised. A feasible design is now defined as one in which thermal properties and functions are not allowed to violate their physical limits, as well as other design constraints, anywhere in the condenser.

In CONDIP there are three basic thermal properties which could create the above mentioned problems if they fall below a certain value. They are steam saturation pressure, steam flow and steam temperature. Because of the direct relationship between steam saturation pressure and temperature, it was possible to deal with them simultaneously. The solutions that were developed to overcome the effects of these thermal violations determined the extent which CONDIP would optimize.

1. Steam Flow Effects

One source of mathematical instabilities within the program is if steam flow over the tubes falls to zero or below. It is intuitively obvious that steam flow can not physically fall below zero and that in order to keep the program running the steam flow rate must be kept greater than zero. However, correcting for this alone would certainly alter the results of that particular condenser design, perhaps even imply a feasible design.

To indicate to the optimizer an infeasible design was actually encountered - one in which steam flow had dropped below zero - the penalty function WTST was created. Since the condenser analysis is performed sector by sector and assuming there are J sectors in the condenser, then there had to be arrangements for J penalty constraints. This prompted the creation of the array, WTST(J), representing constraint penalty functions for each sector. The absolute

magnitude of these functions were directly related to both the severity of the steam flow violation and the number of dry tubes remaining in the sector. WTST(J) ranged in value from negative infinity to zero, where a value of zero represented a condenser design in which no flow violations occurred. Thus, WTST(J) were constrained functions whose lower limit was zero. For example, during an analysis, if steam flow was determined to fall below zero, then WTST for that sector would be given some negative value. In subsequent designs, as the number of dry tubes approached zero and better designs were obtained, then the magnitude of the penalty function approached zero indicating no constraint violation.

Since penalty constraints are entirely contrived relationships with no real physical basis, it is desirable to minimize their number to avoid the possibility of sending inaccurate signals to the optimizer.

To eliminate the need to use the WTST penalty functions as constraints, the values of WTST(J) were consolidated at the end of the sector analysis into the condenser steam exit-fraction constraint. Normally, steam exit-fraction ranges from zero to one and is simply equal to:

$$\frac{\text{steam leaving the condenser}}{\text{steam entering the condenser}}$$

By incorporating the WTST violations into steam exit-fraction, the exit-fraction was made a continuous function ranging in value from negative infinity to one. The negative steam exit-fraction represented a partially dry condenser and its magnitude was in direct proportion to the number of dry tubes. Thus instead of having to evaluate and calculate gradients for J number of WTST(J) constraints, the optimizer simply had to evaluate a previously defined and now expanded exit-fraction constraint.

It should be stressed that making steam exit-fraction continuous through zero was equally as important as eliminating the need for additional constraints. It can be reasonably assumed that for all practical condenser applications, exit steam fraction will always be limited to some positive number near zero. Here is where one applies the physical knowledge of the condenser and its relation to the thermal property of steam flow. As explained earlier, dry tubes represent an over-designed condenser. Thus the natural tendency is for the optimizer to alter those design variables so as to create a more compact condenser. As this occurs, steam exit-fraction will naturally increase. The upper active limit of that constraint will determine the optimum feasible design. While it is not necessary to have a lower limit for steam exit-fraction, it is very important for it to be a continuous smooth function especially in the region near the upper limit. It is therefore critical to properly define the penalty functions $WTST(J)$ in a way so as to provide a smooth transition from the negative, artificial values of negative steam exit-fraction to the real, positive values.

Since the steam flow penalty functions will not be used as constraints, the analytical results will provide gradient information to the optimizer. However, once steam flow has been determined to fall below zero, steam flow for that first dry row of tubes and all subsequent rows must be fixed up with dummy values to allow the program analysis to continue. How that "fix-up" is accomplished will ultimately determine the search direction for the optimizer.

Physically, once steam flow has gone to zero, there should be no further latent heat transfer, no subsequent condensate production, and further pressure losses should be only due to the flow of non-condensable gases. It is necessary to make the computer generated analysis reflect as

closely as possible these physical realities. Since the optimizer no longer has the penalty functions to use in calculating a search direction, other constraint values obtained from the analysis will dictate the next search direction. Gradients will also be calculated using these results and the determination of the next search direction will incorporate these gradients as well. In the case of negative steam flow, steam flow and condensate production over dry rows were given nominal values which were as small as the computer analysis would tolerate. These extremely small values closely approximate zero steam flow and generate results which resemble physical reality as closely as possible.

The following example is provided to better illustrate the logic used in CONDIP to handle negative steam flow. CONDIP determines flow rate through each row in each sector. During a sector analysis, CONDIP calculates the condensate generated at a given row and subtracts that value from the steam flow entering that row to calculate the steam leaving. The exiting steam flow rate is then checked to determine whether steam flow has gone to zero. If it has not, then the analysis continues. If it has, then the following two events occur.

The penalty function, $WTST(J)$, is calculated for that sector and dummy values are inserted for steam flow and condensate rate at the row where the violation occurred. For the remainder of the analysis condensate generation and subsequent steam flow calculations are bypassed and the remaining rows in the sector are fixed up with dummy values for steam flow and condensate. The analysis continues utilizing these dummy values in all appropriate heat transfer and pressure calculations. At the conclusion of the sector analysis, the values of the penalty functions, $WTST(J)$, of each sector are incorporated into the steam exit-fraction.

If the analysis revealed zero dry tubes then WTST(J) for all sectors would be zero and the steam exit-fraction would simply be calculated as:

$$\frac{\text{steam leaving the condenser}}{\text{steam entering the condenser}}$$

If, however, dry tubes were encountered in the condenser analysis then WTST(J) of some or all the sectors would be negative and dependent in magnitude on the number of dry tubes in each of the J sectors, as well as the severity of the steam flow violation. Steam flow leaving any sector which has gone dry would be zero and steam exit-fraction would be evaluated as:

$$\frac{\text{steam leaving any wet sectors}}{\text{steam entering the condenser}}$$

plus a weighted value of all the WTST(J) penalty function values. Using the relationships just described, it is apparent that steam exit-fraction: is negative if condenser tubes are dry; approaches zero as the design becomes feasible; and is greater than zero if there is steam leaving the condenser.

2. Steam Pressure and Temperature Effects

The other possible source of mathematical instability occurs when steam pressure falls below some preset limit. If pressure falls to zero, numerous mathematical singularities will be generated. Yet, before this situation can occur steam temperature will have already fallen below inlet coolant temperature causing singularities in the log mean temperature difference (LMTD) heat transfer calculation. Thus, the lower pressure limit which cannot be physically exceeded is not zero but the minimum saturation pressure established by the inlet coolant temperature. In CONDIP, this lower limit is given the variable name, PTLIM.

As steam flows through the condenser, pressure continually decreases due to friction losses and therefore, it is evaluated at each row in each sector. When the steam saturation pressure drops below PTLIM, indicating a physical violation of realistic limits, then the creation of a penalty function and a corresponding "fix up" of saturation pressure is required to allow the program to continue. The treatment of the problem was therefore analogous to the previous situation dealing with negative steam flow.

PTST(J) was the penalty function devised to indicate to the optimizer that the pressure limit, PTLIM, was violated in any of the J sectors. Values of these constraints ranged from negative infinity to zero, depending on the degree and location in the condenser of the violation. Since pressure is calculated on a row by row basis in each sector, the magnitudes of the pressure penalty functions were directly dependent not only on how much the calculated pressure dropped below PTLIM, but also on the number of rows remaining in the sector. Thus, as the condenser approached a feasible design the PTST(J) constraint values approached zero, indicating lessening violation of the minimum pressure.

As emphasized earlier, it is important to minimize the number of constraints, not only to avoid the possibility of sending confusing signals to the optimizer but also to reduce cost and improve program efficiency. This was accomplished here by inserting dummy values not only into the violated pressure variables but also associated thermal properties such as condensate generation, heat transfer coefficients and heat transfer rates for the row where the violation occurred and all subsequent rows in the sector. The dummy values were chosen such that realistic gradient information would be sent to the optimizer. The proper choice of "fix-up" values for these variables resulted in

the elimination of penalty functions as design constraints, and provided sufficient information to determine subsequent search directions.

It is necessary to understand the influence that steam pressure and temperature exert on the overall condenser analysis. With this knowledge it will be easier to predict the physical designs which could cause violations of the pressure limit. PTLIM is violated due to excessive steam flow pressure losses. As explained earlier, these large pressure losses would result from large steam velocities that are found in condensers which are too tightly designed. Thus, the particular condenser design is incapable of handling the required steam load, implying an infeasible design. Understanding this relationship will aid in choosing the appropriate "fix-up" values which will indicate to the optimizer that when the pressure limit is violated an infeasible condenser has been designed.

Physically, When steam temperature falls below coolant inlet temperature (PTLIM is violated) there is no heat transfer from the steam to the coolant and no additional steam is condensed. These physical realities must be reflected in the condenser analysis. Therefore, in subsequent rows, condensation and heat transfer rates were set equal to zero. Since there is no further condensation, the steam exit-fraction is equal to the steam flow at the point of violation divided by the total flow into the condenser. Thus PTLIM indirectly determines the exit steam fraction of the infeasible design. This relationship between exit-fraction and the PTLIM violation is what makes the penalty constraints obsolete. If PTLIM is violated early in the steam's passage through the condenser, steam exit-fractions will be large, violating its upper constraint limit and thus reflecting an underdesigned condenser. As the condenser design improves, then exit-fractions will decrease.

Physically, this can only be accomplished if the condenser design "opens up", reducing pressure losses in the condenser. Consequently, as condenser designs become larger, steam exit-fractions decrease and the condenser is driven towards a feasible design.

The following example illustrates the logic employed by CONDIP to handle steam pressure and temperature violations within the analysis. Condenser inlet flow is divided by the number of sectors in the condenser. Condenser inlet saturation pressure is determined by the steam inlet temperature. Entrance pressure losses are calculated and subtracted from the inlet pressure. The resulting pressure is checked against PTLIM and a violation at this point indicates a totally infeasible condenser in which no steam is condensed. Steam exit-fraction will thus be equal to one. If the saturation pressure is greater than PTLIM the analysis continues row by row through the sector. Pressure losses over each row are calculated and subtracted from the row inlet pressure to determine pressure into the next row of tubes. If this next-row steam pressure is determined to fall below PTLIM, then a thermal violation has occurred requiring "fix up". Subsequent rows are made to indicate zero condensate generation and zero heat transfer. Steam flow over the remaining rows is maintained at a constant value, which will subsequently be used to determine steam exit-fraction. Pressure variables over the remaining rows are given small positive values just large enough to allow the analysis to continue. Although all heat transfer and condensate calculations will be bypassed, the analysis must be allowed to continue so that pressure losses will continue to be calculated based on the steam flow at the point of violation. This is important since steam flow adjustments to the sectors are based on certain pressure comparisons between the sectors. The cumulative sum of all row pressure losses

in each of the sectors must be equal to within some tolerance. If they are not then steam flow into each of the sectors is altered so that the exit pressures from each sector converge to some common value. Thus, an accurate reflection of true pressure losses is important to this calculation.

The value of the steam exit-fraction is again determined to be the single constraint necessary to drive subsequent condenser designs to a feasible optimum configuration. The pressure penalty constraints proved to be superfluous information, but the corresponding variable "fix-up" was critical in the determination of search direction.

C. LIMITATIONS

During the development of CONDIP, it became apparent that steam exit-fraction would become the key constraint during optimization of any objective function. A feasible design implies that steam exit-fraction is a small positive number perhaps somewhere between zero and 0.1 percent. As explained earlier, violations of either steam flow or pressure physical limits resulted in penalty functions and variable "fix-up" which were later directly or indirectly incorporated in the calculation of steam exit fraction. Thus any feasible design, let alone the optimum one, centers on the limits placed upon this design constraint. Any number of design variable combinations will yield a feasible design, and each design variable affects steam exit-fraction differently. The intertwined, complex calculations used to ultimately determining exit-fraction are done by sector and row with each design variable repeatedly playing a factor. For example, the profound effect of both vapor shear and condensate inundation on the shell-side heat transfer coefficient and consequently steam exit-fraction, is

indirectly determined by numerous design variables. However, their effects are impossible to predict. The cascading effect of the thousands of calculations performed during the course of a design analysis is to ultimately create a single, highly non-linear variable in the form of the steam exit-fraction, upon which design decisions will be made.

As more design variables were involved in the analysis, the optimizer had difficulty determining their often conflicting effects on both the objective function and the steam exit-fraction. A small perturbation of each of the design variables independently would yield gradients indicating design improvement. But when these gradients were evaluated simultaneously to actually determine the direction of the subsequent design, their combined effect would actually indicate either no improvement of the objective function or a violation of the steam exit fraction design constraint. The end result would be that the optimization process would stall as no feasible search direction could be obtained. Larger perturbations to the design variables were required to properly evaluate their relative effects on the objective function and any active or violated constraints. This would enable the optimizer to overcome either small inconsistencies or discontinuities in the objective function and the constraint functions which would otherwise prevent the optimizer from reaching the optimum design. This was accomplished during data input by changing the normalized finite difference step from 0.01 to about 0.1. Increasing the finite difference is not without its drawbacks. As the optimum objective value is approached, the optimizer overlooks the subtle effects of small changes in the design variables because of the relatively large perturbations. Thus, depending on the initial design variables, the optimizer will improve the design to some point near, but necessarily not, the optimum.

When a design becomes feasible, steam exit-fraction will always become an active constraint. But the stated goal is not in achieving a feasible design but in driving the design to a feasible optimum. However, this iterative process can not be accomplished at the expense of violating a constraint and it was here that further complication was introduced. The initial impetus in any optimization process is to first obtain a feasible design. However, once the very small steam exit-fractions are obtained that are necessary for a feasible design, the exit-fraction becomes extremely sensitive to any further design variable changes. Thus any effort to further improve the current design could easily cause exit fraction to increase. Even slight increases would be perceived as violations of the constraint limit and thus prevent further optimization from the first feasible design. There are two possible solutions to this problem. Either increase the upper limit on the exit-fraction constraint or redefine the constraint. COPEs formulates the general constraint function in such a way as to allow the user to increase the active region about the constraint limit. This is accomplished here by increasing the normalization factor in the following expression for the exit-fraction constraint function:

$$\frac{BU - EXITFR}{SCAL1} \leq 0.$$

where BU is the upper constraint bound, EXITFR is the exit-fraction constraint value and SCAL1 is the normalization factor for this constraint. Increasing the normalization factor reduces the optimizer's sensitivity to constraint violations by enlarging the range of constraint values in which the constraint is active. This enlarges the region of feasibility and allows the optimizer more flexibility in altering design variables by reducing the risk of violating

the constraint. The overall effect is that the design optimization can continue but at the expense of accurate constraint limits. The normalization factor used effectively for the exit-fraction in CONDIP analysis was approximately 0.1.

One of the stated objectives was to create a robust program which would consistently yield the single best optimum design independent of the initial design and not get hung up on a relative optimum. As it was explained earlier, although relative optimums represented design improvement, they also indicated the inability of the optimizer to locate the single best or true optimum design. However, the objective was achieved for only three design variables. When more than three design variables were used, the optimum designs became loosely dependent on the initial input, although not in any predictable way. This is not to say that the condenser design did not optimize. By incorporating the finite difference and scaling normalization on exit-fraction as described above, final designs did yield objective function values which were continually within about ten percent of the true optimum regardless of the initial design. However, there was just no guarantee that the single, best optimum design could be consistently obtained. In summary, the reasons why CONDIP did not consistently optimize to the single, true optimum were: the extreme non-linearity of the steam exit-fraction, the need for a large finite difference gradient, and the need for a normalization factor for the exit-fraction upper limit constraint.

While the optimum design solutions obtained from CONDIP may be sufficient, there are several ways to improve the results and increase the chances of obtaining the best possible design. The easiest way is to try several initial input values until the user is satisfied that the best solution has been obtained. The problem with this approach is

that it is both costly and time consuming. A second recommendation is to couple an extremely simplified version of the condenser analysis with the optimizer to obtain a educated guess as to what the optimum design should be. The results of this analysis could then be used as input for CONDIP. OPCODE1, which utilizes the HEI methods in its analysis, is a likely candidate. The advantage of this approach is that a quicker, cheaper analysis can be used to obtain a rough idea of the anticipated optimum design. CONDIP can then use these design results to obtain even better and more accurate solutions, faster. There is still no guarantee, however, that the true optimum will be solved. Perhaps with the development of more robust and versatile optimizers, ones which uses numerical techniques and methods that are better suited to this type of problem than CONMIN, more precise solutions can be obtained. However, there is little more that can be done to simplify the analysis of the steam exit-fraction and subsequently linearize the problem.

IV. DESCRIPTION OF THE MAIN AND SUPPORTING SUBROUTINES

A. MAJOR SUBROUTINES

The following section contains a brief description of the major subroutines in CONDIP. The appropriate flow diagrams are also provided to better illustrate and complement the explanations. For further information concerning the various subroutines and functions see the CONDIP listing in Appendix C and ORCON1 [Ref. 2].

1. ANALIZ

This subroutine basically arranges CONDIP in a standardized form which is compatible with COPES/CONMIN. COPES uses a variable flag, ICALC, to coordinate the optimization process with ANALIZ. Utilizing this flag ANALIZ then calls the input, analysis and output portions of CONDIP as required. When COPES sets ICALC equal to one ANALIZ reads in all initial input. This is the only time any input can be entered. When ICALC equals two, COPES works with CONMIN to optimize the design. ANALIZ makes available the analysis portion of the program to be used repeatedly by CONMIN. When COPES sets ICALC equal to three, the optimization is complete and ANALIZ calls all applicable output subroutines. Figure 4.1 illustrates the flow process for ANALIZ.

2. INPUT

This subroutine enters all initial input of data by which the initial design is determined. The resultant design may be either feasible or infeasible, subject to the limitations previously discussed, so it is not critical what values are initially assigned to the design variables.

However, the initial input is screened to prevent the introduction of totally unrealistic values of variables into the program. For example, initial tube thickness, tube inner diameter, tube number and tube length are all checked to ensure that their values are greater than zero. If any of the screened initial inputs do not satisfy the minimum requirements, then the program exits prior to entry into the optimizer. The limits of the design variables and constraints will prevent similar situations from occurring during the analysis. Figure 4.2 presents the flow diagram for the INPUT subroutine.

3. OUT3

This subroutine simply prints all the initial values entered in the INPUT subroutine.

4. ORCON

This subroutine calculates the bundle geometry, flooding factors and such coolant flow parameters as pressure loss, flow rate, and pumping power. There are two options available to determine bundle geometry, each with certain advantages and disadvantages.

Option1: The number of rows is entered as a constant and the tube number is determined based on pitch, tube outer diameter, and row spacing. The advantage of this method to determine bundle geometry is that it allows the user to linearly vary pitch and/or tube inner diameter by row. The disadvantage is that tube number is a dependent variable. The optimizer is therefore limited in determining the optimum design by the specified number of rows.

Option2: The number of tubes can be used as a design variable while the number of rows is determined by tube number, row spacing, pitch and tube outer diameter. There

is more flexibility in this method of condenser design but it is not possible to linearly vary tube pitch and inner diameter. The condenser bundle is generated from a specified inner void out, and all the appropriate condenser geometry is determined for one of the identical 30 degree sectors. Overall bundle volume is then calculated as is the ratio of tube hole area to tube sheet area.

Once the basic condenser geometry has been determined, the code then proceeds through an algorithm to calculate baffle location based on an input value specifying the number of baffles desired in the condenser bundle. After this has been completed, flooding factors are determined. That is, the number of tubes in a vertical row above the central tube in each row is calculated. This is done for each of the six sectors on one side of a circular bundle. Symmetry is assumed for the other side. These flooding factors are later used in calculations to determine the effect of condensate inundation on shell-side heat transfer coefficients.

Finally, ORCON calculates coolant mass flow, coolant velocity, header pressure difference and pumping power based on the type of coolant flow input received. The flow chart in Figure 4.3 is a simple illustration of the logic used in ORCON. From ORCON, the subroutine SECALC is called.

5. SECALC

This subroutine determines all the parameters of each of the sectors in the condenser by row. The first calculation made in SECALC is the determination of the cooler geometry, if there is one. Entrance pressure losses into the condenser bundle are calculated for each sector and saturation pressure is checked to ensure that it is greater than PTLIM. From this point, much of the remaining

subroutine is comprised of two do-loops with one nested inside the other. The outer loop cycles through however many sectors are in the condenser model. The inner loop cycles through the rows in the sectors. Pressure, temperature, mixture velocity, steam flow and condensate flow are calculated at each sector row. The subroutine HETTRN is called repeatedly to provide the necessary heat transfer information. Pressure and steam flow is checked continually at each row to ensure that neither falls below its predetermined lower limits. In the event that either situation occurs, the appropriate penalty function and fix-up procedure is implemented to enable the analysis to continue. As previously discussed, these values are chosen to reflect as accurately as possible real conditions which would occur when steam flow or pressure violate their physical limits.

Once all the sectors have been analyzed the cumulative steam-side pressure losses from each sector are compared. Steam pressure at the inner void must be uniform, therefore the sector pressure losses are required to be equal within some allowable tolerance. If they are not, then the distribution of inlet steam flow into each sector is altered to force the pressure losses to converge to a single value. Once steam flow to the sectors has been adjusted, the sector and row analysis in SECALC is repeated until the pressure losses within each sector approach a common value. After the pressure comparison has been satisfied, certain overall condenser parameters are calculated such as steam exit-fraction, bundle heat load, and steam-side pressure drops.

Finally, if a cooler is required, the subroutine COOLEX is called. Otherwise the condenser analysis is complete. The flow diagram for SECALC is presented in Figure 4.4.

6. HETTRN

This subroutine is called repeatedly in SECALC to solve for all shell and tube-side heat transfer properties for each row in each sector of the condenser. In particular, values for the overall heat transfer coefficient and log mean temperature difference are utilized by SECALC in computing condensate production and heat transfer rate at each row of tubes.

On entering this subroutine, a series of estimates for certain row variables are calculated. Based on an assumed initial value for the overall heat transfer coefficient, the exit coolant temperature and corresponding film temperature are calculated. Utilizing these temperatures, the LMTD, thermal resistances, individual heat transfer coefficients and numerous other heat transfer parameters are then calculated. Finally, another value for the overall heat transfer coefficient is determined based on the above-mentioned analysis, and this final value is subsequently compared to the initial value. If they are not in agreement, within a specified degree of tolerance, then the initial value for the overall heat transfer coefficient is updated and the entire process is repeated until the initial and final values converge. This iterative process is necessary as temperature dependent heat transfer coefficients, film temperature drops, and exit coolant temperatures are all being calculated simultaneously.

Note that it is in HETTRN that the concepts of vapor shear and condensate inundation are incorporated. Heat transfer coefficients are corrected for both effects based on the calculations presented earlier. Also note that since steam temperature is never allowed to drop below inlet coolant temperature in the calling subroutine SECALC, resultant LMTD calculations in HETTRN will not yield singularities.

Once all the heat transfer variables have been determined, control is returned to SECALC where the appropriate results are utilized and stored. The appropriate flow diagram for HETTRN presented in Figure 4.5.

7. COOLEX

This subroutine solves for all the necessary parameters required in the cooler analysis. The cooler is assumed to be of rectangular cross-section with the height of the cooler not to exceed the difference between the condenser inner and outer radii. The values used for tube pitch and tube diameters in the cooler are the same as the innermost row of the condenser bundle.

Steam exits the condenser bundle, collects in the inner void and enters the bottom row of the cooler. The steam then proceeds vertically up through the cooler. The physical location of the cooler is not a prerequisite to the subsequent design, although it is expected that the cooler will be placed within the condenser bundle, thus the limit on cooler height.

The first calculation in COOLEX determines the steam velocity at minimum cross-section in the first row of tubes, VLCMAX. VLCMAX is directly proportional to the amount of steam and non-condensable gas entering the cooler as well as the cooler geometry. Therefore the constrained limits for VLCMAX will play a major factor in the overall condenser design.

Subsequent row analysis is treated identically as in SECALC. However, all pertinent heat transfer data are calculated directly within COOLEX, making it independent of HETTRN. Steam pressure and steam flow are checked at each row to ensure that the appropriate limits are not violated and all thermodynamic parameters are calculated. At the conclusion of COOLEX, cooler performance variables such as

heat load, exit-fraction steam, steam pressure losses and overall heat transfer coefficients are calculated and control is returned to SECALC. The flow diagram for the COOLEX subroutine is illustrated in Figure 4.6.

8. OUT2

This subroutine prints the overall condenser bundle results including heat load, steam exit-fraction, overall heat transfer coefficient, overall condenser LMTD and bundle volume. Normally, OUT2 is called once after the initial design is analyzed and again after the optimum design has been determined. Final design variable values such as tube number, coolant flow, tube pitch, tube wall thickness and tube inner diameter are also printed.

9. OUT2C

This subroutine prints the cooler results as well as the combined cooler/condenser results. This subroutine is called from the subroutine OUT2 and is called only if a cooler is required and subsequently designed. Therefore, these results will always be printed in conjunction with OUT2 output.

10. OUT3

This subroutine prints a very detailed output of the condenser and cooler results by row and sector. Nearly all the thermodynamic and heat transfer properties are presented, thus providing a rather complete picture of conditions everywhere in the condenser. This is extremely helpful in determining, for example, where additional heat transfer enhancement would be most beneficial, or where baffles should be best located to reduce the effects of condensate inundation.

B. SUPPORTING SUBROUTINES

The following is a brief description of supporting functions and subroutines called frequently by the main subroutines.

1. DFSVTY: This subroutine returns the value of the mutual diffusivity of the steam and non-condensable gas present.
2. XTR: This function subroutine transforms the calculated data, received in the argument list, to the log values and performs a linear regression on two or more points using the model.
3. AMUFN: This function subroutine calculates the viscosity of the non-condensable gas in $\text{lbm}/(\text{ft}\cdot\text{sec})$.
4. BMUFN: This function subroutine calculates the viscosity of a saline solution in the range of 0-24 percent concentration and temperatures of 40-210 °F in $\text{lbm}/(\text{hr}\cdot\text{ft})$.
5. CPAFN: This function subroutine returns a value for the heat capacity of the inert, non-condensable gas mixed in with the steam in units of $\text{Btu}/(\text{lbm}\cdot\text{mol}\cdot^\circ\text{F})$.
6. CPFN: This function subroutine calculates the specific heat of a saline solution units of $\text{Btu}/(\text{lbm}\cdot^\circ\text{F})$.
7. CPSEFN: This function subroutine calculates the heat capacity of steam in $\text{Btu}/(\text{lbm}\cdot\text{mol}\cdot^\circ\text{F})$.
8. HFGFN: This function subroutine returns a value for the latent heat of vaporization of water in Btu/lbm .
9. PRSDRP: This subroutine returns the shell-side pressure drop across a row of tubes in psia .
10. PSATFN: This function subroutine calculates saturation

pressure of steam as function of temperature. Pressure is returned in units of psia.

11. ROEFN: This function subroutine calculates the density of a saline solution of concentration range 0-24 percent and temperature range of 40-300 °F. Density is returned in units of lbm/(cu.ft.).

12. SKBFN: This function subroutine calculates the thermal conductivity of a saline solution of concentration range 0-24 percent and a temperature range of 40-300 °F. Thermal conductivity is in (Btu)/(hr-f-°F).

13. TSATFN: This function subroutine returns the value for steam temperature in °R given a pressure in psia.

14. VGFN: This function subroutine calculates the specific volume of steam as a function of temperature and pressure. It has units of (cu.ft.)/lbm.

15. SWITCH: This function subroutine reverses the order of a stored array.

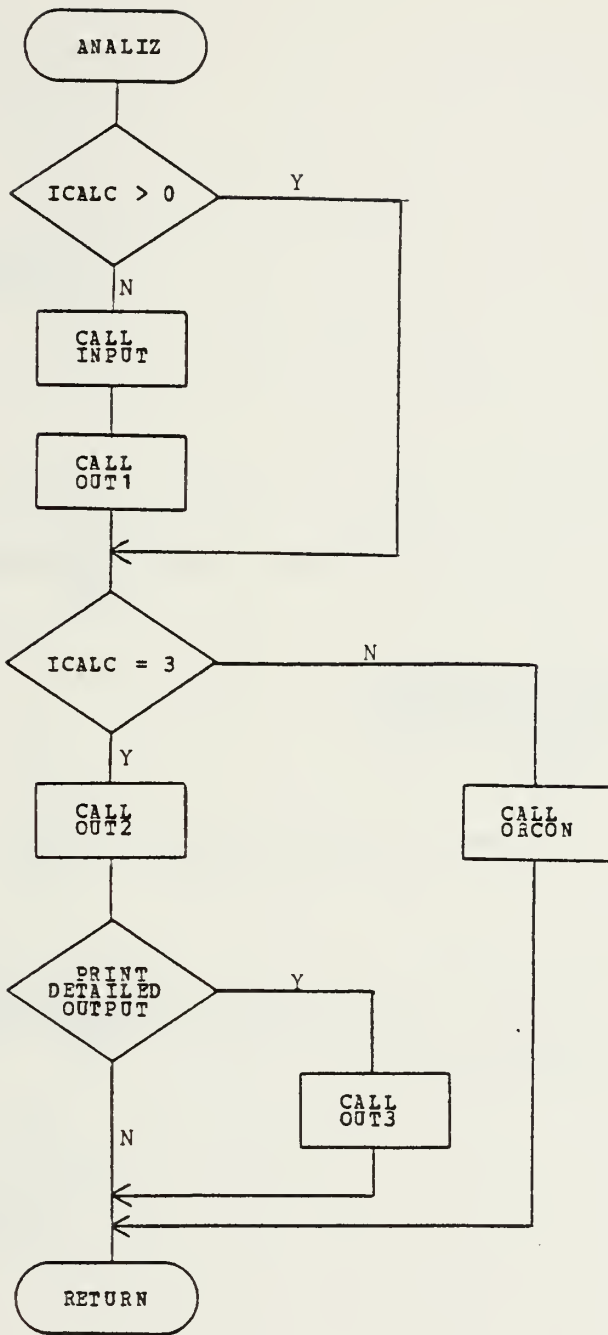


Figure 4.1 Flow Diagram for the ANALIZ Subroutine.

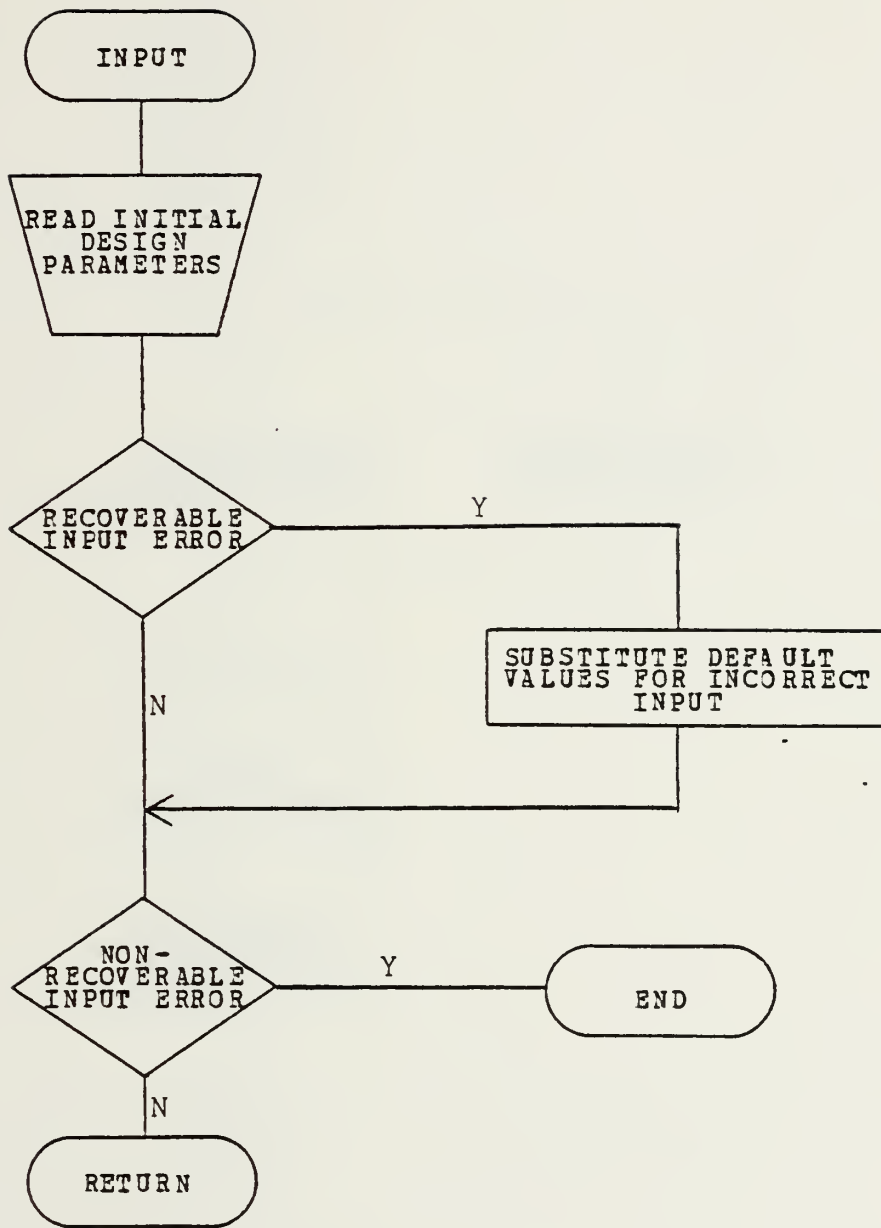


Figure 4.2 Flow Diagram for the INPUT Subroutine.

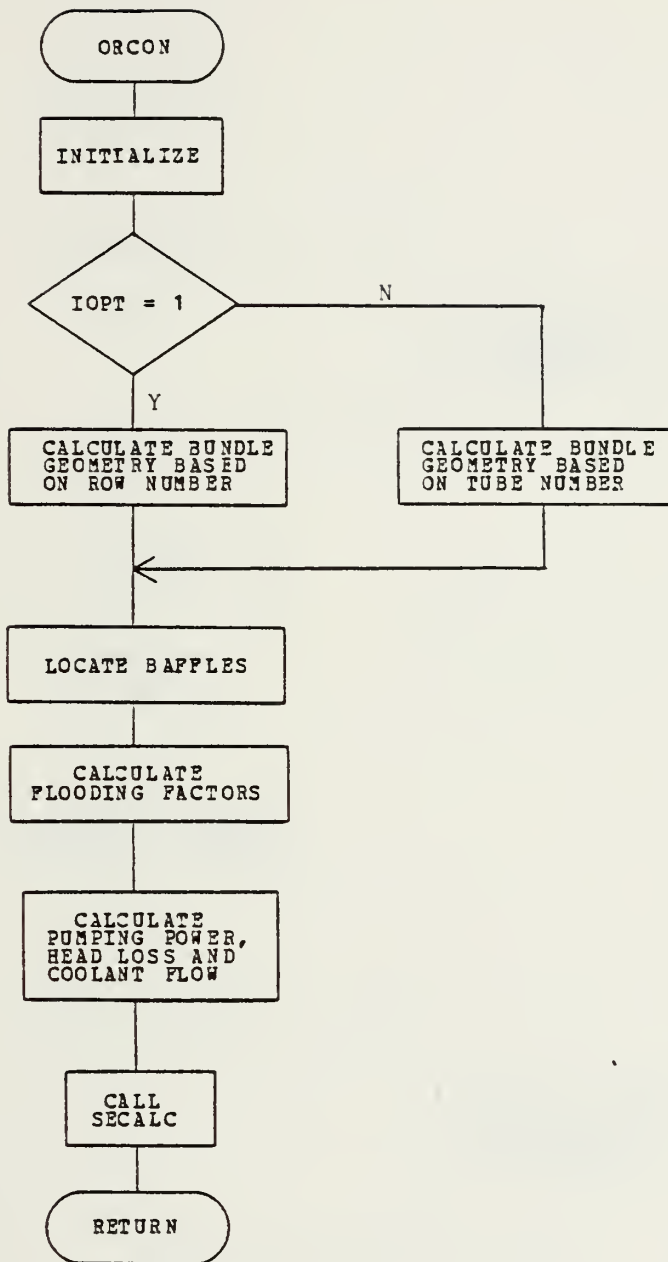


Figure 4.3 Flow Diagram for the ORCON Subroutine.

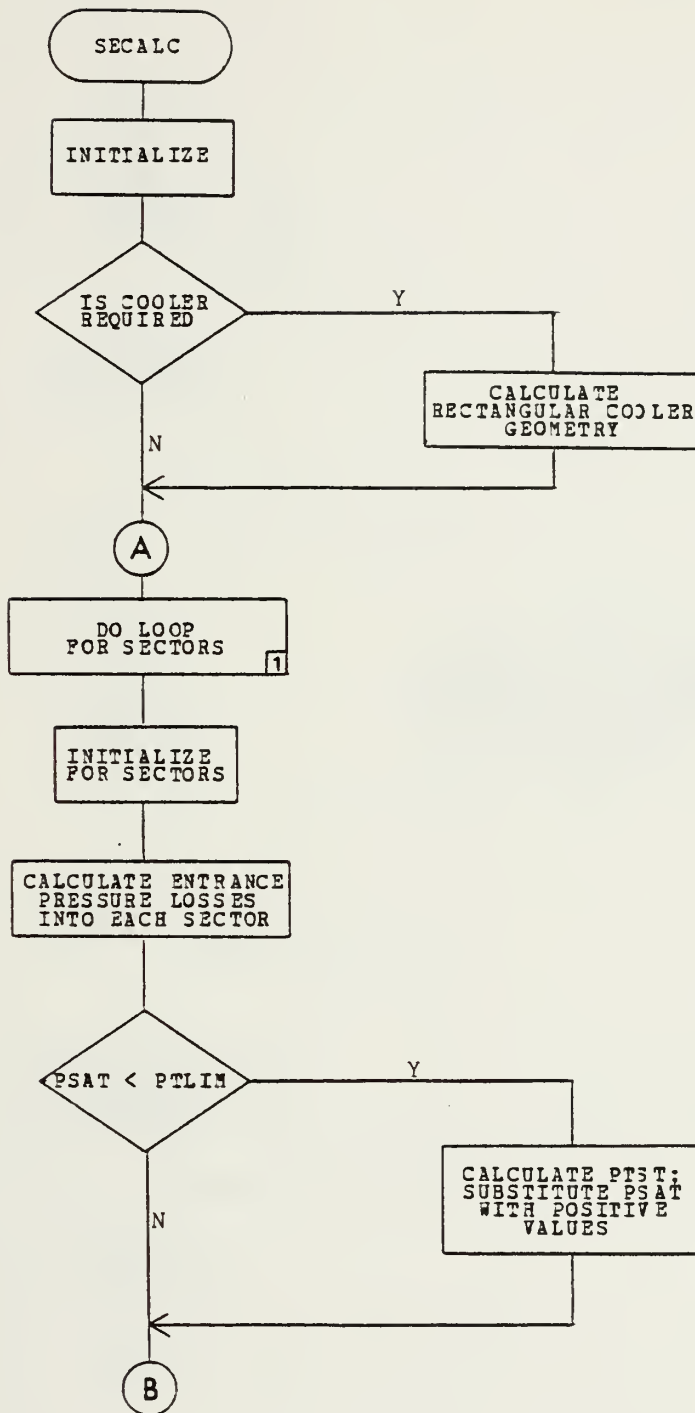
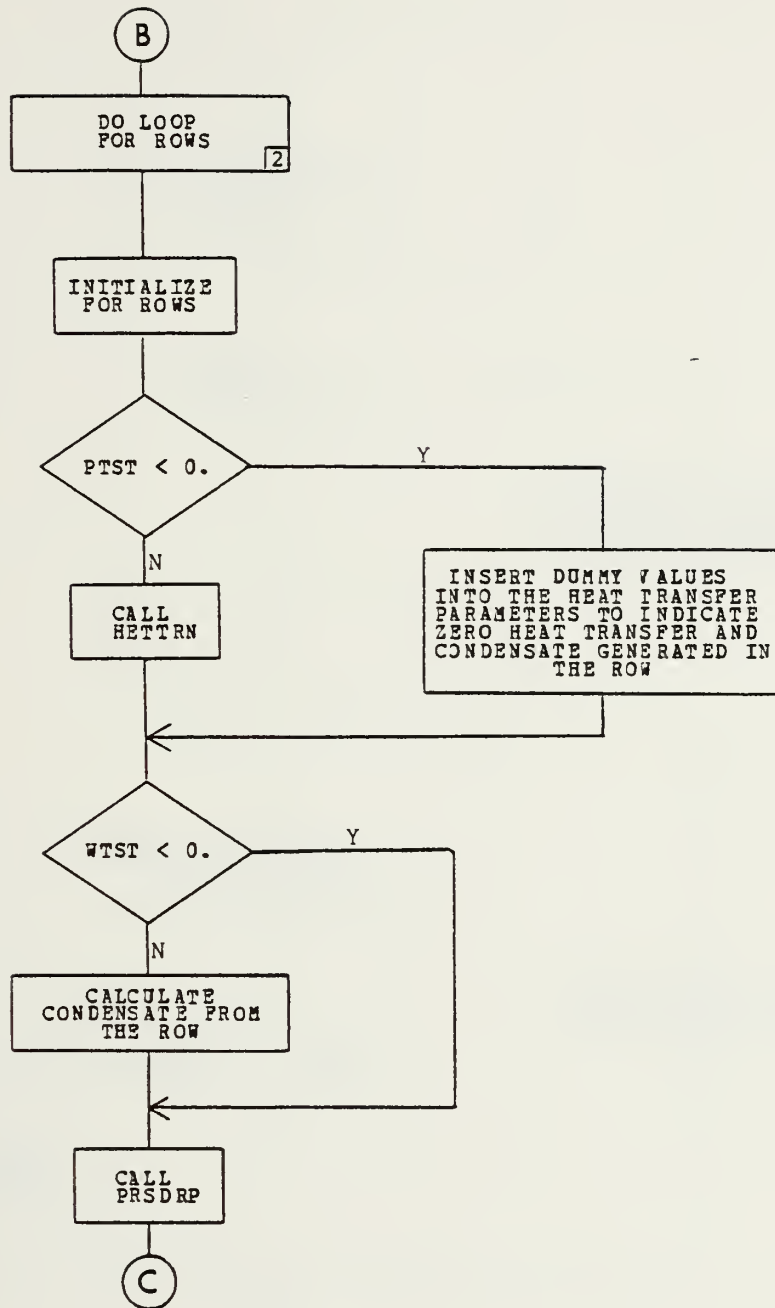
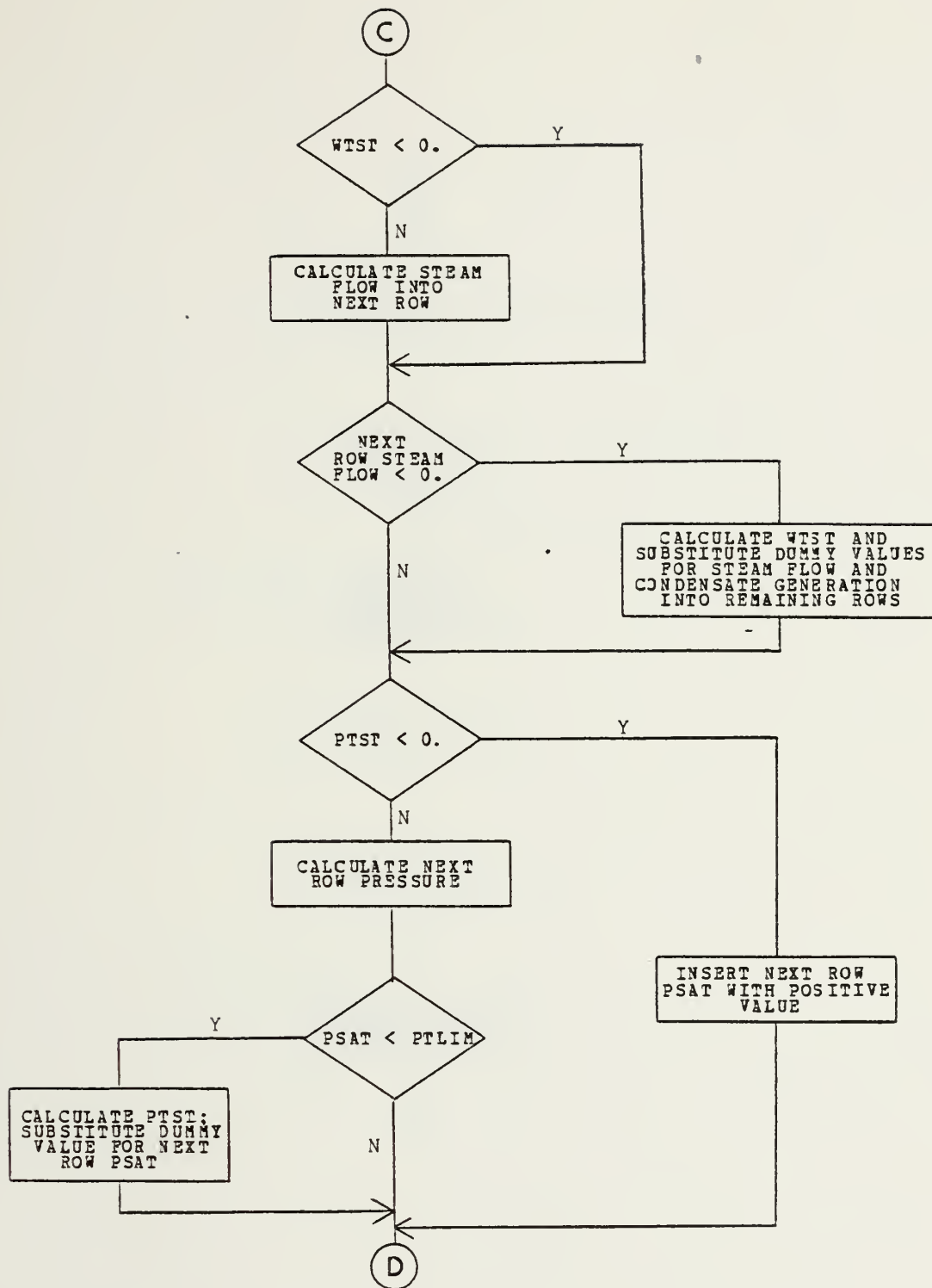


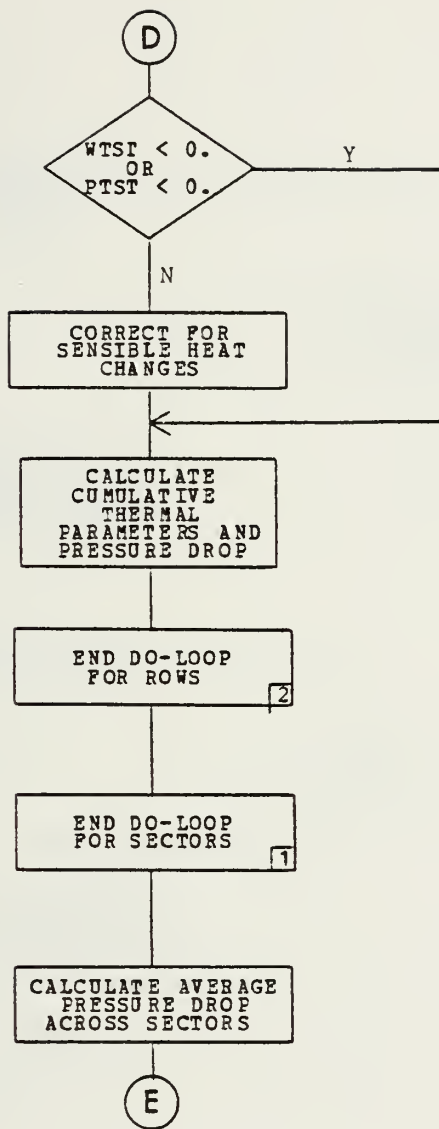
Figure 4.4 Flow Diagram for the SECALC Subroutine.



