COMMIX-PPC: A Three-Dimensional Transient Multicomponent Computer Program for Analyzing Performance of Power Plant Condensers

Volume II: User's Guide and Manual

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As approved by the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy, the COMMIX-PPC computer code was developed by modifying the in-house version of the COMMIX-2A computer code. The development of COMMIX-PPC is a team effort and the participants are listed below according to their activities.

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Overall Project Direction and Management: W. T. Sha

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Abstract

The COMMIX–PPC computer program is an extended and improved version of earlier COMMIX codes and is specifically designed for evaluating the thermal performance of power plant condensers. The COMMIX codes are general–purpose computer programs for the analysis of fluid flow and heat transfer in complex industrial systems. In COMMIX–PPC, two major features have been added to previously published COMMIX codes. One feature is the incorporation of one–dimensional conservation of mass, momentum, and energy equations on the tube side, and the proper accounting for the thermal interaction between shell and tube side through the porous medium approach. The other added feature is the extension of the three–dimensional conservation equations for shell–side flow to treat the flow of a multicomponent medium.

COMMIX–PPC is designed to perform steady–state and transient three–dimensional analysis of fluid flow with heat transfer in a power plant condenser. However, the code is designed in a generalized fashion so that, with some modification, it can be used to analyze processes in any heat exchanger or other single–phase engineering applications.

The following unique features are retained from other COMMIX codes:

- *Porous–Medium Formulation.* COMMIX–PPC uses a new porous–medium formulation with the parameters of volume porosity, directional surface porosity, distributed resistance, and distributed heat source or sink. With this formulation, the COMMIX code can model an anisotropic flow domain with stationary structures, and it can be used to treat irregular geometries. The porous–medium formulation with the additional parameter of directional surface porosity represents a unified approach to thermal–hydraulic analysis. Because of this feature, it is now possible to perform a multidimensional thermal–hydraulic simulation of either a single engineering component, such as a rod bundle, reactor plenum, or piping system, or of a multicomponent system that is a combination of two or more engineering components.

- *New Finite–Volume Formulation for equations of Conservation of Mass, Momentum, and Energy Equations.* The momentum formulation employs the concept of a volume–averaged velocity as used in COMMIX–1C. It makes the numerical calculation more robust than in previous COMMIX versions. It also makes the location of pressure change coincide with that of density change for one–dimensional flows. In addition, the new discretized momentum equations also satisfy the one–dimensional Bernoulli equation.

- *Three Matrix Solvers.* In COMMIX–PPC, three matrix solvers, the successive overrelaxation method, the direct matrix inversion method, and the

preconditioned conjugate gradient method for a symmetric matrix, are available to solve the pressure equation and scalar transport equations. Depending on the size of the computational domain, the user can choose the solver that is best suited for a given problem. These three matrix solvers greatly increase the flexibility and efficiency of numerical computation for COMMIX-1C compared to previous codes.

- *Geometrical Package.* A special geometrical package has been developed and implemented to permit modeling of any complex geometry in the most storage-efficient way.

Volume I (Equations and Numerics) of this report describes in detail the basic equations, formulation, solution procedures, and models for auxiliary phenomena. Volume II (User's Guide and Manual) contains the input instruction, flow charts, sample problems, and descriptions of available options and boundary conditions.

COMMIX-PPC is a product of the continuing evolution of the family of COMMIX codes. The technical contents of the latest version of COMMIX-1C, when appropriate and relevant, will be duplicated here.

CONTENTS

FIGURES

TABLES

Executive Summary

The COMMIX (*Component Mixing*) code is a general-purpose computer program for the analysis of fluid flow in real-world engineering systems. Because the needs of users have changed since its inception in 1976, the code has undergone several stages of development, and several versions/extensions are now available. The present COMMIX-PPC is yet another extension, designed specifically for the purpose of analyzing the performance of power plant condensers. To meet this objective, two major additions have been incorporated into the code:

- The three-dimensional conservation equations for shell-side flow have been extended to treat the flow of a multicomponent medium. This is necessary because the shell side generally contains a mixture of steam and air. The ability to treat the flow of a multicomponent medium is also essential for assessing the effect of noncondensibles on condenser performance. On the other hand, the computation is simplified by assuming that the steam is at the saturated state and its bulk temperature is determined solely by its partial pressure in the mixture.

- Tube-side fluid flow and heat transfer have been developed and incorporated into the code. The use of one-dimensional conservation equations of mass, momentum, and energy for tube-side flow greatly reduces required computer time without sacrificing accuracy. It also facilitates handling of thermal coupling between the condensation of vapor on the shell side and forced convection of a single-phase liquid on the tube side.

In addition to the foregoing two major additions, several minor modifications and additions have been made, mainly dictated by the consideration of condensation of steam in the presence of noncondensibles. However, it is emphasized that many of the salient features of COMMIX are retained in COMMIX-PPC.