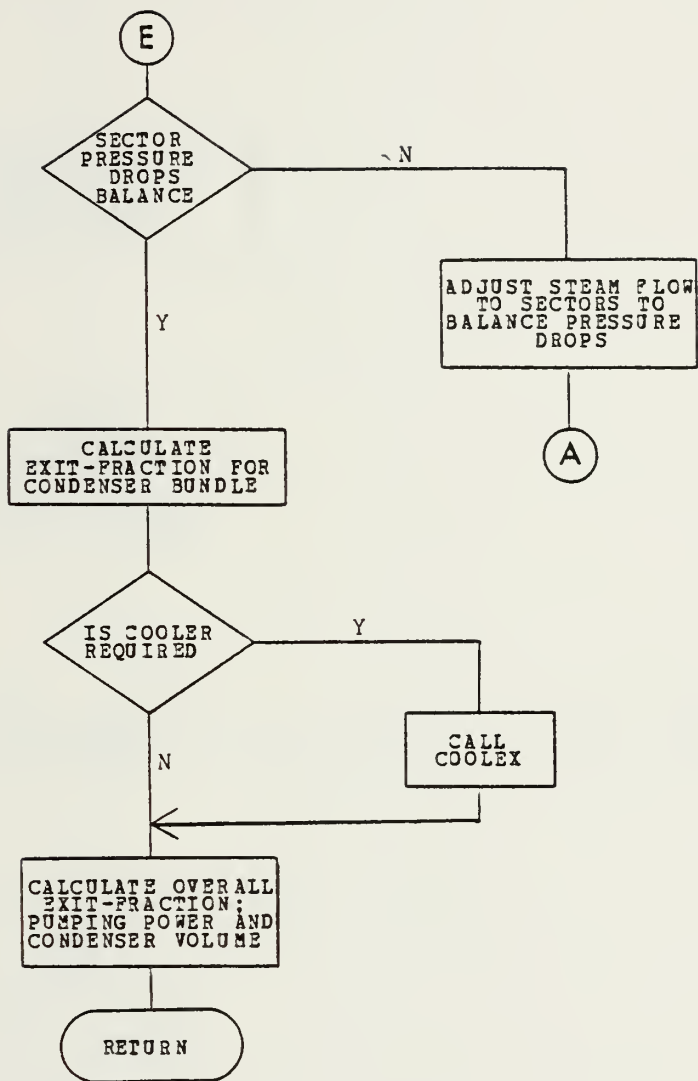
SECALC Flow Diagram (continued)



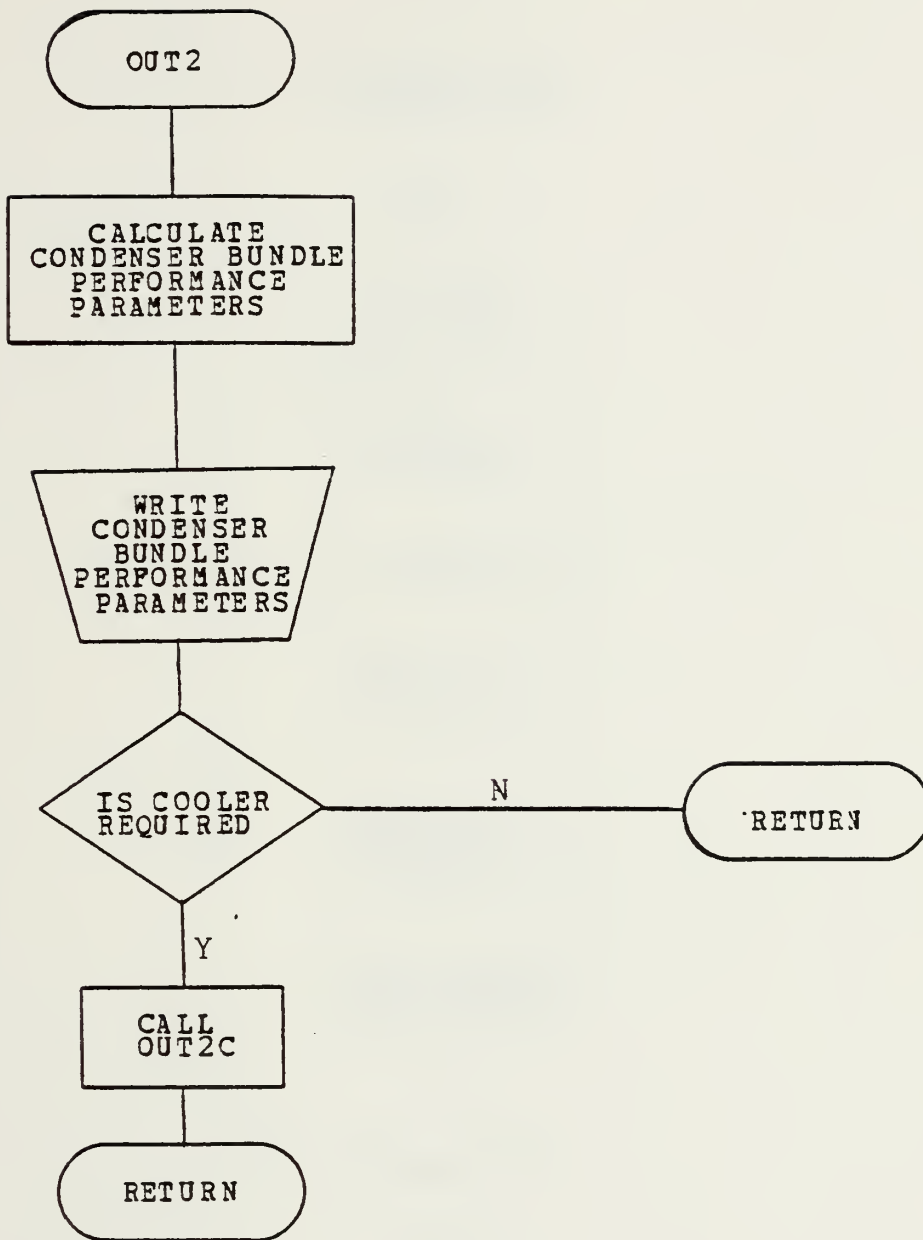
SECALC Flow Diagram (continued)



SECALC Flow Diagram (continued)



SECALC Flow Diagram (continued)



Flow Diagram for the OUT2 Subroutine

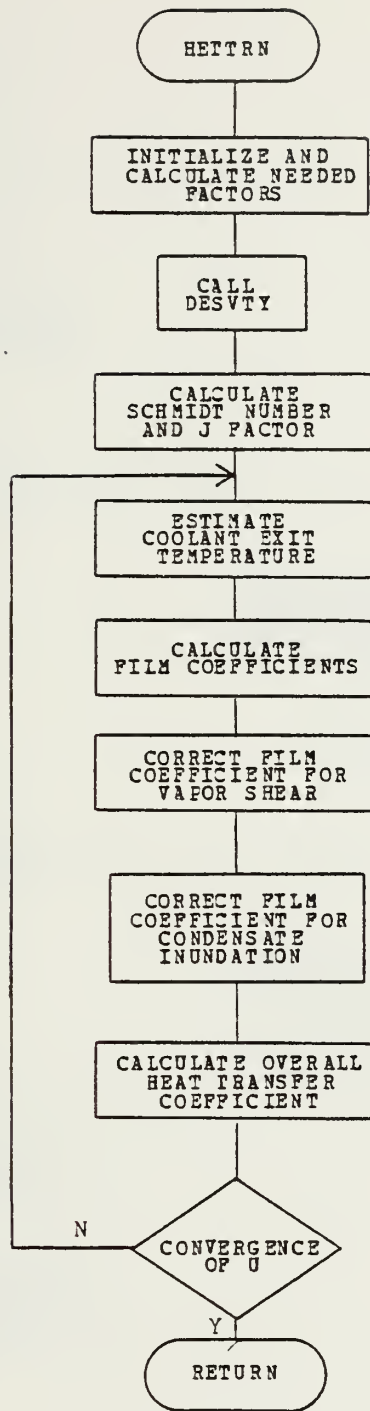


Figure 4.5 Flow Diagram for the HETTRN Subroutine.

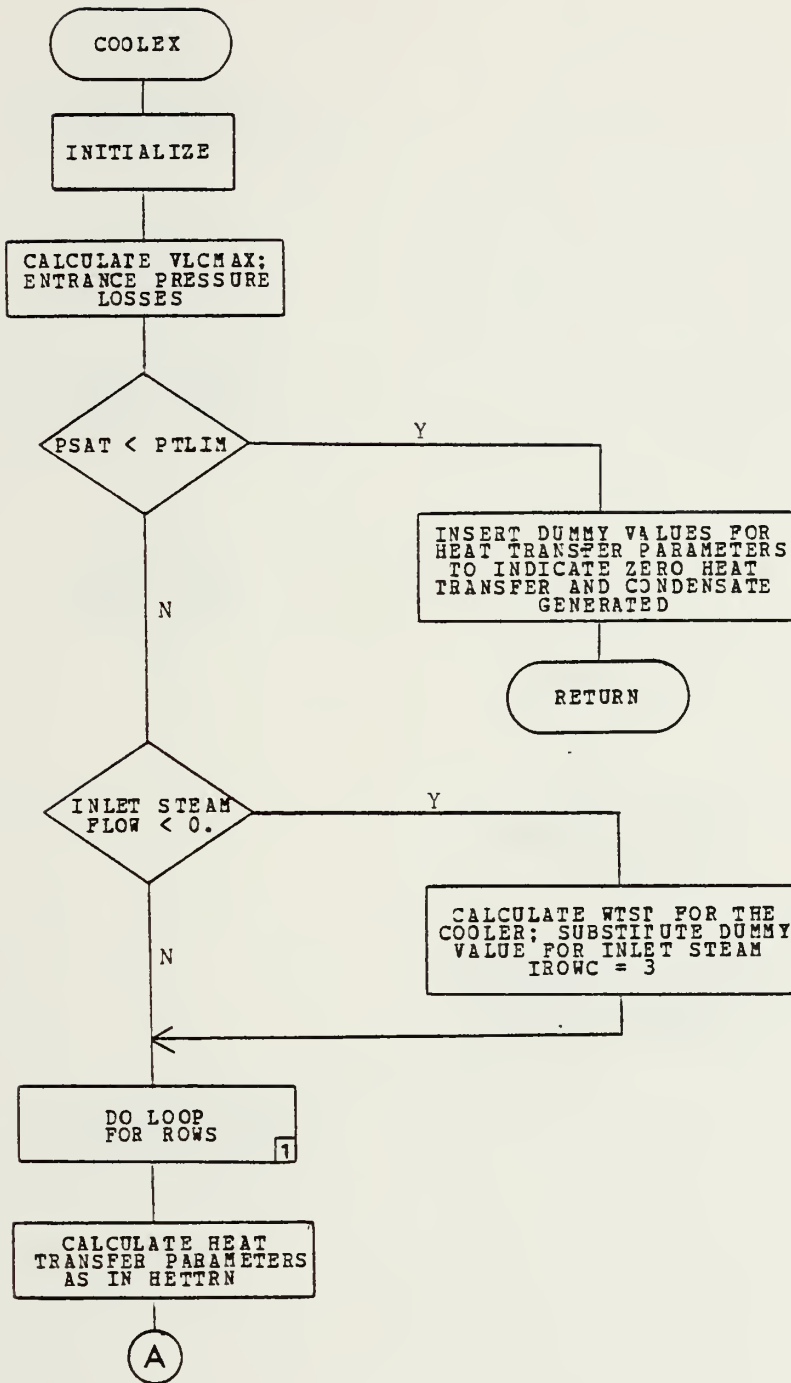
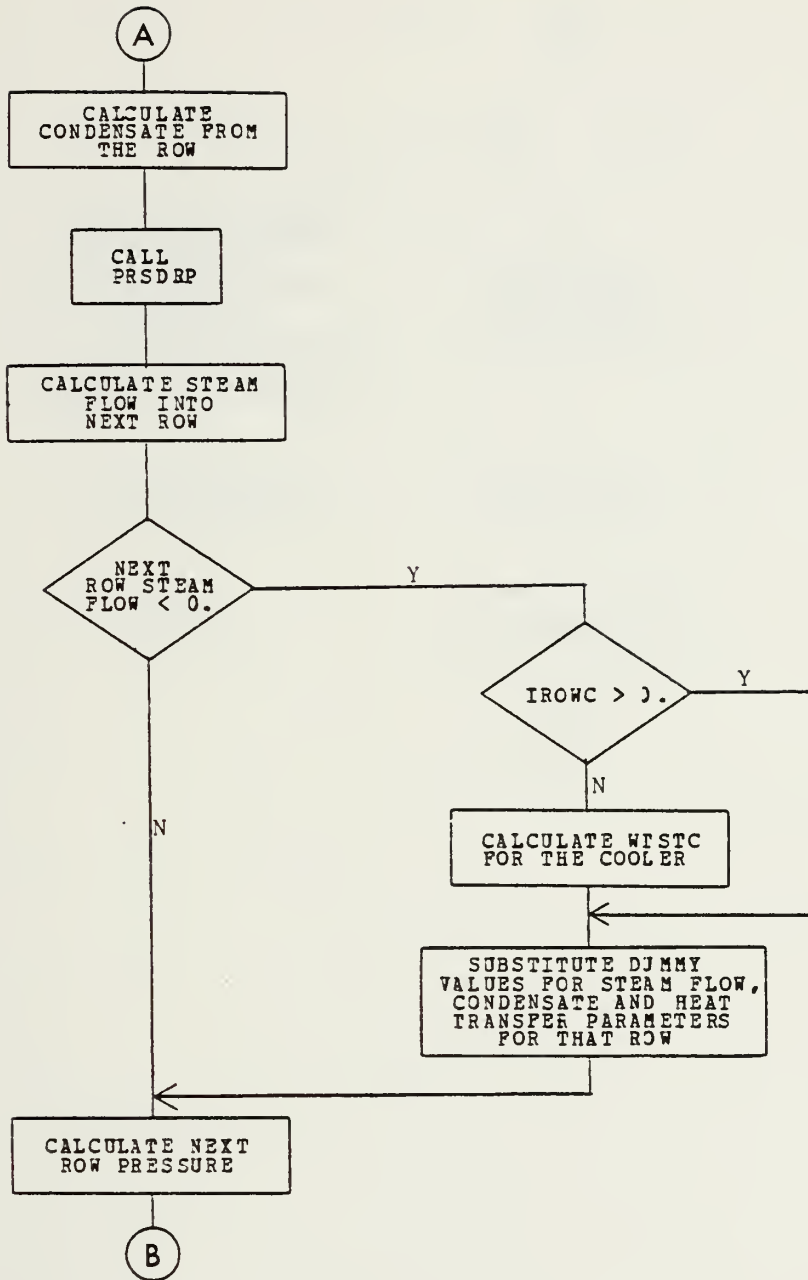
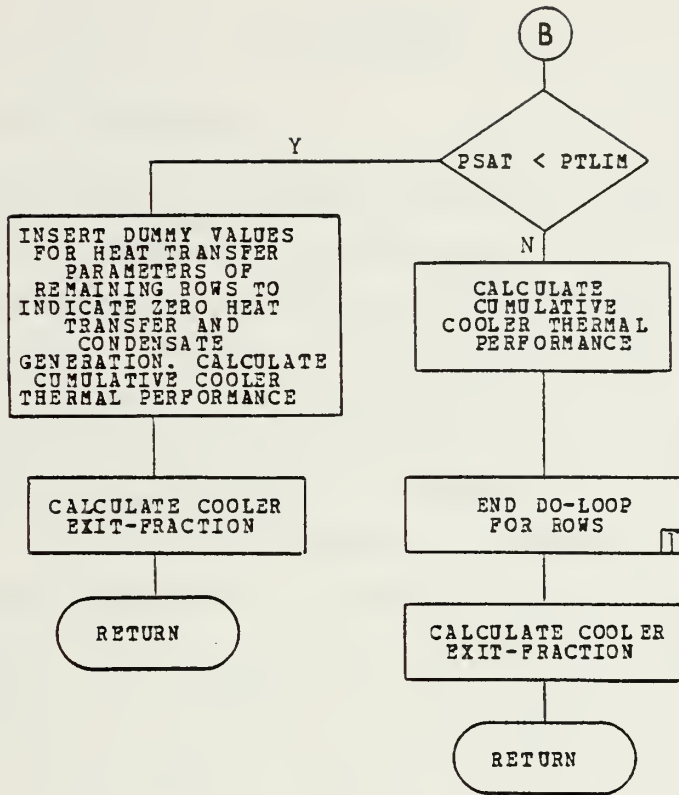


Figure 4.6 Flow Diagram for the COOLEX Subroutine.



COOLEX Flow Diagram (continued)



COOLEX Flow Diagram (continued)

V. RESULTS

A. CONDIP VERIFICATION

It was desirable to verify the single pass capability of CONDIP (i.e. without optimization) as a predictor of condenser performance by comparison with actual experimental data. However, complete and accurate data on condenser design and corresponding performance is not always readily available. Lynch [Ref. 18] encountered this same problem in attempting to verify ORCON1. However, he did manage to locate some actual experimental condenser data, obtained during a test conducted to determine the general performance of the DDG-37 class propulsion machinery [Ref. 16]. The test took place at the Naval Boiler and Turbine Laboratory and was conducted primarily to determine the performance of the turbine and reduction gears. Some limited condenser data was taken as a by-product. The various measurements were obtained as described below:

1. Steam flow measurements were made by weighing the condensate.
2. Cooling water inlet and outlet temperatures were measured by thermometers installed in the inlet and discharge lines.
3. The heat load is calculated based on total steam flow into the condenser multiplied by the difference between inlet steam and condensate enthalpies.
4. Circulating water flow was determined from a heat balance around the condenser. The total heat load was divided by the circulating water heat capacity and temperature rise to obtain flow rate.

5. Condenser inlet pressure was determined by pressure instruments located above the condenser inlet flanges.

6. Non-condensable gas flow was measured by a flowrator.

7. Pressure at the air ejector was measured directly. This pressure and the inlet pressure determined the pressure drop across the condenser.

It should be pointed out that this data were not recorded with the care that normally accompanies scientific data collection. Neither the instruments nor the techniques employed were particularly accurate. The possibility that this observed data are in error casts a cloud over the credibility of the corresponding condenser performance, which was calculated based on those values. However, for a lack of better alternatives, this data and the resulting condenser analysis will be used to determine the reliability of CONDIP.

The DDG-37 condenser geometric design variables obtained from the technical manual [Ref. 15] and input parameters corresponding to a full speed run are presented in Table I. An attempt was made to repeat the design using CONDIP. The results of CONDIP's proposed design as well as the experimental performance are presented for comparison in Table II. Percentages were calculated to quantify the differences between the actual and hypothetical performance.

Before elaborating on the results of this verification, some notable differences between the two designs must be clarified. First, a specific fouling factor was not determined at the time of the experiment and was therefore not provided. A somewhat realistic cleanliness factor of 87.5 percent (fouling factor of .0002) was utilized.

Second, in the DDG-37 condenser the rectangular cooler appears to be inserted directly into the condenser bundle.

However, in order to accommodate the cooler, the bundle must expand or distort. In addition, a void of some dimensions must be provided-for in the center of the bundle to collect any uncondensed steam and non-condensable gases. Diagrams in [Ref. 15] indicate that the DDG-37 condenser is indeed nearly elliptical in shape with bundle axes of 5.67 and 7.17 feet. Although it is apparent that a void does exist, exact dimensions can not be readily determined from the available information.

CONDIP approximates this design by creating separately a circular condenser bundle and a rectangular cooler, the height of which cannot exceed the difference between the outer and inner bundle radii. A circular void of pre-determined size is provided-for when determining the condenser bundle geometry. Subsequent volume calculations are performed on the condenser bundle and cooler separately and the overall condenser volume is computed as simply their sum.

Although CONDIP does not exactly duplicate the geometric configuration of the DDG-37 condenser, it was possible to manipulate certain initial design variables in order to cause CONDIP to develop an approximately equivalent configuration. These variables were chosen because, for small changes in their values, there is a rather significant change in the bundle geometry with relatively small effects on the overall condenser performance. Since there are no specific dimensions provided for the inner void in the DDG-37 technical manual, it was picked to be one of the design variables to be adjusted. Row spacing was also adjusted because it satisfied the conditions described above. Through trial and error a combination of row spacing and inner void radius were determined, from which CONDIP yielded a geometric design similar to the DDG-37 condenser and that satisfied condenser requirements specified in

[Ref. 17]. In this particular case, the void diameter and row spacing were determined to be 1.1 feet and 1.35 inches respectively. This arrangement enabled the condenser model to closely approximate the tube sheet area ratio of the actual DDG-37 condenser. This manipulation, however, must be interpreted as another source of error and innacuracy when comparing CONDIP's condenser performance with the experimental results.

Lastly, condenser designs in [Ref. 15] reveal that three different tube patterns were employed in the DDG-37 condenser. In addition, two different values for tube pitch were used - a pitch of 1.4 in the condenser bundle and a pitch of 1.3 in the cooler. This situation cannot be duplicated in CONDIP. Therefore a constant pitch of 1.40 and a uniform tube pattern were utilized throughout the condenser.

The design approximations utilized in CONDIP to try to geometrically simulate the actual DDG-37 condenser introduce significant uncertainty into subsequent design comparisons. This, coupled with the fact that the data collected is also suspect, would imply that it is rather difficult to verify CONDIP's analysis with the information available. It should also be noted that CONDIP is sensitive to even small variance in either the data collected (i.e. steam inlet temperature) or the approximated design variables. However, despite the above-mentioned problems associated with equating CONDIP's condenser to the DDG-37 condenser, the experimental data obtained from the DDG-37 condenser still provide the best available base upon which to make a reasonable determination of CONDIP's capabilities and limitations.

In comparing the results in Table II, it is immediately clear that there is significant difference between certain condenser performance parameters predicted by CONDIP and the corresponding experimentally derived condenser performance. Already, much has been said about the numerous geometric

approximations used to model the DDG-37 condenser. But questionable data and geometric manipulations may not completely explain the 13 percent exit-fraction and general poor performance generated in CONDIP's analysis. Its values for the average overall heat transfer coefficient and heat rejected were significantly lower than the experimental results. One source of the problem lies in the actual heat transfer analysis performed in the code. Lynch [Ref. 18] graphically illustrated how sensitive this analysis is to the effects of condensate inundation. In particular, by making small changes - within the allowable ranges - in the constants used in Eissenberg's correlations for condensate rain, significant improvement could be realized in the overall heat transfer characteristics of the condenser. CONDIP's results, when compared to the experimental data support the argument that the values currently used in the inundation correlations are rather conservative in nature, and cause the overall analysis to yield a poor performance for the given steam load and condenser design.

Therefore, in order to present CONDIP with a fair test to determine its credibility as a design predictor, some additional work must be first accomplished. A condenser geometrically identical to the general model created in CONDIP should be constructed with complete and accurate data acquisition systems to establish a thorough data base from which to compare. Also, more research should be performed on the effects of condensate inundation and velocity shear to obtain more precise correlations in determining their overall effects on the film heat transfer coefficients.

One last additional point should be mentioned. In comparing the steam-side pressure drops through the condenser, it was shown that CONDIP's pressure losses were nearly 72 percent larger than the actual physical measurements. However this radical difference is mainly due to the

high pressure losses experienced at the entrance of the cooler as a large volume of steam tried to force its way through the small available area. Therefore, the significance of this large disagreement in results is relatively minor and can be treated simply as a consequence of the more important heat transfer limitations in the comparison run.

Although the goal of verifying CONDIP as a design predictor has proven elusive, it was still possible to demonstrate its capabilities through comparison studies. Therefore, the remaining emphasis in this thesis is to show the ability of CONDIP (in combination with the optimizer COPES/CONMIN) to take an initial design with a given framework of constraints and design variables, and obtain better designs based on a desired objective function.

B. EXPLANATION OF THE CASE STUDIES

The following case studies were devised to best exercise the capabilities of CONDIP. They were made as realistic as possible so as to simulate the problem of condenser design and specification confronting the engineer during the early stages of power plant design. The condenser performance returned by CONDIP during the verification run and contained in Table II will serve as a baseline for comparing the results of each case study. The baseline condenser performance is based on the design parameters from the DDG-37 condenser listed in Table I. It was stated earlier that CONDIP's optimization results are slightly sensitive to the initial design if more than three design variables are used. Since all the cases involve eight or more design variables it would be best, for the purposes of comparison, to start from the same initial design in all cases. Therefore, the initial design variables used for the verification run and contained in Table I will be utilized as the baseline

design. Although many of these initial design variables will be allowed to change during optimization, certain basic condenser requirements will not. They include: steam flow into the condenser, inlet steam saturation pressure and temperature, cooling water injection temperature, the fraction of non-condensable gases in the steam, the tube fouling factor, and the tube material. It should be noted that although there was an initial value for row spacing given in Table I, row spacing was not used as a design variable during any of the optimizations. Instead, the program used the default method of row spacing calculation available in the code where the rows are spaced such that a 60-degree equilateral triangle pattern of concentric rows is obtained. Row spacing is therefore dependent on tube pitch and tube outer diameter by the following relation:

$$RSPA = (SDDO * ODOI) * .866 \quad (\text{eqn } 5.1)$$

where RSPA is row spacing, SDDO is tube pitch, and ODOI is tube outer diameter in inches.

There are a few key points to be kept in mind when comparing the results of the case studies with the baseline. First, the baseline design is an infeasible and inadequate design. Its performance indicates that it is not capable of supporting the required steam load by returning a steam exit-fraction in excess of 13 percent. So any gains in the objective function that were realized in the case studies is even more remarkable since it is a necessary condition that the optimum design be a feasible design, defined as having an exit-fraction not greater than 1 percent. Second, the percent change referred to when analyzing the results is calculated based on the baseline design. Thus the baseline serves as a uniform frame of reference. Next, it should be noted that because of the large number of design variables

and constraints, intuition on how an optimized result will turn out is not always applicable. Finally, it will be easier to understand the effects of the various design parameters by keeping in mind the following, very basic, heat transfer correlation:

$$Q = U * A * LMTD \quad (\text{eqn 5.2})$$

where Q is the rate of heat released as the steam condenses; U is the overall heat transfer coefficient; A is the heat transfer surface area; and LMTD can be interpreted as the thermal driving force between the steam and the coolant. Q is directly dependent on steam flow and pressure into the condenser, the percentage of that steam that is condensed, and any subcooling of the condensate. For a given steam load and a very small exit-fraction Q is nearly constant as the optimized results in all the case studies will indicate.

1. Constraint Framework for CONDIP

In order to simulate an actual trade-off study, the constraints and their respective limits were kept constant for all the case studies. The condenser was to be designed with a maximum bundle diameter of ten feet, a maximum and minimum tube outer diameter of 0.625 and 1.25 inches respectively, a steam exit-fraction of not more than 1 percent, a maximum cooler inlet velocity (VLCMAX) of 200 feet/second, and a ratio of tube sheet hole area to total tube sheet area of less than 0.30.

The constraint on bundle diameter was chosen somewhat arbitrarily. It seems unlikely that this limit would be realistically exceeded, although certainly space requirements would dictate the exact configuration. Tube outer diameter is dependent on the values for tube wall thickness and tube inner diameter. Thus the limits imposed on tube

outer diameter represent realistic restrictions on the possible combinations of inner diameter and wall thickness. These restrictions are based loosely on anticipated tube structural and strength requirements and correspond to values of normally available tubes [Ref. 19]. The maximum limit of 200 feet/second for VLCMAX was also a somewhat arbitrary but realistic limit. It is assumed that steam velocities often exceed that value in the condenser bundle.

It is recalled that steam exit-fraction will play a significant role in the determination of the final optimum design. The baseline exit-fraction of 13 percent predicted by CONDIP for the DDG-37 condenser is unsatisfactory. Therefore a more reasonable upper limit of 1 percent was placed on this constraint. Although CONDIP will return a much more conservative design if 1 percent vice 13 percent is used as the upper limit, the subsequent design will be much more credible.

Finally, the amount of tube sheet material that can be removed by drilling for the installation of condenser tubes is specified at 24 percent of the total tube sheet area in [Ref. 17]. This area ratio limit represents a structural limit imposed to ensure that the tube sheets do not fail due to heat and pressure stresses in the condenser. However, CONDIP does not take into account the space between the condenser and tube shell normally used in area ratio calculations as blank tube sheet area. For this reason and to allow more flexibility in the design analysis, the constraint limit was set at 30 percent.

In summary, the general design constraints and the associated upper and lower bounds were:

$$0.625 \leq \text{tube outer diameter (inch)} \leq 1.25$$

$$1.0 \leq \text{bundle diameter (feet)} \leq 10.0$$

$$\text{steam exit-fraction (\%)} \leq 1.0$$

$$\text{VLCMAX (ft/sec)} \leq 200.0$$

$$\text{area ratio} \leq .30$$

These design constraints and associated bounds were used in all the case studies except where specifically modified.

2. Design Variable Framework for CONDIP

At least eight design variables were used in all the case studies. They include tube inner diameter, tube wall thickness, tube pitch, the number of tubes in the condenser, tube length, the inner void radius, the percent of the tubes in the cooler, and cooling water velocity. Side constraints were placed on all of these variables to correspond to either realistic physical limits or available standardized materials.

Tube wall thickness was not allowed to fall below 0.022 inches (BWG 24) or exceed .109 inches (12 BWG), sizes normally available commercially. Tube inner diameter was restricted to values between .407 and 1.206 inches so as to yield tube outer diameters within the limits specified earlier.

Tube pitch is defined as the ratio of the center to center spacing between adjacent tubes in a row to the tube outer diameter. Tube pitch is an accurate measure of how closely packed the tube bundle is. Generally accepted values for pitch lie in the range of 1.3 to 1.7. However, to provide more latitude in the design process this design variable was allowed to vary in the range between 1.1 to 2.0.

There is no guidance available as to the allowable range for tube length in the condenser. Since the lower limit was not expected to be crucial, it was set randomly at 1.0 feet. The upper limit of 25.0 feet was a realistic limit considering the size of the tube diameter being worked with. Inner void radius and the percent of tubes in the cooler were chosen to be design variables simply to enhance the

flexibility of the code in designing the condenser model. The bounds for both variables were entirely arbitrary with only common sense as the determining factor. The upper and lower limits on the percent of tubes in the cooler was established as 10.0 and 2.0 percent respectively. The upper and lower bounds on the inner void radius was set at 1.0 and 0.1 feet.

Cooling water velocity generally ranges from three to nine feet per second in value for all common tube materials, except titanium which has an upper limit of 15 feet per second. Exceeding these upper limits risks excessive tube erosion and material damage. Finally the number of tubes was permitted to vary between 1000 and 8000 tubes for the purpose of improving design flexibility. It is extremely unlikely that, for most propulsion applications, tube number would fall below 1000. The upper limit was simply chosen as a realistic cutoff point in terms of complexity, cost and maintainability.

In summary, the general design variables and the associated side-constraints were:

$$0.407 \leq \text{tube inner diameter (inches)} \leq 1.206$$

$$0.022 \leq \text{tube thickness (inches)} \leq 0.109$$

$$2.0 \leq \text{percent of tubes in cooler} \leq 10.0$$

$$0.10 \leq \text{inner void radius (feet)} \leq 1.0$$

$$3.0 \leq \text{coolant velocity (ft/sec)} \leq 9.0$$

$$1.0 \leq \text{tube length (feet)} \leq 25.0$$

$$1000 \leq \text{tube number} \leq 8000$$

$$1.1 \leq \text{tube pitch} \leq 2.0$$

As in the case of design constraints, these design variables and their respective limits were used consistently in all the case studies unless otherwise specified.

C. CASE STUDIES USING CONDIP

1. Case One

The objective of this case was to minimize condenser volume. The final results of the optimization along with the initial parameters is listed in Table III.

These results show a 16 percent decrease in condenser volume with a corresponding 24 percent increase in pumping power. The source of the improvement can be understood by noting the following:

1) Tube wall thickness was reduced from 0.049 to 0.022, the minimum side-constraint, thus allowing tube inner diameter to increase while maintaining a minimum tube outer diameter.

2) The number of tubes shrank slightly as did tube length, resulting in a smaller heat transfer surface area.

3) Tube pitch increased markedly, causing a reduction in steam pressure losses which then ensured that high values for steam saturation pressure and temperature would be maintained throughout the condenser. The large pitch also reduced steam velocities, allowing the cooler inlet velocity limit to be satisfied. Row spacing decreased from the initial value of 1.35 inches, thus decreasing condenser volume.

4) Cooling water velocity increased to the maximum allowable value of 9 ft/sec which correspondingly resulted in larger head losses and coolant flow, causing overall pumping power to increase.

As cooling water velocity increased and tube wall thickness decreased, then their respective thermal resistances were diminished. The cumulative effect was to improve the overall heat transfer coefficient. LMTD rose primarily as a result of the higher steam temperatures throughout the condenser. It is apparent by looking at equation 5.2 that increasing the driving forces for heat

transfer, such as the overall heat transfer coefficient and LMTD, allows the heat transfer surface area to decrease. This resulted in a similar reduction in condenser volume.

The constraint limits that prevented further design improvement were the upper bound on the cooling water velocity, the upper limit on the tube sheet area and the upper limit on VLCMAX.

2. Case Two

The objective of this case was to minimize the pumping power required to overcome the tube-side head losses and drive the cooling water through the condenser tubes. The final results of the optimization are presented along with the initial design in Table IV.

The results indicate a dramatic 90 percent reduction in required pumping power with an equally large 120 percent increase in condenser volume. The major factors involved in the design improvement along with their relative effects are briefly explained below:

1) Tube inner diameter increased 27 percent while tube thickness remained relatively unchanged. Thus tube outer diameter was caused to increase.

2) The number of tubes in the condenser rose significantly, along with tube length. This, coupled with the enlarged tube outer diameter resulted in nearly doubling the heat transfer area.

3) Tube pitch increased 29 percent, which allowed steam saturation pressure and temperature to be maintained at consistently large values in the condenser. This had a benefiting effect on the associated LMTD calculation. The large pitch also helped satisfy the steam velocity limit into the cooler. The tube spacing decreased from the initial value of 1.35, but by a smaller amount than the previous case because of the large values for tube pitch and outer diameter.

4) Cooling water velocity dropped to the minimum allowable limit of 3 ft/sec. This had the effect of reducing tube-side head losses and coolant flow through the condenser. Consequently, pumping power was drastically reduced.

The combined effect of all these changes can again be put in perspective by looking at equation 5.2. For the given steam and corresponding heat load, the heat transfer area increased drastically, allowing both LMTD and the overall heat transfer coefficient to decrease. A smaller overall heat transfer implies a smaller convective tube-side contribution which in turn permits coolant velocity to reduce to its lowest allowable value. The LMTD decrease is explained by the fact that cooling water was spending more time in the tubes, thus causing the average cooling water temperature to rise. However, the subsequent reduction in LMTD was minimized by the fact that a high steam temperature was maintained in the condenser.

There were no active constraints in this design outside of cooling water velocity which prevented further design improvement. However, the penalty paid in terms of a huge condenser volume, appears prohibitive.

3. Case Three

The objective of this case was to minimize pumping power while holding condenser volume constant at the initial value of 432 cubic feet. This was a particularly interesting test case as the results in Table V bear out. The required pumping power was reduced by nearly 38 percent with no change in volume. The effects of the design changes which resulted in the design improvement are presented below:

1) Tube inner diameter increased noticeably. However, the effects of this increase on tube outer diameter was minimized by a large drop in tube wall thickness. Thus, tube outer diameter remained relatively unchanged.

2) The number of tubes experienced a minor reduction, while tube length increased. The overall effect was to increase heat transfer surface area.

3) Tube pitch again rose by nearly 25 percent, causing steam saturation temperature and pressure to maintain a nearly constant value throughout the condenser. This had a beneficial effect on the LMTD between the steam and the cooling water. The larger pitch also had the additional effect of reducing steam velocity thus allowing the subsequent design to satisfy the upper limit on steam velocity into the cooler (VLCMAX). The combination of tube pitch and tube outer diameter resulted in a reduction in row spacing from the initial value of 1.35

4) Cooling water velocity decreased by about 21 percent. This effect was manifested in subsequent pressure head, coolant flow and pumping power calculations.

Looking at equation 5.2 we see the same general pattern emerging as in Case 3, but with more subtlety in the changes. Heat transfer increased, but not at the expense of volume. Cooling water velocity was allowed to decrease while the overall heat transfer coefficient actually rose. One explanation is that as the tube wall got thinner its thermal resistance got smaller which more than offset the loss of convective heat transfer contribution from the coolant. The LMTD dropped slightly due to the higher average coolant temperature of the coolant in the tubes.

The constraints which became active and prevented further improvement in the design include tube sheet area ratio as well as tube wall thickness. However, tube wall thickness was particularly crucial because of its related effect on heat transfer.

4. Case Four

The objective of this case was to minimize condenser volume while holding pumping power constant at the initial value of 55.7 horsepower. The results of this case can be found in Table VI. Chosen to contrast the results in Case 4, the relative improvement in this design objective was not nearly so impressive. Condenser volume shrank by only 12 percent. An explanation of the causes and effects is provided below:

1) Tube inner diameter increased, with a corresponding decrease in tube wall thickness to yield the minimum allowable tube outer diameter.

2) The number of tubes decreased noticeably, tending minimize bundle volume. Note, there was only slight increase in tube length. The overall effect was to similarly reduce heat transfer surface area as condenser volume decreased.

3) Tube pitch again increased significantly, having the same effects on steam pressure, temperature and steam velocity into the cooler as discussed earlier. A large tube pitch benefits the LMTD between the steam and the cooling water. Row spacing was again a factor in reducing condenser volume as before.

4) Cooling velocity decreased slightly as did head loss. But overall coolant flow increased due to an increase in tube inner diameter. The net effect was to maintain pumping power.

Again, referring to equation 5.2 , it is clear that the slight decrease in heat transfer area was offset by the slight rise in LMTD resulting from higher condenser steam temperatures. The significant improvement in overall heat transfer coefficient, therefore, is what makes the heat balance work. The large decrease in tube wall thickness and corresponding reduction in thermal resistance contributed heavily to this improvement.

There were several constraint limits which prevented any additional objective optimization. They include the minimum tube wall thickness, tube sheet area ratio and steam velocity entering the cooler.

5. Case Five

The objective of this case was to minimize condenser volume while exercising CONDIP's capabilities to linearly vary tube pitch and tube inner diameter by row. Thirty-five rows were used, which was the identical number as the initial design. Tube pitch and tube inner diameter of both the outermost and innermost rows served as design variables in this case. However - because tube number is now a dependent variable based on the number of rows, tube pitch, and tube diameter - it could not be used as a design variable. The optimized results of this analysis along with the initial design are presented in Table VII.

The results of this test case indicate a condenser volume which is 20 percent smaller than the initial design as compared to a 16 percent decrease in Case 1. The basic reasons and explanations as to why volume was able to be reduced remain fundamentally the same as in Case 1. Attention will therefore be focussed on the effects of linearly varying pitch and tube diameter. Final tube pitch ranged in value from 1.75 in the inner row to 1.44 in the outer row. Similarly, tube inner diameter ranged from .729 in the inner row to .583 in the outer row.

It is believed that smaller pitch and inner diameter were used in the outer row because of the higher available steam saturation pressure and temperature. The resulting higher steam velocities enhanced the beneficial effects of vapor shear on the external heat transfer coefficient thereby improving heat transfer on the outer rows. As steam pressure decreased, then tube pitch and tube inner diameter

increased to compensate and extract all the available heat from the steam. Consequently, steam velocity decreased and was able to satisfy to the limit imposed on the cooler entrance velocity. The end result is a condenser geometry that makes complete use of the available resources and conforms to the geometry to take advantage of the thermal conditions in the condenser. The big limitation with this approach is that the number of rows is held constant. Thus the subsequent condenser is designed around that value and the subsequent optimum design is a function of the number of rows specified.

TABLE I
Input Design Data

PARAMETER	VALUE
Total number of tubes	5230
Tube length (feet)	10.3
Tube inner diameter (inches)	0.527
Tube wall thickness (inches)	0.049
Tube outer diameter (inches)	0.625
Tube mat'l thermal conductivity btu/(ft-hr-°F)	26.0
Tube pitch	1.38
Percent of tubes in the cooler	7.0
Steam inlet flow (lbm/hr)	161,961
Fraction of non-condensable gas (ppm)	37.1
Steam inlet pressure (psia)	1.294
Steam inlet temperature (°F)	110.52
Coolant inlet velocity (ft/sec)	8.473
Coolant inlet temperature (°F)	75.66
Fouling factor	.0002
Inner void diameter (feet)	1.1
Row spacing (inches)	1.35

TABLE II
CONDIP Verification Results

PARAMETER	EXPERIMENT RESULTS	CONDIP RESULTS	CHANGE (%)
Heat transfer area (sq.ft.)	8805	8814	+0.10
Overall heat transfer coefficient btu/(hr-sq.ft.-°F)	635.2	547.9	-9.5
Log mean temperature difference (°F)	28.24	28.62	+1.3
Coolant temperature rise (°F)	10.61	9.90	-6.7
Coolant mass flow rate (10 ⁷ lbm/hr)	1.503	1.540	+2.5
Condenser volume (cu.ft.)	-----	432.3	-----
Bundle diameter (ft)	5.7 7.2	7.17	-----
Shell-side pressure drop (psia)	0.751	1.29	+71.8
Steam exit-fraction (% of input)	-----	13.3	-----
Heat rejected (10 ⁸ btu/hr)	1.595	1.451	-9.03
Area ratio	0.291	0.266	-8.59

TABLE III
Volume Minimization

PARAMETER	BASELINE RESULTS	OPTIMIZED RESULTS	CHANGE (%)
Total number of tubes	5230	5117	-2.2
% of tubes in cocler	7.0	7.01	+0.1
Tube length (ft)	10.3	9.92	-3.7
Tube inner diam. (in)	.527	.582	+10.4
Tube wall thick. (in)	.049	.022	-55.1
Tube outer diam. (in)	.625	.626	+0.2
Tube pitch	1.4	1.73	+23.6
Void diameter (ft)	1.10	1.34	+21.8
Bundle diameter (ft)	7.17	6.59	-8.1
Condenser volume (cu.ft.)	432.3	362.2	-16.2
Area ratio	0.266	0.300	+12.7
Coolant inlet vel. (ft./sec)	8.473	9.00	+6.2
Coolant mass flow rate (10 ⁷ lbm/hr)	1.540	1.955	+26.9
Head loss (ft H ₂ O)	7.35	7.18	-2.3
Pumping power (hp)	55.69	68.99	+23.9
Coolant temperature rise (°F)	9.90	9.00	-9.1
Log mean temperature difference (°F)	28.62	29.13	+1.8
Heat transfer area (sq.ft.)	8814.	8320.	-5.6
Average overall heat transfer coefficient (btu/(hr-sq.ft.-°F)	574.9	689.9	+20.0
Steam exit-fraction (% of input)	13.3	0.0	-100.
Heat rejected (10 ⁸ btu/hr)	1.451	1.672	+15.2

TABLE IV
Power Minimization

PARAMETER	BASELINE RESULTS	OPTIMIZED RESULTS	CHANGE (%)
Total number of tubes	5230	6393	+22.2
% of tubes in cocler	7.0	7.4	+5.7
Tube length (ft)	10.3	13.34	+29.5
Tube inner diam. (in)	.527	.667	+26.6
Tube wall thick. (in)	.049	.0455	-7.1
Tube outer diam. (in)	.625	.758	+21.3
Tube pitch	1.4	1.812	+29.4
Void diameter (ft)	1.10	1.13	+2.7
Bundle diameter (ft)	7.17	9.25	+29.0
Condenser volume (cu.ft.)	432.3	964.4	+123.1
Area ratio	0.266	0.277	+4.1
Coolant inlet vel. (ft./sec)	8.473	3.00	-64.6
Coolant mass flow rate (10^7 lbm/hr)	1.540	1.067	-30.7
Head loss (ft H ₂ O)	7.35	1.11	-84.9
Pumping power (hp)	55.69	5.84	-89.5
Coolant temperature rise ($^{\circ}$ F)	9.90	16.3	+64.6
Log mean temperature difference ($^{\circ}$ F)	28.62	24.82	-13.3
Heat transfer area (sq.ft.)	8814.	16,921	+92.0
Average overall heat transfer coefficient btu/(hr-sq.ft.- $^{\circ}$ F)	574.9	393.8	-31.5
Steam exit-fraction (% of input)	13.3	1.0	-92.5
Heat rejected (10^8 btu/hr)	1.451	1.654	+14.0

TABLE V
Power Minimization With Volume Constant

PARAMETER	BASELINE RESULTS	OPTIMIZED RESULTS	CHANGE (%)
Total number of tubes	5230	5062	+3.2
% of tubes in cocler	7.0	6.7	-4.3
Tube length (ft)	10.3	11.39	+10.6
Tube inner diam. (in)	.527	.594	+12.7
Tube wall thick. (in)	.049	.022	-55.1
Tube outer diam. (in)	.625	.638	+2.1
Tube pitch	1.4	1.753	+25.2
Void diameter (ft)	1.10	1.14	+3.6
Bundle diameter (ft)	7.17	6.73	-6.1
Condenser volume (cu.ft.)	432.3	431.6	-0.2
Area ratio	0.266	0.297	+11.7
Coolant inlet vel. (ft./sec)	8.473	6.74	-20.5
Coolant mass flow rate (10^7 lbm/hr)	1.540	1.508	-2.1
Head loss (ft H ₂ O)	7.35	4.69	-36.2
Pumping power (hp)	55.69	34.77	-37.6
Coolant temperature rise ($^{\circ}$ F)	9.90	11.6	+17.2
Log mean temperature difference ($^{\circ}$ F)	28.62	27.63	-3.5
Heat transfer area (sq.ft.)	8814.	9631.4	+9.3
Average overall heat transfer coefficient btu/(hr-sq.ft.- $^{\circ}$ F)	574.9	627.3	+9.1
Steam exit-fraction (% of input)	13.3	0.0	-100.
Heat rejected (10^8 btu/hr)	1.451	1.669	+15.0

TABLE VI
Volume Minimization With Power Constant

PARAMETER	BASELINE RESULTS	OPTIMIZED RESULTS	CHANGE (%)
Total number of tubes	5230	4867	-6.9
% of tubes in cocler	7.0	7.2	+2.9
Tube length (ft)	10.3	10.92	+6.0
Tube inner diam. (in)	.527	.581	+10.2
Tube wall thick. (in)	.049	.022	-55.1
Tube outer diam. (in)	.625	.625	0.0
Tube pitch	1.4	1.739	+24.2
Void diameter (ft)	1.10	1.20	+9.1
Bundle diameter (ft)	7.17	6.41	-10.6
Condenser volume (cu.ft.)	432.3	378.4	-12.4
Area ratio	0.266	0.299	+12.4
Coolant inlet vel. (ft./sec)	8.473	8.27	-2.4
Coolant mass flow rate (10^7 lbm/hr)	1.540	1.701	+10.5
Head loss (ft H ₂ O)	7.35	6.67	-9.3
Pumping power (hp)	55.69	55.80	+0.2
Coolant temperature rise (°F)	9.90	10.34	+4.4
Log mean temperature difference (°F)	28.62	28.38	-0.8
Heat transfer area (sq.ft.)	8814.	8697.	-1.3
Average overall heat transfer coefficient btu/(hr-sq.ft.-°F)	574.9	677.4	+17.5
Steam exit-fraction (% of input)	13.3	0.0	-100.
Heat rejected (10^8 btu/hr)	1.451	1.672	+15.2

TABLE VII
Volume Minimization With Linear Variations

PARAMETER	BASELINE RESULTS	OPTIMIZED RESULTS	CHANGE (%)
Total number of tubes	5230	5348	+2.3
% of tubes in cocler	7.0	7.3	+4.3
Tube length (ft)	10.3	8.7	-15.5
Tube inner diam. (in)	.527	*.729 .583	----
Tube wall thick. (in)	.049	.022	-55.1
Tube outer diam. (in)	.625	*.773 .627	----
Tube pitch	1.4	*1.75 1.44	----
Void diameter (ft)	1.10	1.28	+16.4
Bundle diameter (ft)	7.17	6.8	-5.2
Condenser volume (cu.ft.)	432.3	345.8	-20.0
Area ratio	0.266	0.298	+12.0
Coolant inlet vel. (ft./sec)	8.473	9.0	+6.2
Coolant mass flow rate (10^7 lbm/hr)	1.540	2.48	+61.0
Head loss (ft H ₂ O)	7.35	5.84	-20.5
Pumping power (hp)	55.69	71.1	+27.7
Coolant temperature rise (°F)	9.90	7.1	-28.8
Log mean temperature difference (°F)	28.62	30.14	+5.3
Heat transfer area (sq.ft.)	8814.	7746.	-12.1
Average overall heat transfer coefficient btu/(hr-sq.ft.-°F)	574.9	713.1	+24.0
Steam exit-fraction (% of input)	13.3	0.5	-96.2
Heat rejected (10^8 btu/hr)	1.451	1.665	+14.7

* Inner row values followed by outer row values.

VI. CONCLUSIONS

The intent of this research was to create a detailed condenser analysis code capable of being coupled with a numerical optimizer and to test the program to prove its versatility. An additional objective was to validate the analysis with existing data. The results of the test cases were presented in Chapter Five; the resulting conclusions are summarized here.

A. There were significant difficulties encountered in formulating the complex condenser design analysis, CONDIP, in a way that was compatible with the optimizer COPES/CONMIN. However, the majority of those problems were overcome resulting in the creation of a program which, when combined with the optimizer, is capable of taking any initial design, no matter how impractical or infeasible, and solving for an optimum solution based on a set of pre-determined constraints and design variables. There are still some minor limitations as to the degree of optimization, but the final design is usually within 10 percent of the single best optimum. In addition, the test cases indicate that as many as ten design variables and six constraints can be used simultaneously in the design optimization with CONDIP.

B. The test cases demonstrated the effectiveness of CONDIP as a design tool for not only the conceptual design of a condenser, but also in evaluating comparison studies based on any number of design variable combinations. The number of possible combinations of design objectives, design variables and design constraints implies limitless possibilities to be explored and evaluated.

C. An attempt was made to verify CONDIP with existing data with inconclusive results. Part of the blame can be placed on the rather inadequate quality and quantity of the data, but the general performance of CONDIP's condenser indicates a weakness in the analysis. As stated earlier, the source of the this weakness may be found in the correlations used for condensate inundation. The constants used in the expression for correcting shell-side heat transfer coefficients are based somewhat on conjecture. Yet they play a significant role in the overall condenser performance. Despite this limitation, the ability to optimize CONDIP's detailed analysis is a significant step forward over using the traditional and limited HEI method.

D. CONDIP incorporates features that further increase its appeal as a design tool. By possessing the ability to linearly vary pitch and tube diameter, a better understanding of how to improve condenser performance based on its configuration is realized. The capability to incorporate shell-side tube enhancement is another added plus. The possibilities that can now be investigated are limitless.

VII. RECOMMENDATIONS

In addition to the insight that this investigation has given into the generation of automated condenser design programs, it has specifically addressed the shortcomings and pitfalls which may be encountered along the way and offered possible solutions to overcome them. Presented below are recommendations for furthering the development of CONDIP as a completely versatile and accepted design program.

A. Since the weak link and the most significant unknown in condenser analysis is the effect of condensate rain in typical condenser environments, subsequent research should be devoted to investigating this phenomenon and developing more precise analytic correlations. In particular, the effects of velocity and flow direction on the condensate film should be attended to.

B. Perhaps in conjunction with the above, a test condenser should be constructed which is geometrically similar to the model proposed in CONDIP in order to physically observe and record the condenser performance. This data could then be used to either verify CONDIP or strengthen some of its analysis. In addition, this condenser should be built such that the tube bank can be arranged in any combination of pitch, tube diameter and row spacing to fully appreciate the effects of these variables.

C. A series of sensitivity studies should be conducted on CONDIP to fully exercise its capabilities and determine the relative effects of various design variables on condenser performance. Tradeoff studies similar to those performed in this research would be most beneficial to fully understand condenser behavior.

D. Additional subroutines should be created which would allow tube enhancement to be a design variable. This involves developing correlations between heat transfer enhancement and associated frictional losses. This type of relationship can be developed for both tube-side and shell-side enhancement.

E. Finally, it is recommended that additional refinement be performed on the code to increase its capability and flexibility. One such way is to somehow allow pitch, tube diameter and tube wall thickness to vary linearly by row while still allowing the number of tubes to be a design variable. The options available are limitless.

APPENDIX A
GLOSSARY

While it would most beneficial to present a complete glossary of all the variables used in CONDIP, the sheer number makes it difficult to present a comprehensive list. However, CONDIP makes liberal use of comment cards to define as many variables as possible to make the code easier to follow. Therefore, the computer listing in Appendix C is available for reference. A list of the possible design variables and constraints is provided here along with its corresponding position in the GLOBCM common block for easy reference in writing the appropriate COPES data cards. In addition, it will be specified whether these variables can be used as design constraints or design variables.

1. ALST: The length of the condenser and cooler tubes in feet. ALST is to be used only as a design variable.
2. DELWP: The pressure difference between the inlet and outlet coclant headers of the condenser bundle in psi. DELWP is to be used only as a design variable.
3. DELWPC: The pressure difference between the inlet and outlet coolant headers of the condenser bundle in psi. DELWPC is to be used only as a design constraint.
4. GFLOW: The mass flow rate of the coolant in lbm/hour. GFLOW cannot be used as a design variable simultaneously with VELBI. Otherwise it can be used as a design variable or a design constraint.
5. SIDI: The tube inner diameter of the innermost row of

- the condenser bundle in inches. SIDI is to be used only as a design variable.
7. SIDO: The tube inner diameter of the outermost row of the condenser bundle in inches. If there is no linear variation of tube inner diameter then this variable represents the tube inner diameter of the entire condenser bundle. SIDO is to be used only as a design variable.
8. PHP: The coolant pumping power in horsepower. PHP is to be used only as a design constraint.
9. RSPA: The spacing between concentric rows in the condenser bundle in inches. RSPA is to be used only as a design variable.
10. RADINS: The inner void radius of the condenser bundle in feet. RADINS is to be used only as a design variable.
11. REWI: The tube-side Reynolds number of the coolant in the innermost row of the condenser bundle. REWI is to be used only as a design constraint.
12. REWO: The tube-side Reynolds number of the coolant in the outermost row of the condenser bundle. If there is no linear variation of tube inner diameter then this variable represents the tube-side Reynolds number of the entire condenser bundle. REWO is to be used only as a constraint.
13. SDDI: Tube pitch (tube spacing/tube outer diameter) of the innermost row of the condenser bundle. SDDI is to be used only as a design variable.
14. SDDO: The tube pitch of the outermost row of the condenser bundle. If there is no linear variation of tube pitch then this variable represents the tube pitch for the entire condenser bundle. SDDO is to be used only as a design variable.

15. SLDI: Ratio of tube length to tube outer diameter of the outermost row of the condenser bundle. SLDI is to be used only as a design constraint.

16. SLDO: Ratio of tube length to tube outer diameter of the outermost row of the condenser bundle. If there is no linear variation of tube pitch then this variable represents the tube pitch for the entire condenser bundle. SLDO is to be used only as a design constraint.

17. VELBI: The velocity of the coolant in feet/sec. VELBI cannot be used as a design variable simultaneously with GFLOW. Otherwise it can be used as either a design constraint or as a design variable.

18. XW1: The ratio of tube thickness to tube inner diameter. XW1 can be used only as a design variable.

19. XW2: Tube thickness in inches. XW2 is to be used only as a design variable. XW2 and XW1 cannot be used simultaneously.

20. VOL1: The overall condenser and cooler volume in cubic feet. VOL1 is to be used only as a design constraint.

21. VOL2: The volume occupied by the tube bank, excluding the volume of the inner void, in cubic feet. VOL2 is to be used only as a design constraint.

22. TNOTOT: The total number of tubes in the condenser and cooler combined. If Option 1 is being used then TNOTOT is to be used only as a design constraint. If Option 2 is being used then TNOTOT is to be used only as a design variable.

23. BNDRAD: The condenser bundle in feet. BNDRAD is to be used only as a design constraint.

24. ARATIO: The ratio of the total cross-sectional area of

the tubes (based on the tube outer diameter) to the tube sheet area. ARATIO is to be used only as a design constraint.

25. ODII: The tube outer diameter of the innermost row in inches. ODII is to be used only as a design constraint.

26. ODOI: The tube outer diameter of the outermost row in inches. If there is no linear variation of tube inner diameter then this variable represents the tube outer diameter of the entire condenser bundle. ODOI is to be used only as a design constraint.

27. VLCMAX: The maximum allowable steam velocity into the cooler. VLCMAX can be used only as a design constraint and only when a cooler is being designed in the system.

28. PRCCLR: The percent of the total number of tubes in the cooler. PRCCLR can be used only as a design variable.

APPENDIX B
USERS MANUAL FOR CONDIP

This appendix describes the data cards that are necessary in order to couple any design program with COPES/CONMIN. Also described are cards illustrating data input required by CONDIP to initiate analysis. Thus, the data is divided into the COPES/CONMIN program section and the CONDIP-based condenser design program section.

The COPES data is segmented into "blocks" for convenience. All formats are alphanumeric for title, end and stop cards; F10 for real data; and I10 for integer data. The formatted input may be overridden by inserting commas between data entries. Comment cards may be inserted anywhere in the data stack prior to the end card and are identified by a dollar sign (\$) in column 1. The COPES data stack must terminate with an end card containing the word "END" in column 1-3. It should be noted that information pertaining only to single analysis and optimization is presented here. Information concerning the other options available in COPES along with further explanation of COPES capabilities can be found in [Ref. 13].

The analysis data is also segmented into blocks for convenience and they begin immediately following the "END" card in the COPES data. No comment cards are permitted here, and the analysis data stack must terminate with the word "STOP" in columns 1-4. This is where the initial design values are placed for entry into CONDIP.

Default values are recommended for use in the following COPES data cards unless otherwise noted. It is recommended that these values in the COPES data blocks be used until the user becomes familiar with the program. In addition a

sample data input is illustrated in figure B.1 at the end of this appendix.

DATA BLOCK A

DESCRIPTION: COPES Title Card

FORMAT: 20A4

1	2	3	4	5	6	7	8
TITLE							

REMARKS:

- 1) This line is available for a brief description.

DATA BLOCK B

DESCRIPTION: COPES Program Control Parameters

FORMAT: 7I10

1	2	3	4	5	6	7	8
NCALC	NDV						

FIELD

CONTENTS

- 1 NCALC: Calculation control
 - 0 Read input and stop. Data of blocks A-B is required. Remaining data is optional.
 - 1 One cycle through the program. Data of blocks A-B is required. Remaining data is optional.
 - 2 Optimization. Data of blocks A-I is required. Remaining data is optional.
- 2 NDV: Number of independent design variables in optimization or optimum sensitivity study.

REMARKS:

- 1) Field 1 determines program execution
- 2) Fields 3-8 are to be left blank for the CONDIP application of COPES/CONMIN.

DATA BLOCK C

DESCRIPTION: COPES Integer Optimization Control Parameters

FORMAT: 8I10

1	2	3	4	5	6	7	8
IPRINT	ITMAX	ICNDIR	NSCAL	ITRM	LINOBJ	NACMX1	NFDG

FIELD

CONTENTS

- 1 IPRINT: Print control used in optimization program, CONMIN.
0 No print during optimization.
1 Print initial and final optimization information.
2 Print above plus function value and design variable values at each iteration.
3 Print above plus constraint values, direction vector and move parameter at each iteration.
4 Print above plus gradient information.
5 Print above plus each proposed design vector, objective function and constraints during the one-dimensional search. required. Remaining data is optional.
- 2 ITMAX: Maximum number of optimization iterations allowed. DEFAULT = 20.
- 3 ICNDIR: Conjugate direction restart parameter. DEFAULT = NDV+1.
- 4 NSCAL: Scaling parameter. GT.0 - Scale design variables to order of magnitude one every NSCAL iterations. LT.0 - Scale design variables according to scaling values input. DEFAULT = No scaling.
- 5 ITRM: Number of subsequent iterations which must satisfy relative or absolute convergence criterion before optimization process is terminated. DEFAULT = 3.
- 6 LINOBJ: Linear objective function identifier. If the optimization objective is known to be a linear function of the design variables, set LINOBJ = 1. DEFAULT = Non-Linear.
- 7 NACMX1: one plus the maximum number of active constraints anticipated. DEFAULT = NDV+2.

DATA BLOCK C (Continued)

<u>FIELD</u>	<u>CONTENTS</u>
8	NFDG: Finite difference gradient identifier.
0	All gradient information is computed by finite difference.
1	Gradient of objective is computed analytically. Gradients of constraints are computed by finite difference.
2	All gradient information is computed analytically

REMARKS:

- 1) The value of NSCAL = 0 is suggested and ITRM = NACMX1 = 0 should be used.
- 2) The value of IPRINT may be reduced when the user becomes familiar with the optimization output.
- 3) The default values will be used if the card is either left blank or a value of zero is entered.
- 4) Because of the complexity of the problem it is necessary to have a large value for ITMAX so the problem will not be terminated prematurely. Recommended value is ITMAX = 40
- 5) The complexity of the condenser analysis ensure that no function can be considered linearly dependent on any combination of variables. This justifies using the DEFAULT value for LINOBJ.

DATA BLOCK D

DESCRIPTION: COPES Floating Point Optimization Program Parameters

FORMAT: 8F10

1	2	3	4	5	6	7	8
FDCH	FDCHM	CT	CTMIN	CTL	CTLMIN	THETA	PHI

FIELD

CONTENTS

- 1 FDCH: Relative change in design variables in calculating finite difference gradients. DEFAULT = 0.01
- 2 FDCHM: Minimum absolute step in finite difference gradient calculations. DEFAULT = 0.001.
- 3 CT: Constraint thickness parameter. DEFAULT = -0.1.
- 4 CTMI: Minimum absolute value of CT considered in the optimization process. DEFAULT = 0.004
- 5 CTL: Constraint thickness parameter for linear and side constraints.
- 6 CTLMIN: Minimum absolute value of CTL considered in the optimization process. DEFAULT = 0.001
- 7 THETA: Mean value of push-off factor in the method of feasible directions. DEFAULT = 1.0
- 8 PHI: Participation coefficient, used if one or more constraints are violated. DEFAULT = 5.0.

DATA BLOCK D (continued)

FORMAT: 2F10

1	2	3	4	5	6	7	8
DELFUN	DABFUN						

FIELD

CONTENTS

- 1 DELFUN: Minimum relative change in objective function to indicate convergence of optimization process. DEFAULT = 0.001.
- 2 DABFUN: Minimum absolute change in objective function to indicate convergence of the optimization process. DEFAULT = 0.001 times the initial objective value.

REMARKS:

1) Note that data for Data Block D is entered on two separate cards. A blank card indicates the default value is to be used.

2) If the NDV is greater than 3, the recommended value for FDCH is between 0.05 and 0.10.

DATA BLOCK E

DESCRIPTION: Total Number of Design Variables, Design Objective Identification and Sign on Design Objective.

FORMAT: 2I10, F10

1	2	3	4	5	6	7	8
NDVTOT	IOBJ	SGNOPT					

FIELD

CONTENTS

- 1 NDVTOT: Total number of variables linked to the design variables. NDVTOT must be greater or equal to NDV. This option allows two or more parameters to be assigned to a single design variable. The value of each parameter is the value of the design variable times a multiplier which may be different for each parameter.
DEFAULT = NDV.
- 2 IOBJ: Global variable number associated with objective function in optimization or optimum sensitivity analysis.
- 3 SGNOPT: Sign used on objective of optimization to identify whether function is to be maximized or minimized. +1.0 indicates maximization; -1.0 indicates minimization.
DEFAULT = -1.0

REMARKS:

1) Currently there are not any variables in CONDIP which are linked to any of the design variables. Therefore the DEFAULT value is used for NDVTOT.

DATA BLOCK F

DESCRIPTION: Design Variable Bounds, Initial Values, and Scaling Factors.

FORMAT: 4F10

1	2	3	4	5	6	7	8
VLB	VUB	X	SCAL				

FIELD

CONTENTS

- | | | |
|---|-------|--|
| 1 | VLB: | Lower bound on the design variable. |
| 2 | VUB: | Upper bound on the design variable. |
| 3 | X: | Initial value of the design variable.
If X is non-zero, this will supercede the value initialized by subroutine ANALIZ. |
| 4 | SCAL: | Design variable scale factor. Not used if NSCAL \geq 0 in Block C |

REMARKS:

- 1) There must be one separate data card for each design variable. Therefore there will be NDV data cards.
- 2) For all applications with CONDIP, initial values for the design variables will be entered through the INPUT subroutine called in ANALIZ.

DATA BLOCK G

DESCRIPTION: Design Variable Identification

FORMAT: 2I10,F10

1	2	3	4	5	6	7	8
NDSGN	IDSGN	AMULT					

FIELD

CONTENTS

- 1 NDSGN: Design variable number associated with the variable.
- 2 IDSGN: Global variable number associated with the variable.
- 3 AMULT: Constant multiplier on the variable. The value of the variable will be the value of the design variable, NDSGN, times AMULT. DEFAULT = 1.0.

REMARKS:

1) There must be one separate card for each of the NDVTOT design variables. These data cards must follow the same order as the corresponding design variable parameter cards in Block F.

DATA BLOCK H

DESCRIPTION: Number of Constrained Parameters.

FORMAT: I10

1	2	3	4	5	6	7	8
NCONS							

FIELD

CONTENTS

1 NCONS: Number of constraint SETS in the
 optimization problem.

REMARKS:

1) If two or more adjacent parameters in the Global common block have the same limits imposed, these are part of the same constraint set.

DATA BLOCK I

DESCRIPTION: Constraint Identification and Bounds.

FORMAT: 3I10

1	2	3	4	5	6	7	8
ICON	JCON	LCON					

FIELD

CONTENTS

- 1 ICON: First Global number corresponding to the constraint set.
- 2 JCON: Last Global number corresponding to the constraint set. DEFAULT = ICON.
- 3 LCON: Linear constraint identifier for this set of constrained variables. LCCN = 1 indicates linear constraints. DEFAULT = 0 = Nonlinear constraint.

REMARKS:

- 1) In CONDIP there is only Global number and thus one constraint that comprise a constraint set. Therefore the DEFAULT value is used for JCON.
- 2) All the constraints in this analysis are nonlinear. The DEFAULT value was therefore used for LCON as well.
- 3) This is the first card of a two card set which must be read together.

DATA BLOCK I (Continued)

FORMAT: 4F10

1	2	3	4	5	6	7	8
BL	SCAL1	BU	SCAL2				

FIELD

CONTENTS

- 1 BL: Lower bound on the constrained variables.
Value less than $-2.0E+15$ is assumed
unbounded
- 2 SCAL1: Normalization factor on lower bound.
DEFAULT = Max of ABS(BL) or 0.1.
- 3 BU: Upper bound on the constrained variables.
Value greater than $+2.0E+15$ is assumed
unbounded.
- 4 SCAL2 Normalization factor on upper bound.
DEFAULT = Max of ABS(BU) or 0.1.

REMARKS:

1) The normalization factor can usually be defaulted, with the notable exception of exit-fraction. the normalization factor used for this constraint is usually ten times the upper bound.

DATA BLOCK P

DESCRIPTION: COPES Data 'END' Card.

FORMAT: 3A1

1	2	3	4	5	6	7	8
END							

FIELD

CONTENTS

1 The word 'END' in column 1-3.

REMARKS:

- 1) This card must appear at the end of the COPES data.
- 2) This ends the COPES input deck.

DATA BLOCK AA

DESCRIPTION: Geometry Option

FORMAT: I5

1	2	3	4	5	6	7	8
IOPT							

FIELD

CONTENTS

- | | | |
|---|------|--|
| 1 | IOPT | Two condenser geometric options |
| | 1 | IOPT = 1. Number of condenser rows is a input as a constant; the number of tubes is a dependent variable. Use data blocks EE, FF, and GG. |
| | 2 | IOPT = 2. Number of tubes is allowed to be an independent variable and the number of rows is a dependent variable. Use data blocks HH and II. DEFAULT value is IOPT = 2. |

REMARKS:

1) Data is right-justified and blanks will be interpreted as zeros.

2) If IOPT = 1, a smaller finite difference (FDCH) can be utilized in data Block D. This is because with this option the design analysis is less sensitive to the problems discussed earlier. Recommended using the DEFAULT value of 0.01 for FDCH.

DATA BLOCK BB

DESCRIPTION: Condenser Orientation

FORMAT: 1I5,3F10

1	2	3	4	5	6	7	8
ISEC	SECWID	PHI	PRCCLR				

FIELD

CONTENTS

- | | | |
|---|--------|---|
| 1 | ISEC | The number of sectors in the condenser. |
| 2 | SECWID | Sector width in degrees of arc. |
| 3 | PHI | Symmetry angle measure from the vertical. |
| 4 | PRCCLR | The percent of the tubes in the cooler. |

REMARKS:

- 1) Data BB is required, no matter what geometry option is chosen.
- 2) The only limitation on ISEC and SECWID is that their product is less than 360 degrees. If the product is exactly 360 degrees, certain trigonometric functions will return a singularity.
- 3) PHI is that angle from the vertical that cuts the condenser in half.
- 4) Data is right-justified and blanks will be interpreted as zeros.

DATA BLOCK CC

DESCRIPTION: Void Size, Tube Length, Row Spacing

FORMAT: 3F10

1	2	3	4	5	6	7	8
RADINS	ALST	RSPA					

FIELD

CONTENTS

- | | | |
|---|--------|---|
| 1 | RADINS | The inner void radius; feet. |
| 2 | ALST | The tube length; feet. |
| 3 | RSPA | Concentric row spacing about the void;
inches. |

REMARKS:

1) Data CC is required, no matter what geometry option is chosen.

DATA BLOCK DD

DESCRIPTION: Tube Material Parameters

FORMAT: I5,4F10

1	2	3	4	5	6	7	8
IWALL	XW	TUBESW	SKW	FOUL			

FIELD

CONTENTS

- | | | |
|---|--------|---|
| 1 | IWALL | A Flag indicating the tube thickness specification.
1 IWALL = 1. Tube thickness is input as ratio of tube thickness to tube inner diameter.
2 IWALL = 2. Tube thickness is input in inches. |
| 2 | XW | The input for wall thickness, dependent on the value for IWALL. |
| 3 | TUBESW | Specific weight of the tube material; lbm/(cu.ft.) |
| 4 | SKW | Tube material thermal conductivity; (btu-ft)/(sq.ft.-hr-°F) |
| 5 | FOUL | Tube fouling factor. |

REMARKS:

- 1) Data DD is required, no matter what geometry option is chosen.
- 2) Data is right-justified and blanks will be interpreted as zeros.

DATA BLOCK EE

DESCRIPTION: Number of Rows

FORMAT: I5

1	2	3	4	5	6	7	8
NOROWS							

FIELD

CONTENTS

1 NOROWS The number of concentric rows in the
 condenser bundle built around the center
 void

REMARKS:

- 1) Data EE is used only when IOPT = 1
- 2) Data is right-justified and blanks will be interpreted as zeros.

DATA BLOCK FF

DESCRIPTION: Tube Inner Diameter

FORMAT: 1I5,2F10

1	2	3	4	5	6	7	8
MDIAM	SIDO	SIDI					

FIELD

CONTENTS

- | | | |
|---|-------|--|
| 1 | MDIAM | A flag to indicate whether tube inner diameter will linearly vary by row through the condenser bundle. |
| | 1 | MDIAM = 1. Tube inner diameter is uniform through the condenser bundle. |
| | 2 | MDIAM = 2. Tube inner diameter varies linearly through the bundle by row. |
| 2 | SIDO | Tube inner diameter of the outer row; inches. |
| 3 | SIDI | Tube inner diameter of the inner row; inches. |

REMARKS:

- 1) Data FF is used only when IOPT = 1
- 2) Data is right-justified and blanks will be interpreted as zeros.
- 3) Cooler tubes use the inner diameter of the innermost bundle row.
- 4) The DEFAULT value is MDIAM = 1

DATA BLOCK GG

DESCRIPTION: Tube Pitch

FORMAT: 1I5,2F10

1	2	3	4	5	6	7	8
MPITCH	SDDO	SDDI					

FIELD

CONTENTS

- | | | |
|---|--------|---|
| 1 | MPITCH | A flag to indicate whether tube pitch will linearly vary by row through the condenser bundle.
1 MPITCH = 1. Tube pitch is uniform through the condenser bundle.
2 MPITCH = 2. Tube pitch varies linearly through the bundle by row. |
| 2 | SDDO | Tube pitch of the outer row; |
| 3 | SDDI | Tube pitch of the inner row; |

REMARKS:

- 1) Data GG is used only when IOPT = 1
- 2) Data is right-justified and blanks will be interpreted as zeros.
- 3) Cooler tubes use the pitch of the innermost bundle row.
- 4) The DEFAULT value is MPITCH = 1

DATA BLOCK HH

DESCRIPTION: Tube Inner Diameter and Tube Pitch

FORMAT: 2F10

1	2	3	4	5	6	7	8
SIDO	SDDO						

FIELD

CONTENTS

- | | | |
|---|------|--|
| 1 | SIDO | Tube inner diameter for the entire condenser; inches |
| 2 | SDDO | Tube pitch for the entire condenser |

REMARKS:

- 1) Data HH is used only when IOPT = 2.
- 2) Data is right-justified and blanks will be interpreted as zeros.
- 3) In the calculations, SIDDI is set equal to SIDO and SDDDI is set equal to SDDO. This avoids the need for two systems of nomenclature for each geometry option.

DATA BLOCK II

DESCRIPTION: Total Number of Tubes in the Condenser

FORMAT: F12

1	2	3	4	5	6	7	8
TNOTOT							

FIELD

CONTENTS

1 TNOTOT The total number of tubes in the
 condenser (cooler and the bundle).

REMARKS:

- 1) Data II is used only when IOPT = 2.
- 2) Data is right-justified and blanks will be interpreted as zeros.

DATA BLOCK JJ

DESCRIPTION: Inlet Steam Mixture.

FORMAT: 15,2F10

1	2	3	4	5	6	7	8
JGAS	WSI	WNCIR					

FIELD

CONTENTS

- | | | |
|---|-------|---|
| 1 | JGAS | A Flag indicating the type of non-condensable gas entering the system.
1 JGAS = 1. This indicates that the gas is air.
2 JGAS = 2. This indicates that the gas is carbon dioxide.
3 JGAS = 3. This indicates that the gas is a mixture of the two. |
| 2 | WSI | Steam flow rate entering the condenser; lbm/hr. |
| 3 | WNCIR | Ratio of the non-condensable gas flow to inlet steam flow; lbm/hr. |

REMARKS:

- 1) Data JJ is required, no matter what geometry option is chosen.
- 2) Data is right-justified and blanks will be interpreted as zeros.

DATA BLOCK KK

DESCRIPTION: Inlet Temperatures.

FORMAT: 2F10

1	2	3	4	5	6	7	8
STBI	STSAT1						

FIELD

CONTENTS

- | | | |
|---|--------|--|
| 1 | STBI | Coolant inlet temperature; °F. |
| 2 | STSAT1 | Inlet steam saturation temperature;
°F. |

REMARKS:

- 1) Data KK is required no matter, what geometry option is chosen.
- 2) Data is right-justified and blanks will be interpreted as zeros.

DATA BLOCK LL

DESCRIPTION: Cooling Water Parameters

FORMAT: 2F10

1	2	3	4	5	6	7	8
IFLOW	X5						

FIELD

CONTENTS

- 1 IFLOW A control flag for cooling water specifications.
 - 1 IFLOW = 1. Input pressure drop across cooling water headers in psia.
 - 2 IFLOW = 2. Input cooling water velocity in ft/sec.
 - 3 IFLOW = 3. Input coolant flow in lbm/hr.
- 2 X5 Actually input the value for flow into this variable. The specification for flow to be determined by IFLOW

REMARKS:

- 1) Data LL is required, no matter what geometry option is chosen.
- 2) Data is right-justified and blanks will be interpreted as zeros.
- 3) X5 acts as a temporary all-purpose storage variable for whatever expression for coolant flow is used.

DATA BLOCK MM

DESCRIPTION: Internal Enhancement Regions

FORMAT: I5

1	2	3	4	5	6	7	8
NEI							

FIELD

CONTENTS

1 NEI Number of internal enhancement regions.
 A value between 1 and 6.

REMARKS:

- 1) Data MM is optional. There must be NEI subsequent data cards providing the necessary parameters for each region.
- 2) enhancement can only be used if IOPT = 1.
- 3) Data is right-justified and blanks will be interpreted as zeros.
- 4) This value was zero for all runs.

DATA BLOCK NN

DESCRIPTION: Internal Enhancement Parameters

FORMAT: 2I5,3F10

1	2	3	4	5	6	7	8
NRNI	NETI	ENI	BC	BE			

FIELD

CONTENTS

- | | | |
|---|------|--|
| 1 | NRNI | Row number of first row in internal enhancement region. |
| 2 | NETI | Number of tubes in each internal enhancement region. |
| 3 | ENI | Internal heat transfer enhancement factor. |
| 4 | BC | Coefficient in internally enhanced tube coolant pressure drop calculation. |
| 5 | BE | Exponent in coolant pressure drop calculation. |

REMARKS:

- 1) Data NN is optional. However, if NEI is greater than zero then there must be NEI "NN" data cards to provide the necessary data for each enhancement region.
- 2) enhancement can only be used if IOPT = 1.
- 3) Data is right-justified and blanks will be interpreted as zeros.
- 4) These values are constant for entire run and cannot be changed by the optimizer.
- 5) This value was zero for all runs.

DATA BLOCK 00

DESCRIPTION: External Enhancement Regions

FORMAT: I5

1	2	3	4	5	6	7	8
NEE							

FIELD

CONTENTS

1 NEE Number of external enhancement regions.
 A value between 1 and 6.

REMARKS:

- 1) Data 00 is optional. There must be NEE subsequent data cards providing the necessary parameters for each region.
- 3) Data is right-justified and blanks will be interpreted as zeros.
- 4) This value was zero for all runs.

DATA BLOCK PP

DESCRIPTION: External Enhancement Parameters

FORMAT: 2I5,2F10

1	2	3	4	5	6	7	8
NRNE	NETE	ENO	ENH				

FIELD

CONTENTS

- | | | |
|---|------|---|
| 1 | NRNE | Row number of first row in external enhancement region. |
| 2 | NETE | Number of tubes in each external enhancement region. |
| 3 | ENI | External heat transfer enhancement factor. |
| 4 | ENH | Steam-side pressure drop factors. |

REMARKS:

- 1) Data PP is optional. However, if NEE is greater than zero then there must NEE "PP" data cards to provide the necessary data for each enhancement region.
- 2) Data is right-justified and blanks will be interpreted as zeros.
- 3) Enhancement can only be used if IOPT = 1.
- 4) These values are constant for an entire run and cannot be changed by the optimizer.
- 5) This value was zero for all runs.

DATA BLOCK QQ

DESCRIPTION: Baffle Options

FORMAT: I5

1	2	3	4	5	6	7	8
IBAF							

FIELD

CONTENTS

1 IBAF A flag to be used to determine baffle number and location.

REMARKS:

- 1) Data QQ is optional.
- 2) Data is right-justified and blanks will be interpreted as zeros.
- 3) These values are constant for an entire run and cannot be changed by the optimizer.
- 4) Additional specified baffles were not used in any of the runs. This value was zero for all runs.

DATA BLOCK RR

DESCRIPTION: Baffle Location

FORMAT: I5

1	2	3	4	5	6	7	8
JBAF							

FIELD

CONTENTS

1 JBAF An array containing baffle locations

REMARKS:

- 1) Data RR is optional.
- 2) Data is right-justified and blanks will be interpreted as zeros.
- 3) These values are constant for an entire run and cannot be changed by the optimizer.
- 4) Additional specified baffles were not used in any of the runs. This value was zero for all runs.

DATA BLOCK SS

DESCRIPTION: Detailed Printout

FORMAT: I5

1	2	3	4	5	6	7	8
IPRT							

FIELD

CONTENTS

1 IPRT A flag to generate a detailed output
 of the condenser analysis (OUT3)

REMARKS:

- 1) Data SS is optional.
- 2) Data is right-justified and blanks will be interpreted as zeros.
- 3) These values are constant for an entire run and cannot be changed by the optimizer.
- 4) This value was zero for all runs.

VOLUME MINIMIZATION - CIRCULAR CONDENSOR

```

2,8
1,40,,9,,,20
.10

1,20,-1.
1.0,2.0E+15
1000.,8000.
1.1,2.
3.,9.0
.022,,.109
.407,1.206
.1,1.
2.,10.
1,1
2,22
3,14
4,17
5,19
6,7
7,10
8,29
5
4
-2.0E+15,,, .01, .01
23
.5,,5.
24
.1,,,30
26
.625,,1.25
28
-2.E+15,,200.
END
      2
      12  29.99   180.           7.0
0.55    .049   10.3          282.           26.0           .0002
      2
      .527    1.40
5230.0
      1  161970. .0000371
76.66   110.52
      2    8.473
      0
      0
      0
      0
  
```

Figure B.1 Sample Data Input.

APPENDIX C
CONDIP LISTING

The following Appendix contains a complete listing for CONDIP. An effort has been made to make the program as readable as possible through liberal use of comment cards.


```

SUBROUTINE ANALIZ (ICALC)
IF (ICALC.GT.2) RETURN
IF (ICALC.GT.1) GO TO 10
ICOUNT=0
CALL INPUT (IPRT)
CALL OUT1
IF (ICALC.EQ.3) GO TO 20
CALL ORCON (ICALC)
GO TO 30
CALL OUT2
ICOUNT = 1
IF (IPRT.NE.0.AND.ICOUNT.NE.0) CALL OUT3
RETURN
END
C*****
C*****
C*****
C-----
C INP 1          SUBROUTINE INPUT
C                INPUT CALLED BY ANALIZ WITH ICALC = 1
C
C ZZ INP-1
C  COMMON /GLOB/CM/ ALST,DELWP,DELWPC,EXITQA,GFLOW,SIDI,SIDO,PHP,RSPA,
1RADINS,REWI,REWO,SDDI,SDDO,SLDI,SLDO,VELBI,XW1,XW2,VOL1,VOL2,TNUT0
2T,BNDRAD,ARATIO,ODI,ODO,VLCCMAX,PRCCCLR
C  COMMON /INPT/ BC(6),BE(6),ENH(6),ENO(6),FDUL,PHI,SKW,SIBI,SC
1TSAI,TUBESW,WNCIR,IOP1,PTST(15),SECWID,I,IBAF,ISEC,JGAS,MD
2IAM,MPITCH,NEE,NEI,NETE(6),NRNE(6),NRNI(6),NOROWS,WTST(15)
3,WSI,PFILL
C  COMMON /INPTI/ IFLOW,IWALL
C$-----
C INP 2
C          READ ENTERING DATA SET
C
C ALST = TUBE LENGTH IN FEET
C BC = COEFFICIENT IN INTERNALLY ENHANCED TUBE COULANT PRESSURE
C     DROP CALCULATION.
C BE = EXPONENT IN COOLANT PRESSURE DROP CALCULATION.
C DELWP = INTERNAL HEAT TRANSFER ENHANCEMENT FACTORS.
C ENH = INTERNAL HEAT TRANSFER ENHANCEMENT FACTORS.
C ENO = EXTERNAL HEAT TRANSFER ENHANCEMENT FACTORS.

```

C0N00G10
C0N00020
C0N00030
C0N00040
C0N00050
C0N00060
C0N00070
C0N00080
C0N00090
C0N00100
C0N00110
C0N00120
C0N00130
C0N00140
C0N00150
C0N00160
C0N00170
C0N00180
C0N00190
C0N00200
C0N00210
C0N00220
C0N00230
C0N00240
C0N00250
C0N00260
C0N00270
C0N00280
C0N00290
C0N00300
C0N00310
C0N00320
C0N00330
C0N00340
C0N00350
C0N00360
C0N00370
C0N00380
C0N00390
C0N00400
C0N00410
C0N00420
C0N00430
C0N00440
C0N00450
C0N00460
C0N00470
C0N00480

CON00490
 CON00500
 CON00510
 CON00520
 CON00530
 CON00540
 CON00550
 CON00560
 CON00570
 CON00580
 CON00590
 CON00600
 CON00610
 CON00620
 CON00630
 CON00640
 CON00650
 CON00660
 CON00670
 CON00680
 CON00690
 CON00700
 CON00710
 CON00720
 CON00730
 CON00740
 CON00750
 CON00760
 CON00770
 CON00780
 CON00790
 CON00800
 CON00810
 CON00820
 CON00830
 CON00840
 CON00850
 CON00860
 CON00870
 CON00880
 CON00890
 CON00900
 CON00910
 CON00920
 CON00930
 CON00940
 CON00950
 CON00960

FOUL = TUBE FOULING FACTOR.
 GFLOW = COOLANT MASS FLOW RATE LBM/HR
 IBAF = CONTROL FLAG FOR BAFFLE OPTIONS
 IPRT = CONTROL FLAG FOR COOLING WATER SPECIFICATION.
 ISEC = CONTROL FLAG FOR OUTPUT SECTOR (EXTENDED OUTPUT IF IPRT>0.)
 IWALL = CONTROL FLAG FOR CONDENSER THICKNESS SPECIFICATION.
 JGAS = ARRAY CONTAINING BAFFLE THICKNESS OR 3
 MDIAM = CONTROL FLAG FOR LINEAR VARIATION IN TUBE DIAMETER.
 MPITCH = CONTROL FLAG FOR LINEAR VARIATION IN TUBE PITCH.
 NEE = NUMBER OF TUBES IN EACH ENHANCEMENT REGION.
 NETE = NUMBER OF TUBES IN EACH EXTERNAL ENHANCEMENT REGION.
 NETI = NUMBER OF TUBES IN EACH INTERNAL ENHANCEMENT REGION.
 NOROW = NUMBER OF ROWS IN THE CONDENSER ENHANCEMENT REGION.
 NRNI = ROW NUMBER OF FIRST ROW IN EXTERNAL ENHANCEMENT REGION.
 SIDI = TUBE ID AT INSIDE ROW -- IN
 SIDO = TUBE ID AT OUTSIDE ROW -- IN
 SIOPT = FLAG TO INDICATE WHICH GEOMETRY MODULE IS BEING USED
 IF OPT=1 THEN ROWS IS A CONSTANT IN THE MODEL AND
 VARIATION IN PITCH AND TUBE DIAMETER IS PERMITTED.
 IF OPT=2 THEN TNOTUT IS A DESIGN VARIABLE AND LINEAR
 VARIATIONS ARE NOT PERMITTED.
 = SYMMETRY ANGLE MEASURED FROM THE VERTICAL
 RADA = BUNDLE INSIDE RADIUS - FT
 RSPA = TUBE ROW INSIDE RADIUS - FT
 SDDI = PITCH AT INSIDE ROW
 SDDO = PITCH AT OUTSIDE ROW
 SECWID = SECTOR RIAL THERMAL F DEGREES OF ARC
 SKWI = TUBE MATE INLET TEMP
 STBII = COOLANT INLET TEMP
 STSATI = INLET STM SAT TEMP F
 TNOTUT = TOTAL NUMBER OF TUBES IN THE CONDENSER/COOLER
 TUBESW = SPECIFIC WEIGHT OF THE TUBE MATERIAL LBM/CU FT
 VELBI = COOLANT FLOW VELOCITY FT/SEC
 WNCIR = RATIO OF N/C MASS FLOW TO STEAM MASS FLOW
 WSI = STM FLOW RATE LBM/HR
 XW1 = TEMP INPUT VALUE OF XW1 AND XW2
 XW2 = RATIO OF TUBE WALL THICKNESS TO TUBE ID
 = TUBE WALL THICKNESS INCHES

ZZZ INP-2

 READ (5,330) IOPT
 READ (5,340) ISEC, SECWID, PHI, PRCLR
 READ (5,360) RADINS, ALST, RSPA

CC


```

C      READ (5,400) IWALL,XW,TUBESW,SKW,FOUL
C      IF ((IOPT.GE.2).OR.(IOPT.LT.1)) GO TO 10
10     READ (5,380) NROWS
      READ (5,370) MDIAM,SIDO,SIDI
      READ (5,370) MPITCH,SDDO,SDDI
      GO TO 20
      READ (5,360) SIDO,SDDO
      READ (5,390) TNOTOT
      MPITCH=1
      MDIAM=1
C
C      IF (MDIAM.EQ.1) SIDI=SIDO
      IF (MPITCH.EQ.1) SDDI=SDDO
      IW=IWALL
      IF (IWALL.NE.2) IW=1
      XW1=0.
      XW2=0.
      IF (IW.EQ.1) XW1=XW
      IF (IW.EQ.2) XW2=XW
      READ (5,350) JGAS,WSI,WNCIR
      READ (5,410) STBI,STSAT1
      READ (5,420) IFLOW,X5
      IF L=IFLOW
      GFLOW=0.
      VELBI=0.
      DELWP=0.
      IF (IFLOW.EQ.1) DELWP=X5
      IF (IFLOW.EQ.2) VELBI=X5
      IF (IFLOW.EQ.3) GFLOW=X5
      READ (5,430) NEI
      IF (NEI.EQ.0) GO TO 40
      IF ((NEI.LT.0).AND.(NEI.GT.6)) GO TO 120
      DO 30 I=1,NEI
      READ (5,440) NRNI(I),NETI(I),ENI(I),BC(I),BE(I)
      IF (NEE.EQ.0) GO TO 60
      IF ((NEE.LE.0).OR.(NEE.GT.6)) GO TO 120
      DO 50 I=1,NEE
      READ (5,450) NRNE(I),NETE(I),ENOE(I),ENH(I)
      IF ((IBAF.LE.-2).OR.(IBAF.GT.1SEC)) GO TO 120
      IF ((IBAF.EQ.0).OR.(IBAF.EQ.-1)) GO TO 80
      DO 70 I=1,IBAF
      READ (5,430) JBAF(I)
      CONTINUE
      READ (5,430) IPRT

```

```

CON00970
CON00580
CON00590
CON01000
CON01010
CON01020
CON01030
CON01040
CON01050
CON01060
CON01070
CON01080
CON01090
CON01100
CON01110
CON01120
CON01130
CON01140
CON01150
CON01160
CON01170
CON01180
CON01190
CON01200
CON01210
CON01220
CON01230
CON01240
CON01250
CON01260
CON01270
CON01280
CON01290
CON01300
CON01310
CON01320
CON01330
CON01340
CON01350
CON01360
CON01370
CON01380
CON01390
CON01400
CON01410
CON01420
CON01450
CON01440

```


CON01450
 CON01460
 CON01470
 CON01480
 CON01490
 CON01500
 CON01510
 CON01520
 CON01530
 CON01540
 CON01550
 CON01560
 CON01570
 CON01580
 CON01590
 CON01600
 CON01610
 CON01620
 CON01630
 CON01640
 CON01650
 CON01660
 CON01670
 CON01680
 CON01690
 CON01700
 CON01710
 CON01720
 CON01730
 CON01740
 CON01750
 CON01760
 CON01770
 CON01780
 CON01790
 CON01800
 CON01810
 CON01820
 CON01830
 CON01840
 CON01850
 CON01860
 CON01870
 CON01880
 CON01890
 CON01900
 CON01910
 CON01920

```

C$ INP 3
C
C TEST FOR RECOVERABLE INPUT ERRORS
C
C ZZZ INP-3
C-----
IF ((IOPT.EQ.1).OR.(IOPT.EQ.2)) GO TO 90
WR ITE (6,460) IOPT
WR ITE (6,510)
IOPT=2
IF ((IOPT.EQ.2) GO TO 110
IF ((MDIAM.EQ.2).OR.(MDIAM.EQ.1)) GO TO 100
WR ITE (6,460) MDIAM
WR ITE (6,480)
WR ITE (6,510)
MDIAM=1
IF ((MPITCH.EQ.1).OR.(MPITCH.EQ.2)) GO TO 110
WR ITE (6,460)
WR ITE (6,490) MPITCH
WR ITE (6,510)
MPITCH=1
IF ((IWALL.EQ.1).OR.(IWALL.EQ.2)) GO TO 120
WR ITE (6,460)
WR ITE (6,500) IWALL
WR ITE (6,510)
IWALL=1
C$ INP 4
C
C LOCATE NON-RECOVERABLE INPUT ERRORS
C
C ZZZ INP-4
C-----
IERR=0
IF ((ISEC.GT.0).AND.(ISEC.LE.15)) GO TO 130
IERR=1 (6,520)
WR ITE (6,530) ISEC
X2=SECWID*FLOAT(ISEC)
IF ((X2.LE.360.).AND.(X2.GT.0.)) GO TO 140
WR ITE (6,520) X2
WR ITE (6,540)
WR ITE (6,550) ISEC,SECWID
IERR=1
IF ((IOPT.EQ.2) GO TO 150
IF ((NROWS.GT.0).AND.(NROWS.LE.99)) GO TO 160
IERR=1
WR ITE (6,520)
  