A major unique feature of COMMIX is its porous-medium formulation, which was rigorously derived through local volume averaging. The formulation makes use of the concept of volume porosity, directional surface porosity (a dimensionless vector quantity associated with a surface element), distributed resistance, and distributed heat source or sink. Volume porosity is the ratio of the volume occupied by fluid in a control volume to the total control volume. Surface porosity is similarly defined as the ratio of the area available for fluid flow through a control surface to the total control surface area. Both arise naturally in the averaging process. In the conventional porous-medium formulation, only the volume porosity, distributed resistance, and distributed heat source are used. The concept of directional surface porosity is relatively new. It facilitates the modeling of anisotropic structural resistance to flow. Irregular geometries can also be adapted in the present porous-medium formulation.

The predictive capability of the numerical analysis of fluid flow and heat transfer in complicated engineering systems, e.g., nuclear reactor cores or the shell side of a steam condenser, depends strongly on how well the distributed resistances are modeled. The resistances would vary with their orientation relative to the general flow direction and are oftentimes not known a priori. The directional surface porosity is a geometrical quantity

and can be accurately and unambiguously calculated. Its introduction lessens the dependency of the velocity field on the modeling of the flow resistance and hence, improves the accuracy of the numerical prediction. This is a major advantage of the present porous–medium formulation.

The finite–volume formulation used in COMMIX for the mass, momentum, and energy conservation equations has recently been extended to include variable–density flows. The modified formulation employs the concept of a volume–average mass–weighted velocity. As a consequence, the numerical procedure is more robust than the previous COMMIX versions. It also forces the location of pressure change to coincide with that of density change in one–dimensional flows. In addition, the discretized momentum equation also satisfies the one–dimensional Bernoulli equation.

The COMMIX code provides detailed implied velocity and temperature fields for the system under consideration. The conservation equations of mass, momentum, and energy, and the transport equations of the turbulence parameters are solved as boundary–value problems in space and initial–value problems in time. The discretized equations are obtained by integrating the conservation equations over a control volume. The code is flexible and has a wide range of applicability. It is capable of solving thermal–hydraulic problems involving either a single engineering component, such as a rod bundle, reactor plenum, piping system, or heat exchanger, or an engineering system that consists of a combination of these components.

COMMIX uses a fully implicit solution scheme called SIMPLEST–ANL. It is a modification of the well–known numerical procedure SIMPLER. The code has a modular structure, and permits the use of either Cartesian or cylindrical coordinate systems. COMMIX–PPC contains physical–property packages for water vapor and liquid water. In addition to these two packages, an option is available for users to input simplified property correlations that are valid in the desired range of applications.

There are three matrix solvers in COMMIX–PPC: the successive overrelaxation method (SOR), the direct matrix inversion method (DMIM), and the preconditioned conjugate gradient method (PCG). SOR and DMIM are suitable for both symmetric and nonsymmetric matrices and are selected for solving the pressure equation and scalar transport equations. PCG is only applicable to a symmetric matrix and thus may be used only for the pressure equation. Depending on the size of the matrix, the user may choose the particular solver that is best suited for the problem in question. With the availability of the three matrix solvers, the efficiency of the numerical computation capability of COMMIX–PPC is greatly increased.

Another unique feature of the COMMIX code is its geometry package. The basic concept is to use computational cells (either in Cartesian or cylindrical coordinates) as building blocks that are stacked to approximate the shape of the physical systems under consideration. Then, volume porosity and directional surface porosity are used to account for differences between the geometry used in the computation and the actual configuration. This feature permits the COMMIX code to model irregular and complex geometries with relative ease. Furthermore, the computer storage requirement of the COMMIX code is optimized; only the computational cells used in the calculations are counted.

Volume I, Equations and Numerics, of this report describes in detail the basic conservation equations, finite–volume formulation, turbulence modeling, one–dimensional

treatment of tube–side flow, and solution procedures. Auxiliary models for the following phenomena are also described:

- Momentum interaction between fluid and stationary solid structures.

- Thermal interaction between shell– and tube–side fluid and stationary solid structures.

In Vol. II, User's Guide and Manual, we provide flow charts, descriptions of subroutines, geometry modeling, initialization procedures, input descriptions, etc. A sample problem is included to familiarize readers with the input/output structures of the code. Also included is a sensitivity study of the effects of both condenser inlet air mass fraction and exit mass flow rate at the extraction pipe on steam condensation rate. Wherever applicable, technical content of COMMIX–1C is duplicated here.

1   Introduction

1.1   Purpose

COMMIX (*Component Mixing*) is a general–purpose computer code for the analysis of heat transfer and fluid flow encountered in real engineering systems. Since the development of COMMIX–1 in 1976, many features have been added and/or refined to augment the code's applicability. Consequently, COMMIX has become a general–purpose computer code with a very wide range of applications. Although developed originally for nuclear–reactor applications, COMMIX can be used, with minor modification, to analyze fluid flow and heat transfer processes in other engineering systems.