```


CONO1930
 CONO1940
 CONO1950
 CONO1960
 CONO1970
 CONO1980
 CONO1990
 CONO2000
 CONO2010
 CONO2020
 CONO2030
 CONO2040
 CONO2050
 CONO2060
 CONO2070
 CONO2080
 CONO2090
 CONO2100
 CONO2110
 CONO2120
 CONO2130
 CONO2140
 CONO2150
 CONO2160
 CONO2170
 CONO2180
 CONO2190
 CONO2200
 CONO2210
 CONO2220
 CONO2230
 CONO2240
 CONO2250
 CONO2260
 CONO2270
 CONO2280
 CONO2290
 CONO2300
 CONO2310
 CONO2320
 CONO2330
 CONO2340
 CONO2350
 CONO2360
 CONO2370
 CONO2380
 CONO2390
 CONO2400

```

C 150      WRITE (6,560) NCROWS
          GO TO 160
          IF (TNOTOT.GT.0) GO TO 160
          IERR=1
          WRITE (6,520)
          WRITE (6,570) TNOTOT
C 160      IF (RADINS.GT.0.) GO TO 170
          IERR=1
          WRITE (6,520)
          WRITE (6,580) RADINS
          IF (ALST.GT.0.) GO TO 180
          IERR=1
          WRITE (6,520)
          WRITE (6,590) ALST
          IF (SIDO.GT.0.) GO TO 190
          IERR=1
          WRITE (6,520)
          WRITE (6,600) SIDO
          IF ((MDIAM.EQ.1).OR.(SIDI.GT.0.)) GO TO 200
          IERR=1
          WRITE (6,520)
          WRITE (6,610) SIDI
          IF (SDDO.GT.1.) GO TO 210
          IERR=1
          WRITE (6,520)
          WRITE (6,620) SDDO
          IF ((MPITCH.EQ.1).OR.(SDDI.GT.1.)) GO TO 220
          IERR=1
          WRITE (6,520)
          WRITE (6,630) SDDI
          IF (IWI.EQ.2) GO TO 230
          IF (XWI.GT.0.) GO TO 240
          IERR=1
          WRITE (6,520)
          WRITE (6,640) XWI
          GO TO 240
          X=XW2*2
          IF (X.GT.0.) GO TO 240
          IERR=1
          WRITE (6,520)
          WRITE (6,650) XW2
          IF ((WNCIR.GE.0.).AND.(WNCIR.LT.1.)) GO TO 250
          IERR=1
          WRITE (6,520)
          WRITE (6,660) WNCIR
          IF ((STBI.GT.-32.).AND.(STBI.LT.212)) GO TO 260
  
```



```

IERR=1
WR I TE (6,520)
IF (STBI.LT.STSAT1) GO TO 270
IERR=1
WR I TE (6,520) STBI,STSAT1
IF ((IFLOW.GT.0).OR.(IFLOW.LE.3)) GO TO 280
IERR=1
WR I TE (6,520)
IF ((NEI.GE.0) .AND.(NEI.LE.6)) GO TO 290
IERR=1
WR I TE (6,520)
IF ((NEE.GE.0) .AND.(NEE.LE.6)) GO TO 300
IERR=1
WR I TE (6,520)
IF ((IBAF.GE.-1) .AND.(IBAF.LE.ISEC)) GO TO 310
IERR=1
WR I TE (6,520)
IF (IERR.EQ.0) GO TO 320
STOP
RETURN
FORMAT (I5,3F10.5)
FORMAT (I5,F10.5,F10.7)
FORMAT (4F10.5)
FORMAT (I5,F10.5,F10.5)
FORMAT (I5)
FORMAT (F12.5)
FORMAT (I5,4F10.5)
FORMAT (2F10.5)
FORMAT (I5,F10.5)
FORMAT (I5)
FORMAT (2I5,3F10.5)
FORMAT (2I5,2F10.5)
FORMAT (I10,3I1)
FORMAT (I1,22H INPUT VALUE OF OPT = ,15,27H OUT OF RANGE, OPT SET
1 TO 2)
FORMAT (I1,21H INPUT VALUE OF MDIAM=,15,29H OUT OF RANGE, MDIAM SE
1 TO 1)
FORMAT (I1,22H INPUT VALUE OF MPITCH=,15,30H OUT OF RANGE, MPITCH
1 SET TO 1)
FORMAT (I1,21H INPUT VALUE OF IWALL=,15,29H OUT OF RANGE, IWALL SE
CON0 2410
CON0 2420
CON0 2430
CON0 2440
CON0 2450
CON0 2460
CON0 2470
CON0 2480
CON0 2490
CON0 2500
CON0 2510
CON0 2520
CON0 2530
CON0 2540
CON0 2550
CON0 2560
CON0 2570
CON0 2580
CON0 2590
CON0 2600
CON0 2610
CON0 2620
CON0 2630
CON0 2640
CON0 2650
CON0 2660
CON0 2670
CON0 2680
CON0 2690
CON0 2700
CON0 2710
CON0 2720
CON0 2730
CON0 2740
CON0 2750
CON0 2760
CON0 2770
CON0 2780
CON0 2790
CON0 2800
CON0 2810
CON0 2820
CON0 2830
CON0 2840
CON0 2850
CON0 2860
CON0 2870
CON0 2880

```



```

510 1T TO 1) (1H ,26H EXECUTION CONTINUES ..... CON02890
520 1FORMAT (1H0 ,38H*** RUN TERMINATED DURING ..... CON02900
530 1FORMAT (1H ,43H RANGE OF ALLOWABLE ISEC IS 1 THRU 15, ISEC=,15) CON02910
540 1FORMAT (1H ,60H CONDENSER ANGULAR WIDTH IS OUT OF RANGE 0 TO 360 DE CON02930
1G, WIDTH=,E10.5,5H DEG.) CON02940
550 1FORMAT (1H ,5H ISEC=,15,10H SECWID=,E10.3) CON02950
560 1FORMAT (1H ,49H NUMBER OF ROWS MUST BE IN RANGE 0 TO 100, NOROWS=,1 CON02960
15) CON02970
570 1FORMAT (1H ,51H THE NUMBER OF TUBES MUST BE GREATER THAN 0, TNOTOT= CON02980
1,F12.5) CON02990
580 1FORMAT (1H ,48H BUNDLE RADIUS MUST BE GREATER THAN ZERO, RADINS=,E1 CON03000
10.3) CON03010
590 1FORMAT (1H ,44H TUBE LENGTH MUST BE GREATER THAN ZERO, ALST=,E10.3) CON03020
600 1FORMAT (1H ,50H TUBE INNER DIAMETER MUST BE GREATER THAN 0, $ID0 =, CON03030
1E10.3) CON03040
610 1FORMAT (1H ,50H TUBE INNER DIAMETER MUST BE GREATER THAN 0, SID0 =, CON03050
1E10.3) CON03060
620 1FORMAT (1H ,40H TUBE PITCH MUST BE GREATER THAN 1, SDD0=,E10.3) CON03070
630 1FORMAT (1H ,40H TUBE PITCH MUST BE GREATER THAN 1, SDD1=,E10.3) CON03080
640 1FORMAT (1H ,75H RATIO OF TUBE THICKNESS TO TUBE INNER DIAMETER MUST CON03090
1 BE GREATER THAN 0, XW1=,E10.3) CON03100
650 1FORMAT (1H ,49H TUBE THICKNESS MUST BE GREATER THAN 0, XW2=,E10.3) CON03110
660 1FORMAT (1H ,93H RATIO OF N/C GASSES TO STM FLOW MUST BE LESS THAN 0 CON03120
1NE AND GREATER THAN EQUAL TO ZERO, WNCIR=,E10.3) CON03130
670 1FORMAT (1H ,63H INJECTION TEMP MUST BE GREATER THAN 52 AND LESS THA CON03140
1N 212, STBI=,E10.3) CON03150
680 1FORMAT (1H ,58H INJECTION TEMP MUST BE LESS THAN EXHAUST TRUNK TEMP CON03160
1, STBI=,E10.3,8H STSAT=,E10.3) CON03170
690 1FORMAT (1H ,31H FLOW MUST BE 1, 2 OR 3. IFLOW=,15) CON03180
700 1FORMAT (1H ,73H NUMBER OF INTERNAL ENHANCEMENT REGIONS MUST BE BETW CON03190
1EEN ZERO AND SIX, NEI=,15) CON03200
710 1FORMAT (1H ,73H NUMBER OF EXTERNAL ENHANCEMENT REGIONS MUST BE BETW CON03210
1EEN ZERO AND SIX, NEE=,15) CON03220
720 1FORMAT (1H ,50H IBAF MUST BE BETWEEN -1 AND ISEC INCLUSIVE. IBAF=, CON03230
15,7H ISEC=,15) CON03240
730 1FORMAT (1H ,40H (IF USER WANTS IBAF=ISEC+1, SET IBAF=-1)) CON03250
END CON03260
C ***** CON03270
C ***** CON03280
C ***** CON03290
C ***** CON03300
C ***** CON03310
C ***** CON03320
C ***** CON03330
C ***** CON03340
C ***** CON03350
C ***** CON03360
SUBROUTINE OUT1
C-----
C OUT1 1
C
C ZZZ OUT1-1
C SEE INP-2 FOR VARIABLE DEFINITIONS

```



```

C-----
COMMON /GLOBCCM/ ALST, DELWLP, DELWPC, EXITQA, GFLOW, SIDI, SIDD, PHP, RSPA,
1R, REMWO, SDDI, SDDO, SLDI, SLDL, VELBI, XW1, XW2, VOL1, VOL2, TNOTD
2T, BNDRAD, ARATIO, ODOI, SDDC, VLCMAX, PRCCCLR
COMMON /INPT/ BC(6), BE(6), ENH(6), ENI(6), ENO(6), FOU, PHI, SKW, STBI, S
1TSATI, TUBESW, NNCIR, IOPT, PTST(15), SECWID, IBAF, ISEC, JBAF(16), JGAS, MD
2IAM, MPITCH, NEE, NETI(6), NETI(6), NRNE(6), NRNI(6), NOROWS, WTST(15)
3, WSY, PFI, IFLOW, IWALL
WR ITE (6,60)
WR ITE (6,70)
WR ITE (6,80)
WR ITE (6,90)
WR ITE (6,100)
WR ITE (6,90)
WR ITE (6,80)
WR ITE (6,110)
WR ITE (6,120)
WR ITE (6,130)
WR ITE (6,140)
WR ITE (6,150)
WR ITE (6,150)
IF (IOPT.EQ.2) GO TO 10
IF (IIE (6,160) NOROWS
WR ITE (6,180) RADIS
WR ITE (6,190) ALST
WR ITE (6,200) MDIAM
IF (MDIAM.EQ.0) GO TO 20
WR IIE (6,210) SIDD
WR IIE (6,240)
GO TO 30
WR IIE (6,220) SIDD, SIDI
WR IIE (6,230) MPITCH
IF (MPITCH.EQ.0) GO TO 40
WR IIE (6,260) SDDO
WR IIE (6,280)
GO TO 50
WR IIE (6,270) SDDO, SDDI
WR IIE (6,250) IWALL
IF (IWALL.EQ.1) WRITE (6,300) XW1
IF (IWALL.EQ.2) WRITE (6,290) XW2
WR IIE (6,310) TUBESW
WR IIE (6,320) SKW
WR IIE (6,330) FGUL
IF (JGAS.EQ.1) WRITE (6,360)
IF (JGAS.EQ.2) WRITE (6,370)
IF (JGAS.EQ.3) WRITE (6,380)
WR IIE (6,340) WSI
CONO3370
CONO3380
CONO3390
CONO3400
CONO3410
CONO3420
CONO3430
CONO3440
CONO3450
CONO3460
CONO3470
CONO3480
CONO3490
CONO3500
CONO3510
CONO3520
CONO3530
CONO3540
CONO3550
CONO3560
CONO3570
CONO3580
CONO3590
CONO3600
CONO3610
CONO3620
CONO3630
CONO3640
CONO3650
CONO3660
CONO3670
CONO3680
CONO3690
CONO3700
CONO3710
CONO3720
CONO3730
CONO3740
CONO3750
CONO3760
CONO3770
CONO3780
CONO3790
CONO3800
CONO3810
CONO3820
CONO3830
CONO3840

```



```

WRITE (6,350) WNCIR
WRITE (6,390) STBI
WRITE (6,400) STSATI
WRITE (6,410) IFLOW
IF (IFLOW.EQ.3) WRITE (6,420) GFLOW
IF (IFLOW.EQ.2) WRITE (6,430) VELBI
IF (IFLOW.EQ.1) WRITE (6,440) DELWP
WRITE (6,450) NEI
WRITE (6,460) NEE
WRITE (6,470) IBAF
RETURN
FORMAT (1H,51H
1/62H ALST 3
2/62H DELWP EXITOA GFLOW SIDI 5 SIDO 7
3//62H REMI 21 SDDI 13 SDDO 14 SLDI 15 SLDQ 16
4//61H RADINS 20 SDDI 22 SDDO 23 SLDI 24 SLDQ 25
5//62H XW2 VDL1 VOL2 TNOTOT BNDRAD ARATIO OUII
6//56H T (1H,15X,28H*****
FORMAT (1H,15X,16X,28H*****
FORMAT (1H,15X,16X,1H*,26X,1H*)
FORMAT (1H,15X,16X,28H* CONDIP ENTERING DATA SET *)
1M VERT)
1
FORMAT (1H,15X,53H% OF TOTAL TUBES ASSIGNED TO COOLER IS PRCCLR
1
FORMAT (1H,19HNUMBER OF TUBE ROWS,13X,15)
FORMAT (1H,15X,32HNUMBER OF TUBES IN THE CONDENSOR,8X,F12.5)
FORMAT (1H,15X,20HBUNDLE INSIDE RADIUS,12X,F10.4,16X,4HFEEET)
FORMAT (1H,15X,11HTUBE LENGTH,19X,F10.2,5X,11X,4HFEEET/)
FORMAT (1H,15X,37HFLAG FOR TUBE OD VARIATION IS MDIAM =,12)
FORMAT (1H,15X,20HTUBE INSIDE DIAMETER,9X,F10.4,14X,6HINCHES)
FORMAT (1H,15X,20HTUBE INSIDE DIAMETER/15X,13X,11HOUTSIDE ROW,7X,
1F10.2,6HINCHES/14X,10HINSIDE RADIATION IS MPITCH =,12)
FORMAT (1H,15X,36HFLAG FOR PITCH IS A CONSTANT THRU BUNDLE/)
FORMAT (1H,15X,39HTUBE DIAMETER WALL INPUT UNIT IS Iwall =,12)
FORMAT (1H,15X,40HTUBE CIRCUMFERENTIAL PITCH,4X,F10.2)
FORMAT (1H,15X,26HTUBE CIRCUMFERENTIAL PITCH/15X,13X,11HOUTSIDE R
LOW,7X,1
FORMAT (1H,15X,14X,10HINSIDE ROW,7X,F11.3/)
FORMAT (1H,15X,29HTUBE CIRCUMFERENTIAL PITCH,5,11X,6HINCHES)
FORMAT (1H,15X,19HTUBE THICKNESS,11X,F13.5,11X,6HINCHES)
FORMAT (1H,15X,31HWALL THICKNESS TO TUBE ID RATIO,F10.3)
FORMAT (1H,15X,25HTUBE WALL SPECIFIC WEIGHT,5X,F10.2,9X,8HLB/FT**
13)
CONO 3850
CONO 3860
CONO 3870
CONO 3880
CONO 3890
CONO 3900
CONO 3910
CONO 3920
CONO 3930
CONO 3940
CONO 3950
CONO 3960
CONO 3970
CONO 3980
CONO 3990
CONO 4000
CONO 4010
CONO 4020
CONO 4030
CONO 4040
CONO 4050
CONO 4060
CONO 4070
CONO 4080
CONO 4090
CONO 4100
CONO 4110
CONO 4120
CONO 4130
CONO 4140
CONO 4150
CONO 4160
CONO 4170
CONO 4180
CONO 4190
CONO 4200
CONO 4210
CONO 4220
CONO 4230
CONO 4240
CONO 4250
CONO 4260
CONO 4270
CONO 4280
CONO 4290
CONO 4300
CONO 4310
CONO 4320

```


C ORC 3

ENTERING POINT FOR ICALC = 2

C ZZ ORC-3

CONTINUE

DO 30 I=1, ISEC

WTST(I)=0.

PTST(I)=0.

C ORC 4

BUNDLE GEOMETRY

TUBE PITCH IS DEFINED AS THE RATIO OF TUBE CENTER TO CENTER SPACING TO TUBE OD, MEASURED ALONG A ROW OF CONSTANT BUNDLE RADIUS. ROW RADIAL SEPARATION IS NOT DIRECTLY RELATED TO PITCH.

AOTFLW = AREA OPEN TO STEAM FLOW IN EACH ROW I OF A SECTOR

AHOLES = AREA OF THE ENDS OF THE TUBES

ARATIO = TOTAL AREA OF THE ENDS OF THE TUBES DIVIDED BY THE SHEET AREA THRU WHICH THE TUBES PASS

ARCPR = CIRCUMFERENTIAL ARC LENGTH OF EACH SECTOR PER UNIT RADIUS OF THE ROW BEING CONSIDERED

ALST = TUBE LENGTH FT

BNDRAD = TUBE BUNDLE RADIUS - FT

CSP = TUBE CNTR - CNTR SPACING AT A GIVEN ROW

CSP I = CSP FOR INNER ROW

CSP O = CSP FOR OUTER ROW

DELDCSP = RADIAL CHANGE IN CSP PER ROW FT

DELWID = CHANGE IN TUBE OD / CONDENSER MINUS ONE SECTOR DEG

FCWID = ANGULAR WIDTH OF CONDENSER

ISEC = NUMBER OF SECTORS IN THE SECTOR

NOROWS = NO. OF ROWS IN EACH SECTOR

OD = TUBE OD ON A GIVEN ROW FT

OD OI = TUBE OD, OUTER ROW - IN

OD IF = TUBE OD, INNER ROW - FT

OD OF = TUBE OD, OUTER ROW - FT

PRCCLR = PERCENT OF TOTAL TUBES ASSIGNED TO COOLER

RAD = RADIUS OF A GIVEN ROW FT

RADINS = BUNDLE INSIDE RADIUS - FT

RADIUS = RADIUS OF ROW I FT

RCORR = A CORRECTION FACTOR INTRODUCED TO SMOOTH THE STEP DIFF

ROWS = A CORRECTION FACTOR INTRODUCED TO SMOOTH THE STEP DIFF

RSPA = NO OF ROWS IN CONDENSER

RSPA = TUBE ROW RADIAL SEPARATION, IN

CNO5290
CNO5300
CNO5310
CNO5320
CNO5330
CNO5340
CNO5350
CNO5360
CNO5370
CNO5380
CNO5390
CNO5400
CNO5410
CNO5420
CNO5430
CNO5440
CNO5450
CNO5460
CNO5470
CNO5480
CNO5490
CNO5500
CNO5510
CNO5520
CNO5530
CNO5540
CNO5550
CNO5560
CNO5570
CNO5580
CNO5590
CNO5600
CNO5610
CNO5620
CNO5630
CNO5640
CNO5650
CNO5660
CNO5670
CNO5680
CNO5690
CNO5700
CNO5710
CNO5720
CNO5730
CNO5740
CNO5750
CNO5760


```

C      RSPF = TUBE ROW RADIAL SEPARATION, FT
C      SDDI = TUBE PITCH ON INSIDE ROW
C      SDDO = TUBE PITCH ON OUTSIDE ROW
C      SECA = TEMP VALUE FOR SECANG DEG
C      SECANG = ANGLE FROM THE VERTICAL PASSING THROUGH EACH SECTOR
C      SECFLG = THE NUMBER OF SECTORS IN THE CONDENSER
C      SECWID = SECTOR WIDTH IN DEGREES OF ARC
C      SIDI = TUBE ID FOR EACH ROW - FT
C      SIDI1 = TUBE ID FOR INNER ROW IN FEET
C      SIDI2 = TUBE ID FOR INNER ROW IN INCHES
C      SIDI3 = TUBE ID FOR OUTER ROW IN FEET
C      SIDI4 = TUBE ID FOR OUTER ROW IN INCHES
C      SIDOF = LINEAR VARIATION OF TUBE INNER DIAMETER
C      DELSCF = NO. OF TUBES IN ROW I OF EACH SECTOR
C      TBNPR = NO. OF TUBES IN CONDENSER + COOLER
C      TNO1 = TOTAL NO. OF TUBES IN CONDENSER MODEL
C      TNO2 = TOTAL NUMBER OF TUBES
C      TNR = NUMBER OF TUBES IN A ROW OF A SECTCR
C      TPARE = TUBE DENSITY /UNIT AREA FOR EACH ROW TUBES/FT**2
C      TSAREA = TUBE SHEET AREA
C      VOL1 = CONDENSOR VOLUME
C      VOL2 = STORED CONDENSER VOLUME
C      VOL1C = VOLUME ACTUALLY OCCUPIED BY THE CONDENSOR TUBE BUNDLE
C      XW1 = RATIO OF TUBE WALL THICKNESS TO TUBE OD
C      XW2 = TUBE WALL THICKNESS INCHES
C
C      NOTE: ADD CALC FOR SID
C
C      NOTE: RADIAL ROW SEPARATION IS CALCULATED
C      AS THE AVERAGE OF CSPI AND CSPO UNLESS
C      RSPA HAS A NON-ZERO VALUE FOR INPUT.
C
C      VALUES CARRIED INTO THIS ROUTINE
C      COMMON/NEW/ - , SECWID , NOROWS , RADINS , SDDO , SDDI ,
C      COMMCN/NEW/ - , ODI1 , ODI2 , RSP , ISEC ,
C
C      ZZZ ORC-4
C-----
C      IF (MDIAM.EQ.1) SIDI=SIDO
C      IF (MPITCH.EQ.1) SDDI=SDDO
C      AR CPR=6.283/360.*SECWID
C      TNOS=0.0
C      SECFLG=FLOAT(ISEC)
C
C      IF (IOPT.EQ.2) GO TO 50
C
C      COMPUTATION OF GEOMETRY WHEN IOPT = 1
C      NOROWS IS A CONSTANT

```

```

CON05770
CON05780
CON05790
CON05800
CON05810
CON05820
CON05830
CON05840
CON05850
CON05860
CON05870
CON05880
CON05890
CON05900
CON05910
CON05920
CON05930
CON05940
CON05950
CON05960
CON05970
CON05980
CON05990
CON06000
CON06010
CON06020
CON06030
CON06040
CON06050
CON06060
CON06070
CON06080
CON06090
CON06100
CON06110
CON06120
CON06130
CON06140
CON06150
CON06160
CON06170
CON06180
CON06190
CON06200
CON06210
CON06220
CON06230
CON06240

```


CON06250
 CON06260
 CON06270
 CON06280
 CON06290
 CON06300
 CON06310
 CON06320
 CON06330
 CON06340
 CON06350
 CON06360
 CON06370
 CON06380
 CON06390
 CON06400
 CON06410
 CON06420
 CON06430
 CON06440
 CON06450
 CON06460
 CON06470
 CON06480
 CON06490
 CON06500
 CON06510
 CON06520
 CON06530
 CON06540
 CON06550
 CON06560
 CON06570
 CON06580
 CON06590
 CON06600
 CON06610
 CON06620
 CON06630
 CON06640
 CON06650
 CON06660
 CON06670
 CON06680
 CON06690
 CON06700
 CON06710
 CON06720

```

AH OLES=0.
ROWS=FLOAT(NROWS)
SIDOF=SIDO/12.
SIDIF=SIDI/12.
DELSDF=(SIDOF-SIDIF)/(ROWS-1.)
IF (XW2.GT.0) ODOF=SIDOF+XW2/6.
IF (XW2.LE.0) ODOF=SIDOF+(2*SIDOF*XW1)
IF (XW2.LE.0) ODOF=SIDIF+(2*SIDIF*XW1)
ODOI=ODOCF*12.
ODOI=ODOI*(ODOF-ODOI)/(ROWS-1.)
DELODF=DELODF*12.
CSPO=SDCO*ODOF
CSPI=SDCI*ODOI
DELCSP=(CSPO-CSPI)/(ROWS-1.)
RSPF=.866*(CSPO+CSPI)/2.
RSP=RSPF*12.
IF (RSPA.NE.0.) RSP=RSPA
BNDRAD=RADINS+RSPF*(ROWS-1.)
DO 40 I=1,NROWS
RAD=BNDRAD-RSPF*FLOAT(I-1)
CSP=CSPC-DELCSP*FLOAT(I-1)
TPAR(I)=1./(CSP*RSPF)
TNR=ARCPR*RAD/CSP
OD=ODOF-DELODF*FLOAT(I-1)
SID(I)=SIDOF-DELSDF*FLOAT(I-1)
ADFLW(I)=(CSP-OD)*TNR
ADTFLW(I)=ADFLW(I)*ALST
TNOS=TNOS+TNR
RADIUS(I)=RAD
AH OLES=AH OLES+PI*(ODOF**2)*TNR/4.
TBNPR(I)=TNR
TN0=TNOS*SECF LG
AH OLES=AH OLES#SECF LG
TN0TOT=TN0*100./(100.-PRCCLR)
GO TO 100

```

CONTINUE
 COMPUTATION OF BUNDLE GEOMETRY IF IOPT = 2
 SIDI=SIDO
 SDDI=SDDO
 ERR1=0.

C 40 C 50 C C C C C

CON06730
 CON06740
 CON06750
 CON06760
 CON06770
 CON06780
 CON06790
 CON06800
 CON06810
 CON06820
 CON06830
 CON06840
 CON06850
 CON06860
 CON06870
 CON06880
 CON06890
 CON06900
 CON06910
 CON06920
 CON06930
 CON06940
 CON06950
 CON06960
 CON06970
 CON06980
 CON06990
 CON07000
 CON07010
 CON07020
 CON07030
 CON07040
 CON07050
 CON07060
 CON07070
 CON07080
 CON07090
 CON07100
 CON07110
 CON07120
 CON07130
 CON07140
 CON07150
 CON07160
 CON07170
 CON07180
 CON07190
 CON07200

```

TNO C=0.
TNOS=0.
TNR=0.
TDIFF=0.
SIDIF=SIDO/12.
SIDIF=SIDI/12.
IF (XW2.GT.0) ODOF=SIDOF+XW2/6.
IF (XW2.GT.0) ODI=SIDIF+XW2/6.
IF (XW2.LE.0) ODOF=SIDOF+(2*SIDOF*XW1)
IF (XW2.LE.0) ODI=SIDIF+(2*SIDIF*XW1)
ODOI=ODOF*12.
ODII=ODI*12.
DELODF=0.
CSPD=CELODF
CSPQ=SDDO*ODOF
CSPI=SDDI*ODIF
DELCSP=0.
RSPF=.866*(CSPD+CSPI)/2.
RSP=RSPF*12.
IF (RSPA.NE.0.) RSP=RSPA
RSPF=RSP/12.

      DETERMINE THE NUMBER OF TUBES IN THE CONDENSOR
      ALL SECTORS ARE IDENTICAL IN GEOMETRY
      BEGINNING WITH THE INNERMOST ROW, CALCULATE THE NUMBER
      OF RCWS IN THE CONDENSOR

I=1
NROWS=1
TNO=TNO+TOT*(100.-PRCCLR)/100.
RADIUS(I)=RADINS
SID(I)=SIDOF
TNR=(ARCPR#RADIUS(I))/CSPD
TNOS=TNOS+TNR

      CHECK TO ENSURE THAT THE NUMBER OF TUBES IN THE SECTOR
      HAS NOT EXCEEDED THE NUMBER OF TUBES AVAILABLE

IF (TNOS.LT.(TNO/SECFLG)) GO TO 70
TNOS=TNOS-TNR
TNO C=TNOS*SECF LG
TDIFF=TNO-TNOC
TBNPR(I)=TDIFF/SECFLG
PFILL=TBNPR(I)/TNR
GO TO 80

TPAR(I)=1./(CSPD*RSPF)

```

C C C C C C 60 C C C C 70

CON07690
 CON07700
 CON07710
 CON07720
 CON07730
 CON07740
 CON07750
 CON07760
 CON07770
 CON07780
 CON07790
 CON07800
 CON07810
 CON07820
 CON07830
 CON07840
 CON07850
 CON07860
 CON07870
 CON07880
 CON07890
 CON07900
 CON07910
 CON07920
 CON07930
 CON07940
 CON07950
 CON07960
 CON07970
 CON07980
 CON07990
 CON08000
 CON08010
 CON08020
 CON08030
 CON08040
 CON08050
 CON08060
 CON08070
 CON08080
 CON08090
 CON08100
 CON08110
 CON08120
 CON08130
 CON08140
 CON08150
 CON08160

```

IF (ISEC.EQ.1) GO TO 110
FCWID=SECWID*(SECFG-1.)
DO 110 I=1,ISEC
SECA=(PHI-FCWID/2.)+SECWID*(I-1)
IF (SECA.GT.360.) SECA=SECA-360.
SECANG(I)=SECA
110 C
DUMMY=ALST*PI*SECWID*SECFLG/360.
BNDRA1=BNDRAD
VOL1=DUMMY*BNDRA1**2
VOL1C=VCL1
C
IF TNOTOT IS A DESIGN VARIABLE THEN THE INCREASE OF VOLUME AND
C OUTSIDE BUNDLE RADIUS MUST BE A GRADUAL PROCESS AND NOT A STEP
C INCREASE OR DECREASE
C
IF (IOPT.EQ.1) GO TO 120
RCORR=RSPF
RCORR=RCORR*((1.-PFILL))
BNDRAD=BNDRAD-RCORR
VOL1=DUMMY*BNDRAD**2
VOL1C=VCL1
C
VOL2=DUMMY*(BNDRAD**2-RADINS**2)
120 C
C COMPUTE THE AREA RATIO WHICH IS THE AREA OF TUBE HOLES DIVIDED
C BY THE TUBE SHEET AREA
C
TSAREA=PI*(BNDRAD**2)*SECFLG*SECWID/360.
ARATIO=AHLES/TSAREA
C$-----
C ORC A4
C
C TEMP OUTPUT SECTION
C
C THIS SECTION FOR DEBUGGING AID
C
C ZZZ ORC-A4
C-----
ORCA4=0.
IF (ORCA4.NE.1.) GO TO 150
WR ITE (6,650)
WR ITE (6,660)
WR ITE (6,700)
WR ITE (6,670)
WR ITE (6,700)
WR ITE (6,680)
WR ITE (6,700)
RSPF,RSP,TNOS

```



```

190 IT=JBAF(I)
    BAFA(I)=PHI I-FCWI+SECI*FLOAT(IT-1)
    GO TO 210
200 BAFA(I)=PHI I-FCWI
    BAFA(2)=PHI I+FCWI
    IBAFT=2
    JBAF(1)=1
    JBAF(2)=ISEC+1
    CONTINUE
210 -----
C$ ORC A5
C ORC A5
C ZZZ ORC-A5
C -----
    ORCA5=0
    IF (ORCA5.NE.1) GO TO 240
    WR ITE (6,750) IBAF, IBAFT
    WR ITE (6,760) IBAF, IBAFT
    WR ITE (6,770)
    DO 220 I=1, IBAFT
    WR ITE (6,780) I, JBAF(I)
    WR ITE (6,790)
    DO 230 I=1, IBAFT
    X=BAFA(I)*180./PI
    WR ITE (6,800) X, BAFA(I)
    CONTINUE
220 -----
C$ ORC 6
C ORC 6
C ZZZ ORC-6
C -----
    DO 430 IS=1, ISEC
    SECA=SECANG(IS)*PI/180.
    SEC=PI/2.-SECA
    IF ((SECA.GT.0.) .AND. (SECA.LT.PI)) GO TC 270
    DO 250 I=1, IBAFT
    BAFA(I)=BAFA(I)
    IF (BAFAT.GT.SECA) GO TO 260
    CONTINUE
    BAF=PI/2.-BAFAT
    IF ((BAFAT.GT.0.) .AND. (SECA.LT.0.)) BAF=PI/2.
    GO TO 300
250 DO 280 I=1, IBAFT
260 J= IBAFT+1-I
    BAFA(I)=BAFA(J)
    IF (BAFAT.LT.SECA) GO TO 290
    CONTINUE
270
280

```

LOCATE ACTIVE BAFFLE FOR EACH SECTOR

CON08650
 CON08660
 CON08670
 CON08680
 CON08690
 CON08700
 CON08710
 CON08720
 CON08730
 CON08740
 CON08750
 CON08760
 CON08770
 CON08780
 CON08790
 CON08800
 CON08810
 CON08820
 CON08830
 CON08840
 CON08850
 CON08860
 CON08870
 CON08880
 CON08890
 CON08900
 CON08910
 CON08920
 CON08930
 CON08940
 CON08950
 CON08960
 CON08970
 CON08980
 CON08990
 CON09000
 CON09010
 CON09020
 CON09030
 CON09040
 CON09050
 CON09060
 CON09070
 CON09080
 CON09090
 CON09100
 CON09110
 CON09120


```

BAF=PI/2.
GO TO 300
BAF=PI/2.-BAFAT
CONTINUE
IF (BAFAT.LT.0.) BAF=PI/2.
C$-----
C  ORC A6
C  TEMP OUTPUT SECTION
C  ZZZ ORC-A6
C-----
ORCA6=C.
IF (ORCA6.NE.1.) GO TO 310
WRITE (6,810)
WRITE (6,820)
X=SEC*180./PI
WRITE (6,830)
X=BAF*180./PI
WRITE (6,840) X,BAF
CONTINUE
310-----
C  ORC 7

```

CALCULATE FLOODING FACTORS

```

AN = SUMMING REGISTER FOR NO. OF TUBES
NT = NO. OF TUBES OVER THE TARGET TUBE
BAF = ANGLE ABOUT HORIZONTAL OF 1ST BAFFLE ABOVE CURRENT SECTOR
DELODF = SECT ORC-4
D1 = FARTHEST DIST FROM HORIZONTAL TO CURRENT ROW INTERSECTION
D2 = SHORTEST DIST FROM HORIZONTAL TO CURRENT ROW INTERSECTION
IR = ROW NO. OF CURRENT TARGET TUBE
IS = SECTOR NO. OF CURRENT TARGET TUBE
ITR = ROW NO. FOR 1ST ROW TO BE SUMMED IN UPPER QUADRANT
I1 = ROW WHOSE CONTRIBUTION TO ANT IS BEING CALCULATED
I2 = ROW COUNTER IN UPPER QUADRANT CALCULATION
NROWS = NO. OF ROWS IN THE CONDENSER - FT
OD = TUBE OD IN ROW BEING CONSIDERED
ODOF = TUBE DIAMETER IN OUTER ROW
RADIUS = RADIAL SEPARATION - FT
RSPF = RADIUS OF UPPER OR LOWER BOUNDARY OF ROW I1
SEC = ANGLE FROM HORIZONTAL OF CURRENT SECTOR MIDPOINT
SECA = ANGLE FROM HORIZONTAL BAFFLES
TEST = TEST FOR VERTICAL UNIT AREA TUBE FROM COND CENTER
TPAR = TUBE DENSITY PER CURRENT TUBE FROM COND CENTER
XC = HORIZONTAL DIST. OR CURRENT TUBE FROM COND CNTR - FT
XCS = XC SQUARED
YC = VERTICAL (+/-) DIST OF CURRENT TUBE FROM COND CNTR - FT

```

CON09130
CON09140
CON09150
CON09160
CON09170
CON09180
CON09190
CON09200
CON09210
CON09220
CON09230
CON09240
CON09250
CON09260
CON09270
CON09280
CON09290
CON09300
CON09310
CON09320
CON09330
CON09340
CON09350
CON09360
CON09370
CON09380
CON09390
CON09400
CON09410
CON09420
CON09430
CON09440
CON09450
CON09460
CON09470
CON09480
CON09490
CON09500
CON09510
CON09520
CON09530
CON09540
CON09550
CON09560
CON09570
CON09580
CON09590
CON09600

ZT = VERT DIST FROM TARGET TUBE TO BAFFLE INTERSECTION

FT

```

C      ZZZ ORC-7
C-----
C      ORCA7=0
C      IF (ORCA7.EQ.1.) WRITE (6,860)
C      DO 420 IR=1,NOROWS
C      IF (IS.EQ.1) AND (IR.GE.20) ORCA7 = 1.
C      ITR=IR
C      AN=0.
C      OD=ODF-DELODF*FLOAT(IR-1)
C      R1=RADIUS(IR)
C      YC=R1*SIN(SEC)
C      XC=R1*CCS(SEC)
C      XS=XC*XC
C      TEST=ABS(ABS(BAF)-PI/2.)
C      X=OD*12.
C      IF (ORCA7.EQ.1.) WRITE (6,870) IR,IS
C      IF (ORCA7.EQ.1.) WRITE (6,880) X,R1,YC,XC,TEST
C      IF (TEST.GT.1E-2) GO TO 320
C      ZT=1E10
C      GO TO 330
C      ZT=XC*TAN(BAF)
C      XC=ABS(XC)
C      IF (YC.GT.0.) GO TO 370
C      IF (ORCA7.EQ.1.) WRITE (6,890) ZT
C      D1=YC
C      DO 340 I1=IR,NOROWS
C      R1=RADIUS(I1)-RSPF/2.
C      IF (R1.LE.XC) GO TO 350
C      D2=-1.*SQRT(R1*R1-XC*XC)
C      IF (ORCA7.EQ.1.) WRITE (6,900) I1,R1,D2
C      IF (D2.GT.ZT) GO TO 360
C      IF (ORCA7.EQ.1.) WRITE (6,910)
C      AN=AN+(D2-D1)/(RSPF*2.)
C      IF (ORCA7.EQ.1.) WRITE (6,920) D1,D2,AN
C      D1=D2
C      CONTINUE
C      D2=-D2
C      IF (ORCA7.EQ.1.) WRITE (6,940)
C      IF (D2.GT.ZT) GO TO 410
C      ITR=NORCWS
C      D1=D2
C      IF (ORCA7.EQ.1.) WRITE (6,950)
C      GO TO 380
C      AN=AN-D1/(RSPF*2.)
C      D1=0.
C      ITR=I1

```

320

330

340

350


```

360 IF (ORCA7.EQ.1.) WRITE (6,930) AN, ITR
    GO TO 380
    AN=AN+(ZT-D1)/(RSPF#2.)
    IF (ORCA7.EQ.1.) WRITE (6,960)
    GO TO 410
370 D1=YC
    IF (ORCA7.EQ.1.) WRITE (6,970) D1
380 DO I=1, ITR
    I1=RADIUS(I1)+RSPF/2.
    R1=SQRT(R1#R1-XCS)
    D2=SQRT(R1#R1-XCS)
    IF (ORCA7.EQ.1.) WRITE (6,980) IR, I1, R1
    IF (ORCA7.EQ.1.) WRITE (6,990) D1, D2, ZT
    IF (D2.GT.ZT) GO TO 400
    AN=AN+(D2-D1)/(RSPF#2.)
    IF (ORCA7.EQ.1.) WRITE (6,1000) AN
390 D1=D2
    GO TO 410
400 AN=AN+(ZT-D1)/(RSPF#2.)
    IF (ORCA7.EQ.1.) WRITE (6,1010)
410 NF=AN+1.0
    RNF=NF
    ANT(IR, IS)=RNF
    IF (ORCA7.EQ.1.) WRITE (6,1020) IS, IR, AN
420 CONTINUE
430 CONTINUE
    ORCA7=0.
    IF (ORCA7.NE.1.) GO TO 450
    DO 440 I=1, NROWS
440 WRITE (6,850) I, (ANT(I, J), J=1, ISEC)
450 CONTINUE
C$-----
C ORC 9
C
C PUMPING POWER CALCULATION
ALST = TUBE LENGTH FT
A1 = COEF IN FF CALCULATION
B1 = EXP IN FF CALCULATION
CBI = COOLANT SALT CONCENTRATION IN WT PRCNT LBM/SEC
CMDTOT = COOLANT MASS FLOW/TUBE IN EACH ROW
DELWPT = TOTAL COOLANT MASS FLOW THROUGH CONDENSER LBM/SEC
FF = TUBE HEAD LOSS FACTORS
HEAD = FT**2/SEC**
SID = STORED INNER TUBE DIAMETER
TID = STORED INNER VALUE FOR TUBE INNER DIAMETER
SLD = STORED (LENGTH/TUBE INNER DIAMETER) RATIO
SLDDO = SLD RATIO OF TUBES IN OUTER ROW

```

```

CON10090
CON10100
CON10110
CON10120
CON10130
CON10140
CON10150
CON10160
CON10170
CON10180
CON10190
CON10200
CON10210
CON10220
CON10230
CON10240
CON10250
CON10260
CON10270
CON10280
CON10290
CON10300
CON10310
CON10320
CON10330
CON10340
CON10350
CON10360
CON10370
CON10380
CON10390
CON10400
CON10410
CON10420
CON10430
CON10440
CON10450
CON10460
CON10470
CON10480
CON10490
CON10500
CON10510
CON10520
CON10530
CON10540
CON10550
CON10560

```



```

C          SLDI = SLD RATIO OF TUBES IN INNER ROW
C          SLDI = THE AVERAGE OF SLD0 AND SLDI
C          HLOSS = HEAD LOSS
C          REW = REYNOLDS # OF COOLANT IN THE OUTER ROW
C          REWD = REYNOLDS # OF TUBES IN INNER ROW
C          REWI = REYNOLDS # OF TUBES IN THE OUTER ROW
C          PHP = PUMPING POWER IN HP
C          PHPCCN = PUMPING POWER OF THE CONDENSER BUNDLE ONLY
C          DELWPC = PRESSURE LOSS THRU TUBES IN PSI
C          GFLOW = OVERALL COOLANT FLOW IN LBM/HR
C          RHOW = DENSITY OF COOLANT
C          XMUW = VISCOSITY OF COOLANT
C          VELBI = COOLING WATER VELOCITY IN FT/SEC
C
C          ZZZ ORC-9
C-----
ORCA9=0.
RHOW=RDEFN(CBI,STBI)
XMUW=BMUFN(CBI,STBI)/3600.
XNUW=XMUW/RHOW
CMTOT=0.
IF ((GFLOW.GT.0.) .OR. (VELBI.GT.0.)) GO TO 530
HEAD=2.*DELWP*.144.*SG/RHOW
DO 520 IR=1,NOROWS
IF (ORCA9.EQ.1.) WRITE (6,1030) IR
ITEM=IR-1
IF (ITEM.EQ.0) ITEM=1
VG=VW(ITEM)
IF (ORCA9.EQ.1.) WRITE (6,1040) IR,ITEM,VG
IENHAN=0
IF (NEI.EQ.0) GO TO 480
DO 460 IT=1,NEI
NRNI1=NRNI(IT)
NRNI2=NRNI1+NEI(IT)-1
IF (IR.GE.NRNI1.AND.IR.LE.NRNI2) GO TO 470
CONTINUE
GO TO 480
IENHAN=1
AL=BC(IT)
BI=BE(IT)
TID=SID(IR)
SLD=ALST/TID
IF (IR.EQ.1) SLD0=SLD
IF (IR.EQ.NOROWS) SLDI=SLD
IF (ORCA9.EQ.1.) WRITE (6,1050) TID,SLD,IR
REW=VG*TID/XNUW
IF (ORCA9.EQ.1.) WRITE (6,1060) REW,TID,XNUW
IF (IENHAN.EQ.1) GO TO 510
CON10570
CON10580
CON10590
CON10600
CON10610
CON10620
CON10630
CON10640
CON10650
CON10660
CON10670
CON10680
CON10690
CON10700
CON10710
CON10720
CON10730
CON10740
CON10750
CON10760
CON10770
CON10780
CON10790
CON10800
CON10810
CON10820
CON10830
CON10840
CON10850
CON10860
CON10870
CON10880
CON10890
CON10900
CON10910
CON10920
CON10930
CON10940
CON10950
CON10960
CON10970
CON10980
CON10990
CON11000
CON11010
CON11020
CON11030
CON11040

```



```

500 IF (REW,GE,51904.4) GO TO 500
    AL=.3164
    BI=-.25
    GO TO 510
500 AL=.184
    BI=-.2
    CONTINUE
    IF (ORCA9.EQ.1.) WRITE (6,1070) A1,B1,REW
    FF=AL*REW*(BI)
    HLOSS=(1.1+FF*SLD)
    IF (ORCA9.EQ.1.) WRITE (6,1080) FF,SLD,HLOSS,HEAD
    VG1=SQRT(HEAD/HLOSS)
    TEST=ABS(VG-VG1)/VG
    IF (ORCA9.EQ.1.) WRITE (6,1090) TEST,VG,VG1
    VG=VG1
    IF (TEST.GT.0.01) GO TO 490
    IF (IR.EQ.1) REMO=REW
    IF (IR.EQ.NOROWS) REWI=REW
    CMDOT(IR)=PI*TIID**2*VG*RHOW/4.
    VW(IR)=VG
    CMTOT=SECFG*CMDOT(IR)*TBNPR(IR)+CMTOT
    PHPCON=PHP
    DELWPC=DELWP
    GO TO 600
530 A=0.540 IR=1,NROWS
    TID=SID(IR)
    IF (IR.EQ.1) SLD0=ALST/TID
    IF (IR.EQ.NOROWS) SLDI=ALST/TID
    A=A+TID*PI*TBNPR(IR)/4.
    TID=(SLD0+SLDI)/2.
    IF (GFLCW.LE.0.) GO TO 550
    VX=GFLCW/((RHOW*A*SECFG)*3600.)
    CMTOT=GFLOW/3600.
    GO TO 560
    CMTOT=VELBI*RHOW*A*SECFG
    VX=VELBI
    REW=VX*TIID/XNJW
    IF (REW.GT.51904.4) GO TO 570
    FF=.3164*REW*(-.25)
    GO TO 580
    FF=.184*REW*(-.2)
    DELWPC=(1.1+FF*SLD)
    DO 590 IR=1,NROWS
    CMDOT(IR)=PI*SID(IR)**2*VX*RHOW/4.
    VW(IR)=VX

```

```

CON11050
CON11060
CON11070
CON11080
CON11090
CON11100
CON11110
CON11120
CON11130
CON11140
CON11150
CON11160
CON11180
CON11190
CON11200
CON11210
CON11220
CON11230
CON11240
CON11250
CON11260
CON11270
CON11280
CON11290
CON11300
CON11310
CON11320
CON11330
CON11340
CON11350
CON11360
CON11370
CON11380
CON11390
CON11400
CON11410
CON11420
CON11430
CON11440
CON11450
CON11460
CON11470
CON11480
CON11490
CON11500
CON11510
CON11520

```



```

RE WO=VX*SID(I)/XNUW
RE WI=VX*SID(NROWS)/XNUW
HEAD=2.*DELWPC*144.*SG/RHOW
PHP=CM*CT*DELWPC*144./(RHOW*550.)
PHPCON=PHP
DELWP=DELWPC
CONTINUE
HFG=HFGFN(STSAT1)
STBZES=(WSI*HFG)/(CPB*CMT*3600.)*STBI
C$-----
C  UR C A9
C  ZZ ORC-A9
C  -----
ORCA9=0.
IF (ORCA9.NE.1.) GO TO 630
WR ITE (6,1100) RHOW
WR ITE (6,1110) XMUW
WR ITE (6,1120) XNUW
WR ITE (6,1130) HEAD
WR ITE (6,1140) REW.FF
WR ITE (6,1150) DELWP
WR ITE (6,1160) SLDI,SLDO
WR ITE (6,1170) REWI,REWO
WR ITE (6,1180) CMTO
WR ITE (6,1190) PHP
WR ITE (6,1200) PHP
WR ITE (6,1210)
DO 610 I=1,NROWS
WR ITE (6,1220) I,VW(I)
610
DO 620 I=1,NROWS
WR ITE (6,1220) I,CMDOT(I)
620
630 CONTINUE
C$-----
C  UR C 10
C  ZZ ORC-10
C  -----
CALL SECALC (ARCPR,DELODF,ODIF,ODOOF)
RETURN
FORMAT (1H,46HTHE NUMBER OF ROWS EXCEEDS THE MAXIMUM ALLOWED)
640
FORMAT (1H,24HOUTPUT SECTION FOR ORC-4)
650
FORMAT (1H,10HDODF
,10HCELODF
,10HDELCS
,10HDELCS
,10HSP
,10HSP
,10HSAREA
,10HARATIO
,10HTBNPR
,10HTPAR
)
660
670
680
690
700
710

```



```

720 1) FORMAT (1H0,10HSEANG )
730 1) FORMAT (1H ,4F10.6)
740 1) FORMAT (1H ,4F10.5)
750 1) FORMAT (1H1,24HOUTPUT FOR SECTION ORC-5)
760 1) FORMAT (1H0,7HIBAF = ,I4,5X,8HIBAF = ,I4)
770 1) FORMAT (1H0,22HFOR I = : JBAF(I) = )
780 1) FORMAT (1H ,3X, I4, 8X, I4)
790 1) FORMAT (1H0,36HBAF FLE ANGLES IN DEGREES AND RADIAN)
800 1) FORMAT (1H ,3X, F6.1,3X, F6.4)
810 1) FORMAT (1H1,24HOUTPUT FOR SECTION ORC-6)
820 1) FORMAT (1H0,50HANGLES ARE MEASURED CNTR-CLCK WISE FKOM HORIZONTAL)
830 1) FORMAT (1H0,16HCURRENT SECTOR = ,I3,16H ANGLE IN DEG = ,F6.1,21H AN
1) NGLE IN RADIAN = ,F6.4)
840 1) FORMAT (1H0,32HANGLE OF ACTIVE BAFFLE IN DEG. = ,F6.1,14H IN RADIA
1) NS = ,F6.4)
850 1) FORMAT (1H ,13, 2X, 6(F5.2,2X))
860 1) FORMAT (1H0,28H*** OUTPUT FOR ORC-7 *** )
870 1) FORMAT (1H0,5HROW = ,I4,11H SECTOR = ,I4)
880 1) FORMAT (1H ,4HOD = ,F6.4,10H RADIUS = ,F6.2,6H YC = ,F6.2,6H XC = ,
1) F6.2,8H TEST = ,E10.3)
890 1) FORMAT (1H0,36HTARGET TUBE IN LOWER QUADRANT, ZT = ,F20.4)
900 1) FORMAT (1H ,15HHLWR QUAD - ROW = ,I3,5H RI = ,F7.3,5H D2 = ,F7.3)
910 1) FORMAT (1H ,18HBAF FLE WAS NOT HIT)
920 1) FORMAT (1H ,15HSTILL LWR - D1 = ,F7.3,5H D2 = ,F7.3,5H AN = ,F6.2)
930 1) FORMAT (1H ,34H PASSING INTO UPPER QUADRANT - AN = ,F6.2,15H CURREN
1) T ROW = ,I4)
940 1) FORMAT (1H ,30HMOVING THRU VOID TO UPPER QUAD)
950 1) FORMAT (1H ,22HBAF FLE NOT HIT IN VOID)
960 1) FORMAT (1H ,28HBAF FLE HIT IN LOWER QUADRANT)
970 1) FORMAT (1H ,35HTARGET TUBE IS IN UPPER QUAD - D1 = ,F8.4)
980 1) FORMAT (1H ,37HCALCULATING IN UPPER QUAD - TRGET RW = ,I4,12H CALC
1) ROW = ,I4,11H CORR RAD = ,F8.4)
990 1) FORMAT (1H ,4HD1 = ,F6.3,6H D2 = ,F6.3,6H ZI = ,E10.3)
1000 1) FORMAT (1H ,34HUPPER QUAD - BAFFLE NOT HIT - AN = ,F6.2)
1010 1) FORMAT (1H ,23HUPPER QUAD - BAFFLE HIT)
1020 1) FORMAT (1H0,26H** FINAL FOR TARGET ** IS = ,I4,4H IR = ,I4,5H ANT = ,F8.
1)
1030 1) FORMAT (1H ,16HAT DO LOOP - IR = ,I4)
1040 1) FORMAT (1H ,9HTEMP IR = ,I4,7H ITEM = ,I4,5H VG = ,E10.3)
1050 1) FORMAT (1H ,16HABOVE 380 - TID = ,E10.3,6H SLD = ,E10.3,5H IR = ,I4)
1060 1) FORMAT (1H ,16HBELOW 380 - REW = ,E10.3,6H TID = ,E10.3,7H XNUM = ,E10
1)
1070 1) FORMAT (1H ,12HAT 400 - A1 = ,E10.3,5H B1 = ,E10.3,6H REW = ,E10.3)
1080 1) FORMAT (1H ,3HFF = ,E10.3,5H SLD = ,E10.3,7H HLCSS = ,E10.3,6H HEAD = ,E10
1)
1090 1) FORMAT (1H ,5HTEST = ,E10.3,5H VG = ,E10.3,6H VG1 = ,E10.3)
1100 1) FORMAT (1H1,16HOUTPUT FOR ORC-9)

```

```

CON12010
CON12020
CON12030
CON12040
CON12050
CON12060
CON12070
CON12080
CON12090
CON12100
CON12110
CON12120
CON12130
CON12140
CON12150
CON12160
CON12170
CON12180
CON12190
CON12200
CON12210
CON12220
CON12230
CON12240
CON12250
CON12260
CON12270
CON12280
CON12290
CON12300
CON12310
CON12320
CON12330
CON12340
CON12350
CON12360
CON12370
CON12380
CON12390
CON12400
CON12410
CON12420
CON12430
CON12440
CON12450
CON12460
CON12470
CON12480

```



```

1110 FORMAT (1H0,8H RHC = ,E10.3,10H LBM/FT**3)
1120 FORMAT (1H ,8H MU = ,E10.3,11H LBM/SEC-FT)
1130 FORMAT (1H ,8H NU = ,E10.3,10H FT**2/SEC)
1140 FORMAT (1H ,8H HEAD = ,E10.3,13H FT**2/SEC**2)
1150 FORMAT (1H ,8H REW = ,E10.3,3X,6HFF = ,E10.3)
1160 FORMAT (1H ,8H DELWP = ,E10.3,4H PSI)
1170 10UITSIDE ROW = ,F6.2)
1180 1=,E10.3)
1190 FORMAT (1H ,24HCOOLANT MASS FLOW RATE = ,F15.3,8H LBM/SEC)
1200 FORMAT (1H ,24HPUMPING POWER REQUIRED = ,F10.2,3H HP)
1210 FORMAT (1H ,37HCOOLANT VELOCITY IN EACH ROW - FT/SEC)
1220 FORMAT (1H ,14,3X, F10.3)
END
C *****
C *****
C *****
C-----
SUBROUTINE SECALC (ARCPR,DELODF,ODIF,ODCF)
C-----
C SEC 1
C-----
SUBROUTINE SECALC
C-----
SUBROUTINES CALLED BY SECALC
HETTRN
C-----
FUNCTION ROUTINES CALLED BY SECALC
, TSATFN , VGFN , HFGFN , CPAFN ,
C-----
ZZZ SEC-1
C-----
COMMON /GLOBCM / ALST, DELWP, DELWPC, EXITOA, GFLOW, SIDI, SIDO, PHP, RSPA,
1RADINS, REWI, REWO, SDOI, SDOO, SLDI, SLOO, VELBI, XW1, XW2, VOL1, VOL2, TNOTU
2T, BNDR, AL, ARATIO, ODOI, SDDC, VLCCMAX, PRCCCLR
COMMON /INPT/ BC(6), BE(6), ENH(6), ENI(6), ENO(6), FOUL, PHI, SKW, STBI, S
1T5ATL, TUBESW, WNCIR, IOPT, PST(15), SECWID, IBAF, ISEC, JBAF(16), JGAS, MDC
2IAM, MPITCH, NEE, NEI, NETE(6), NRNE(6), NRNI(6), NOKOWS, WTST(15)
3, WSI, PFILL
COMMON /ORCL/ AOTFLW(100), SID(100), TBNPR(100), AOLFLW(100), CMDOT(10
10)
COMMON /OUT/ DELOD, SMTBI, SMTB2, SMWB, SUMQ, TNG, VEL2, FR
COMMON /OUTC/ EXITFC, EXITFR, HTCLR, ACC, SUMQC, SDIC, SDDC, UBARW, SMWBC,
1SMTBIC, SMTB2C, VWBAR(100,15), PMIX(100,15), CUMDP(100,15), DELP(15), GFLW(100,15), WTS(100,15), WTS2(100,15), WTS3(100,15), WTS4(100,15), WTS5(100,15), WTS6(100,15), WTS7(100,15), WTS8(100,15), WTS9(100,15), WTS10(100,15), WTS11(100,15), WTS12(100,15), WTS13(100,15), WTS14(100,15), WTS15(100,15)
COMMON /SEC/ ALMTD(100,15), PSAT(100,15), QOA(100,15), RC(100,15), ROU(100,15), VEL(100,15), WGS(100,15), WGS2(100,15), WGS3(100,15), WGS4(100,15), WGS5(100,15), WGS6(100,15), WGS7(100,15), WGS8(100,15), WGS9(100,15), WGS10(100,15), WGS11(100,15), WGS12(100,15), WGS13(100,15), WGS14(100,15), WGS15(100,15)
COMMON /SHI(100,15), SHN(100,15), STSAT(100,15), UN(100,15), VEL(100,15), WGS(100,15), WGS2(100,15), WGS3(100,15), WGS4(100,15), WGS5(100,15), WGS6(100,15), WGS7(100,15), WGS8(100,15), WGS9(100,15), WGS10(100,15), WGS11(100,15), WGS12(100,15), WGS13(100,15), WGS14(100,15), WGS15(100,15)
COMMON /V NRE(100,15), VPSHH(100,15), WCND(100,15), WGS(100,15), WP(15), WPS(100,15), WPS2(100,15), WPS3(100,15), WPS4(100,15), WPS5(100,15), WPS6(100,15), WPS7(100,15), WPS8(100,15), WPS9(100,15), WPS10(100,15), WPS11(100,15), WPS12(100,15), WPS13(100,15), WPS14(100,15), WPS15(100,15)

```



```

4) WSP(15) AMWNC,CBI,CPB,PI,SG,IFIRST
COMMON /CONST/ AMWNC,CBI,CPB,PI,SG,IFIRST
COMMON /COOL1/ VEL C(100),PMIXC(100),PSATC(100),WSEC(100)
1) ALMTDC(100),SHNFC(100),RCC(100),RUTC(100),VNRFC(100),
2) VPSHC(100),HEFFC(100),WCNDC(100),GFLWC(100),QAC(100),
3) SUMDPC(100)
COMMON /COOL/ IVNOC,HNOC,INOC,TSATEX,PMXEXT,AMLSEX,WSEXIT,VELEXT,T
182C,ENHIC,ENHOC,ENHFC,SHWINC,WBC
DIMENSION C(15)

```

```

C$-----
C SEC 2
C-----
C INITIALIZE : OLD ORC 8,9
C PART - 1
C

```

```

ALST = TUBE LENGTH FT
AMOLNC = TOTAL MOLES OF N/C GAS ENTERING CONDENSER
AMOLSS = MOLES OF STM ENTERING COND
AMOLST = SUM OF MOLES OF STM AND N/C ENTERING COND
AMWNC = MOLECULAR WEIGHT OF N/C
ANNT = TOTAL NO OF TUBE IN 360 DEG COND
ARAT = RATIO OF OUTSIDE ROW MIN FLOW AREA TO SECTOR FACE AREA
ARCPR = CIRCUMFERENTIAL ARC LENGTH PER UNIT RADIUS
AOTFLW = AREA OPEN TO FLOW IN A ROW OF TUBES IN A SECTOR FT**2
BNDRAD = TUBE BUNDLE OD FT
DELODF = CHANGE IN TUBE OD PER ROW FT
DELP12 = ENTRANCE STM PRESS LOSS PSI
DELP23 = STM PRESS LOSS AS STM IS ACCEL INTO FIRST ROW PSI
G2 =
HFG = STEAM LATENT HEAT OF VAPORIZATION BTU/LBM
NOROWS = NO OF ROWS IN THE CONDENSER
ODOF = TUBE OD, INSIDE ROW FT
ODIF = TUBE OD, INSIDE ROW FT
ODOI = TUBE OD, INSIDE ROW IN
ODOI1 = TUBE OD, INSIDE ROW IN MIXTURE ENTERING COND PSIA
PMIX1 = PRESS OF STEAM - N/C PRESS PSIA
PSATI = ENTERING SATURATION PRESSURE THE STEAM CAN GO BEFORE THE
PTLIM = LOWEST SATURATION TEMPERATURE FALLS BELOW INLET
CORRESPOND TEMPERATURE RESULT IS O HEAT TRANSFER
COOLANS = BUNDLE VOID RADIUS FT
ROWS = NO OF ROWS IN THE CONDENSER
SECFAR = FACE AREA FOR ONE SECTOR
SMTBI = NO OF SECTORS IN THE CONDENSER MODEL * FLOW RATE)
SMTWB = ROW BY ROW SUM OF (COOLANT FLOW
SMTB2 = ROW BY ROW SUM OF (COOLANT OUTLET TEMP * FLOW RATE)
SUMQ = ROW BY ROW SUM OF (HEAT DUTY ON TUBES
SG = GRAVITY FACTOR 32.2

```

```

CON12970
CON12980
CON12990
CON13000
CON13010
CON13020
CON13030
CON13040
CON13050
CON13060
CON13070
CON13080
CON13090
CON13100
CON13110
CON13120
CON13130
CON13140
CON13150
CON13160
CON13170
CON13180
CON13190
CON13200
CON13210
CON13220
CON13230
CON13240
CON13250
CON13260
CON13270
CON13280
CON13290
CON13300
CON13310
CON13320
CON13330
CON13340
CON13350
CON13360
CON13370
CON13380
CON13390
CON13400
CON13410
CON13420
CON13430
CON13440

```



```

C STSAT1 = ENTERING STM SAT TEMPERATURE SPECIFIC VOL FT**3/LBM 3450
C SVMIX1 = ENTERING N/C GAS SATURATION TEMP FT**3/LBM 3460
C SVNOC1 = ENTERING STEAM SATURATION TEMP FT**3/LBM 3470
C TSAT1 = ENTERING STEAM SATURATION TEMP LBM/HR 3480
C W GAS = N/C GAS FLOW TO EACH SECTOR LBM/HR 3490
C WNCIR = N/C GAS FLOW TO CONDENSER LBM/HR 3500
C WNCIR = RATIO OF MASS FLOW OF N/C TO MASS FLOW OF STEAM 3510
C WS = STEAM FLOW TO EACH SECTOR LBM/HR 3520
C WSI = TOTAL STM FLOW TO CONDENSER LBM/HR 3530
C VEL1 = MIXTURE VELOCITY PRIOR TO ENTERING FIRST ROW FT/SEC 3540
C VEL2 = MIXTURE VELOCITY IN FIRST ROW OF TUBES FT/SEC 3550
C IVNOC = THE NUMBER OF VERTICAL TUBES IN THE COOLER 3560
C IHNOC = THE NUMBER OF HORIZONTAL TUBES IN THE COOLER 3570
C HTCLR = THE HEIGHT OF THE COOLER FT**3/LBM 3580
C VGI = ENTERING STM SPECIFIC VOL FT**3/LBM 3590
C
C ZZZ SEC-2 3600
C-----
C ROWS=FLOAT(NROWS) 3610
C TNOC=0. 3620
C IVNOC=1. 3630
C IF (PRCCLR.EQ.0.0) GO TO 10 3640
C
C COMPUTE THE NUMBER OF VERTICAL AND HORIZONTAL ROWS IN THE COOLER 3650
C IF THERE IS ONE 3660
C
C SDDC=SDDI 3670
C TNOC=(PRCCLR/(100.-PRCCLR))*TNO 3680
C HTCLR=BNDRAD-RADINS 3690
C VNOC=(HTCLR/(SDDC*ODIF*0.886))+1. 3700
C IHNOC=TNOC/VNOC 3710
C HNOC=FLOAT(IHNOC) 3720
C VNOC=TNOC/HNOC 3730
C IVNOC=VNOC+.5 3740
C VNOC=FLOAT(IVNOC) 3750
C
C KSTOP=NROWS+1 3760
C SECFLG=FLOAT(I SEC) 3770
C WNCI=WSI*WNCIR 3780
C IPILOOP=0 3790
C WSAVE=(WSI+WNCI)/SECFLG 3800
C
C INITIALIZE TEST VARIABLES TO 0 3810
C 3820
C 3830
C 3840
C 3850
C 3860
C 3870
C 3880
C 3890
C 3900
C 3910
C 3920

```


CON13530
 CON13940
 CON13950
 CON13560
 CON13970
 CON13980
 CON13590
 CON14000
 CON14010
 CON14020
 CON14030
 CON14040
 CON14050
 CON14060
 CON14070
 CON14080
 CON14090
 CON14100
 CON14110
 CON14120
 CON14130
 CON14140
 CON14150
 CON14160
 CON14170
 CON14180
 CON14190
 CON14200
 CON14210
 CON14220
 CON14230
 CON14240
 CON14250
 CON14260
 CON14270
 CON14280
 CON14290
 CON14300
 CON14310
 CON14320
 CON14330
 CON14340
 CON14350
 CON14360
 CON14370
 CON14380
 CON14390
 CON14400

```

STBIR=STBI+459.69
PTLIM=PSATFN(STBIR)
TSATI=STSATI+459.69
PSATI=PSATFN(TSATI)
AMOLNC=WNCI/AMWNC
HF G=HFGFN(STSATI)
AMOLSS=WSI/18.015
AMOLST=AMOLSS+AMOLNC
PMIX1=PSATI*(AMOLST/AMOLSS)
VGI=VGFN(TSATI,PMIX1)
SVNCI=10.729*TSATI/(AMWNC*PMIX1)
G2=288.0*SG*SVMIX1
SM TBI=0.0
SM WB=0.0
WB=0.
SM TB2=0.0
SUMQ=0.0
CUMDRY=0.
SUBFLO=0.
NBAD=0
WCNDAV=0.
SUBAVE=0.

```

COMPUTE THE PRESSURE LOSSES AT THE ENTRANCE OF THE SECTOR

```

SECFAR=ARCPR*(BNDRAD+ODDF/2.)*ALST
ARAT=AOTFLW(1)/SECFAR
VEL1=(WSI+WNCI)*SVMIX1/(3600.0*SECFAR*SECFLG)
VEL2=VEL1/ARAT
IF (ARAT<0.715) 30,30,40
DELP12=0.4*(1.25-ARAT)*VEL2**2/G2
GO TO 50
DELP12=0.75*(1.0-ARAT)*VEL2**2/G2
DELP23=(VEL2**2)/G2

```

TEMP OUTPUT SECTION

```

SEC A2
ZZZ SEC-A2
SEC A2=0.
IF (SEC A2.EQ.0.) GO TO 70
DO 60 I=1,I SEC
WRITE (6,610)
WRITE (6,620)
WRITE (6,700) WSI,WNCI

```



```

CON14890
CON14900
CON14910
CON14920
CON14930
CON14940
CON14950
CON14960
CON14970
CON14980
CON14990
CON15000
CON15010
CON15020
CON15030
CON15040
CON15050
CON15060
CON15070
CON15080
CON15090
CON15100
CON15110
CON15120
CON15130
CON15140
CON15150
CON15160
CON15170
CON15180
CON15190
CON15200
CON15210
CON15220
CON15230
CON15240
CON15250
CON15260
CON15270
CON15280
CON15290
CON15300
CON15310
CON15320
CON15330
CON15340
CON15350
CON15360

PSAT = SATURATED STEAM PRESS
PTLIM = SAME AS PSAT
PTLIM = LOWEST SATURATION PRESSURE THE STEAM CAN GO BEFORE THE
CORRESPONDING SATURATION TEMPERATURE FALLS BELOW INLET
COOLANT TEMPERATURE. THE RESULT IS 0 HEAT TRANSFER
TAL = SAT STEAM TEMP IN RANKIN
STSAT = STATIC STEAM TEMP F
VG = SPECIFIC VOLUME OF STEAM FT**3/LB
AMWNC = MOLECULAR WEIGHT OF N/C GASSES
VMIX = SPECIFIC VOLUME OF N/C GAS FT**3/LB
WS = STEAM FLOW TO A ROW OF TUBES IN A SECTOR LB/HR
WGAS = FLOW OF N/C TO A SECTOR LB/HR
WNC = SAME AS WGAS
ADTFLW = AREA OPEN TO FLOW IN A BANK OF TUBES
VEL = STEAM-N/C MIXTURE VELOCITY IN A ROW OF TUBES

ZZZ SEC-3
DO 390 J=1, ISEC
INITIALIZE SECTOR TEST VARIABLES
WTST(J)=0.
PTST(J)=0.
CHECK1=0.
CHECK2=0.
SUBRAT=0.
TUBDRY=0.
II=0
DELP(J)=0.
DELPP=0.
DELP TP=0.
PMIX(1,J)=PMIX1-DELP12-DELP23
PSAT(1,J)=PMIX*(AMOLSS/AMOLST)

CHECK TO SEE IF SATURATION PRESSURE INTC THE SECTOR IS BELOW THE
SATURATION PRESSURE CORRESPONDING TO THE COOLANT INLET TEMPERATURE
(PTLIM). STEAM SATURATION PRESSURE CAN ONLY FALL TOO LOW DUE TO
EXCESSIVE ENTRANCE PRESSURE LOSSES (DELP12, DELP23)

IF (PSAT(1,J).GT.PTLIM) GO TO 90

IF PSAT<PTLIM THEN DUMMY VALUES MUST BE INSERTED FOR PSAT,PMIX
AND DELPP IN ORDER TO KEEP THE PROGRAM RUNNING. A VALUE FOR PTST
IS ALSO DETERMINED.

PTST(J)=PSAT(1,J)-PTLIM-NOROWS
RTG=FLOAT(NOROWS+1)

```



```

NRWSP3=NOROWS+1
DELPP=PTLIM/(RTG+1.)
CHECK2=-2.
DO 80 M=1,NRWSP3
  PSAT(M,J)=PTLIM-(M-1)*DELPP
CONTINUE
PMIX(1,J)=PSAT(1,J)/(AMOLSS/AMOLST)

PAL=PSAT(1,J)
TAL=TSATFN(PAL)
STSAT(1,J)=TAL-459.69
VG=VGFN(TAL,PMIX(1,J))
VNC=(10.729*TAL)/(AMWNC*PMIX(1,J))
VMIX=1.0/((AMOLSS/(VG*AMOLST))+((AMCLNC/(VNC*AMOLST))))
VEL(1,J)=(WS(1,J)+WGAS(J))*VMIX/(3600.0*AOFLW(1))
WNC=WGAS(J)
AMOLSC=WNC/AMWNC

C$-----
C SEC A3          TEMP OUTPUT SECTION
C
C ZZZ SEC-A3
C-----
SECA3=0.
IF (SECA3.NE.1.) GO TO 100
WRITE (6,760) J
WRITE (6,770) PMIX(1,J),PSAT(1,J)
WRITE (6,780) STSAT(1,J),TAL
WRITE (6,790) VG,VNC,VMIX
WRITE (6,800) VEL(1,J)
100 CONTINUE

C$-----
C SEC 4          DO LOOP ON ROWS - HEREAFTER REFERRED TO AS
C                   MAIN ROW LOOP
C
C THIS SECTION IS INSIDE THE MAIN SECTOR LOOP. IT
C INITIALIZES SOME VARIABLES PRIOR TO CALLING HETTRN
C IN SEC-5.
C
C I = ROW NUMBER          DUMMY VARIABLE
C IL = ROW NUMBER        TO FLOW IN A ROW OF TUBES FT**2
C AXO = AREA OPEN       AS AXO
C AOFLW = AREA AS AXO
C L = SECTOR NUMBER    DUMMY VARIABLE IN A SECTOR
C J = SECTOR NUMBER    OF TUBES
C NOROWS = NUMBER     OF ROWS OF TUBES
C DELODF = CHANGE     IN TUBE OD / ROW

```

```

CON1 5370
CON1 5380
CON1 5390
CON1 5400
CON1 5410
CON1 5420
CON1 5430
CON1 5440
CON1 5450
CON1 5460
CON1 5470
CON1 5480
CON1 5490
CON1 5500
CON1 5510
CON1 5520
CON1 5530
CON1 5540
CON1 5550
CON1 5560
CON1 5570
CON1 5580
CON1 5590
CON1 5600
CON1 5610
CON1 5620
CON1 5630
CON1 5640
CON1 5650
CON1 5660
CON1 5670
CON1 5680
CON1 5690
CON1 5700
CON1 5710
CON1 5720
CON1 5730
CON1 5740
CON1 5750
CON1 5760
CON1 5770
CON1 5780
CON1 5790
CON1 5800
CON1 5810
CON1 5820
CON1 5830
CON1 5840

```


CON15850
 CON15860
 CON15870
 CON15880
 CON15890
 CON15900
 CON15910
 CON15920
 CON15930
 CON15940
 CON15950
 CON15960
 CON15970
 CON15980
 CON15990
 CON16000
 CON16010
 CON16020
 CON16030
 CON16040
 CON16050
 CON16060
 CON16070
 CON16080
 CON16090
 CON16100
 CON16110
 CON16120
 CON16130
 CON16140
 CON16150
 CON16160
 CON16170
 CON16180
 CON16190
 CON16200
 CON16210
 CON16220
 CON16230
 CON16240
 CON16250
 CON16260
 CON16270
 CON16280
 CON16290
 CON16300
 CON16310
 CON16320

```

C-----
C  OD = TUBE OD          FT
C  ODOF = TUBE CD, OUTSIDE ROW FT
C  XDW = TUBE WALL THICKNESS FT
C  AXI = LOG MEAN INNER SURFACE AREA FT**2
C  AO = LOG MEAN OUTER SURFACE AREA FT**2
C  AW = LOG MEAN TUBE SURFACE AREA FT**2
C  SHMINV = INVERSE OF WALL HEAT X-FER COEF HR-FT**2-F/BTU
C  PTLIM = LOWEST SATURATION PRESSURE THE STEAM CAN GO BEFORE THE
C  CORRESPONDING SATURATION TEMPERATURE FALLS BELOW INLET
C  COOLANT TEMPERATURE RESULT IS 0 HEAT TRANSFER
C  SKW = TUBE THERMAL CONDUCTIVITY BTU-F/HR-FT**2-F
C  TID = TUBE INNER DIAMETER FT
C  WST = STEAM FLOW TO A ROW IN A SECTOR LBM/HR
C-----
C  ZZZ SEC-4
C-----
C  DO 380 IL=1,NROWS
C  I=IL
C  L=J
C  IJX=0
C  LQ=0
C  WB=CMDOF(I)*3600.
C  AXO=AOTFLW(I)
C  ODOF=DELODF*FLOAT(IL-1)
C  TID=SID(IL)/2.
C  XW=(OD-TID)/2.
C  AI=ALST*PI*TID
C  AO=ALST*PI*OD
C  AXI=PI*(TID/2.)**2
C  SDW=(OD-TID)/ALOG(OD/TID)
C  AW=ALST*PI*SDW
C  SHMINV=(AO*XW)/(SKW*AW)
C  WST=WS(IL,J)
C-----
C  IF (WST.LE.0) WRITE (6,600) J,IL
C-----
C  SEC A4
C-----
C  ZZZ SEC-A4
C-----
C  SECA4=0.
C  IF (SECA4.NE.1) GO TO 110
C  WRITE (6,810) IL
C  WRITE (6,820) AI,AO
C  WRITE (6,830) TID,AXI

```


WRITE (6,840) SDW,AW
 WRITE (6,850) SHWINV
 CONTINUE

110
 SEC 5

CALL TO HETRN AND PRSDRP

THIS SECTION INSIDE BOTH MAIN ROW AND SECTOR LOUPS

STSAT = STEAM SATURATION TEMP F
 ANST = TARGET TUBE LOCATION IN VERTICAL ROW
 WNS = STEAM FLOW TO A ROW OF A SECTOR LBM/HR
 WNC = N/C FLOW TO A ROW OF A SECTOR LBM/HR
 UN = OVERALL HEAT TRANSFER COEFF FOR ONE ROW OF TUBES IN A SECT.
 ALMTD = LMTD FOR A ROW IN A SECTOR F
 HOMCI = STSAT - COOLANT INLET TEMP
 HOMCO = STSAT - OF OUTER TUBE FILM
 STFO = AVE TEMP OF TUBE TRANSFER COEF.
 SHI = INTERNAL TUBE FILM HEAT TRANSFER COEF.
 SHN = EXTERNAL TUBE FILM HEAT TRANSFER COEF
 RC = RATIO OF N/C GAS TO STM AT ONE ROW OF TUBES
 ROUT = EXTERNAL HEAT TRANSFER COEF
 AXO = AREA OPEN TO FLOW IN A ROW OF TUBES FT**2
 VNRE = REYNOLDS NUMBER
 DUMMY = OUTLET COOLANT TEMP F
 VPSHH = N/C GAS FILM HEAT TRANSFER COEF
 HEFF = SECTOR NUMBER
 L = SECTOR NUMBER
 HFG = STEAM LATENT HEAT OF VAPORIZATION BTU/LBM
 WCND = COND ENSAITE FROM ONE ROW OF TUBES IN A SECTOR LBM/HR
 AO = OUTER SURFACE AREA OF A TUBE FT**2
 PTLIM = LOWEST SATURATION PRESSURE THE STEAM CAN GO BEFORE THE
 CORRESPONDING SATURATION TEMPERATURE FALLS BELOW INLET
 COOLANT TEMPERATURE. IN A GIVEN ROW OF A SECTOR
 TBNPR = NUMBER OF TUBES IN A ROW
 TAL = SATURATED STEAM TEMP
 VMIX = SPECIFIC VOLUME OF STM-N/C MIXTURE FT**3/LBM
 SDO = TUBE OD FT
 VPSH = FRICTION FACTOR USED IN PRESSURE DROP CALC
 DELPTP = PRESSURE DROP ACROSS A ROW OF TUBES PSI
 ENHF = PRESSURE DROP FRICTION FACTOR ENHANCEMENT
 ENHF = PRESSURE DROP FRICTION FACTOR ENHANCEMENT FACTOR, STM SIDE.

CON16330
 CON16340
 CON16350
 CON16360
 CON16370
 CON16380
 CON16390
 CON16400
 CON16410
 CON16420
 CON16430
 CON16440
 CON16450
 CON16460
 CON16470
 CON16480
 CON16490
 CON16500
 CON16510
 CON16520
 CON16530
 CON16540
 CON16550
 CON16560
 CON16570
 CON16580
 CON16590
 CON16600
 CON16610
 CON16620
 CON16630
 CON16640
 CON16650
 CON16660
 CON16670
 CON16680
 CON16690
 CON16700
 CON16710
 CON16720
 CON16730
 CON16740
 CON16750
 CON16760
 CON16770
 CON16780
 CON16790
 CON16800

ZZZ SEC-5

CHECK TO ENSURE THAT THE SATURATION PRESSURE IN AN EARLIER ROW


```

C      CALCULATION HAS NOT DROPPED BELOW THE SATURATION PRESSURE          CON1 6810
C      CORRESPONDING TO THAT OF THE INLET COOLANT TEMPERATURE (PTLIM) FOR  CON1 6820
C      A GIVEN SECTOR. IF IT HAS, CHECK2<0 AND WE SKIP HETTRN CALCS SINCE  CON1 6830
C      DUMMY VARIABLES HAVE BEEN INSERTED FOR PSAT                          CON1 6840
C      IF (CHECK2.LT.0) GO TO 120                                           CON1 6850
C                                                                              CON1 6860
C      CALL HETTRN (ALST,AXO,I,L,OD,WB,SHWINV,STSAT(I,L),TID,WNC,WST,ALMT  CON1 6870
C      1D(I,L),ENHF,HEFF(I,L),HOMCI,HOMCO,RC(I,L),RCUI(I,L),SHI(I,L),SHN(I  CON1 6880
C      2,L),STFO,VP$HH(I,L),UN(I,L),VNRE(I,L),ENHI,ENHO,SDDU)             CON1 6890
C                                                                              CON1 6900
C      CHECK TO SEE IF THE FIRST ROW IN THE SECTOR HAS STEAM SATURATION  CON1 6910
C      HAS DROPPED BELOW PTLIM. IF IT HAS THEN CHECK2<0 AND I=1.          CON1 6920
C      DUMMY VALUES MUST THEN BE PLACED IN THOSE VARIABLES NORMALLY     CON1 6930
C      RETURNED BY HETTRN SINCE HETTRN HAS BEEN BYPASSED.                CON1 6940
C                                                                              CON1 6950
C      IF ((CHECK2.GE.0).OR.(I.NE.1)) GO TO 130                            CON1 6960
C                                                                              CON1 6970
C      SINCE THE SATURATION STEAM PRESSURE IS BELOW PTLIM THEN THE STEAM  CON1 6980
C      TEMPERATURE IS BELOW COOLANT INLET TEMPERATURE. THIS MEANS NO     CON1 6990
C      HEAT IS REMOVED FROM THE STEAM AND THE ALMTD IS 0. THE COOLANT    CON1 7000
C      OUTLET TEMP IS THE SAME AS THE COOLANT INLET TEMP AND THE TUBE     CON1 7010
C      FILM TEMP IS THE SAME AS COOLANT INLET TEMPS. THE REMAINING      CON1 7020
C      VARIABLE VALUES ARE APPROXIMATED.                                  CON1 7030
C                                                                              CON1 7040
C      ALMTD(1,J)=0.                                                       CON1 7050
C      HOMCI=0.                                                             CON1 7060
C      HOMCO=0.                                                             CON1 7070
C      VP$HH(1,J)=STB I                                                    CON1 7080
C      HEFF(1,J)=1.E+8                                                      CON1 7090
C      RC(1,J)=.161E-3                                                      CON1 7100
C      VNRE(1,J)=.9E+5                                                       CON1 7110
C      SHI(1,J)=.136E+4                                                       CON1 7120
C      SHN(1,J)=.136E+5                                                       CON1 7130
C      UN(1,J)=655.                                                          CON1 7140
C      ROUT(1,J)=.136E+5                                                    CON1 7150
C      STFO=STBI                                                            CON1 7160
C      GO TO 150                                                            CON1 7170
C                                                                              CON1 7180
C      CHECK TC SEE IF A ROW OTHER THAN THE FIRST ONE IN THE SECTOR HAS  CON1 7190
C      HAD STEAM SATURATION DROP BELOW PTLIM. IF IT HAS THEN CHECK2<0.   CON1 7200
C      DUMMY VALUES MUST THEN BE PLACED IN THOSE VARIABLES NORMALLY    CON1 7210
C      RETURNED BY HETTRN SINCE HETTRN HAS BEEN BYPASSED.                CON1 7220
C                                                                              CON1 7230
C      IF (CHECK2.LT.0) GO TO 140                                           CON1 7240
C      ENHFSV=ENHF                                                         CON1 7250
C      GO TO 150                                                            CON1 7260
C                                                                              CON1 7270
C                                                                              CON1 7280

```



```

C      CHECK2 < 0, THAT INDICATES THAT THE SATURATION STEAM PRESSURE
C      IS BELOW PTLIM AND THUS THE STEAM TEMPERATURE IS BELOW COOLANT
C      INLET TEMPERATURE. THIS MEANS THAT NO HEAT IS REMOVED FROM THE
C      STEAM AND THE ALMTD IS 0. THE COOLANT OUTLET TEMP EQUALS THE
C      COOLANT INLET TEMP AND THE TUBE FILM TEMP IS THE SAME AS THE
C      COOLANT INLET TEMP. THE REMAINING VARIABLES ARE GIVEN THE LAST
C      GOOD VALUES RETURNED BY HETTRN.
C      ALMTD(I,J)=0.
C      HOMCI=0.
C      HOMCO=0.
C      VPSHH(I,J)=STBI
C      HEFF(I,J)=HEFF(I-1,J)
C      RC(I,J)=RC(I-1,J)
C      VNRE(I,J)=VNRE(I-1,J)
C      SHI(I,J)=SHI(I-1,J)
C      SHN(I,J)=SHN(I-1,J)
C      UN(I,J)=UN(I-1,J)
C      ROUT(I,J)=ROUT(I-1,J)
C      STFO=STBI
C      ENHF=ENHFSV
C      TB2=VPSHH(I,L)
C      HFG=HFGFN(SISAT(I,J))
C      CHECK TO SEE IF STEAM FLOW IN A SECTOR HAS ALREADY GONE TO 0
C      IF IT HAS CHECK1<0 AND DUMMY VALUES HAVE ALREADY BEEN ASSIGNED
C      TO WCNC.
C      IF (CHECK1.LT.0.) GO TO 160
C      WCND(I,J)=UN(I,J)*AO*ALMTD(I,J)/HFG*TBNPR(I)
C      CHECK TC SEE IF SATURATION PRESSURE HAS ALREADY GONE BELOW PTLIM
C      AND DUMMY VARIABLES HAVE BEEN ASSIGNED TO DELPTP
C      IF (CHECK2.LT.0) GO TO 170
C      CALL PRSDRP (TAL,VMIX,WS(I,J),WNC,AXO,OD,VPSH,DELPTP,ENHF)
C      CONTINUE
C      JX=0
C      -----
C      SEC A5                                TEMP OUTPUT SECTION
C      -----
C      ZZSEC=A5
C      -----
C      SECA5=0.

```

```

CON1 7290
CON1 7300
CON1 7310
CON1 7320
CON1 7330
CON1 7340
CON1 7350
CON1 7360
CON1 7370
CON1 7380
CON1 7390
CON1 7400
CON1 7410
CON1 7420
CON1 7430
CON1 7440
CON1 7450
CON1 7460
CON1 7470
CON1 7480
CON1 7490
CON1 7500
CON1 7510
CON1 7520
CON1 7530
CON1 7540
CON1 7550
CON1 7560
CON1 7570
CON1 7580
CON1 7590
CON1 7600
CON1 7610
CON1 7620
CON1 7630
CON1 7640
CON1 7650
CON1 7660
CON1 7670
CON1 7680
CON1 7690
CON1 7700
CON1 7710
CON1 7720
CON1 7730
CON1 7740
CON1 7750
CON1 7760

```



```

IF (SECAS.NE.1) GO TO 170
WR IITE (6,860) I,J
WR IITE (6,910) TB2,UN(I,L),VNRE(I,L)
WR IITE (6,870) ALMD(I,L),HEFF(I,L)
WR IITE (6,880) HOMCI,HOMCO
WR IITE (6,890) RC(I,L),ROUT(I,L)
WR IITE (6,900) SHI(I,L),SHN(I,L)
WR IITE (6,920) WNC,WS(I,L)
WR IITE (6,930) DELPTP,VPSH
WR IITE (6,940) WCND(I,J),HFG
WR IITE (6,950) AD,TBNPR(I)

```

```

C$-----
C SEC 6

```

```

TEST FOR POSITIVE STM FLOW AND SAT PRESS

WS = STM FLOW TO ONE ROW IN A SECTOR LB/HR
WNC = CONDENSATE FROM ONE ROW OF TUBES IN A SECTOR LB/HR
WNC = N/C GAS FLOW TO ONE ROW OF TUBES IN A SECTOR LB/HR
AXO = AREA OPEN TO FLOW IN A ROW OF A SECTOR
GFLW = MASS FLOW RATE OF MIXTURE IN A TUBE BUNDLE LB/(HR-FT**2)
I = ROW NUMBER
AMOLS = MOLES OF STEAM IN A ROW OF A SECTOR
PMIX = PRESS OF STM - N/C MIXTURE
DELPTP = PRESS DROP ACROSS A ROW OF TUBES
AMWNC = MOLECULAR WEIGHT OF N/C
PSAT = SATURATED STEAM PRESS
J = SECTOR NUMBER
STSAT = SATURATED STEAM TEMP - F
TSAT = SATURATED STEAM TEMP - R
PAL = DUMMY FOR PSAT
CHECK1 = INDICATOR THAT NEG. STEAM FLOW HAS BEEN ENCOUNTERED
CHECK2 = INDICATOR ANALYSIS SSKP SATFN(STBI) HAS BEEN
ENCOUNTERED IN SECTOR
PTEST = NEXT ROW PRESSURE VALUE TO CHECK FOR A BAD VALUE
WTEST = NEXT ROW STEAM FLOW TO CHECK FOR A NEGATIVE VALUE
WTSI = TEST VARIABLE WHICH IS NEGATIVE WHEN NEGATIVE STEAM FLOW
IS ENCOUNTERED IN A SECTOR
PTST = TEST VARIABLE WHICH IS A NEGATIVE WHEN PSAT DROPS BELOW
PTLIM IN A SECTOR

```

```

ZZZ SEC-6
-----
CHECK TO SEE IF STEAM FLOW HAS ALREADY GONE TO 0 IN AN EARLIER
ROW CALCULATIO AND FIXUP HAS BEEN MADE TO WS AND WCND
170 IF (CHECK1.LT.0) GO TO 180
WS (I+1,J)=WS(I,J)-WCND(I,J)

```

```

CON1 7770
CON1 7780
CON1 7790
CON1 7800
CON1 7810
CON1 7820
CON1 7830
CON1 7840
CON1 7850
CON1 7860
CON1 7870
CON1 7880
CON1 7890
CON1 7900
CON1 7910
CON1 7920
CON1 7930
CON1 7940
CON1 7950
CON1 7960
CON1 7970
CON1 7980
CON1 7990
CON1 8000
CON1 8010
CON1 8020
CON1 8030
CON1 8040
CON1 8050
CON1 8060
CON1 8070
CON1 8080
CON1 8090
CON1 8100
CON1 8110
CON1 8120
CON1 8130
CON1 8140
CON1 8150
CON1 8160
CON1 8170
CON1 8180
CON1 8190
CON1 8200
CON1 8210
CON1 8220
CON1 8230
CON1 8240

```



```

C      CHECK TO SEE IF STEAM FLOW OF NEXT ROW IS 0 AND DUMMY VALUES
C      MUST BE ASSIGNED TO WS AND WCND TO ALLOW THE PROGRAM TO CONTINUE
C
C      IF (WS(I+1,J).LE.1.) I1I1=1
C      IF (WS(I+1,J).LE.1.) GO TO 300
C
C      BEGIN COMPUTING NEXT ROW PRESSURES
C
C      AMOLS=WS(I+1,J)/18.015
C      SECA6=0.
C      I1I1=0
C
C      CHECK TC SEE IF SATURATION PRESSURES HAVE ALREADY GONE BELOW
C      PTLIM AND STANDARD FIXUP TO PSAT HAS BEEN MADE. PRESSURE FALLING
C      BELOW PTLIM IS CONSIDERED ONLY FOR THE CASE OF EXCESSIVE PRESSURE
C      LOSSES ONLY AND NOT AS A CONSEQUENCE OF LOSS OF STEAM FLOW
C
C      IF (CHECK2.GE.0) GO TO 190
C      PAL=PSAT(I+1,J)
C      IF (I.EQ.1) DELPTP=DELPP/(AMOLS/(AMOLS+WNC)/AMWNC)
C      PMIX(I+1,J)=PMIX(I,J)-DELPTP
C      IF (PMIX(I+1,J).LE..001) PMIX(I+1,J)=.001
C      GO TO 230
C
C      PMIX(I+1,J)=PMIX(I,J)-DELPTP
C      PSAT(I+1,J)=PMIX(I+1,J)*AMOLS/(AMOLS+WNC)/AMWNC)
C      PAL=PSAT(I+1,J)
C      PTEST=PSAT(I+1,J)
C      IF (SECA6.NE.1) GO TO 200
C      IF (SECA6.EQ.1) WRITE (6,1020) I,J
C      IF (SECA6.EQ.1) WRITE (6,970) WS(I,J),WS(I+1,J)
C      IF (SECA6.EQ.1) WRITE (6,1000) PSAT(I,J),PSAT(I+1,J)
C
C      CHECK FCR NEXT ROW SATURATION PRESSURE TO SEE IF DROPS BELOW PTLIM
C
C      IF (PTEST-PTLIM) 210,210,230
C
C      PSAT(I+1) < PTLIM AND SUBSEQUENT ROW PRESSURES MUST BE FIXED
C      UP WITH DUMMY VALUES IN ORDER TO KEEP THE PROGRAM RUNNING.
C      P SAT, AND DELPP ARE GIVEN DUMMY VALUES.
C
C      IK2=I+1
C      SECA6=0.
C      NR WSP2=NOROWS+1
C      ROTOG=FLOAT(NR WSP2-I)
C      DELPP=PTLIM/(ROTOG+1)
C
CON18250
CON18260
CON18270
CON18280
CON18290
CON18300
CON18310
CON18320
CON18330
CON18340
CON18350
CON18360
CON18370
CON18380
CON18390
CON18400
CON18410
CON18420
CON18430
CON18440
CON18450
CON18460
CON18470
CON18480
CON18490
CON18500
CON18510
CON18520
CON18530
CON18540
CON18550
CON18560
CON18570
CON18580
CON18590
CON18600
CON18610
CON18620
CON18630
CON18640
CON18650
CON18660
CON18670
CON18680
CON18690
CON18700
CON18710
CON18720

```



```

C      DELPP IS AN ARBITRARY INCREMENTAL PRESS. DROP OVER REMAINING ROWS
C      DO 220 IK=IK2, NRWSP2
C      PSAT(IK, J)=PSAT(IK-1, J)-DELPP
C      CONTINUE
C      X1=PTEST-PTLIM
C      X2=PSAT(I, J)
C
C      CALCULATE PTST WHICH IS A TEST VALUE INDICATING THAT SATURATION
C      PRESSURES WERE REACHED IN THE ANALYSIS FROM WHICH THE SATURATION
C      CORRESPONDING TSAT IS EXCEEDED BY THE INLET COOLANT TEMP (IE PTLIM
C      WAS VIOLATED) A LARGE NEGATIVE VALUE FOR PTST INDICATES A BAD
C      CONDENSOR DESIGN IN WHICH PTLIM WAS VIOLATED EARLY IN THE SECTOR
C      ANALYSIS. AS THE CONDENSOR MODEL IMPROVES AND SATURATION PRESSURE
C      STAYS ABOVE PTLIM THEN PTST CONVERGES TO 0.
C      PTST(J)=(X1/(X2-X1))-FLUAT(NOROWS-I)
C      CHECK2=-2
C      PAL=PSAT(I+1, J)
C      PMIX(I+1, J)=PMIX(I, J)-DELPTP
C      IF (PMIX(I+1, J).LE..001) PMIX(I+1, J)=.001
C
C      IF (SECA6.EQ.1) WRITE (6, 990) I, J
C      IF (SECA6.EQ.1) WRITE (6, 1000) PSAT(I, J), PSAT(I+1, J)
C      IF (SECA6.EQ.1) WRITE (6, 1010) PTST(J)
C
C      GO TO 230
C$-----
C      SEC 7
C      CORRECTION TO CONDENSATE RATE FOR
C      SENSIBLE HEAT
C
C      PAL = SAT STM PRESS
C      STFO = AVE TEMP OF OUTER TUBE FILM
C      UN = OVERALL HEAT X-FER CUEF FOR A ROW OF TUBES
C      AO = TUBE OUTER SURFACE AREA
C      ALMTD = LMTD
C      TBNPR = NUMBER OF TUBES IN A ROW OF A SECTOR
C      WS = STEAM FLOW TO A ROW OF A SECTOR
C      WNC = N/C FLOW TO A ROW OF A SECTOR
C      JGAS = FLAG FOR TYPE OF N/C
C      AMWNC = MOLECULAR WEIGHT OF N/C
C      TAL = SAT STM TEMP ENTERING SECTOR R
C      WCNDP = CONDENSATE FROM ONE ROW CORRECTED FOR SENSIBLE
C      HEAT CHANGE LB/HR
C      WCND = CONDENSATE FROM ONE ROW
C      JX =
C      IDENT = USER INPUT IDENTIFICATION STRING FOR RUN