Many industries and organizations involved in the design and/or analysis of nuclear reactors are already using COMMIX. However, due to its generalized formulation and the manner in which it is structured, COMMIX has also been found to be a useful tool in other disciplines. Hence, the number of COMMIX users is expected to increase in the future. We have prepared this report keeping in mind prospective users who can benefit from a comprehensive description of the code.

In describing COMMIX–PPC, we had two distinct goals. One was to convey to the reader the capabilities of COMMIX, the equations it solves, and how they are solved; this was done in Volume I of this report. The second goal was to present a step–by–step procedure for the use of COMMIX. Accordingly, the procedure was described in sufficient detail so the usual difficulty of comprehending someone else's code is minimized. This, of course, is not an easy task, but we have attempted it in Volume II.

We stress here that, while extending previous COMMIX versions to COMMIX–PPC, we have tried to retain the original structure and format of COMMIX as much as possible. Therefore, previous COMMIX users will have little difficulty in adapting and running their problems with the COMMIX–PPC version.

Volume I, Equations and Numerics, describes the basic equations, formulations of the discretized equations, auxiliary models, solution procedures, etc. Vol. II, User's Guide and Manual, describes all information needed by the user, e.g., input description, flow chart,

solution methods, sample problems, output formats, and user's options. The results of a sensitivity study of the effects of both condenser inlet air mass fraction and exit mass flow rate at the air extraction pipe on steam condensation rate are presented. Wherever applicable, technical content of COMMIX-1C is duplicated here.

1.2 Organization of the Report

This volume describes the step-by-step procedure in sufficient detail so that a reader unfamiliar with the COMMIX code may begin using it with minimum difficulty.

An introduction is presented in Sec. 1. Section 2 describes the overall structure of the program, including the flow chart and solution sequence. For a user to start numerical simulation, the first step is to model the geometry. In Sec. 3, we describe the geometrical conventions used in COMMIX, recommend modeling procedures, and suggest ways to prepare geometry-related input for the code. Section 4 addresses the initialization of the variables, including simplified procedures for shell-side, as well as tube-side, flows, and describes several available boundary condition options.

The modeling of the thermal interaction between a fluid and solid structures is discussed in Sec. 5; that of the momentum interaction between a fluid and the solid structures is given in Sec. 6. The solution procedure is presented in Sec. 7. In COMMIX-PPC, we have implemented three matrix solvers: the successive overrelaxation (SOR) method, the direct matrix inversion method (DMIM), and the preconditioned conjugate gradient (PCG) method. The user can select a matrix solver, depending on the nature of the problem. The choice of these solvers is discussed in terms of convergence rate and computation efficiency.

Auxiliary inputs, such as turbulence modeling, heat transfer correlations, and physical property determination, are described in Sec. 8.

COMMIX requires initial estimation of the steady-state distribution of all dependent variables regardless of whether the analysis is for a steady-state problem or for a transient simulation. All inputs required for such steady-state calculation are described in Sec. 9. The details related to transient simulations are presented in Sec. 10. In Sec. 11, the input/output procedures and related variables are described. Section 12 discusses global mass and thermal energy balances, and Sec. 13 contains final concluding remarks.

Appendix A summarizes all input variables for convenient reference by the user. Appendix B lists all subroutines, together with a brief description of their functions, and Appendix C contains a list of resistance correlations.

To illustrate the capabilities of COMMIX-PPC, a sample problem, along with its description, input, and output, is presented in Appendix D. Appendix E presents a sensitivity study of the effect of both condenser inlet air mass fraction and exit mass flow rate at the air extraction pipe on steam condensation rate.

2 Structure of COMMIX–PPC

2.1 Overall Flow Chart

The overall structure of the computer program is illustrated by the simplified flow chart presented in Fig. 1, where ϕ represents the dependent variables. The major steps are as follows:

- The numerical simulation begins with grid specification and the calculation of all geometrical quantities that are needed frequently in later work. Reading of the geometry input is done in the subroutine GEOM3D. Calculation of all geometrical quantities is done in the subroutine BOXES, for which either the Cartesian or the cylindrical coordinate system may be selected.

- Next, the initial values of all variables are either specified or calculated. The subroutine INITAL is the main subroutine for initialization. It sets up the default values, reads NAMELIST/DATA/, and calls appropriate subroutines (see Table 1 for reading input data, calculating initial values, and printing, if desired, of input and control parameters).

- The tube-side computational cell location cards are read in the subroutine TBINPR, and the geometrical quantities are computed.

- After completion of the initialization, the subroutine OUTPUT is called to print initial values of all desired variables.