```

CON18730
CON18740
CON18750
CON18760
CON18770
CON18780
CON18790
CON18800
CON18810
CON18820
CON18830
CON18840
CON18850
CON18860
CON18870
CON18880
CON18890
CON18900
CON18910
CON18920
CON18930
CON18940
CON18950
CON18960
CON18970
CON18980
CON18990
CON19000
CON19010
CON19020
CON19030
CON19040
CON19050
CON19060
CON19070
CON19080
CON19090
CON19100
CON19110
CON19120
CON19130
CON19140
CON19150
CON19160
CON19170
CON19180
CON19190
CON19200


```

C      AMOLS = MOLES OF STEAM IN A ROW OF A SECTOR
C      PMIX  = PRESSURE OF STEAM - N/C MIXTURE
C      PSAT  = SATURATED STEAM PRESS
C      STSAT = SATURATED STEAM TEMP R
C      STSAT = SATURATED STEAM TEMP F
C
C      ZZZ SEC-7
C-----
C 230  TSAT=TSATFN(PAL)
C      SECA7=0.
C      STSAT(I+1,J)=TSAT-459.69
C      IF (STSAT(I+1,J)-STFO) 240,240,250
C      STSAT(I+1,J)=STFO
C      TSAT=STSAT(I+1,J)+459.69
C      CONTINUE
C      WCNDP=(UN(I,J)*AO*ALMTD(I,J)*TBNPR(I,J)-(WS(I,J)*CPSFN(TSAT)/18.015+
C      1WNC*CPAFN(TSAT,JGAS)/AMWNC)*(TAL-TSAT))/HFG
C      IF (SECA7.EC.1) WRITE (6,1070) WCND(I,J),WCNDP
C      IF (SECA7.EQ.1) WRITE (6,1080) TAL,TSAT
C
C      CHECK TO SEE IF WCND IS 0 WHICH CAN OCCUR IF PSAT HAS DRIPPED
C      BELOW PTLIM (CHECK2<0). IF IT HAS THERE IS NO HEAT TRANSFER FROM
C      THE STEAM AND NO NEED TO CORRECT FOR SENSIBLE HEAT
C      IF (CHECK2.LT.0) WCNDP=WCND(I,J)
C
C      CHECK TO SEE IF STEAM FLOW HAS ALREADY GONE TO 0 (CHECK<0)
C      AND WCND HAS BEEN FIXED UP WITH DUMMY VALUES
C      IF (CHECK1.LT.0) WCNDP=WCND(I,J)
C      IF CONDENSATE FLOW HAS GONE TO 0 AVOID ITERATIONS
C      IF (WCND(I,J).EQ.0.) GO TO 290
C      IF EITHER CHECK IS TRUE THEN AVOID CORRECTIVE ITERATION TO WCND
C      IF (ABS(WCNDP/WCND(I,J))-1.01-.005) 290,260,260
C      JX=JX+1
C      IF (JX-50) 280,280,270
C      IF (SECA7.EQ.1) WRITE (6,1120) IDENT,I,J,I,J
C      GO TO 290
C      WCND(I,J)=WCNDP
C      GO TO I70
C      CONTINUE
C      SECA6=0.
C
C 260
C 270
C 280
C 290

```

```

CON19210
CON19220
CON19230
CON19240
CON19250
CON19260
CON19270
CON19280
CON19290
CON19300
CON19310
CON19320
CON19330
CON19340
CON19350
CON19360
CON19370
CON19380
CON19390
CON19400
CON19410
CON19420
CON19430
CON19440
CON19450
CON19460
CON19470
CON19480
CON19490
CON19500
CON19510
CON19520
CON19530
CON19540
CON19550
CON19560
CON19570
CON19580
CON19590
CON19600
CON19610
CON19620
CON19630
CON19640
CON19650
CON19660
CON19670
CON19680

```



```

C      CHECK TO SEE IF STEAM FLOW HAS GONE TO 1 IN AN EARLIER ROW
C      CALCULATION AND SUBSEQUENT ROWS HAVE BEEN FIXED UP WITH DUMMY
C      VALUES. A NEGATIVE CHECK1 INDICATES FIXUP HAS BEEN MADE FOR
C      THAT SECTOR
C      IF (CHECK1.GE.0) GO TO 300
C      GO TO 350
C      WTEST=WS(I+1,J)
C      CHECK THE NEXT ROW TO SEE IF STEAM FLOW < 1
C      IF (WTEST-1.) 310,310,340
C      IF STEAM FLOW HAS GONE TO 1 THEN A STANDARD FIXUP IS MADE TO
C      ALLOW THE PROGRAM TO CONTINUE AND DUMMY VALUES FOR STEAM FLOW
C      AND CONDENSATE ARE ENTERED INTO THE REMAINING ROWS. IF STEAM FLOW
C      HAS GONE TO 1 THAT INDICATES ZERO STEAM FLOW. A VERY SMALL NUMBER
C      WILL BE USED TO SIMULATE 0 STEAM FLOW IN THE REMAINING ROWS.
C      IK1=I+1
C      ROTOGO=FLOAT(NROWS-I)
C      WSEND=(WTEST-1.)/(WS(I,J)-WTEST+1.)
C      WTST(J)=WSEND-ROTOGO
C      IF (SECA6.EQ.1) WRITE (6,960) I,J
C      IF (SECA6.EQ.1) WRITE (6,970) WS(I,J),WTEST
C      IF (SECA6.EQ.1) WRITE (6,980) WTST(J)
C      CALCULATE NEGATIVE FLOW RATE FOR USE IN CALCULATING EXTIIFR
C      DO 320 KK=IK1,NCROWS
C      TUBDRY=TUBDRY+TENPR(KK)
C      CONTINUE
C      TUBDRY=TUBDRY-WSEND*TBNPR(I)
C      CUMDRY=CUMDRY+TUBDRY
C      SUBRAT=WCND(I-1,J)/TBNPR(I)
C      SUBAVE=SUBAVE+SUBRAT
C      NBAD=NBAD+1
C      SUBFLO=SUBFLO+SUBRAT*TUBDRY
C      NRWSP1=NROWS+1
C      RSTOGO=FLOAT(NRWSP1-I)
C      WS(I,J)=(1.0)*RSTOGO+1)
C      WCND(I,J)=WS(I,J)
C      DELWS=WS(I,J)/(RSTOGO+1)
C      DELWC=WCND(I,J)/(RSTOGO+1)
CON15690
CON15700
CON15710
CON15720
CON15730
CON15740
CON15750
CON15760
CON15770
CON15780
CON15790
CON15800
CON15810
CON15820
CON15830
CON15840
CON15850
CON15860
CON15870
CON15880
CON15890
CON15500
CON15510
CON15520
CON15530
CON15540
CON15550
CON15560
CON15590
CON20000
CON20010
CON20020
CON20030
CON20040
CON20050
CON20060
CON20070
CON20080
CON20090
CON20100
CON20110
CON20120
CON20130
CON20140
CON20150
CON20160

```



```

330 DO 330 IK=IK1, NRMSPI
C      IF (SECA6.EQ.1) WRITE (6,970) WS(IK,J)
C      WS(IK,J)=WS(IK-1,J)-DELWS
C      WCND(IK,J)=WCND(IK-1,J)-DELWC
C
C      CALCULATE A VALUE FOR THE TEST VARIABLE (WTST) INDICATING 0 OK
C      NEGATIVE STEAM FLOW. A LARGE NEGATIVE VALUE FOR WTST INDICATES
C      A VERY LEAD CONDENSOR MODEL WHERE NEGATIVE STEAM FLOW WAS
C      ENCOUNTERED EARLY IN THE SECTORS. AS THE CONDENSOR MODEL IMPROVES
C      STEAM FLOW STAYS POSITIVE THROUGHOUT THE CONDENSOR AND WTST
C      CONVERGES TO 0.
C
C      CHECK1=-2
C      IF (I11.EQ.1) GO TO 180
C      GO TO 350
C      WCND(I,J)=WCNDP
C      WS(I+1,J)=WS(I,J)-WCND(I,J)
C      GFLW(I,J)=(WS(I,J)+WNC)/AXO
C      AMOLS=WNC(I+1,J)/18.015
C
C      CHECK TO SEE IF PRESURE HAS ALREADY GONE BELOW PTLIM
C      AND DUMMY VALUES ARE IN THE PRESSURE ARRAY (CHECK2<0)
C
C      IF (CHECK2.LT.0.) GO TO 360
C
C      PSAT(I+1,J)=PMIX(I+1,J)*AMOLS/(AMOLS+WNC/AMWNC)
C      TSAT=TSATFN(PSAT(I+1,J))
C      STSAT(I+1,J)=TSAT-459.69
C
C-----
C$ SEC A7
C
C      TEMP OUTPUT SECTION
C
C      ZZZ SEC-A7
C-----
C      IF (SECA7.NE.1.) GO TO 370
C      WRITE (6,1030) I,J
C      WRITE (6,1040) WS(I,J),WCND(I,J)
C      WRITE (6,1050) TSAT,STSAT(I,J)
C      WRITE (6,1060) GFLW(I,J),PSAT(I,J)
C-----
C$ SEC 8
C
C      COMPLETION OF MAIN ROW AND SECTOR LOOPS
C
C      NOTE THAT THE MAIN ROW LOOP IS COMPLETED IN LINE 380,
C      AND THE MAIN SECTOR LOOP IS COMPLETED IN LINE 390.
C
C      VG = SPECIFIC VOLUME OF STM
C      VMIX = SPECIFIC VOLUME OF STM-N/C MIXTURE

```

```

CON20170
CON20180
CON20190
CON20200
CON20210
CON20220
CON20230
CON20240
CON20250
CON20260
CON20270
CON20280
CON20290
CON20300
CON20310
CON20320
CON20330
CON20340
CON20350
CON20360
CON20370
CON20380
CON20390
CON20400
CON20410
CON20420
CON20430
CON20440
CON20450
CON20460
CON20470
CON20480
CON20490
CON20500
CON20510
CON20520
CON20530
CON20540
CON20550
CON20560
CON20570
CON20580
CON20590
CON20600
CON20610
CON20620
CON20630
CON20640

```



```

CON2 0650
CON2 0660
CON2 0670
CON2 0680
CON2 0690
CON2 0700
CON2 0710
CON2 0720
CON2 0730
CON2 0740
CON2 0750
CON2 0760
CON2 0770
CON2 0780
CON2 0790
CON2 0800
CON2 0810
CON2 0820
CON2 0830
CON2 0840
CON2 0850
CON2 0860
CON2 0870
CON2 0880
CON2 0890
CON2 0900
CON2 0910
CON2 0920
CON2 0930
CON2 0940
CON2 0950
CON2 0960
CON2 0970
CON2 0980
CON2 0990
CON2 1000
CON2 1010
CON2 1020
CON2 1030
CON2 1040
CON2 1050
CON2 1060
CON2 1070
CON2 1080
CON2 1090
CON2 1100
CON2 1110
CON2 1120

AMOLS = MOLES OF STM TO A ROW
TSAT = STM SATURATION TEMP R
PMIX = ST -N/C MIXTURE PRESSURE
AMWNC = MOLECULAR WEIGHT OF N/C GASSES
VNC = SPECIFIC VOLUME OF N/C GASSES
WNC = N/C FLOW TO A ROW OF A SECTOR
AMOLSC = MOLES OF A N/C TO A SECTOR
VEL = STM-N/C MIXTURE VELOCITY IN A ROW OF TUBES
WS = STM FLOW TO A ROW IN A SECTOR LB/HR
AOTFLW = AREA OPEN TO STM FLOW IN A ROW OF TUBES
SMTBI = SUM OF (COOLANT INLET TEMP*COOLANT FLOW RATE)
WB = COLLANT FLOW TO ONE TUBE IN THE CONDENSER
STBI = COOLANT INLET TEMP
TBNPR = NUMBER OF TUBES IN A ROW OF A SECTOR
SMTWB = ROW BY ROW SUM OF COOLANT FLOW
SMTB2 = ROW BY ROW SUM OF (COOLANT OUTLET TEMP*FLOW RATE)
TB2 = COOLANT OUTLET TEMP FOR A TUBE
SUMQ = COOLANT DUTY ON ROWS OF TUBES
UN = OVERALL HEAT X-FER COEF FOR A ROW
AO = TUBE OUTER SURFACE AREA
ALMTC = LMTD
QOA = HEAT FLUX ACROSS TUBE WALL
CUMDP = ACCUMULATED PRESS DROP FROM INLET TO CURRENT ROW
PMIX = ACCESS OF STM-N/C MIXTURE
PHP = OVERALL POWER TO DRIVE THE COOLANT THROUGH THE CONDENSER
AND THE COOLER TUBES IN HP.
DELP = PRESSURE DROP ACROSS A SECTOR
DELP TP = PRESSURE DROP ACROSS A ROW
TAL = SAT STEAM TEMP R
I = ROW NUMBER
IT = DUMMY LOOP VARIABLE (IT = 1)
SVMIX1 = SPECIFIC VOLUME OF STM-N/C MIXTURE ENTERING CONDENSER
WGAS = FLOW OF N/C GAS TO A SECTOR
AOTFLW = AREA OPEN TO STEAM FLOW IN A ROW OF TUBES
C = USED TO ADJUST STEAM FLOW TO MATCH PRESS DROPS IN SEC-10

C ZZZ SEC-8
-----
370 VG=VGFN(TSAT,PMIX(I+1,J))
AMOLSC=WNC/AMWNC
VNC=(10.729*TSAT)/(AMWNC*PMIX(I+1,J))
VMIX=1.0/((AMJLS/(VG*(AMOLS+AMOLSC)))+(AMOLSC/(VNC*(AMOLS+AMOLSC)))
1))
IF (I.EQ.NDROWS) GOTO 190
VEL(I+1,J)=(WS(I+1,J)+WNC)/(AOTFLW(I+1,J))*VMIX/3600.0
SMTBI=SMTBI+WB*STBI*TBNPR(I)
SMTWB=SMTWB+WB*TBNPR(I)
SMTB2=SMTB2+WB*TBNPR(I)*TB2
SUMQ=SUMQ+UN(I,J)*AO*ALMTC(I,J)*TBNPR(I)

C

```



```

380      GOA(I,J)=UN(I,J)*ALMTD(I,J)
      CUMDP(I,J)=(PMIX(I)-PMIX(I+1,J)
      DELP(J)=DELP(J)+DELP(T)
      TAL=TSAT
      CONTINUE
      C(J)=(WS(I,J)+WGAS(J))/SQRT(DELP(J))
C      INCLUDE ONLY THOSE SECTORS WHERE STEAM FLOW HAS NOT GONE TO 0
C      IN STMSUM SO AS NOT TO INCLUDE DUMMY VALUES IN THE CALCULATION
C      OF EXIT STEAM FRACTION
      IF (CHECK1.GE.0) STMSUM=STMSUM+WS(NOROWS+1,J)
390      CONTINUE
C$-----
C      SEC A8
C      ZZZ SEC-A8
C-----
      SECA8=0.
      IF (SECA8.NE.1.) GO TO 410
      WR ITE (6,1050)
      DO 400 I=1,ISEC
      WR ITE (6,1100) WTST(I),PTST(I)
400      CONTINUE
410      CONTINUE
C$-----
C      SEC 9
C      ZZZ SEC-9
C-----
      PMXEXT=0.
      DELPVE=0.
      PSUM=0.
      VELEXT=0.
      DO 420 I=1,ISEC
      PAL=PSAT(KSTOP,I)
      PSUM=PSUM+PAL/VEL(NOROWS+1,I)
      VELEXT=VELEXT+DELP(I)
      DELPVE=DELPVE+DELP(I)
      PMXEXT=PMXEXT+PMIX(NOROWS+1,I)
420      CONTINUE
      MAKE PTST AND EXIT STEAM FRACTION VARIABLES CONTINUOUS
      THIS IS DONE TO SATISFY AND ENHANCE OPTIMIZER CALCULATIONS. IF
      THE VARIABLE PTST IS GIVEN THE LAST ROW +1 PRESSURE VALUES. IF
      IT IS NON-NEGATIVE. IN ORDER TO MAKE EXIT STEAM FRACTION
      (EXIT FR) CONTINUOUS. THE VARIABLE FR IS CREATED WHICH INCORPORATES
      NUMBERS OF ALL THE SECTORS. IF THE VALUES ARE LARGE NEGATIVE
      THROUGHOUT THE CONDENSOR THEN FR-->-1. AS WTST VALUES APPROACH 0 INDICATING STEAM
      THROUGHOUT THE CONDENSOR THEN FR IS THEN ADDED TO EXITFR

```

```

CON21130
CON21140
CON21150
CON21160
CON21170
CON21180
CON21190
CON21200
CON21210
CON21220
CON21230
CON21240
CON21250
CON21260
CON21270
CON21280
CON21290
CON21300
CON21310
CON21320
CON21330
CON21340
CON21350
CON21360
CON21370
CON21380
CON21390
CON21400
CON21410
CON21420
CON21430
CON21440
CON21450
CON21460
CON21470
CON21480
CON21490
CON21500
CON21510
CON21520
CON21530
CON21540
CON21550
CON21560
CON21570
CON21580
CON21590
CON21600

```



```

C          TO MAKE IT CONTINUOUS FROM 1-->-1 REFLECTING THE CONDENSOR IN
C          NO STEAM IS EXTRACTED AND THE CONDENSOR WHERE ALL THE TUBES ARE
C          DRY.
C          DO 430 J=1, ISEC
C          IF (PTST(I).GE.0.) PTST(I)=PSAT(NOROWS+1,I)-PTLIM
C          WT SAV=WT SAV+WT ST(I)
C          FR =-(SUBFLO)/W SI
C          DELPVE=DELPVE/SECF LG
C          DO 450 J=1, ISEC
C          IF (ABS(DELP(J)/DELPVE-1.0)-.01) 450,450,440
C          IF (ABS(DELPVE).GT.0.001) GO TO 460
C          GO TO 580
C          CONTINUE
C          DLPVES=DELPVE
C          CONSM=0.0
C          WNCFR=WNCI/(WNCI+W SI)
C          DO 470 J=1, ISEC
C          CONSM=CCNSM+C(J)
C          CONTINUE
C          DELPVE=(WSAVE*SECF LG)**2/CONSM**2
C          DELPVE=(DELPVE+DLPVES)/2.0
C          DMAX=ABS(DELPVE-DELP(1))
C          JMAX=1
C          DO 480 J=2, ISEC
C          DHOLD=ABS(DELPVE-DELP(J))
C          IF (DHOLD.LE.DMAX) GO TO 480
C          DMAX=DHCLD
C          JMAX=J
C          CONTINUE
C          WSPT=0.0
C          WPT=0.0
C          DO 500 J=1, ISEC
C          WP(J)=C(J)*SQR T(DELPVE)
C          WSP(J)=WP(J)*W SI/(WNCI+W SI)
C          IF (J.EQ.JMAX) GO TO 500
C          FAC=WSP(J)-WS(1,J)
C          AFAC=ABS(FAC)
C          IF (AFAC.LT.1.E-3) GO TO 490
C          CHGSC=0.5*WS(1,J)*.26
C          IF (IPLCCOP.GT.3) CHGSC=CHGSC/IPLCCOP*2.0
C          WSP(J)=WS(1,J)+FAC/AFAC*SQR T(AFAC)*CHGSC
C          CONTINUE
C          WSPNT=WSP+WSP(J)
C          WGAS(J)=WSP(J)*WNCFR
C          WP(J)=WSP(J)+WGAS(J)

```

CON21610
CON21620
CON21630
CON21640
CON21650
CON21660
CON21670
CON21680
CON21690
CON21700
CON21710
CON21720
CON21730
CON21740
CON21750
CON21760
CON21770
CON21780
CON21790
CON21800
CON21810
CON21820
CON21830
CON21840
CON21850
CON21860
CON21870
CON21880
CON21890
CON21900
CON21910
CON21920
CON21930
CON21940
CON21950
CON21960
CON21970
CON21980
CON21990
CON22000
CON22010
CON22020
CON22030
CON22040
CON22050
CON22060
CON22070
CON22080


```

500      WPT=WPT+WP(J)
        CONTINUE
        WSP(JMAX)=WSI-WSPT
        WSPT=WSPT+WSP(JMAX)
        WGAS(JMAX)=WSP(JMAX)*WNCFR
        WP(JMAX)=WSP(JMAX)+WGAS(JMAX)
        WPT=WPT+WP(JMAX)
        ILOOP=ILOOP+1
C
C      CHECK FOR STEAMM ADJUSTMENTS WHICH TRY TO PUT TO LOW A STEAM
C      VALUE INTO A SECTOR
C
510      IFAIL=0
        DO 520 K=1,ISEC
        COMP=WSI/200.
        IF (WSP(K).LT.COMP) IFAIL=K
        IF (WSP(K).LT.COMP) WRITE(6,999)
        FORMAT(1X,'STEAM FLOW ADJUSTMENT WAS REQUIRED.')
        IF (WSP(K).LT.COMP) GO TO 530
        CONTINUE
        GO TO 550
520      DIFF=2.*COMP-WSP(IFAIL)
        WSP(IFAIL)=2.*COMP
        ADJ=DIFF/FLOAT(ISEC-1)
        DO 540 J=1,ISEC
        IF (J.EQ.IFAIL) GO TO 540
        WSP(J)=WSP(J)-ADJ
        CONTINUE
        GO TO 510
530      CONTINUE
C
540      DO 560 J=1,ISEC
        WS(1,J)=WSP(J)
        IF (ILOOP-50) 20,20,570
        WRITE(6,1110) IDENT
550      INCORPORATE FR INTO EXITFR TO MAKE IT CONTINUOUS FROM 1-->-1
C
560      EXITFR=STMSUM/WSI+FR
        WSEXIT=STMSUM
        VELEXIT=VELEXIT/SECFLG
        DELPVE = DELPVE/SECFLG
        PMXEXT = PMXEXT/SECFLG
        TSATEX = TSATEX/PSUM
        AMLSEX=STMSUM/18.015
        IF ((STMSUM.LE.0.).AND.(PRCCLR.GT.0.)) AMLSEX=1.0/18.015
        EXITFC=1.
        IF (PRCCLR.EQ.0.0) EXITOA=EXITFR

```

```

CON2 2090
CON2 2100
CON2 2110
CON2 2120
CON2 2130
CON2 2140
CON2 2150
CON2 2160
CON2 2170
CON2 2180
CON2 2190
CON2 2200
CON2 2210
CON2 2220
CON2 2230
CON2 2240
CON2 2250
CON2 2260
CON2 2270
CON2 2280
CON2 2290
CON2 2300
CON2 2310
CON2 2320
CON2 2330
CON2 2340
CON2 2350
CON2 2360
CON2 2370
CON2 2380
CON2 2390
CON2 2400
CON2 2410
CON2 2420
CON2 2430
CON2 2440
CON2 2450
CON2 2460
CON2 2470
CON2 2480
CON2 2490
CON2 2500
CON2 2510
CON2 2520
CON2 2530
CON2 2540
CON2 2550
CON2 2560

```



```

CON22570
CON22580
CON22590
CON22600
CON22610
CON22620
CON22630
CON22640
CON22650
CON22660
CON22670
CON22680
CON22690
CON22700
CON22710
CON22720
CON22730
CON22740
CON22750
CON22760
CON22770
CON22780
CON22790
CON22800
CON22810
CON22820
CON22830
CON22840
CON22850
CON22860
CON22870
CON22880
CON22890
CON22900
CON22910
CON22920
CON22930
CON22940
CON22950
CON22960
CON22970
CON22980
CON22990
CON23000
CON23010
CON23020
CON23030
CON23040

IF (PRCCLR.EQ.0.0) GO TO 590
CALL TO COOLER, IF THERE IS ONE
ENHIC=ENHI
ENHOC=ENHO
ENHFC=ENHF
SHWINC=SHWINV
TB2C=TB2
WBC=WB
IF (NBAD.GT.0) WCNDAV=SUBAVE/FLOAT (NBAD)
CALL COCLEX (TBDRYC,WCNDAV,SBFLOC,WSOUT)
CALCULATE OVERALL POWER REQUIRE TO DRIVE THE COOLANT
PHP=PHP*(SMWBC/(SMWBC+SMWB))+1.1
CALCULATE THE OVERALL COOLER/CONDENSER VOLUME
VOL1=(VOL1+VOLC)
CALCULATE OVERALL EXIT FRACTION
IF ((EXITFR.GT.0.) .AND. (EXITFC.GT.0.)) EXITOA=EXITFR*EXITFC
IF ((EXITFR.GT.0.) .AND. (EXITFC.GT.0.)) RETURN
EXITOA=WSOUT/WSI+(-(SUBFLO+SBFLOC)/WSI)
RETURN
FORMAT (1X,7HSECTOR ,I3,2X,5HROW ,I4)
FORMAT (1H1,37HWSI OUTPUT ,FOR SEC-2 *****)
FORMAT (1H0,10HWSI ,10HWGAS(I) )
FORMAT (1H0,10HWS(1,I) ,10HAOTFLW(I) )
FORMAT (1H0,10HFG ,10HSTSAT1 )
FORMAT (1H0,10HTSAT1 ,10HPMIX1 )
FORMAT (1H0,10HPSAT1 ,10HAMDLSS ,10HAMDLST )
FORMAT (1H0,10HPSAT1 ,10HAMDLSS )
FORMAT (1H0,10HVNCL ,10HVMIX1 )
FORMAT (1H0,10HVG1 ,10HG2 )
FORMAT (1H ,2F10.3 )
FORMAT (1H ,3F10.3 )
FORMAT (1H0,10HSECFAR ,10HARAT )
FORMAT (1H0,10HVEL1 ,5HVEL2 )
FORMAT (1H0,10HDELPI ,5HDELPI2 )
FORMAT (1H ,2F10.4 )
FORMAT (1H1,29HOUTPUT FOR SEC-3 -SECTOR NO. I2)
FORMAT (1H0,36HENTERING PRESSURES IN PSI - MIXTURE=,E10.3,13H SATU
RATION= ,E10.3)
FORMAT (1H ,21HENTERING STM TEMPS - ,F6.2,4F F ,F6.2,2H R)

```

C
C
C

C
C
C

C
C

C
C
C

C

590
600
610
620
630
640
650
660
670
680
690
700
710
720
730
740
750
760
770
780


```

790 FORMAT (1H,32HENT SP. VOL. IN FT**3/LBM - STM=,E10.3,9H N/C GAS=, CON23050
1E10.3,9H MIXTURE=,E10.3) CON23060
800 FORMAT (1H,23HENTERING STM VELOCITY =,E10.3,8H FT/SEC) CON23070
810 FORMAT (1H0,33H** OUTPUT FOR SEC-4 - ROW NUMBER, I4) CON23080
820 FORMAT (1H0,33HTUBE WALL AREA - SQ.FT. - INSIDE=,E10.3,10H OUTSIDE CON23090
1E=,E10.3) CON23100
830 FORMAT (1H,9HTUBE ID=,F6.3,30H FT - TUBE X-SECTIONAL AREA =,E10 CON23110
1.3,6H FT**2) CON23120
840 FORMAT (1H,24HLOG MEAN TUBE THICKNESS=,E10.3,25H FT - LOG MEAN TU CON23130
1BE AREA=,E10.3,6H FT**2) CON23140
850 FORMAT (1H,30HINVERSE WALL HEAT X-FER COEF =,E10.3,17H HR-FT**2-F CON23150
1/B TU) CON23160
860 FORMAT (1H0,22HIN SECALC, SEC-5, ROW,,I4,9H, SECTOR,,I3) CON23170
870 FORMAT (1H,7HALMTD =,E10.3,8H HEFF =,E10.3) CON23180
880 FORMAT (1H,7HOMCI =,E10.3,8H HOMCG =,E10.3) CON23190
890 FORMAT (1H,7HRC =,E10.3,8H KOUT =,E10.3) CON23200
900 FORMAT (1H,7HSHI =,E10.3,8H SHN =,E10.3) CON23210
910 FORMAT (1H,7HTB2 =,E10.3,8H UN =,E10.3,8H VNRE =,E10.3) CON23220
920 FORMAT (1H,7HWC =,E10.3,8H WS =,E10.3) CON23230
930 FORMAT (1H,7HDELP TP=,E10.3,8H VPSH =,E10.3) CON23240
940 FORMAT (1H,7HWCND =,E10.3,8H HFG =,E10.3) CON23250
950 FORMAT (1H,7HAO =,E10.3,8H TBNPR =,E10.3) CON23260
960 FORMAT (1H0,32HNEG STEAM MASS FLOW IN SEC-6 ROW,I4,10H OF SECTOR,I CON23270
14) CON23280
970 FORMAT (1H,18HCURRENT FLOW RATE=,F12.6,17H NEXT FLOW RATE=,F12.6 CON23290
1) CON23300
980 FORMAT (1H,8HWTSI (I)=,F12.6) CON23310
990 FORMAT (1H0,30HNEGATIVE SAT PRESS IN SEC-6 ROW, I4,9H SECTOR, I4) CON23320
1000 FORMAT (1H,18HCURRENT SAT PRESS=,E10.3,11H NEXT ROW=,E10.3) CON23330
1010 FORMAT (1H,8HPTST (I)=,E10.3) CON23340
1020 FORMAT (1H,25HNO PROBLEMS IN SE-6, ROW=,I4,8H SECTOR=,I4) CON23350
1030 FORMAT (1H0,23HOUT PUT FROM SEC-7, ROW, I4,11H OF SECTOR, I4) CON23360
1040 FORMAT (1H,9HWS (I, J) =,E10.3,13H WCOND (I, J) =,E10.3) CON23370
1050 FORMAT (1H,6HTSAT =,E10.3,14H STSAT (I, J) =,E10.3) CON23380
1060 FORMAT (1H,11HGFLW (I, J) =,E10.3,13H PSAT (I, J) =,E10.3) CON23390
1070 FORMAT (1H,28HSEC-7, BELOW 130, WCOND (I, J) =,E10.3,8H WCONDUP=,E10.3 CON23400
1) CON23410
1080 FORMAT (1H,22HSEC-7, BELOW 130, TAL=,E10.3,6H TSAT=,E10.3) CON23420
1090 FORMAT (1H1,3X,4HWTST, 8X,4HP TST/) CON23430
1100 FORMAT (1H, E10.3,2X, E10.3,2X, E10.3) CON23440
1110 FORMAT (1H1,19A4,A3,40HNO CONVERGENCE IN COND. DELTA P (IPL00P)) CON23450
1120 FORMAT (1H1,19A4,A3/I10,5X,2HI=,I2,5X,2HJ=,I1/I10,24HNO CONVERGENC CON23460
1E FOR WCND (I, I2, I1, I1)) CON23470
1END CON23480
CON23490
CON23500
CON23510
CON23520

```

```

C *****
C *****
C *****

```



```

SUBROUTINE HETTRN (ALST,AXO,IR,LJ,CD,WB,SHW,INV,ST$AT,TID,WNC,WST,A
1LMTD,ENHF,HEFF,HOMCI,HOMCD,RC,ROUT,SHI,SHNF,STFO,TB2,VNF,XNRE,ENHI
2,ENHO,SDD)
-----
C$ HET 1
SUBROUTINE HETTRN
HETTRN CALLED BY: SECALC
SUBROUTINES CALLED BY HETTRN:
,DSFVTY,
FUNCTION ROUTINES CALLED BY HETTRN:
,PSATFN,SMUFN,AMUFN,HFCFN,SKBFN,
,BMUFN,CPFN,ROEFN,
-----
DEC 69 REV. COLBJ,FDAVE
COMMON /INPT/ BC(6),BE(6),ENH(6),ENI(6),ENO(6),FOUL,PHI,SKW,STBI,S
1T$ATL,TUBESW,WNCIR,IOPT,PTST(15),SECWID,JBAF,I$EC,JBAF(16),JGAS,MD
2IAM,MPITCH,NEE,NEI,NETE(6),NETI(6),NRNE(6),NRNI(6),NOROWS,WTST(15)
3,W$SI,PFILL
COMMON /ORC2/ ANT(100,15),STB2ES,VH(100)
COMMON /CONST/ AMWNC,CBI,CPB,PI,SG,IFIRST
DIMENSION R2(3),E2OK(3)
HETTON=0
IF (HETCN.NE.1.) GO TO 10
M5=1
WRITE (6,310) M5
WRITE (6,320) IR,LJ
WRITE (6,330) OD,TID
WRITE (6,340) SHW,INV,ST$AT
WRITE (6,350) WST,WNC
-----
C$ HET 2
DATA INITIALIZATION:
BB = COOLANT FLOW IN TUBE LBM/HR-FT**2
DGFLM = CALCULATED TEMP DROP ACROSS FILM???
DLFLM = CALCULATED TEMP DROP ACROSS LIQUID FILM???
HEFF = NONCONDENSIBLE FILM HEAT TRANSFER COEF, BTU/HR-FT**2-F
UEST = ESTIMATED OVERALL HEAT TRANSFER COEF
VALUES FOR USE IN SUBROUTINE D$SVTY
E2OK = FORCE CONSTANT FOR NONCOND GAS
R2 = GAS COLLISION DIAMETER IN ANGSTROMS
ZZZ HET-2
-----
10 IF (WNC.EQ.0.) DGFLM=0.
IF ((LJ.EQ.1).AND.(IR.EQ.1)) GO TO 20
CON23530
CON23540
CON23550
CON23560
CON23570
CON23580
CON23590
CON23600
CON23610
CON23620
CON23630
CON23640
CON23650
CON23660
CON23670
CON23680
CON23690
CON23700
CON23710
CON23720
CON23730
CON23740
CON23750
CON23760
CON23770
CON23780
CON23790
CON23800
CON23810
CON23820
CON23830
CON23840
CON23850
CON23860
CON23870
CON23880
CON23890
CON23900
CON23910
CON23920
CON23930
CON23940
CON23950
CON23960
CON23970
CON23980
CON23990
CON24000

```


CON24010
 CON24020
 CON24030
 CON24040
 CON24050
 CON24060
 CON24070
 CON24080
 CON24090
 CON24100
 CON24110
 CON24120
 CON24130
 CON24140
 CON24150
 CON24160
 CON24170
 CON24180
 CON24190
 CON24200
 CON24210
 CON24220
 CON24230
 CON24240
 CON24250
 CON24260
 CON24270
 CON24280
 CON24290
 CON24300
 CON24310
 CON24320
 CON24330
 CON24340
 CON24350
 CON24360
 CON24370
 CON24380
 CON24390
 CON24400
 CON24410
 CON24420
 CON24430
 CON24440
 CON24450
 CON24460
 CON24470
 CON24480

```

IF (IR.EQ.1) GO TO 30
UE ST=UESTSV
HEFF=HEFFSV
DGFLM=DGFLMS
DLFLM=DLFLMS
TB2=TB2SV
XNRET=XNRES
GO TO 40
IF (IFIRST.EQ.0) GO TO 30
HEFF=2100.
DATA UEST,DGFLM,DLFLM,XNRET/700.,0.05,2.0,100000./
DATA R2,E2OK/3.617,3.996,3.838,97.0,190.0,140.75/
TB2=STB2ES
IFIRST=0
GO TO 40
UE ST=UEST1
HEFF=HEFF1
DGFLM=DGFLM1
DLFLM=DLFLM1
TB2=TB21
XNRET=XNRE1
CONTINUE
  
```

FDAVE IS AN INPUT ITEM WITH A VALUE BETWEEN 0 AND 1 RELATED TO TUBE SPACING AND ORIENTATION.
 FDAVE=C.5

```

BNF=ANT(IR,LJ)
IF (BNF.LT.1.) BNF=1.
BB=WB/(PI*TIID*TIID/4.)
AI=PI*TIID*ALST
AO=PI*CC*ALST
ENHI=1.
ENHF=1.
ENHO=1.
IF (NEI.EQ.0) GO TO 60
DO 50 I=1,NEI
ITEM1=NRNI(I)
ITEM2=ITEM1+NETI(I)-1
IF ((I.GE.EQ.0) AND. (I.LE.ITEM2)) ENHI=ENI(I)
IF (NEI.EQ.0) GO TO 80
DO 70 I=1,NEE
ITEM1=NRNE(I)
ITEM2=ITEM1+NETE(I)-1
IF (I.LT.ITEM.OR.I.GT.ITEM2) GO TO 70
EHNO=ENO(I)
  
```


CON24490
 CON24500
 CON24510
 CON24520
 CON24530
 CON24540
 CON24550
 CON24560
 CON24570
 CON24580
 CON24590
 CON24600
 CON24610
 CON24620
 CON24630
 CON24640
 CON24650
 CON24660
 CON24670
 CON24680
 CON24690
 CON24700
 CON24710
 CON24720
 CON24730
 CON24740
 CON24750
 CON24760
 CON24770
 CON24780
 CON24790
 CON24800
 CON24810
 CON24820
 CON24830
 CON24840
 CON24850
 CON24860
 CON24870
 CON24880
 CON24890
 CON24900
 CON24910
 CON24920
 CON24930
 CON24940
 CON24950
 CON24960

```

ENHF=ENF(I)
CONTINUE
CONTINUE
IF (HETCN.NE.1.) GO TO 90
M5=2
WRITE (6,310) M5
WRITE (6,360) UEST,HEFF
WRITE (6,370) DGFLM,DLFLM
WRITE (6,380) TB2,XNRET
WRITE (6,390) BNF,AXO,AI
WRITE (6,400) ENHI,ENHO

```

```

C$ HET 3
-----
          CALCULATE SUBPROGRAM INITIAL VALUES
AMOLSS & AMOLSC ARE MOLECULAR WEIGHTS USED TO CALCULAT
AMWAV , THE MIXTURE MOLECULAR WEIGHT.
AXO = AREA OF TUBE BANK OPEN TO FLOW/TUBE
BB = COOLENT FLOW IN TUBE LB/HR-FT**2
GMAX = STEAM-NC FLOW LB/FT**2-HR
HSTO = LATENT HEAT OF VAPE ORIZATION OF THE STEAM
JGAS = INDICATOR FOR TYPE OF N/C GAS PRESENT
K = COUNTER FOR NUMBER OF ITERATIONS
PSAT = STEAM SATURATION PRESS IN PSI
RC = RATIO OF NON-CONDENSIBLES TO TOTAL FLOW IN DETERMINATION
RMWNC & RMWSC ARE WEIGHTING FACTORS USED IN DETERMINATION
OF THE MIXTURE VISCOSITY.
OD = TUBE OUTER DIAMETER
STBAVE = AVERAGE COOLANT TEMP
STBI = INLET COOLANT TEMP
STSAT = LOCAL STEAM SAT TEMP F
STWCG = TUBE OUTER WALL TEMP
TB2TH = OUTLET COOLANT TEMP
WBOTH = SUM OF WS AND WNC
WNC = NON-CONDENSIBLE FLOW LB(MASS)/HR
WST = STM FLOW TO ROW BEING CONSIDERED LB(M)/HR
XNRE = MIXTURE REYNOLDS NUMBER
VALUES CARRIED INTO THIS ROUTINE
COMMONC , AMWNC
ORC2 - , AMWNC
COMMONC/NEW/ - , STBI , JGAS ,
PASS LIST - , STSAT ,
SEC3 - , STSAT ,
HET2 - , DLFLM , DGFLM , OD , AXO , WST , WNC ,
, PSATFN , SMUFN , AMUFN , HFGFN ,
FUNCTION ROUTINES CALLED IN HET-3

```

70
80

CON24970
 CON24980
 CON24990
 CON25000
 CON25010
 CON25020
 CON25030
 CON25040
 CON25050
 CON25060
 CON25070
 CON25080
 CON25090
 CON25100
 CON25110
 CON25120
 CON25130
 CON25140
 CON25150
 CON25160
 CON25170
 CON25180
 CON25190
 CON25200
 CON25210
 CON25220
 CON25230
 CON25240
 CON25250
 CON25260
 CON25270
 CON25280
 CON25290
 CON25300
 CON25310
 CON25320
 CON25330
 CON25340
 CON25350
 CON25360
 CON25370
 CON25380
 CON25390
 CON25400
 CON25410
 CON25420
 CON25430
 CON25440

```

C ZZZ HET-3
C-----
90 K=0
    WBOTH=WST+WNC
    RC=WNC/(WBOTH)
    TSAT=STSAT+459.69
    GMAX=(WBOTH)/AXO
    PSAT=PSATFN(TSAT)
    AMOLSS=WST/18.015
    AMOLSC=WNC/AMWNC
    AMOLT=AMOLSS+AMOLSC
    AMWAV=(WBOTH)/AMOLT
    RMWNC=SQRT(AMWNC)*AMOLSC/AMOLT
    RMWSC=4.24444*AMOLSS/AMOLT
    AVIS=(SMJFN(TSAT)*RMWSC+AMUFN(TSAT,JGAS)*RMWNC)/(RMWSC+RMWNC)
    HSTO=HFGFN(STSAT)
    STBAVE=(STBI+TB2)/2.0
    DELFLM=DLFLM
    DLGFLM=DGFLM
    STWO=STSAT-DELFLM-DLGFLM
    STFO=(STSAT+STWO)/2.0
    XNRE=OD*(WBOTH)/(AXO*3600.*AVIS)
    IF (HETCN.NE.1.) GO TO 100
M5=3
WR ITE (6,310) M5
WR ITE (6,410) GMAX,PSAT
WR ITE (6,420) AMOLSS,AMOLSC,AMOLT
WR ITE (6,430) RMWNC,RMWSC
WR ITE (6,440) AVIS,HSTO,XNRE
WR ITE (6,450) STBAVE,STFO,STWO
WR ITE (6,460) DELFLM,DLGFLM
C$-----
C HET 5
C-----
C COLBY J FACTOR CALCULATION AND BRANCH
C WNCI = TOTAL WEIGHT OF NONCOND ENTERING CONDENSER
C IF NO NONCOND, THEN SKIP DIFFUSIVITY CALCULATION.
C-----
C ZZZ HET-5
100 CONTINUE
    COLBJ=EXP(0.53883-0.544*ALOG(XNRE))
    IF (HETCN.NE.1.) GO TO 110
M5=5
WR ITE (6,310) M5
WR ITE (6,470) COLBJ,WNC
IF (WNC.EQ.0.) GO TO 120
110

```


C\$-----
HET 6

PREPARATION FOR CALL TO SUBROUTINE DFSVTY;
CALCULATE SCHMIDT NUMBER AND PARAMETER CJ.

THIS SECTION IS BRANCHED AROUND IF NO NONCOND GASSES ARE
PRESENT.

AMWAV = STEAM-N/C GAS MIXTURE MOLECULAR WEIGHT
AVIS = AVG VISCOSITY OF STEAM-N/C GAS MIXTURE
CJ = PARAMETER USED IN CALCULATION OF THE HEAT TRANSFER COEF.
SEE EQUATION 11 IN APP B
DD = DIFFUSIVITY (SEE NOTE)
DDG = DUMMY PASSING PARAMETER FOR SUB DFSVTY
E2OK = N/C GAS FORCE CONSTANT (SEE SUB DFSVTY)
PATM = SAT PRESS IN ATM
PGB = NONCOND PARTIAL PRESSURE
PSAT = STEAM SATURATION PRESSURE PSI
R = N/C GAS COLLISION DIAMETER (SEE SUB DFSVTY)
TSAT = STEAM SATURATION TEMP
TSATK = SATURATION TEMP IN DEGREES KELVIN
XNSCH = SCHMIDT NUMBER

NOTE: PATM, PGB, AND TSATK ARE USED FOR CALL TO DFSVTY
SEE NOTE IN HET-3, BUT REM PGB IS USED AGAIN
IN HET-12.

NOTE: 18.015 IS THE MOLECULAR WEIGHT OF WATER
2.655 IS THE STEAM COLLISION DIAMETER IN ANGSTROMS
363. IS THE STEAM FORCE CONSTANT USED IN DFSVTY

NOTE: ONLY DG (DIFFUSIVITY IN CM**2/SEC) IS MODIFIED IN
SUBROUTINE DFSVTY.

NOTE: 0.258 CONVERTS UNITS OF DIFFUSIVITY FROM
CM**2/SEC TO FT**2/HR, AND 3600 CONVERTS
VISCOSITY FROM LB(F)-HR TO LB(F)-SEC.
IN XNSCH CALC, .258*3600 = 928.8

ZZZ HET-6

PATM=PSAT/14.7
PGB=PSAT*(AMOL SC/AMOLSS)
TSATK=TSAT/1.8
CALL DFSVTY (T SATK, PATM, 18.015, AMWNC, 2.655, R2(JGAS), 363., E2OK(JGAS
1), 0., 0., DG, DGG)
XNSCH=(AVIS*TSAT*10.73/((PSAT+PGB)*AMWAV*DG))*928.8

CON25450
CON25460
CON25470
CON25480
CON25490
CON25500
CON25510
CON25520
CON25530
CON25540
CON25550
CON25560
CON25570
CON25580
CON25590
CON25600
CON25610
CON25620
CON25630
CON25640
CON25650
CON25660
CON25670
CON25680
CON25690
CON25700
CON25710
CON25720
CON25730
CON25740
CON25750
CON25760
CON25770
CON25780
CON25790
CON25800
CON25810
CON25820
CON25830
CON25840
CON25850
CON25860
CON25870
CON25880
CON25890
CON25900
CON25910
CON25920

CJ=COLBJ*GMAX/(XNSCH**0.066667)
 IF (HETCN.NE.1.) GO TO 120
 M5=6
 WRITE (6,310) M5

```

C$-----
C HET 7
C-----
C BEGIN ITERATIVE CALCULATIONS FOR:
C   HEAT TRANSFER COEF
C   TEMP DROP ACROSS LIQUID FILM
C   TEMP DROP ACROSS N/C FILM (IF ANY)
C
C THE PROGRAM CONTINUES TO RETURN HERE UNTIL ONE
C OR MORE OF THE FOLLOWING CONDITIONS ARE MET:
C 1) CHANGE IN THE CALCULATED HEAT TRANSFER COEF IS
C   LESS THAN 0.1% OF THE PREVIOUS VALUE AND AT LEAST
C   FOUR ITERATIONS HAVE BEEN MADE.
C 2) CHANGE IN THE CALCULATED TEMP ACROSS THE LIQUID
C   FILM IS LESS THAN 0.01 DEGREES AND THE CHANGE
C   IN CALCULATED TEMP DIFF ACROSS THE GAS FILM
C   IS LESS THAN 0.001 DEGREES.
C 3) TEN ITERATIONS HAVE BEEN COMPLETED.
C
C AI = INTERNAL SURFACE AREA OF ONE TUBE FT**2
C AO = EXTERNAL SURFACE AREA OF ONE TUBE FT**2
C BB = COOLANT FLOW IN TUBE LBM/HR-FT**2
C BMU = COOLANT VISCOSITY LBM/HR-FT
C BNF = TUBE FLOODING FACTOR
C CBI = COOLANT CONCENTRATION
C ENHI = INTERNAL FILM COEF ENHANCEMENT FACTOR
C ENHO = EXTERNAL FILM COEF ENHANCEMENT FACTOR
C RIN = RESISTANCE TO HEAT TRANSFER DUE INNER FILM
C TID = TUBE ID FT
C OD = TUBE OD FT
C SHBI = SPECIFIC FILM HEAT OF COOLANT BTU/LBM-F
C SHI = INTERNAL FILM HEAT TRANSFER COEF BTU/HR-FT**2-F
C SHMK = EXTERNAL FILM HEAT TRANSFER COEF BTU/HR-FT**2-F
C SKBO = THERMAL CONDUCTIVITY OF THE COOLANT BTU-FT/HR-FT**2-F
C STBAVE = AVE COOLANT TEMP.
C STFO = AVE TEMP OF OUTER LIQUID FILM (SEE NOTE)
C STSAT = LOCAL SAT TEM
C TB2 = OUTLET COOLANT TEMP. (SEE NOTE ON TB2 IN HET-3)
C WB = COOLANT FLOW RATE PER TUBE LBM/HR
C XNRFB = REYNOLDS NUMBER OF COOLANT
C XNPRB = PRANDTL NUMBER OF COOLANT
C
C NOTE: SHMK IS CALCULATED FIRST WITHOUT TAKING FLOODING
C INTO ACCOUNT. SEE NUSSELT EQN PG. 16.
  
```


CON26410
 CON26420
 CON26430
 CON26440
 CON26450
 CON26460
 CON26470
 CON26480
 CON26490
 CON26500
 CON26510
 CON26520
 CON26530
 CON26540
 CON26550
 CON26560
 CON26570
 CON26580
 CON26590
 CON26600
 CON26610
 CON26620
 CON26630
 CON26640
 CON26650
 CON26660
 CON26670
 CON26680
 CON26690
 CON26700
 CON26710
 CON26720
 CON26730
 CON26740
 CON26750
 CON26760
 CON26770
 CON26780
 CON26790
 CON26800
 CON26810
 CON26820
 CON26830
 CON26840
 CON26850
 CON26860
 CON26870
 CON26880

NOTE: STFO IS INITIALLY GUESSED BASED ON STWO WHICH IS IN TURN BASED ON DLFLM AND DGFLM. DGFLM AND DLFLM ARE INITIALIZED BY DATA STATEMENT UPON ENTERING THIS SUBROUTINE. ALL FOUR OF THESE VARIABLES ARE UPDATED BELOW.

```

ZZZ HE T-7
-----
120 TB2=STSAT-(STSAT-STBI)/EXP(UEST*AO/(WB*CPFN(CBI,STBAVE)))
    STBAVE=(STBI+TB2)/2.
    SKBO=SKBFN(O.,STFO)
    SKB=SKBFN(CBI,STBAVE)
    BMU=BMUFN(CBI,STBAVE)
    SHBI=CPFN(CBI,STBAVE)
    XNREB=TBID*BB/BMU
    XNPRB=SHBI*BMU/SKB
    SHI=0.023*(XNREB)**0.8*XNPRB**0.33333*(SKB/TID)*ENHI
    RIN=AO/(SHI*AI)
    SHMK=0.725*(SKBO**3*ROEFN(O.,STFO)**2*HFGFN(STFO)*416975040.0/(BM
    1UFN(O.,STFO)*OD*DELFLM)**.25*ENHO
  
```

THIS IS THE PLACE TO ENTER CORRECTIONS TO THE EXTERNAL FILM COEFF. THE FOLLOWING IS A CORRECTION ACCORDING TO FUJII, ET AL. TO ACCOUNT FOR THE EFFECTS OF VAPOR SHEAR AT HIGH VAPOR REYNOLDS NUMBERS.

```

SHMK1=SHMK*OD/SKB0
ANUS=SHMK*OD/SKB0
EMUL=BMUFN(O.,TSAT)
EMUS=SMUFN(TSA,T)*3600.
RHOL=R0EFN(O.,TSAT)
RHOS=1./VGFN(TSAT,PSAT)
VISRA=(EMUS/RHOS)/(EMUL/RHOL)
RETP=XNRE*VISRA
TERM=SQRT(RETP)/ANUS
IF (TERM.LT..278) GO TO 130
ANUSP=1.24*(ANUS**0.8)*(RETP**0.1)
GO TO 140
ANUSP=ANUS*0.70/0.725
SHMKP=ANUSP*SKBO/OD
SHMK=SHMKP
  
```

```

IF (HETCN.NE.1.) GO TO 150
M5=7
WRITE (6,310) M5
WRITE (6,480) TB2,STBAVE
  
```


WR ITE (6, 490) SKBO, SKB
 WR ITE (6, 500) BMU, SHBI
 WR ITE (6, 510) XNRE, B, XNPRB
 WR ITE (6, 520) SHI, RIN, SHMK

C\$ HET 9

TEST FOR TUBE FLOODING, MODIFY
 SHMK AS NEEDED

THIS SECTION MODIFIES THE EXTERNAL HEAT TRANSFER
 COEF GIVEN BY NUSSELT EQN. FOR TUBE FLOODING.

BNF = CALCULATED TUBE FLOODING FACTOR (SEE NOTE BELOW)
 FDAVE = INPUT VALUE OF TUBE FLOODING FACTOR (SEE NOTE BELOW)
 FDAVN & FDAVM ARE INTERMEDIATE VALUES USED LATER.
 FOUL = TUBE FOULING FACTOR INPUT BY USER
 RFACT = SUM OF THERMAL RESISTANCES NEGLECTING GAS FILM
 RIN = RESESTANCE TO HEAT X-FER DUE TO INTERNAL FILM
 SHNF = EXTERIOR HEAT X-FER COEF, SHMK MODIFIED FOR RAIN
 SHWINV = INVERSE OF WALL HEAT TRANSFER COEF

NOTE: ADD CALC FOR FDAVE CURRENTLY UNDEF
 NOTE: CALC FOR FDAVM AND FDAVN SHOULD BE MOVED
 ABOVE LINE 40.

ZZZ HET-9

 150 CONTINUE

INUNDATION EFFECT MAY BE BYPASSED BY SETTING BNF = 1.

BNF = 1.
 IF (FDAVE.LT.0. OR .BNF.LT.2.) GO TO 160
 FDAVN=0.6*FDAVE+(1.-0.5647*FDAVE)/BNF**.20
 FDAVM=0.6*FDAVE+(1.-0.5647*FDAVE)/(BNF-1.)**.20
 SHNF=SHMK*(BNF*FDAVN-(BNF-1.)*FDAVM)

GO TO 170
 SHNF=0.95*(BNF*.9-(BNF-1.))**.9)*SHMK
 RFACT=RIN+SHWINV+FOUL+1./SHNF
 IF (HETCN.NE.1.) GO TO 180

M5=9

WR ITE (6, 310) M5
 WR ITE (6, 530) FDAVN, FDAVM
 WR ITE (6, 540) SHNF, RFACT

C\$ HET 10

CON2 6890
 CON2 6900
 CON2 6910
 CON2 6920
 CON2 6930
 CON2 6940
 CON2 6950
 CON2 6960
 CON2 6970
 CON2 6980
 CON2 6990
 CON2 7000
 CON2 7010
 CON2 7020
 CON2 7030
 CON2 7040
 CON2 7050
 CON2 7060
 CON2 7070
 CON2 7080
 CON2 7090
 CON2 7100
 CON2 7110
 CON2 7120
 CON2 7130
 CON2 7140
 CON2 7150
 CON2 7160
 CON2 7170
 CON2 7180
 CON2 7190
 CON2 7200
 CON2 7210
 CON2 7220
 CON2 7230
 CON2 7240
 CON2 7250
 CON2 7260
 CON2 7270
 CON2 7280
 CON2 7290
 CON2 7300
 CON2 7310
 CON2 7320
 CON2 7330
 CON2 7340
 CON2 7350
 CON2 7360

CON27370
 CON27380
 CON27390
 CON27400
 CON27410
 CON27420
 CON27430
 CON27440
 CON27450
 CON27460
 CON27470
 CON27480
 CON27490
 CON27500
 CON27510
 CON27520
 CON27530
 CON27540
 CON27550
 CON27560
 CON27570
 CON27580
 CON27590
 CON27600
 CON27610
 CON27620
 CON27630
 CON27640
 CON27650
 CON27660
 CON27670
 CON27680
 CON27690
 CON27700
 CON27710
 CON27720
 CON27730
 CON27740
 CON27750
 CON27760
 CON27770
 CON27780
 CON27790
 CON27800
 CON27810
 CON27820
 CON27830
 CON27840

```

      CALCULATE LOG-MEAN TEMP-DIFFERENCE
      THIS CALCULATION IS COMPLETED ONCE DURING EACH
      ITERATION. UPON COMPLETION, A TEST IS MADE
      FOR THE PRESENCE OF N/C GASSES. IF ANY
      GAS IS PRESENT, PROGRAM BRANCHES TO LINE 110 (HET-12).
      IF NOT, THEN PROGRAM FLOWS TO HET-11, BELOW.

      ALMTD = LMTD          DIFF BETWEEN STEAM AND COOLANT OUTLET
      HOMCO = TEMP        DIFF BETWEEN STEAM AND COOLANT AT INLET
      HOMCI = TEMP        CONTROL FLAG
      JRC = PRINT        OF HOMCI TO HOMCO
      RODT = RATIO      OF HOMCI TO HOMCO
      STBI = COOLANT   INLET TEMP
      STSAT = STEAM    SATURATION TEMP
      TB2 = COOLANT   OUTLET TEMP
      WNCI = TOTAL    N/C GAS FLOW TO CONDENSER

      ZZZ HET-10
      -----
      180  HOMCI=STSAT-STBI
          HOMCO=STSAT-TB2
          IF (HOMCO.LT.1.E-15) WRITE(6,20600) HOMCI,HOMCO
          IF (HOMCI.LT.1.E-15) WRITE(6,20600) HOMCI,HOMCO
          IF (HOMCO.LT.1.E-15) HOMCO=1.E-15
          RODT=HOMCI/HOMCO
          IF INLET/OUTLET DELTA T RATIO IS NEAR 1.0, ALMTD = ARITH. AVG.
          IF (RODT.GT.1.1) GO TO 190
          ALMTD=0.5*(HOMCI+HOMCO)
          IF (HETCN.EQ.1.) WRITE (6,670) STSAT,STBI,TB2,LJ,IR,II
          GO TO 200
      190  ALMTD=(HOMCI-HOMCO)/ALOG(RODT)
      200  CONTINUE
          IF (HETCN.NE.1.) GO TO 210
          M5=10
          WRITE (6,310) M5
          WRITE (6,550) HOMCI,HOMCO
          WRITE (6,560) RODT,ALMTD
          IF (WNC.NE.0.) GO TO 230
      210  -----
          C$ HET 11
          CALCULATE FINAL HEAT TRANSFER PARAMETERS
          FOR NO N/C GASSES ENTERING THE CONDENSER.
  
```


CON27850
 CON27860
 CON27870
 CON27880
 CON27890
 CON27900
 CON27910
 CON27920
 CON27930
 CON27940
 CON27950
 CON27960
 CON27970
 CON27980
 CON27990
 CON28000
 CON28010
 CON28020
 CON28030
 CON28040
 CON28050
 CON28060
 CON28070
 CON28080
 CON28090
 CON28100
 CON28110
 CON28120
 CON28130
 CON28140
 CON28150
 CON28160
 CON28170
 CON28180
 CON28190
 CON28200
 CON28210
 CON28220
 CON28230
 CON28240
 CON28250
 CON28260
 CON28270
 CON28280
 CON28290
 CON28300
 CON28310
 CON28320

CONTROL PASSES FROM THIS ROUTINE TO ONE OF TWO PLACES,
 LINE 40 (HET-7) TO START A NEW ITERATION, OR TO
 LINE 170 (HET-13) TO TERMINATE THIS HETTRN CALL
 WHEN ONE OF THE FOLLOWING CRITERIA ARE MET:
 1) 10 ITERATIONS COMPLETED WITHOUT CONDITION 2 BEING
 MET.
 2) CHANGE IN HEAT TRANSFER COEF. LT. 1 PERCENT
 BETWEEN SUCCESSIVE ITERATIONS.

DELFLM = SAVED VALUE OF DLFLM, USED ONLY FOR PRINT
 DGFLM = TEMP DROP ACROSS GAS FILM, SET TO 0 HERE
 DLFLM = TEMP DROP ACROSS LIQUID CONDENSATE FILM
 K = COUNTER FOR NUMBER OF ITERATIONS
 RFACT = SUM OF THERMAL RESISTANCES
 ROUT = EXTERNAL FILM RESISTANCE. (SEE NOTE)
 ROD = TUBE OD
 SHNF = EXTERNAL FILM HEAT X-FER COEF
 SKBO = THERMAL CONDUCTIVITY OF EXTERNAL LIQUID FILM
 STCO = TEMP AT SURFACE OF OUTER LIQUID FILM
 STFO = AVE TEMP OF OUTER LIQUID FILM
 STBAVE = AVE COOLANT TEMP
 STSAT = STEAM SATURATION TEMP
 STWJ = TUBE OUTER WALL TEMP
 UEST = VALUE OF UEST FROM LAST ITERATION FOR PRINT
 UESTS = SAVED VALUE OF UEST, USED ONLY FOR PRINT
 UTEST = SAVED HEAT X-FER COEF.
 XNU = NUSSELT NUMBER

NOTE: CONSIDER REQUIREMENT FOR MINIMUM OF
 FOUR ITERATIONS PRIOR TO UPDATING UEST. COULD
 BE AN ALLOWANCE FOR DELFLM TO CATCH UP IN
 CONVERGENCE. IF SO, TEST DELFLM FOR ITS
 CWN CONVERGENCE, ELIMINATE MIN OF 4 ITERATIONS.

NOTE: ROUT WILL BE REDEFINED AS 1/ROUT
 IN HET-13 PRIOR TO EXIT FROM HETTRN

ZZZ HET-11

 ROUT=1./SHNF
 UTEST=1./RFACT
 XNU=SHNF*OD/SKBO
 IF (ABS(UEST-UTEST)/UTEST.LT..01) GO TO 290
 UESTSV=UEST
 UEST=UTEST
 IF (K.GT.4) UEST=0.5*(UTEST+UESTSV)
 STWO=STSAT-(STSAT-STBAVE)*UTEST/SHNF

CC

STCO=STSAT
STFO=(STCO+STWO)/2.

DGFLM=0.
DLFLM=STCO-STWO
DELFLM=DLFLM

K=K+1

IF (HETCN.NE.1.) GO TO 220

M5=11

WR ITE (6,310) M5 UTEST,UESTSV

WR ITE (6,570) XNU,ROUT

WR ITE (6,580) STWO,STCO,STFO

WR ITE (6,590) DGFLM,DLFLM

WR ITE (6,600) GO TO 120

IF (K.LT.20) GO TO 120

WR ITE (6,640) UTESTSV,UTEST

GO TO 290

220

C\$-----

HET 12

CALCULATE FINAL HEAT TRANSFER PARAMETERS
FOR N/C GASSES ENTERING CONDENSER

PROGRAM CONTROL COMES HERE FROM HET-10. CONTROL PASSES
FROM HERE TO ONE OF TWO PLACES, EITHER LINE 40 (HET-7) TO
BEGIN THE NEXT ITERATION, OR TO LINE 170 (HET-13) WHEN
ONE OF THE FOLLOWING CONDITIONS ARE MET:

- 1) 10 ITERATIONS HAVE BEEN COMPLETED PRIOR TO MEETING
CONDITION 2.
- 2) CHANGES IN UEST.LT..001, IN DLFLM.LT.
.01 AND IN DGFLM.LT..001

ALMTD = LMTD
BONE = CONSTANT IN SOLUTION OF EQN 11A, APP A.

CJ - SEE BONE

CONE - SEE BONE

DELFLM = DLFLM FROM PREVIOUS ITERATION
DELTAU = HEAT DUTY ON HEAT X-FER SURFACE

DENOM =

DGFLM = TEMP DIFF ACROSS N/C GAS FILM

DLFLM = TEMP DIFF ACROSS CONDENSATE FILM

DLGFLM = DGFLM FROM PREVIOUS ITERATION

DTDP = INVERSE OF DPDT (SEE NOTE)

HEFF = N/C GAS HEAT X-FER COEF

HSTO = STEAM LATENT HEAT OF VAPORIZATION

IBT = PRINT CONTROL

IR = CURRENT ROW NUMBER

K = ITERATION COUNTER

LJ = CURRENT SECTOR NUMBER

PGB = PARTIAL PRESSURE OF N/C GASSES

CON2 8330
CON2 8340
CON2 8350
CON2 8360
CON2 8370
CON2 8380
CON2 8390
CON2 8400
CON2 8410
CON2 8420
CON2 8430
CON2 8440
CON2 8450
CON2 8460
CON2 8470
CON2 8480
CON2 8490
CON2 8500
CON2 8510
CON2 8520
CON2 8530
CON2 8540
CON2 8550
CON2 8560
CON2 8570
CON2 8580
CON2 8590
CON2 8600
CON2 8610
CON2 8620
CON2 8630
CON2 8640
CON2 8650
CON2 8660
CON2 8670
CON2 8680
CON2 8690
CON2 8700
CON2 8710
CON2 8720
CON2 8730
CON2 8740
CON2 8750
CON2 8760
CON2 8770
CON2 8780
CON2 8790
CON2 8800


```

CUN2 8810
CUN2 8820
CUN2 8830
CUN2 8840
CUN2 8850
CUN2 8860
CUN2 8870
CUN2 8880
CUN2 8890
CUN2 8900
CUN2 8910
CUN2 8920
CUN2 8930
CUN2 8940
CUN2 8950
CUN2 8960
CUN2 8970
CUN2 8980
CUN2 8990
CUN2 9000
CUN2 9010
CUN2 9020
CUN2 9030
CUN2 9040
CUN2 9050
CUN2 9060
CUN2 9070
CUN2 9080
CUN2 9090
CUN2 9100
CUN2 9110
CUN2 9120
CUN2 9130
CUN2 9140
CUN2 9150
CUN2 9160
CUN2 9170
CUN2 9180
CUN2 9190
CUN2 9200
CUN2 9210
CUN2 9220
CUN2 9230
CUN2 9240
CUN2 9250
CUN2 9260
CUN2 9270
CUN2 9280

RFAC2 = SUM CF THERMAL RESISTANCES NEGLECTING N/C GASSES
ROUT = EXTERNAL HEAT X-FER COEF
OD = TUBE OD
SHNF = EXTERNAL LIQUID FILM HEAT X-FER COEF
SKBO = THERMAL CONDUCTIVITY OF OUTER LIQUID
STBAVE = AVG COOLANT TEMP
STCO = TEMP AT SURFACE OF OUTER LIQUID FILM
STFC = OUTER LIQUID FILM AVG TEMP
STSAT = STM SATURATION TEMP
STWO = TUBE OUTER WALL TEMP
T = AVG LIQUID FILM TEMP IN RANKIN
TDIF = TEMP DIFF BETWEEN SAT STM AND AVE COOLANT TEMP
TSAT = STM SAT TEMP IN RANKIN
UEST & UESTSV - VALUE OF UTEST AND UEST FROM PREVIOUS ITERATION
UTEST = OVERALL HEAT X-FER COEF.
XNU = NUSSELT NUMBER

ZZZ HE T-12
-----
230 CONTINUE
M5 = 12
IF (HEICN.EQ.1.) WRITE (6,310) M5
ST CO = STSAT-DLGFLM
T = (TSA+STCG+459.69)/2.0
DTDP = 1./(((6452.562+2.*837533.2/T)/T**2)*EXP(14.15012--(6+52.562+83
17533.2/T)/T))
BONE = -1.*(CJ*HSTO/ALMTD+(PGB*UTDP/ALMTD+1.)/RFAC2)
CONE = CJ*HSTO/(ALMTD*RFAC2)
UTEST = (-SQRT(BONE**2-4.*CONE))-BONE)/2.
DENOM = 1.-UTEST*RFAC2
IF (DENOM.GT.1.E-7) GO TO 240
HEFF = 1.0E8
GO TO 250
HEFF = UTEST/DENOM
240 CONTINUE
250 ROUT = (HEFF+SHNF)/(HEFF*SHNF)
TDIF = STSAT-STBAVE
IF (TDIF.GT.0) GO TO 260
IF (IBT.EQ.0) WRITE (6,660) STSAT,STBAVE,LJ,IR
IBT = 1
TDIF = .1
CONTINUE
260 DELTAU = TDIF*UTEST
DGLFM = DELTAU/SHNF
STCO = STSAT-DGFLM
STWO = STCO--DLFLM

```


CON2 9770
 CON2 9780
 CON2 9790
 CON2 9800
 CON2 9810
 CON2 9820
 CON2 9830
 CON2 9840
 CON2 9850
 CON2 9860
 CON2 9870
 CON2 9880
 CON2 9890
 CON2 9900
 CON2 9910
 CON2 9920
 CON2 9930
 CON2 9940
 CON2 9950
 CON2 9960
 CON2 9970
 CON2 9980
 CON2 9990
 CON3 0000
 CON3 0010
 CON3 0020
 CON3 0030
 CON3 0040
 CON3 0050
 CON3 0060
 CON3 0070
 CON3 0080
 CON3 0090
 CON3 0100
 CON3 0110
 CON3 0120
 CON3 0130
 CON3 0140
 CON3 0150
 CON3 0160
 CON3 0170
 CON3 0180
 CON3 0190
 CON3 0200
 CON3 0210
 CON3 0220
 CON3 0230
 CON3 0240

HEFFL = HEFF
 DLFLM1 = DLFLM
 DGFLM1 = DGFLM
 TB21 = TB2
 XNREI = XNRE
 CONTINUE
 UESTSV = UEST
 HEFFSV = HEFF
 DGFLMS = DGFLM
 DLFLMS = DLFLM
 TB2SV = TB2
 XNRESV = XNRE
 RETURN
 TOP OF PAGE CHARACTER FOR USE WITH PRT
 (1H, 17H) IN HETTERN -HET, I2)
 (1H, 4H) RCW = I4, I0H SECTOR = I4)
 (1H, 3H) SHOD = F6, 4) TID = F6, 4)
 (1H, 7H) SHWINV = E10.3, 8H WNC = F8, 2)
 (1H, 4H) WST = F8, 2, 6H HEFF = E10.3)
 (1H, 5H) UEST = E10.3, 7H DFLM = E10.3)
 (1H, 6H) DGFLM = E10.3, 8H XNRET = E10.3)
 (1H, 4H) TB2 = E10.3, 5H AO = E10.3, 5H AI = E10.3)
 (1H, 4H) BNF = E10.3, 7H EHN = E10.3)
 (1H, 5H) EHNI = E10.3, 7H PSAT = E10.3)
 (1H, 5H) GMAX = E10.3, 7H AMOLSC = E10.3, 8H AMDLT = E10.3)
 (1H, 7H) AMWNC = E10.3, 9H RMWSC = E10.3)
 (1H, 6H) RMWNC = E10.3, 8H HSTO = E10.3, 7H XNRE = E10.3)
 (1H, 5H) AVIS = E10.3, 7H STFC = E10.3, 7H STWC = E10.3)
 (1H, 7H) STBAVE = E10.3, 7H DLGFLM = E10.3)
 (1H, 7H) DELFLM = E10.3, 9H WNC = E10.3)
 (1H, 6H) COLB = E10.3, 6H STBAVE = E10.3)
 (1H, 4H) SKBO = E10.3, 6H SKBI = E10.3)
 (1H, 5H) SKBO = E10.3, 6H SHBI = E10.3)
 (1H, 4H) BMU = E10.3, 7H XNPRB = E10.3)
 (1H, 6H) XNRE = E10.3, 8H RIN = E10.3, 5H SHMK = E10.3)
 (1H, 4H) SHI = E10.3, 6H RIN = E10.3, 5H SHMK = E10.3)
 (1H, 4H) FAVN = E10.3, 8H RFACT = E10.3)
 (1H, 5H) FNF = E10.3, 8H RFACT = E10.3)
 (1H, 6H) HOMCI = E10.3, 8H HOMCO = E10.3)
 (1H, 5H) RODT = E10.3, 8H ALMTD = E10.3)
 (1H, 6H) UTEST = E10.3, 8H ESTSV = E10.3)
 (1H, 4H) XNU = E10.3, 7H ROUT = E10.3)
 (1H, 5H) STWO = E10.3, 7H STCO = E10.3, 7H STFO = E10.3)
 (1H, 6H) DGFLM = E10.3, 8H DLFLM = E10.3)
 (1H, 5H) CONVERGENCE NOT YET ACHIEVED ON UEST IN HET-12, K=
 (1H, 52H) CONVERGENCE NOT YET ACHIEVED ON DELFLM IN HET-12, K=

300

C\$ 310
 320
 330
 340
 350
 360
 370
 380
 390
 400
 410
 420
 430
 440
 450
 460
 470
 480
 490
 500
 510
 520
 530
 540
 550
 560
 570
 580
 590
 600
 610
 620

CON30730
CON30740
CON30750
CON30760
CON30770
CON30780
CON30790
CON30800
CON30810
CON30820
CON30830
CON30840
CON30850
CON30860
CON30870
CON30880
CON30890
CON30900
CON30910
CON30920
CON30930
CON30940
CON30950
CON30960
CON30970
CON30980
CON30990
CON31000
CON31010
CON31020
CON31030
CON31040
CON31050
CON31060
CON31070
CON31080
CON31090
CON31100
CON31110
CON31120
CON31130
CON31140
CON31150
CON31160
CON31170
CON31180
CON31190
CON31200

DELTPC = PRESSURE LOSS AT COOLER DUE TO VELOCITY CHANGE
DELTPC = PRESS DROP ACROSS A ROW OF TUBES PSI
HEFFC = N/C GAS FILM HEAT TRANSFER COEF
HTCLR = STEAM LATENT HEAT OF VAPORIZATION BTU/LBM
IHNOCC = THE HEIGHT OF THE COOLER
IVNOCC = THE NUMBER OF HORIZONTAL TUBES IN THE COOLER
PAL = SAME AS PSAT
PMIX1 = N/C MIXTURE ENTERING COND PSIA
PSATC = SATURATED STEAM PRESS
PTLIM = LOWEST SATURATION PRESSURE THE STEAM CAN GO BEFORE THE
CORRESPONDING SATURATION TEMPERATURE FALLS BELOW INLET
COOLANT TEMPERATURE RESULT IS 0 HEAT TRANSFER
RCC = RATIO OF N/C GAS TO STEAM AT ONE ROW OF TUBES
RODDC = EXTERNAL HEAT TRANSFER COEF
SDDC = COOLER TUBE PITCH
SDDC = TUBE OD
SHIC = INTERNAL TUBE FILM HEAT TRANSFER COEF
SHNFC = EXTERNAL TUBE FILM HEAT TRANSFER COEF
SMTBIC = ROW BY ROW SUM OF (COOLANT INLET TEMP * FLOW RATE)
SMTWBC = ROW BY ROW SUM OF COOLANT FLOW
SMTB2C = ROW BY ROW SUM OF (COOLANT OUTLET TEMP * FLOW RATE)
SUMQCX = ROW BY ROW SUM OF HEAT DUTY ON TUBES
SVNCEX = ENTERING MIXTURE SPECIFIC VOL FT**3/LBM
SVNSATC = ENTERING N/C GAS SPECIFIC VOL FT**3/LBM
STSATC = STEAM SATURATION TEMP AT A GIVEN ROW F
STFO = STEAM SATURATION TUBE F
TAL = AVERAGE OF OUTER TEMP R
TNOCC = SATURATED STEAM TEMP IN THE COOLER
TSAREA = TUBE SHEET AREA
UNC = OVERALL HEAT TRANSFER COEF FOR ONE ROW OF TUBES IN COOLER
VG = SPECIFIC VOLUME OF STEAM FT**3/LB
VMIX = SPECIFIC VOLUME OF STEAM AND N/C GASSES IN MIXTURE
VNRCC = REYNOLDS NUMBER ON VAPOR SIDE AT A ROW IN COOLER
VNLCC = SPECIFIC VOLUME OF N/C GAS FT**3/LB
VPSHCC = COOLER VOLUME
VPSHCC = COOLER VOLUME
WCNDC = CONDENSATE FROM ONE ROW OF TUBES IN COOLER LBM/HR
WSC = STEAM FLOW TO A ROW OF TUBES IN A SECTOR LB/HR
WNLCC = STEAM FLOW TO A ROW OF COOLER LBM/HR
WNLCC = STEAM FLOW TO A ROW OF COOLER LBM/HR
WSEXIT = TOTAL STEAM FLOW TO COOLER LBM/HR
WNLCC = WNLCC
SDDC = SDDC
SDDMIN = SDDC

CC

CON3 1210
 CON3 1220
 CON3 1230
 CON3 1240
 CON3 1250
 CON3 1260
 CON3 1270
 CON3 1280
 CON3 1290
 CON3 1300
 CON3 1310
 CON3 1320
 CON3 1330
 CON3 1340
 CON3 1350
 CON3 1360
 CON3 1370
 CON3 1380
 CON3 1390
 CON3 1400
 CON3 1410
 CON3 1420
 CON3 1430
 CON3 1440
 CON3 1450
 CON3 1460
 CON3 1470
 CON3 1480
 CON3 1490
 CON3 1500
 CON3 1510
 CON3 1520
 CON3 1530
 CON3 1540
 CON3 1550
 CON3 1560
 CON3 1570
 CON3 1580
 CON3 1590
 CON3 1600
 CON3 1610
 CON3 1620
 CON3 1650
 CON3 1640
 CON3 1650
 CON3 1660
 CON3 1670
 CON3 1680

```

TB2=TB2C
AOC=PI*ALST*SDO
AO=AOC
WB=WBC
FDAVE=0.5
SDIC=SID(NOROWS)
SDI=SDIC
AI=PI*ALST*SDI
SHWINV=SHWINC
ENHI=ENHIC
ENHO=ENHOC
ENHF=ENHFC
STBIR=STBI+459.69
PTLIM=PSATFN(STBIR)
SMWBC=0.0
SMTB2C=0.0
SUMQC=0.0
WSTC=0.0
IKOWC=0.0
WSOUT=0.0
SBFLOC=0.0
SBRATC=0.0
TBDRYC=0.0
AMLSCC=WNCC/AMWNC
AXOC=SDC*HNOC*ALST*(SDDMIN-1.0)
SVGEXT=VGFN(TSATFX,PMXEXT)
SVNCEX=10.729*TSATFX/(AMWNC*(PMXEXT))
AMLT=AMLSEX+AMLSCC
SVMXEX=1.0/(AMLSEX)
VELC(1)=(WSEXT+WNCC)*SVMXEX/(AXOC#3600.0)

VL CMAX=VELC(1)
G2=288.0*SG*SVMXEX
IF (VELC(1)-VELEX) 10,10,20
A2DA1=VELC(1)/VELEX
DELPC1=((1.0-A2DA1)*VELEX**2)/G2
GO TO 50
A2DA1=VELEX/VELC(1)
IF (A2DA1-0.715) 40,40,30
DELPC2=(0.75*(1.0-A2DA1)*VELC(1)**2)/G2
GO TO 50
DELPC1=(0.4*(1.25-A2DA1)*VELC(1)**2)/G2
DELPCT=(VELC(1)-DELPC1)**2-VELEX**2/G2
PSATC(1)=PMIXC(1)*AMLSEX/(AMLSEX+AMLSCC)

RECALCULATE THE AREA RATIO (THE RATIO OF TUBE X-SECTIONAL
AREA TO TTUBE SHEET AREA) TO INCLUDE THE COOLER

```

C
 10
 20
 30
 40
 50
 C
 C
 C

CON3 1690
 CON3 1700
 CON3 1710
 CON3 1720
 CON3 1730
 CON3 1740
 CON3 1750
 CON3 1760
 CON3 1770
 CON3 1780
 CON3 1790
 CON3 1800
 CON3 1810
 CON3 1820
 CON3 1830
 CON3 1840
 CON3 1850
 CON3 1860
 CON3 1870
 CON3 1880
 CON3 1890
 CON3 1900
 CON3 1910
 CON3 1920
 CON3 1930
 CON3 1940
 CON3 1950
 CON3 1960
 CON3 1970
 CON3 1980
 CON3 1990
 CON3 2000
 CON3 2010
 CON3 2020
 CON3 2030
 CON3 2040
 CON3 2050
 CON3 2060
 CON3 2070
 CON3 2080
 CON3 2090
 CON3 2100
 CON3 2110
 CON3 2120
 CON3 2130
 CON3 2140
 CON3 2150
 CON3 2160

```

C      SECFLG=FLOAT(I,SEC)
      TSAREA=PI*(BNDRAD**2)*SECFLG*SECWID/360.
      AHOLESA=ARATIO*TSAR EA
      AHOLESB=AHOLESA*(PI*SDDO**2)*TNO C/4.
      TSAREA=TSAR EA+HTCLR*HNOC*S DDC*SDDC
      ARATIO=AHOLESA/TSAR EA
C      CALCULATE THE COOLER VOLUME
      VOLC=HTCLR*SDDC*SDDC*HNOC*ALST
C      CHECK TO SEE IF INITIAL PRESSURE LOSSES DROP THE PRESSURE
C      BELOW PTLIM
      IF (PSATC(1).GT.PTLIM) GO TO 80
      SUMQC=0.
      NRWSP4=IVNOC+1
      CONSLA=PTLIM/FLOAT(NRWSP4)
      CONSLB=PMXEXT/FLOAT(NRWSP4)
      CUMDPC(1)=PMIX1-PMXEXT
      PSATC(1)=PTLIM
      PMIXC(1)=PMXEXT
      QDACC(1)=0.
      DELPC=PMXEXT
      UNC(1)=700.
      WSC(1)=WSEXIT
      WCNDC(1)=0.
C      DO 60 M=2,NRWSP4
      WSC(M)=WSEXIT
      WCNDC(M)=0.
      PMIXC(M)=PMIXC(M-1)-CONSLB
      PSATC(M)=PSATC(M-1)-CONSLA
      CUMDPC(M)=PMIX1-PMIXC(M)
      CONTINUE
C      DO 70 M=2,IVNOC
      UNC(M)=700.
      QDACC(M)=0.
      ALMTDC(M)=0.
      CONTINUE
      SMWBC=SMWBC+WB*TNO C
      SMTBIC=WB*TNO C*STBI
      SMTB2C=SMTBIC
      EXITFC=1.
      RETURN
C
  
```



```

80      PAL=PSATC(I)
      TAL=TSATFN(PAL)
      STSATC(I)=TAL-459.69
      WSC(I)=WSEXIT
CON32170
CON32180
CON32190
CON32200
CON32210
CON32220
CON32230
CON32240
CON32250
CON32260
CON32270
CON32280
CON32290
CON32300
CON32310
CON32320
CON32330
CON32340
CON32350
CON32360
CON32370
CON32380
CON32390
CON32400
CON32410
CON32420
CON32430
CON32440
CON32450
CON32460
CON32470
CON32480
CON32490
CON32500
CON32510
CON32520
CON32530
CON32540
CON32550
CON32560
CON32570
CON32580
CON32590
CON32600
CON32610
CON32620
CON32630
CON32640

C      CHECK TO SEE IF INLET STEAM TO COOLER IS 0
C      IF (WSC(I).GT.1.) GO TO 90
C
C      ENTER DUMMY VALUES IN COOLER VARIABLES
C      CREATE NEGATIVE FLOW PARAMETER FOR USE IN COMPUTING EXITFRC
CON32290
CON32300
CON32310
CON32320
CON32330
CON32340
CON32350
CON32360
CON32370
CON32380
CON32390
CON32400
CON32410
CON32420
CON32430
CON32440
CON32450
CON32460
CON32470
CON32480
CON32490
CON32500
CON32510
CON32520
CON32530
CON32540
CON32550
CON32560
CON32570
CON32580
CON32590
CON32600
CON32610
CON32620
CON32630
CON32640

C      TDRYC=TNOC
C      SBRATC=WCNDAY
C      SBFLOC=SBRATC*TDRYC
C
C      WSC(I)=1.
C      IROWC=3
C
C      VG=VGFN(TAL,PMIXC(I))
C      AMLSSC=WSC(I)/18.015
C      VNC=10.729*TAL/(AMWNC*PMIXC(I))
C      VMIX=1.07/((AMLSSC/(VNC*(AMLSSC+AMLSCC)))+(AMLSSC/(VNC*(AMLSSC+AMLSCC+
1C))))
C      VVLC(I)=(WSC(I)+WNC)*VMIX/(AXOC*3600.0)
C      NFC=(VNC+1.)/2.0
C      ANFC=NFC
C      IDT=0
C      JRC=0
C      IBT=0
C      DD 450 IK=1,IVNOC
C      I=IK
C      LJ=7
C
C      ROW BY ROW CALCULATION A LA HETTRN
C
C      STSAT=STSATC(I)
C      ANF=ANFC
C      WS=WSC(I)
C      WNC=WNC
C      AXO=AXOC
C      IR=I
C      DATA HEFF,UEST,DGFLM,DLFLM/2100.,700.,0.05,2.0/
C      DATA R2,E2OK / 3.617,3.996,3.838,97.0,109.0,140.75/
C      DATA R2/3.617,3.996,3.838/
C      K=0
C      RC=WNC/(WS+WNC)

```



```

TSAT=STSAT+459.69
GMAX=(WS+WNC)/AXO
PSAT=PSATFN(TSAT)
AMOLSS=WS/18.015
AMOLSC=WNC/AMWNC
AMOLT=AMOLSS+AMOLSC
AMWAV=(WS+WNC)/AMOLT
RMWNC=SQRT(AMWNC)*AMOLSC/AMOLT
RMWSC=4.24444*AMOLSS/AMOLT
AVIS=(SMUFN(TSAT))*RMWSC+AMUFN(TSAT,JGAS)*RMWNC/(RMWSC+RMWNC)
HS=WB/(PI*SDI*SDI/4.)
STBAVE=(STBI+TB2)/2.0
DELFM=DGFLM
DLGFLM=DGFLM
STW=STSAT-DELFM-DLGFLM
STFO=(STSAT+STW)/2.0
XNRE=SDO*(WS+WNC)/(AXO*3600.*AVIS)
IF(XNRE.GE.100.)GO TO 100
CONTINUE
COLBJ=EXP(0.53883-0.544*ALOG(XNRE))
IF(WNCIR.EQ.0.)GO TO 110
PATM=PSAT/14.7
PGB=PSAT*(AMOLSC/AMOLSS)
TSATK=TSAT/1.8
CALL DFSVTY(TSATK,PATM,18.015,AMWNC,2.655,R2(JGAS),363.,E2OK(JGAS)
1),0.,0.,DG,DGG)
C***
C 0.258 CONVERTS CM2/S TO FT2/HR AND 3600. CONVERTS VISCOSITY TO
C LB/F-HR FROM LB-F-S. 0.258 * 3600. = 928.8
C***
XNSCH=(AVIS*TSAT*10.73/((PSAT+PGB)*AMWAV*DG))*928.8
CJ=COLBJ*GMAX/(XNSCH*0.666667)
TB2=STSAT-(STSAT-STBI)/EXP(UEST*AO/(WB*CPFN(CBI,STBAVE)))
STBAVE=(STBI+TB2)/2.
SKBO=SKBFN(0.,STFO)
SKB=SKBFN(CBI,STBAVE)
BMU=BMUFN(CBI,STBAVE)
SHBI=CPFN(CBI,STBAVE)
XNREB=SDI*BB/BMU
XNPRB=SHBI*BMU/SKB
SHI=0.023*(XNREB)*0.8*XNPRB**0.33333*(SKB/SDI)*EIJHI
RIN=AG/(SHI*AI)
BNF=ANF
IF(ANF.LE.1.0)BNF=1.0
SHMK=0.725*(SKBO**3*ROEFN(0.0,STFO)**2*HFGFN(STFO)*410975040.0/(BM
1UFN(0,STFO)*SDO*DELFM))**0.25*ENHO
CON32650
CON32660
CON32670
CON32680
CON32690
CON32700
CON32710
CON32720
CON32730
CON32740
CON32750
CON32760
CON32770
CON32780
CON32790
CON32800
CON32810
CON32820
CON32830
CON32840
CON32850
CON32860
CON32870
CON32880
CON32890
CON32900
CON32910
CON32920
CON32930
CON32940
CON32950
CON32960
CON32970
CON32980
CON32990
CON33000
CON33010
CON33020
CON33030
CON33040
CON33050
CON33060
CON33070
CON33080
CON33090
CON33100
CON33110
CON33120

```



```

C*** ** HOMCI=STSAT-STBI
C HI MCO=STSAT-TB2
C IF (HIMCO.LI.1.E-15) WRITE (6,530) HOMCI,HIMCO,LJ,IR
C IF (HIMCO.LI.1.E-15) HIMCO=1.E-15
C RODT=HCMCI/HIMCO
C IF INLET/OUTLET DELTA T RATIO IS NEAR 1.0, ALMTD = ARITH AVE
C IF (RODT.GT.1.1) GO TO 170
C ALMTD=0.5*(HOMCI+HIMCO)
C IF (JRC.EQ.0) WRITE (6,540) STSAT,STBI,TB2,LJ,IR
C JR C=1
C GO TO 180
170 ALMTD=(HOMCI-HIMCO)/ALGG(RODT)
180 CONTINUE
C IF (WNCIR.NE.0.) GO TO 190
C ROT=1./SHNF
C UTEST=1./RFACT
C XNU=SHNF*SDO/S KBO
C IF (ABS(UEST-UTEST)/UTEST.LT..001) GO TC 260
C UEST=UTEST
C IF (K.GT.4) UEST=0.5*(UTEST+UESTSV)
C STWO=STSAT-(STSAT-STBAVE)*UTEST/SHNF
C STFO=(STCO+STWO)/2.
C DGFLM=0.
C DLFLM=STCO-STWO
C DELFLM=DLFLM
C K=K+1
C IF (K.LT.20) GO TO 110
C WRITE (6,510) UESTSV,UTEST
C GO TO 280
C CONTINUE
C STCO=STSAT-DLGFLM
C T=(TSAT+STCO+455.69)/2.0
C DTDP=1./(((6452.562+2.*837533.2/T)/T**2)*EXP(14.15012-(6452.562+83
17533.2/T)/T))
C BONE=-1.*(CJ*HSTO/ALMTD+(PGB*DTDP/ALMTD+1.)/RFACT)
C BONE=CJ*HSTO/(ALMTD*RFACT)
C TTERM1=BCONE**2
C TTERM2=4.*CONE
C TTERM=TTERM2/TTERM1
C IF (TTERM.LT.0.999999) GO TO 200
C UEST=-BONE/2.
C GO TO 220

```

```

CON33610
CON33620
CON33630
CON33640
CON33650
CON33660
CON33670
CON33680
CON33690
CON33700
CON33710
CON33720
CON33730
CON33740
CON33750
CON33760
CON33770
CON33780
CON33790
CON33800
CON33810
CON33820
CON33830
CON33840
CON33850
CON33860
CON33870
CON33880
CON33890
CON33900
CON33910
CON33920
CON33930
CON33940
CON33950
CON33960
CON33970
CON33980
CON33990
CON34000
CON34010
CON34020
CON34030
CON34040
CON34050
CON34060
CON34070
CON34080

```



```

200 IF ((4.*CONE).GT.(BONE**2)) UTEST=0.
    IF ((4.*CONE).GT.(BONE**2)) GO TO 210
210 UTEST=(-SQRT(BONE**2-4.*CONE))/2.
220 DENOM=1.-UTEST*RFAC
    CONTINUE
    IF (DENOM.GT.1.E-7) GO TO 230
    HEFF=1.0E8
    GO TO 240
230 HEFF=UTEST/DENOM
240 CONTINUE
    ROUT=(HEFF+SHNF)/(HEFF*SHNF)
    TDIF=STSAT-STBAVE
    IF (TDIF.GT.0) GO TO 250
    IF (IBT.EQ.0) WRITE (6,530) STSAT,STBAVE,LJ,IR
    BT=1
    TDIF=.1
250 CONTINUE
    DELTAU=TDIF*UTEST
    DGF LM=DELTAU/HEFF
    DLFLM=DELTAU/SHNF
    STCO=STSAT-DGF LM
    STWO=STCO-DLFLM
    STFO=(STCO+STWO)/2.
    XNU=SDO/(SKB0*ROUT)
    IF (ABS(UTEST-UEST)/UTEST.LT..001) GO TO 260
    DELFLM=DLFLM
    DLGFLM=DGF LM
    UEST=UEST
    K=K+1
    IF (K.GT.4) UEST=0.5*(UEST+UESTSV)
    IF (K.LT.20) GO TO 110
    WRITE (6,510) UESTSV,UEST
    GO TO 280
260 IF (ABS(DELFLM-DLFLM).LT..01) GO TO 270
    DELFLM=DLFLM
    DLGFLM=DGF LM
    K=K+1
    IF (K.LT.20) GO TO 110
    WRITE (6,520) DELFLM,LJ,IR
    IF (ABS(DLGFLM-DGF LM).LT..001) GO TO 280
    DLGFLM=DGF LM
    K=K+1
    IF (K.LT.20) GO TO 110
    WRITE (6,500) DLGFLM,UEST,UTEST,LJ,IR
    VNF=UTEST
    VP SHH=TB2
    XHEFF=HEFF
280

```

```

CON3 4090
CON3 4100
CON3 4110
CON3 4120
CON3 4130
CON3 4140
CON3 4150
CON3 4160
CON3 4170
CON3 4180
CON3 4190
CON3 4200
CON3 4210
CON3 4220
CON3 4230
CON3 4240
CON3 4250
CON3 4260
CON3 4270
CON3 4280
CON3 4290
CON3 4300
CON3 4310
CON3 4320
CON3 4330
CON3 4340
CON3 4350
CON3 4360
CON3 4370
CON3 4380
CON3 4390
CON3 4400
CON3 4410
CON3 4420
CON3 4430
CON3 4440
CON3 4450
CON3 4460
CON3 4470
CON3 4480
CON3 4490
CON3 4500
CON3 4510
CON3 4520
CON3 4530
CON3 4540
CON3 4550
CON3 4560

```



```

310 STSATC(I+1)=STFC
      TSATMN=STSATC(I+1)+459.69
      PMIN=PSATFN(TSATMN)
C
C
C      ENTER DUMMY VALUE FOR NEXT ROW WSC
      WSC(I+1)=1.
C      QGC=(WSC(I)*CPSFN(TAL)/18.015+WNCC*CPAFN(TAL,JGAS)/AMWNC)*(TAL-TSA
1TMN)
      QTC=QGC+WCNDC(I)*HFG
      IF (STSATC(I)-TB2) 320,320,330
320 TB2=STSATC(I)-0.1
330 CONTINUE
      IF (STSATC(I+1).GT.STBI) GO TO 340
      ALMTDC(I)=ALMTDC(I-1)
      GO TO 350
340 CONTINUE
      ALMTDC(I)=(STSATC(I+1)-STBI)-(STSATC(I)-TB2)/ALOG((STSATC(I+1))-S
1TB I)/(STSATC(I)-TB2))
      CONTINUE
      UNCC(I)=QTC/(AO*HNOC*ALMTDC(I))
      AMLSSC=WSC(I+1)/18.015
      PMIXC(I+1)=PMIXC(I)-DELTPC
      PSATC(I+1)=(PMIXC(I+1)*AMLSSC)/(AMLSSC+AMLSSC)
      TSATC=TSATMN
      GO TO 440
C
C
C      AMLSSC=WSC(I+1)/18.015
      PMIXC(I+1)=PMIXC(I)-DELTPC
      PSATC(I+1)=(PMIXC(I+1)*AMLSSC)/(AMLSSC+AMLSSC)
C
C
C      CHECK TO SEE IF STEAM CORRECTIONS FOR DRY TUBES DROVE PSATC TOO LO
      IF ((IRGWC.GT.0).AND.(PSATC(I+1).LE.PTLIM)) WRITE (6,560) I
      IF ((IROWC.GT.0).AND.(PSATC(I+1).LE.PTLIM)) PSATC(I+1)=PSATC(I)
C
C
C      CHECK FOR PRESSURE DROPPING BELOW PTLIM
      IF (PSATC(I+1).GT.PTLIM) GO TO 390
C
C
C      CALCULATE PARAMETERS FOR CURRENT ROW
      PSATC(I)=PTLIM
      CUMDPC(I)=PMIXI-PMIXC(I)
      SUMQC=SUMQC+UNC(I)*AO*ALMTDC(I)*HNOC
      QOAC(I)=UNC(I)*ALMTDC(I)

```

```

CON3 5050
CON3 5060
CON3 5070
CON3 5080
CON3 5090
CON3 5100
CON3 5110
CON3 5120
CON3 5130
CON3 5140
CON3 5150
CON3 5160
CON3 5170
CON3 5180
CON3 5190
CON3 5200
CON3 5210
CON3 5220
CON3 5230
CON3 5240
CON3 5250
CON3 5260
CON3 5270
CON3 5280
CON3 5290
CON3 5300
CON3 5310
CON3 5320
CON3 5330
CON3 5340
CON3 5350
CON3 5360
CON3 5370
CON3 5380
CON3 5390
CON3 5400
CON3 5410
CON3 5420
CON3 5430
CON3 5440
CON3 5450
CON3 5460
CON3 5470
CON3 5480
CON3 5490
CON3 5500
CON3 5510
CON3 5520

```



```

C
SMWBC=SMWBO+WB*HNOC
SMTBIC=SMTBIC+WB*HNOC*STBI
SMTB2C=SMTB2C+WB*HNOC*TB2
NRWSP4=IVNOC+1
RTG=FLOAT(NRWS P4-I)
NRWSP5=I+1
CONST=PMIXC(I)/RTG
CONST2=PTLIM/RTG
CALCULATE PARAMETERS FOR THE REMAINING ROWS
DO 370 M=NRWSP5,NRWSP4
  QOAC(M)=0.
  WSC(M)=WSC(M-1)
  WCNDC(M)=0.
  STSATC(M)=TSATC(M-1)
  PSATC(M)=PSATC(M-1)-CONST2
  PMIXC(M)=PMIXC(M-1)-CONST
  VELC(M)=VELC(M-1)
  CONTINUE
370
C
DO 380 IFX=NRWSP5,IVNOC
  UNC(IFX)=UNC(IFX-1)
  CUMDPC(IFX)=PMIX1-PMIXC(IFX-1)
  SMTBIC=SMTBIC+WB*HNOC*STBI
  SMTB2C=SMTBIC
  QOAC(IFX)=0.
  SMWBC=SMWBC+WB*HNOC
  ALMTDC(IFX)=0.
380
C
DELPC=PMIXC(1)-PMIXC(NRWSP4)
GO TO 460
C
C
PAL=PSATC(I+1)
IF (PAL.GT.0.) GO TO 400
WRITE (6,550) PMIXC(I),I
CONTINUE
TSATC=TSATFN(PAL)
STSATC(I+1)=TSATC-459.69
IF (ABS(TSATC-TAL).LT.0.001) TSATC=TAL-0.001
WCNDP=(UNC(I)*AD*HNOC*ALMTDC(I)-(WSC(I)*CPSFN(TSATC)/18.015+WNCC*C
1PAFN(TSATC,JGAS)/AMWNC)*(TAL-TSATC))/HFG
IF (ABS(WCNDP/WCNDC(I)-1.0)-.005) 430,410,410
WCNDC(I)=WCNDP
JY=JY+1
IF (JY-50) 290,290,420
C
C
C
390
400
410

```

```

CON3 5530
CON3 5540
CON3 5550
CON3 5560
CON3 5570
CON3 5580
CON3 5590
CON3 5600
CON3 5610
CON3 5620
CON3 5630
CON3 5640
CON3 5650
CON3 5660
CON3 5670
CON3 5680
CON3 5690
CON3 5700
CON3 5710
CON3 5720
CON3 5730
CON3 5740
CON3 5750
CON3 5760
CON3 5770
CON3 5780
CON3 5790
CON3 5800
CON3 5810
CON3 5820
CON3 5830
CON3 5840
CON3 5850
CON3 5860
CON3 5870
CON3 5880
CON3 5890
CON3 5900
CON3 5910
CON3 5920
CON3 5930
CON3 5940
CON3 5950
CON3 5960
CON3 5970
CON3 5980
CON3 5990
CON3 6000

```



```

420 WR ITE (6,540) I
430 CONTINUE
WCOND(I)=WGNDC(I)-WCNDC(I)
WSC(I+1)=WSC(I)/18.015
AMLSSC=WSC(I+1)*AMLSSC/(AMLSSC+AMLSSC)
PSATC(I+1)=(PMIXC(I+1)*AMLSSC)/(AMLSSC+AMLSSC)
PAL=PSATC(I+1)
TSATC=TSATFN(PAL)
TSATC(I+1)=TSATC-459.69
VG=VGFN(TSATC,PMIXC(I+1))
VN C=10.729*TSATC/(AMWNC*PMIXC(I+1))
VMIX=1.0/((AMLSSC/(VG*(AMLSSC+AMLSSC)))+(AMLSSC/(VNC*(AMLSSC+AMLSSC
1C))))
VELC(I+1)=(WSC(I+1)+WNCC)*VMIX/(AXDC*3600.0)
SMTBIC=SMTBIC+WB*HNOC*STBI
SMWBC=SMWBO+WB*HNOC
SMTB2C=SMTB2C+WB*HNOC*TB2
SUMQC=SUMQC+UNC(I)*AO*ALMTDC(I)*HNOC
QOAC(I)=UNC(I)*ALMTDC(I)
CUMDPC(I)=PMIX1-PMIXC(I)
TAL=TSATC
ANFC=ANFC-1.0
CONTINUE
DELP C=PMIXC(I)-PMIXC(IVNO C+1)
CONTINUE
CHECK TO SEE IF INLET STEAM FLOW WAS 0
IF (IROWC*LT.2) GO TO 480
NRWSP4=IVNO C+1
SUMQC=0.
DO 470 M=1,NRWSP4
GOAC(M)=0.
ALMTDC(M)=0.
WSC(M)=0.
WCNDC(M)=0.
EXITFC=-999
WSTC=FLOAT(IVNO C)
RETURN
C IF COOLER TUBES WENT DRY CREATING A NEGATIVE EXITFC
C
C
480 IF (WSTC.GE.0.) GO TO 490
EXITFC=-(SBFLOC)/WSC(I)
RETURN
C
C
490 EXITFC=WSC(I+1)/WSC(I)
WSOUT=WSC(I+1)

```

```

CON36010
CON36020
CON36030
CON36040
CON36050
CON36060
CON36070
CON36080
CON36090
CON36100
CON36110
CON36120
CON36130
CON36140
CON36150
CON36160
CON36170
CON36180
CON36190
CON36200
CON36210
CON36220
CON36230
CON36240
CON36250
CON36260
CON36270
CON36280
CON36290
CON36300
CON36310
CON36320
CON36330
CON36340
CON36350
CON36360
CON36370
CON36380
CON36390
CON36400
CON36410
CON36420
CON36430
CON36440
CON36450
CON36460
CON36470
CON36480

```



```

2VP SHHC(100),HEFFC(100),UNC(100),WCNDC(100),GFLWC(100),QDAC(100),C CON3 6970
3UMDPC(100) CON3 6980
COMMON /COOL/ IVNOC,HNOC,TNOC,TSATEX,PMXEXT,AMLSEX,WSEXIT,VELEXT,T CON3 6990
1B2C,ENHIC,ENH3C,ENHFC,SHWINC,WBC CON3 7000
COMMON /OUT2A/ RCOOR,RSPP,PHPCON,VOLIC CON3 7010
DIMENSICN AWTST(15) CON3 7020
DELPVE=0. CON3 7030
AOT=0. CON3 7040
VEL3=0. CON3 7050
CAWT=0. CON3 7060
UBARW=0. CON3 7070
VWBAR=0. CON3 7080
SECFLG=FLOAT(I SEC) CON3 7090
DD 10 I=1,NOROWS CON3 7100
DD =ODD I-DELOC*FLOAT(I-1) CON3 7110
CAWT=CAWT+(CD*OD/144.-SID(I))*SID(I))*TBNPR(I) CON3 7120
AO=3.14159*OD*ALST*TBNPR(I)/12. CON3 7130
VWBAR=VWBAR+VW(I) CON3 7140
AOT=AOT+AO CON3 7150
BUNWT=PI*CAWT*ALST*TUBESW*SECFLG/4. CON3 7160
AOT=AO T*SECFLG CON3 7170
DD 30 J=1,I SEC CON3 7180
DD 20 I=1,NOROWS CON3 7190
UBARW=UBARW+UN(I,J))*TBNPR(I) CON3 7200
VEL3=VEL3+VEL(NOROWS,J) CON3 7210
DELPVE=DELPVE+DELP(J) CON3 7220
CONTINUE CON3 7230
UBARW=UBARW/TNO CON5 7240
VWBAR=VWBAR/FLOAT(NOROWS) CON3 7250
VEL3=VEL3/SECFLG CON3 7260
DELPVE=DELPVE/SECFLG CON3 7270
ADTCND=SUMQ/(UBARW*AOT) CON3 7280
STSATX=TSATEX-459.69 CON3 7290
TDROP1=STSAT(1,1)-STSATX CON3 7300
RSPI=RSPPF*12. CON5 7310
CON3 7320
CON3 7330
CON3 7340
CON5 7350
CON5 7360
CON5 7370
CON3 7380
CON3 7390
CON3 7400
CON3 7410
CON3 7420
CON3 7430
CON3 7440

```

THERE IS THE POSSIBILITY THAT THE AVERAGE INLET COOLANT TEMP
(AVTB1) EQUALS THE AVERAGE OUTLET COOLANT TEMP (AVTB2). WHEN
THE CONDENSER IS COMNFIGURED SUCH THAT NO HEAT IS REMOVED FROM
THE STEAM

10

20

30

C

C

C

C

C

C

CON3 7450
 CON3 7460
 CON3 7470
 CON3 7480
 CON3 7490
 CON3 7500
 CON3 7510
 CON3 7520
 CON3 7530
 CON3 7540
 CON3 7550
 CON3 7560
 CON3 7570
 CON3 7580
 CON3 7590
 CON3 7600
 CON3 7610
 CON3 7620
 CON3 7630
 CON3 7640
 CON3 7650
 CON3 7660
 CON3 7670
 CON3 7680
 CON3 7690
 CON3 7700
 CON3 7710
 CON3 7720
 CON3 7730
 CON3 7740
 CON3 7750
 CON3 7760
 CON3 7770
 CON3 7780
 CON3 7790
 CON3 7800
 CON3 7810
 CON3 7820
 CON3 7830
 CON3 7840
 CON3 7850
 CON3 7860
 CON3 7870
 CON3 7880
 CON3 7890
 CON3 7900
 CON3 7910
 CON3 7920

```

IF (AVTB1.EQ.AVTB2) DTCND2=0.
IF (AVTB1.EQ.AVTB2) UPCOND=UBARM
IF (AVTB1.EQ.AVTB2) GO TO 40

DTCND2=(AVTB2-AVTB1)/ALOG((STSAT1-AVTB1)/(STSAT1-AVTB2))
UPCOND=SUMQ/(AOT*DTCND2)
WRITE (6,60)
WRITE (6,80)
WRITE (6,90)
WRITE (6,100)
WRITE (6,90)
WRITE (6,80)
WRITE (6,70)
WRITE (6,110)
WRITE (6,120)
WRITE (6,130)
WRITE (6,160)
WRITE (6,140) EXITFR

UBARM,ADTCND,DELPVE,TDROP1,VEL2,VEL3
SUMQ
WSI
AOT
EXITFR

DO 50 I=1,ISEC
IF (WTST(I).LT.0.) AWST(I)=-WTST(I)
IF (WTST(I).LT.0.) WRITE (6,150) I,AWST(I)
CONTINUE

WRITE (6,170) TNO,NOROWS
WRITE (6,180) ALST ID,BNDIAM,BL
WRITE (6,190) VOID ID,BNDIAM,BL SIDO,ODDI
IF (MDIAM.EQ.1) WRITE (6,210) SIDI,ODII
IF (MDIAM.EQ.2) WRITE (6,220) SIDO,ODDI
IF (MPITCH.EQ.1) WRITE (6,230) SDDO
IF (MPITCH.EQ.2) WRITE (6,240) SDDI,SDDO
IF (XW2.GT.0.) WRITE (6,250) XW2
IF (XW2.LE.0.) WRITE (6,260) XW1

WRITE (6,270) RSPI
WRITE (6,280) VCLLC,VOL2,BUNWT
WRITE (6,290) AVTB1
WRITE (6,300) AVTB2
WRITE (6,320) SMWB
WRITE (6,330) VWBAR
WRITE (6,310) HDLOSS,PHPCON
WRITE (6,340) DTCND2
WRITE (6,350) UPCOND
WRITE (6,360) PFILL
IF (PRCCLR.LE.0) WRITE (6,370) ARATIO
IF (PRCCLR.GT.0.) CALL OUT2C
RE TURN

```

C

C

40

C

50
C


```

60  (1H1)
70  FORMAT (1H0,31X,29H***** CONDENSER *****//)
80  FORMAT (1H,15X,16X,1H*,27X,1H*)
90  FORMAT (1H,15X,16X,29H** CONDIP SUMMARY OF RESULTS *)
100  FORMAT (1H,10X,56H OVERALL U LOG-MEAN PRESSURE DROP
110  1 VELOC I7Y/10X,54HB/HR-DEG.F DELTA T PSIA
    2 T/SEC/11X,57H-SQ.FT. DEG.F
    3 TLEI//12X,F6.2,3X,F6.2,1P3E10.2//
120  FORMAT (1H,10X,18H HEAT DUTY ,8X,1PE11.4,2X,6H8TU/HR)
130  FORMAT (1H,10X,12H STEAM TO BUNDLE ,2X,1PE11.4,2X,5H1LB/HR)
140  FORMAT (1H,10X,13H HEXIT FRAC. ,7X,1PE11.4//)
150  FORMAT (1H,10X,10H IN SECTOR ,12,2X,29HTHE FRACTION OF DRY ROWS WA
    1S ,F10.6)
160  FORMAT (1H,10X,19HHT. TRF. SURF. AREA,1X,1PE11.4,2X,6HSQ.FT.)
170  FORMAT (1H,1X/10X,16HBUNDLE DIAMETER,,3X,2HFT,7X,F10.2,1X,6HTUBES
    1,15,1X,4HROWS)
180  FORMAT (1H,12X,6H INSIDE,4X,7H OUTSIDE,13X,10HTUBES ARE ,F5.2,1X,7HC
    1FT LONG)
190  FORMAT (1H,12X,F5.2,5X,F5.2,14X,11HBUNDLE IS ,F5.2,1X,7HFT LONG/
    1)
200  FORMAT (1H,10X,20HTUBE INSIDE DIAMETER,15X,F7.4,2X,6H INCHES/1H,1
    10X,21HTUBE OUTSIDE DIAMETER,14X,F7.4,2X,6H INCHES)
210  FORMAT (1H,10X,30HTUBE INSIDE DIAMETER INNER ROW,6X,F7.4,2X,3HIN.
    1/11X,31HTUBE OUTSIDE DIAMETER INNER ROW,5X,F7.4,2X,3HIN.//)
220  FORMAT (1H,11X,30HTUBE INSIDE DIAMETER OUTER ROW,5X,F7.4,2X,3HIN.
    1/11X,31HTUBE OUTSIDE DIAMETER OUTER ROW,5X,F7.4,2X,3HIN.)
230  FORMAT (1H,10X,26HTUBE CIRCUMFERENTIAL PITCH,9X,F7.4)
240  FORMAT (1H,10X,36HTUBE CIRCUMFERENTIAL PITCH INNER ROW,5X,F7.4/1H
    1,10X,36HTUBE CIRCUMFERENTIAL PITCH OUTER ROW,5X,F7.4)
250  FORMAT (1H,10X,14HTUBE THICKNESS,21X,F7.4,2X,6H INCHES)
260  FORMAT (1H,10X,34HRATIO OF TUBE THICKNESS TO TUBE OD,5X,F7.4)
270  FORMAT (1H,10X,28HSPACE BETWEEN CONCENTRIC ROWS,7X,F7.4,2X,3HIN.//)
280  1E SPACE VOLUME ,11X,1PE11.4,2X,6HCU.FT./11X,19HTUBE METAL WEIGHT
    2,1X,1PE11.4,2X,2HLB//)
290  FORMAT (1H,10X,19H INLET WATER TEMP ,5X,F9.2,1X,5HDEG.F)
300  FORMAT (1H,10X,20H OUTLET WATER TEMP ,4X,F9.2,1X,5HDEG.F)
310  FORMAT (1H,10X,9H HEAD LOSS,15X,F9.2,1X,6HFT H2O/11X,13HPUMPING PO
    1WER,11X,F9.2,1X,2HHP//)
320  FORMAT (1H,10X,13HWATER FLOW ,12X,1PE11.4,1X,5H1LB/HR)
330  FORMAT (1H,10X,17HWATER VELOCITY ,8X,1PE11.4,1X,6HFT/SEC//)
340  FORMAT (1H,10X,12H AVG. LMTD ,14X,F7.2,1X,5HDEG.F)
350  FORMAT (1H,10X,9H AVG. U ,17X,F7.2,1X,18H8TU/HR-SQ.FT-DEG.F//)
360  FORMAT (1H,10X,46HTHE PERCENTAGE OF THE OUTERMOST ROW FILLED IS ,
    1F7.4//)
370  FORMAT (1H,10X,18HTHE AREA RATIO IS ,F7.4//)
    END
CON37530
CON37940
CON37950
CON37560
CON37970
CON37980
CON37590
CON38000
CON38010
CON38020
CON38030
CON38040
CON38050
CON38060
CON38070
CON38060
CON38090
CON38100
CON38110
CON38120
CON38130
CON38140
CON38150
CON38160
CON38170
CON38180
CON38190
CON38200
CON38210
CON38220
CON38230
CON38240
CON38250
CON38260
CON38270
CON38280
CON38290
CON38300
CON38310
CON38320
CON38330
CON38340
CON38350
CON38360
CON38370
CON38380
CON38390
CON38400

```


CON3 8890
 CON3 8900
 CON3 8910
 CON3 8920
 CON3 8930
 CON3 8940
 CON3 8950
 CON3 8960
 CON3 8970
 CON3 8980
 CON3 8990
 CON3 9000
 CON3 9010
 CON3 9020
 CON3 9030
 CON3 9040
 CON3 9050
 CON3 9060
 CON3 9070
 CON3 9080
 CON3 9090
 CON3 9100
 CON3 9110
 CON3 9120
 CON3 9130
 CON3 9140
 CON3 9150
 CON3 9160
 CON3 9170
 CON3 9180
 CON3 9190
 CON3 9200
 CON3 9210
 CON3 9220
 CON3 9230
 CON3 9240
 CON3 9250
 CON3 9260
 CON3 9270
 CON3 9280
 CON3 9290
 CON3 9300
 CON3 9310
 CON3 9320
 CON3 9330
 CON3 9340
 CON3 9350
 CON3 9360

```

VWBARC=VWBAR
IF (AVTBIC.EQ.AVTB2C) DTCOL2=0.
IF (AVTBIC.EQ.AVTB2C) UPCCOOL=UBARWC
IF (AVTBIC.EQ.AVTB2C) GO TO 20

DTCOL2=(AVTB2C-AVTBIC)/ALOG((STSATX-AVTBIC)/(STSATX-AVTB2C))
UPCCOOL=SUMQC/(AOTC*DTCOL2)

VALUES FOR OVERALL OUTPUT

AOTOT=AOTC+AOT
TNOT=TNC+TNCC
UBAROA=(UBARW*TNQ+UBARWC*TNOC)/TNQ
DTOA=(SUMQC+SUMQ)/(UBAROA*AOTOT)
DELPOA=PMIXI-PMIXC(IVNOC+1)
DRPOA=STSATI-STSATC(IVNOC+1)
SUMQOA=SUMQC+SUMQ
WTOA=BUNWT*COOLWT
AVTBA=(AVTBI*TNQ+AVTBIC*TNOC)/TNQ
AVTBA=(AVTBI*TNQ+AVTB2C*TNOC)/TNQ
SMWBOA=SMWBC+SMWB
HDLBOA=DELWP*144./62.366
DTOA=(AVTB2A-AVTBIA)/ALOG((STSATI-AVTBIA)/(STSATI-AVTB2A))
UPQA=(SUMQOA/(AOTOT*DTOA))
WRITE (6,40)
WRITE (6,50) JBARWC,ADTCLR,DELPVC,TDROP,VELC(1),VELC(IVNOC)
WRITE (6,60) SUMQC
WRITE (6,70) WSC(1)
WRITE (6,110) AOTC

IF (EXITFC.LT.-900.) WRITE (6,100)
IF (EXITFC.LT.-900.) GO TO 30

WRITE (6,80) EXITFC

IF (WTSTC.LT.0) WRITE (6,90) WTSTC

WRITE (6,120) TNOC,IVNOC
WRITE (6,130) HTCLR,WDCLR
WRITE (6,140) VCLC,COOLWT
WRITE (6,150) AVTBIC
WRITE (6,160) AVTB2C
WRITE (6,170) SMWBC
WRITE (6,180) VWBARC
WRITE (6,190) DTCOL2
WRITE (6,210) UPCCOOL
WRITE (6,220) UPCCOOL
  
```

C

C

C

C

20

C

C

30

C


```

WR ITE (6,230) SDDC
WR ITE (6,250)
WR ITE (6,260) UBAROA,ADTOA,DELPOA,TDRPOA
WR ITE (6,60) SUMQOA
WR ITE (6,110) AOTOT
WR ITE (6,80) EXITOA
WR ITE (6,270) TNOT
WR ITE (6,280) VOL1,WTOA
WR ITE (6,160) AVTB1A
WR ITE (6,170) AVTB2A
WR ITE (6,180) SMWBOA
WR ITE (6,200) HDLSOA,PHP
WR ITE (6,210) DTOA
WR ITE (6,220) UPOA
IF (PR CCLR,GT,0) WRITE (6,240) ARAATIO
RE TURN
FORMAT (1H,31X,29H***** COOLER *****//) TEMP.
FORMAT (1H,10X,56H)OVERALL U LOG-MEAN PRESSURE DROP STEAM
1 VELOCITV/10X,54HB/HR-DEG.F DELTA T PSIA INLET
2 T/SEC//11X,F6.2,4X,1PE9.2,1P3E10.2//) DEG.F
3 TLET//12X,F6.2,3X,F6.2,8X,1PE11.4,2X,6HBTU/HR)
FORMAT (1H,10X,12H)HEAT DUTY COOLER ,2X,1PE11.4,2X,5HLB/HR)
FORMAT (1H,10X,13H)HEXIT FRAC. ,7X,1PE11.4//)
FORMAT (1H,10X,39H)IN COOLER; THE FRACTION CF DRY ROWS WAS,F10.6//)
FORMAT (1H,10X,46H)THE COOLER IS ENTIRELY DRY AND THUS NO EXIT FR/
1)
FORMAT (1H,10X,19H)HT. TRF. SURF. AREA,1X,1PE11.4,2X,6HSQ.FT.)
FORMAT (1H,14X,11H)DIMENSIONS,,7X,2HFT,7X,F10.2,1X,6HTUBES,,15,1X,
14HROWS)
FORMAT (1H,12X,6H)HEIGHT,5X,5HWIDTH)
FORMAT (1H,12X,F5.2,5X,F5.2//)
FORMAT (1H,10X,19H)TOTAL COOLER VOLUME,1X,1PE11.4,2X,2HLB//)
115HCOOLER WEIGHT ,1X,1PE11.4,2X,2HLB//)
FORMAT (1H,10X,19H)INLET WATER TEMP ,5X,F9.2,1X,5HDEG.F)
FORMAT (1H,10X,20H)OUTLET WATER TEMP ,4X,F9.2,1X,5HDEG.F)
FORMAT (1H,10X,13H)WATER FLOW ,1X,1PE11.4,1X,5HLB/HR//)
FORMAT (1H,10X,17H)WATER VELOCITY ,9X,1PE11.4,1X,6HFT/SEC//)
FORMAT (1H,10X,9H)HEAD LOSS,15X,F9.2,1X,6HFT H2O/11X,13HPUMPING PD
1WER,11X,F9.2,1X,2HHP//)
FORMAT (1H,10X,12H)AVG. LMTD ,14X,F7.2,1X,5HDEG.F)
FORMAT (1H,10X,9H)AVG. U ,17X,F7.2,1X,18HTU/HR-SQ.FT-DEG.F)
FORMAT (1H,10X,35H)THE COOLER CIRCUMFERENTIAL PITCH IS,2X,F6.2//)
FORMAT (1H,10X,26H)THE OVERALL AREA RATIO IS ,F7.4//)
FORMAT (1H,31X,29H)*****//)
FORMAT (1H,10X,38H)OVERALL U LOG-MEAN PRESSURE DROP TEMP./10X,36HB
1/HR-DEG.F DELTA T DROP//11X,37H-SQ.FT.
2)SI A DEG.F//12X,F6.2,3X,F6.2,4X,1PE9.2,1PE10.2//)
CON3 9370
CON3 9380
CON3 9390
CON3 9400
CON3 9410
CON3 9420
CON3 9430
CON3 9440
CON3 9450
CON3 9460
CON3 9470
CON3 9480
CON3 9490
CON3 9500
CON3 9510
CON3 9520
CON3 9530
CON3 9540
CON3 9550
CON3 9560
CON3 9570
CON3 9580
CON3 9590
CON3 9600
CON3 9610
CON3 9620
CON3 9630
CON3 9640
CON3 9650
CON3 9660
CON3 9670
CON3 9680
CON3 9690
CON3 9700
CON3 9710
CON3 9720
CON3 9730
CON3 9740
CON3 9750
CON3 9760
CON3 9770
CON3 9780
CON3 9790
CON3 9800
CON3 9810
CON3 9820
CON3 9830
CON3 9840

```



```

10 WR ITE (6,160) I, VW(I), A, OD, SDD, TBNPR(I)
DO 30 J=1, ISEC
WR ITE (6,120) J
DO 20 I=1, NCROWS
DO =ODO I-DELOD*FLOAT(I-1)
AO =3.14159*OD*ALST
Q=UN(I,J)*ALMTD(I,J)*AG
20 WR ITE (6,160) I, Q, CUMDP(I, J), ALMTD(I, J), RC(I, J), VNRE(I, J)
30 CONTINUE
DO 50 J=1, ISEC
WR ITE (6,130) J
DO 40 I=1, NOROWS
40 WR ITE (6,160) I, UN(I, J), ROUT(I, J), HEFF(I, J), SHN(I, J), SHI(I, J)
50 CONTINUE
DO 70 J=1, ISEC
WR ITE (6,150) J
DO 60 I=1, NOROWS
60 WR ITE (6,160) I, WS(I, J), WCND(I, J), STSAT(I, J), PSAT(I, J), PMIX(I, J)
70 CONTINUE
IF (PRCLR, LE.0.) GO TO 110
WR ITE (6,170)
DO 80 I=1, IVNOC
QC=UNC(I)*ALMTDC(I)*AOC
80 WR ITE (6,200) I, QC, CUMDPC(I), ALMTDC(I), RCC(I), VNREC(I)
90 CONTINUE
DO 90 I=1, IVNOC
WR ITE (6,200) I, UNC(I), ROUTC(I), HEFFC(I), SHNFC(I), SHIC(I)
90 CONTINUE
DO 100 I=1, IVNOC
WR ITE (6,200) I, WSC(I), WCND(I), STSATC(I), PSATC(I), PMIXC(I)
100 CONTINUE
RETURN
110
120 FORMAT (1H1/// /15X, 15X, 28HROW BY ROW OUTPUT FOR SECTOR, 13//15X, 3HCEA, 3HCON, 40670
1ROW, 4X, 4HHEAT, 5X, 8HPRESSURE, 3X, 8HLOG MEAN, 3X, 8HRATIO UF, 2X, 10HSFEA, 3HCON, 40680
2M SIDE/15X, 3HNO., 2X, 8HTRANSFER, 5X, 4HDROP, 5X, 9HTEMP DIFF, 2X, 7HN/C, 6CON, 40690
3AS, 3X, 12HREYNOLDS NO./15X, 5X, 8HPER TUBE, 3X, 7HPER ROW, 14X, 10HTD STM, 3HCON, 40700
4 FLW/15X, 6X, 6HBTU/HR, 6X, 3HPSI, 8X, 5HDEG F/)
130 FORMAT (1H1/// /15X, 15X, 47HROW BY ROW HEAT TRANSFER COEFFICIENTS FOR, 3HCON, 40720
1 SECTOR, 13//15X, 14HBTU/HR-FI*2--F//15X, 3HINTERNAL/15X, 3HNO., 4X, 4CON, 40730
2HTER, 3X, 8HEXTERNAL, 3X, 8HLIQ FILM, 3X, 8HLIQ FILM/)
140 FORMAT (1H1/// /15X, 15X, 41HROW BY ROW VALUES OF CONDENSER, 3HCON, 40750
3HTUBE, 7X, 4HTUBE, 5X, 8HGAS FILM, 3X, 8HRCW VALUES OF CONDENSER, 3HCON, 40760
4HTUBE, 7X, 4HTUBE, 5X, 8HGAS FILM, 3X, 8HRCW VALUES OF CONDENSER, 3HCON, 40770
1S//15X, 3HROW, 3X, 7HCOOLANT, 2X, 12HCOOLANT MASS, 3X, 4HTUBE, 7X, 4HTUBE, 4CON, 40780
2X, 9HNUMBER OF/15X, 3HNO., 3X, 21HVELOCITY FLOW/TUBE, 4X, 2HOD, 8X, 5HP, 3HCON, 40790
3ITCH, 3X, 9HTUBES PER/15X, 17X, 6HLM/HR, 6X, 6HINCHES, 14X, 11HROW PER SE, 3HCON, 40800
4C/)

```



```

CID=0.1685/TKOE**1.2063+0.5328/TKOE**0.1579
RTSM=(1./AM1+1./AM2)**0.5
B=(10.7-2.46*RTSM)*1.E-4
DG=8*TK**1.5*RTSM/PATM/R12**2/CID
IF (V1.EQ.0.0) GO TO 40
CONTINUE
DGG=0.0043*TK**1.5*RTSM/PATM/(V1**0.333+V2**0.333)**2
GO TO 40
CONTINUE
WRITE (6,50)
CONTINUE
RETURN
FORMAT (103H0 ** NEITHER FORCE CONSTANTS NCR MOLECULAR VOLUMES EX
LIST AS ARGUMENTS. CALCULATIONS CANNOT PROCEED. **)
END
C
C
C *****
FUNCTION XTR (X,Y,N,T,SW,XIN,YN,M)
C
C FUNCTION XTR ASSUMES A LOG-LOG MODEL IE LOG Y = A + B1 * LOG
C AND PERFORMS A LINEAR LEAST SQUARE REGRESSION ON THE
C TRANSFORMED POINTS, ALL POINTS ARE USED FOR EACH REGRESSION
C EXCEPT FOR THE FIRST, WHICH IS NOT USED AT ALL
C *****
DIMENSION XIN(11),YN(11)
IF (Y.LE.0.) Y=.0001
IF (N.EQ.0) GO TO 30
X1N(N)=ALOG(X)
YN(N)=ALOG(Y)
IF (N.LT.2) GO TO 40
SX1N=0.0
SYN=0.0
IF (M.LT.N-3) M=N-3
DO 10 I=M,N
SX1N=SX1N+XIN(I)
SYN=SYN+YN(I)
CONTINUE
X1BAR=SX1N/(N-M+1)
YBAR=SYN/(N-M+1)
SX12=0.0
SY12=0.0
DO 20 I=M,N
SX12=SX12+(XIN(I)-X1BAR)**2
SY12=SY12+(YN(I)-YBAR)**2
CONTINUE
B1=SX1Y/SX12
A=YBAR-B1*X1BAR
TN=ALOG(T)

```

```

CON41290
CON41300
CON41310
CON41320
CON41330
CON41340
CON41350
CON41360
CON41370
CON41380
CON41390
CON41400
CON41410
CON41420
CON41430
CON41440
CON41450
CON41460
CON41470
CON41480
CON41490
CON41500
CON41510
CON41520
CON41530
CON41540
CON41550
CON41560
CON41570
CON41580
CON41590
CON41600
CON41610
CON41620
CON41630
CON41640
CON41650
CON41660
CON41670
CON41680
CON41690
CON41700
CON41710
CON41720
CON41730
CON41740
CON41750
CON41760

```



```

CON4 1770
CON4 1780
CON4 1790
CON4 1800
CON4 1810
CON4 1820
CON4 1830
CON4 1840
CON4 1850
CON4 1860
CON4 1870
CON4 1880
CON4 1890
CON4 1900
CON4 1910
CON4 1920
CON4 1930
CON4 1940
CON4 1950
CON4 1960
CON4 1970
CON4 1980
CON4 1990
CON4 2000
CON4 2010
CON4 2020
CON4 2030
CON4 2040
CON4 2050
CON4 2060
CON4 2070
CON4 2080
CON4 2090
CON4 2100
CON4 2110
CON4 2120
CON4 2130
CON4 2140
CON4 2150
CON4 2160
CON4 2170
CON4 2180
CON4 2190
CON4 2200
CON4 2210
CON4 2220
CON4 2230
CON4 2240

XTR=EXP((TN-A)/BI)
GO TO 50
M=1
XTR=X*(1.+(Y-T)*5.*SW)
C****
C****
C****
50 IF (ABS(XTR-X)/X.LT.0.1) GO TO 60
XTR=X*(1.+0.1*ABS(Y-T)/(Y-T)*SW)
RETURN
END
60
C
C
FUNCTION AMUFN (T, JGAS)
IMIX=0
GO TO (30,20,10), JGAS
10 IMIX=1
20 CONTINUE
C INERT GAS IS CO2
C* VISCOSITY FOR CARBON DIOXIDE LB/FT-SEC
GAS2=1.0E-5*(-0.046+(2.282E-3+(-6.131E-7+9.699E-11*T)*T)*T)
AMUFN=GAS2
IF (IMIX.EQ.0) RETURN
CONTINUE IS AIR
GAS1=1.0E-5*(0.1490+(0.238E-2)*T-(-.7209E-6)*T**2+(.1184E-9)*T**3)
AMUFN=GAS1
C INERT GAS IS MIXTURE OF AIR & CO2
GAS3=(GAS1+GAS2)/2.0
RETURN
END
C
C
FUNCTION BMUFN (C, T)
VISCOSITY OF SALINE SOLUTION. RANGE OF DATA WAS 0 - 24 PERCENT
CONCENTRATION AND 40 - 210 DEGREES FARENHEIT.
R=T+459.69
BMUFN=DEXP(-0.11591155D+2*C+0.12602329D-1*C*R+0.38637378D+4*C/R+0.
14606532D-2*R+0.47595941D+4/R-0.1059252566D+2)
RETURN
END
C
C
FUNCTION CPAFN (T, JGAS)
IMIX=0
GO TO (30,20,10), JGAS

```



```

10 IMIX=1
20 CONTINUE
C INERT GAS IS CO2
C** HEAT CAPACITY FOR MW = 40.1 BTU/LB-MOL - DEG R
GAS2=0.209*40.1
CP AFN=GAS2
IF (IMIX.EQ.0) RETURN
30 CONTINUE
C INERT GAS IS AIR
C AIR CP, BTU / LB MOLE-DEGREE RANKIN
GAS1=7.139-0.9884E-3*T+0.1393E-5*T**2-0.3367E-9*T**3
CP AFN=GAS1
IF (IMIX.EQ.0) RETURN
C INERT GAS IS MIXTURE OF AIR & CO2
GAS3=(GAS1+GAS2)/2.0
CP AFN=GAS3
RETURN
END
C
C
FUNCTION CPFN (C,T)
IF (C-0.005) 20,20,30
C***EQUATION SPECIFIC HEAT FOR PURE WATER
20 CP=1.0121559+(-0.24618473E-3+0.10282155E-5*T)*T
GO TO 40
C***EQUATION SPECIFIC HEAT FOR BRINE
30 CP=.96946859+(2.*(0.0010404965)*T)-(.91199294*C)+(2.*( -.000648296
159)*C*T)+(2.*(0.0076721469)*C**2)*T)+(6.7981008
2*(C**3))*T)
CP FN=CP
RETURN
END
C
C
FUNCTION CPSFN (T)
C***
C CP SFN CALCULATES THE HEAT CAP OF STEAM IN BTU/LB-MOL-R GIVEN T IN
C DEG R. EQUATIONS FROM H. NORITAKE, BASED ON TABULATED VALUES IN
C NASA TR-R-132
C***
CP SFN=(7.838-(.2531E-3-(.2892E-6-.7693E-10*T)*T)*T)
RETURN
END
C
C
FUNCTION HFGFN (T)
HFGFN=1093.88-0.5703*T+.00012819*T**2-.0000008824*T**3
RETURN
END

```

```

CON4 2250
CON4 2260
CON4 2270
CON4 2280
CON4 2290
CON4 2300
CON4 2310
CON4 2320
CON4 2330
CON4 2340
CON4 2350
CON4 2360
CON4 2370
CON4 2380
CON4 2390
CON4 2400
CON4 2410
CON4 2420
CON4 2430
CON4 2440
CON4 2450
CON4 2460
CON4 2470
CON4 2480
CON4 2490
CON4 2500
CON4 2510
CON4 2520
CON4 2530
CON4 2540
CON4 2550
CON4 2560
CON4 2570
CON4 2580
CON4 2590
CON4 2600
CON4 2610
CON4 2620
CON4 2630
CON4 2640
CON4 2650
CON4 2660
CON4 2670
CON4 2680
CON4 2690
CON4 2700
CON4 2710
CON4 2720

```



```

C
C
CCC
C
CCC
END
SUBROUTINE PRSDRP (TSAT,VMIX,WS,WNC,AXC,SDO,SF,DELPTP,ENHF)
PRSDRP REBUILT ON 9-16-69 TO USE EQUATION FCR SF
SG=32.174
GSTAR=(WS+WNC)/(AXO*3600.)
ANRE=(SCO*GSTAR)/SMUFN(TSAT)
SF=(0.102+52.2/ANRE)*ENHF
DELPTP=SF*GSTAR**2*VMIX/(72.0*SG)
RETURN
END
C
C
FUNCTION PSATFN (T)
PSATFN=2.718**((14.150119-(6452.5621/T)-(837533.21/T**2)))
RETURN
END
C
C
FUNCTION ROEFN (C,T)
DENSITY OF SALINE SOLUTION. RANGE OF DATA WAS 0 - 26 PERCENT
CONCENTRATION AND 40 - 300 DEGREES FARENHEIT.
ROEFN=0.62707172E2+0.49364088E2*C-(0.43555304E-2+0.32554667E-1*C+
10.46076521E-4-0.63240299E-4*C)*T**T
RETURN
END
C
C
FUNCTION SKBFN (C,T)
THERMAL CONDUCTIVITY OF SALINE SOLUTION. RANGE OF DATA
0 - 24 PERCENT CONCENTRATION AND 40 - 300 DEGREES FARENHEIT
SKBFN=(.30157913+.697989E-3*T-.12506E-5*T**2-.2072E-10*T**3)*(-.16
187109*C+1.)
RETURN
END
C
C
FUNCTION SMUFN (T)
SMUFN=1.0E-5*(0.122+(1.001E-3)*T+(2.892E-7)*T**2-(7.693E-11)*T**3)
RETURN
END
C
C
FUNCTION TSAIFN (P)
AA=(ALOG(P)-14.150119)

```

```

CON42730
CON42740
CON42750
CON42760
CON42770
CON42780
CON42790
CON42800
CON42810
CON42820
CON42830
CON42840
CON42850
CON42860
CON42870
CON42880
CON42890
CON42900
CON42910
CON42920
CON42930
CON42940
CON42950
CON42960
CON42970
CON42980
CON42990
CON43000
CON43010
CON43020
CON43030
CON43040
CON43050
CON43060
CON43070
CON43080
CON43090
CON43100
CON43110
CON43120
CON43130
CON43140
CON43150
CON43160
CON43170
CON43180
CON43190
CON43200

```



```

10  DET=6452.5621**2-(4.0*AA*837533.21)
10  IF (DET) 10,20,20
10  CALL EXIT
20  X=(-6452.5621+SQRT(DET))/((2.0*AA)
20  Y=(-6452.5621-SQRT(DET))/((2.0*AA)
30  IF (X-Y) 30,40,40
30  TSATFN=Y
30  GO TO 50
40  TSATFN=X
40  CONTINUE
50  RETURN
50  FORMAT (1H1,37HSUBROUTINE TSATFN FINDS COMPLEX ROOTS)
50  END
C
C  FUNCTION VGFN (T,P)
C  X=ALOG(T/P)
C  VGFN=EXP(((.103758E-2*X-.0177861)*X+1.10267)*X-.72240)
C  RETURN
C  END
C
C  SUBROUTINE SWITCH (A,N)
C  DIMENSION A(N)
C  NN=N+1
C  K=N+1
C  DO 10 I=1,NN
C  T=A(I)
C  A(I)=A(K-I)
C  A(K-I)=T
C  CONTINUE
C  RETURN
C  END
10

```

```

CON43210
CON43220
CON43230
CON43240
CON43250
CON43260
CON43270
CON43280
CON43290
CON43300
CON43310
CON43320
CON43330
CON43340
CON43350
CON43360
CON43370
CON43380
CON43390
CON43400
CON43410
CON43420
CON43430
CON43440
CON43450
CON43460
CON43470
CON43480
CON43490
CON43500
CON43510
CON43520
CON43530
CON43540

```


LIST OF REFERENCES

1. Heat Exchange Institute, Standards for Steam Surface Condensers, Sixth Edition, 1970.
2. Oak Ridge National Laboratory Report ORNL-TM-4248, ORCON1: A Fortran Code for the Calculation of a Steam Condenser of Circular Cross Section, by J.A. Hartford, July 1973.
3. Eissenberg, D.M., An Investigation of the Variables Affecting Steam Condensation on the Outside of a Horizontal Tube Bundle, Ph.D. Thesis, University of Tennessee, December 1972.
4. Fujii, T., Honda, H., and Oda, K., "Condensation of Steam on a Horizontal Tube - the Influence of Oncoming Velocity and Thermal Condition at the Tube Wall," Proc., 18th Nat'l. Heat Transfer Conference, San Diego, August 1979, ASME, pp. 35-43.
5. Johnson, C.M., Marine Steam Condenser Design Using Numerical Optimization, MSME Thesis, Naval Postgraduate School, December 1977.
6. Vanderplaats, G.N., Numerical Optimization Techniques for Engineering Design: With Applications, course notes for a graduate course of the same title presented at the Naval Postgraduate School, Monterey, California, September-December 1983.
7. NASA Ames Research Center Technical Memorandum NASA TM-X-62,282, CONMIN - A Fortran Program for Constrained Function Minimization User's Manual, by G.N. Vanderplaats, August 1973.
8. Naval Postgraduate School Report NPS 69-77-0004, Lastop - A Computer Program for Laser Turret Optimization, by G.N. Vanderplaats and A.E. Fuhs, 1977.
9. Fletcher, R. and Reeves, C.M., "Function Minimization by Conjugate Directions", British Computer Journal, v. 7, n. 2, p. 149-154, 1964.
10. Zoutendijk, G.G., Methods of Feasible Directions, Elsevier, Amsterdam, 1960.
11. Fox, R.L., Optimization Methods for Engineering Design, Addison-Wesley, 1971.
12. Vanderplaats, G.N. and Moses, F., "Structural

Optimization by Methods of Feasible Directions,"
Journal of Computers and Structures, v. 3, p. 739-755,
1973

13. Naval Postgraduate School Report NPS 69-81-003, Copes
- A Fortran Control Program for Engineering Synthesis,
By G.N. Vanderplaats and L.E. Madsen, March 1982.
14. Naval Postgraduate School Report NPS 69-82-005,
Performance Rating of Enhanced Marine Condensers, by
R.H. Nunn and P.J. Marto, August 1982.
15. Naval Ships Systems Command 346-0250, Technical
Manual, Main Condenser and Air Ejector (DLG-6).
16. Naval Boiler and Turbine Laboratory Test T-235, DLG-6
Class Propulsion Machinery, by J.J. Foti, 15 January
1960.
17. Department of the Navy Military Specifications,
MIL-C-15430 J (Ships), Condensers, Steam, Naval
Shipboard, 19 June 1975.
18. Lynch, V.J., A Comparative Study of a Steam Surface
Condenser Computer Model to Field Test Data, MSME
Thesis, Naval Postgraduate School, December 1979.
19. Heat Exchange Institute, Standards for Steam Surface
Condensers, Sixth Edition, 1970.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93943	2
3.	Chairman, Code 69 Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93943	1
4.	Mr. Isidro A. Diaz-Tous EPRI P.O.Box 01412 Palo Alto, California 94303	1
5.	Mr. Ray Kornbau, Code 2721 David Taylor Naval Ship Research and Development Center Bethesda, Maryland 20084	1
6.	Mr. Dan A. Groghan NSEA 05R33 Department of the Navy Naval Sea Systems Command Washington, D.C. 20362	1
7.	Professor R.H. Nunn, Code 69Nn Naval Postgraduate School Monterey, California 93943	3
8.	Lt. Thomas Buckingham 15003 Kamputa Drive Centerville, Virginia 22020	3

205410

Thesis
B8316 Buckingham
c.1 Marine steam conden-
ser design optimiza-
tion.

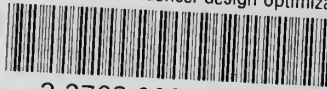
205410

Thesis
B8316 Buckingham
c.1 Marine steam conden-
ser design optimiza-
tion.



thesB8316

Marine steam condenser design optimizati



3 2768 002 07886 7

DUDLEY KNOX LIBRARY