- The solution sequence (details of which are given later) is then executed to calculate the values of all dependent variables at a new time. Subroutine TIMSTP determines the sequence of calling subroutines required during the solution sequence. When the values of all variables at the new time are determined, we return to the main subroutine AMAIN.

- If printing is desired at this point, the subroutine OUTPUT is called and the desired variables are printed.

- If the required number of time steps has been performed, or the maximum computation time or the maximum real time is reached, the computation is terminated and, if requested, the restart data are written on disk file. Otherwise, old time values are updated and the execution continues for the next time step until it converges.

2.2 Solution Sequence

The solution sequence is controlled by the subroutine TIMSTP; its flow diagram is shown in Fig. 2. Subroutine TIMSTP is the heart of the program; it performs the outer iteration loop.
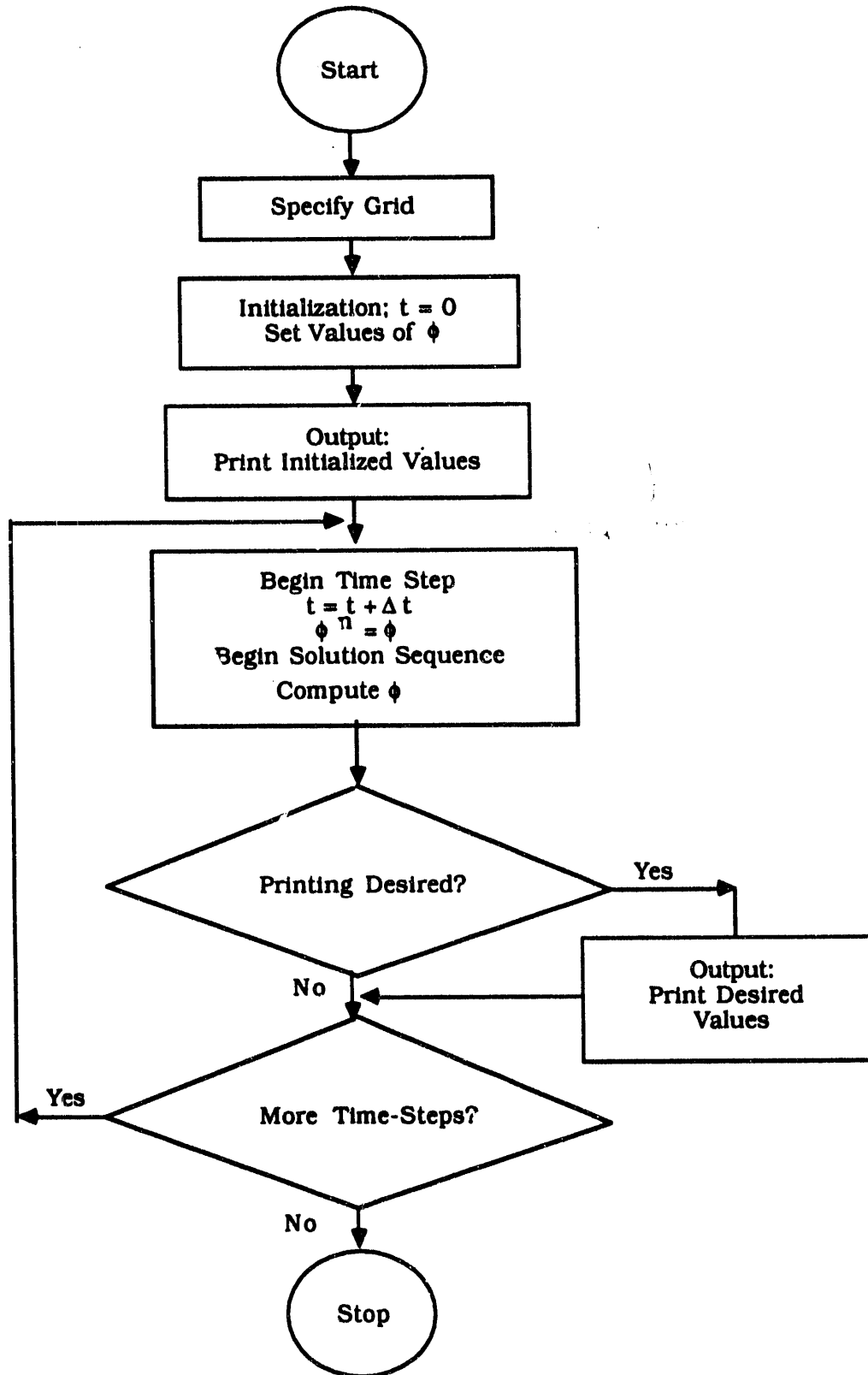
Fig. 1. COMMIX-PPC flow chart

Table 1. Initializing subroutines

Subroutine	Input Data NAMELIST	RECORDS	Function or Parameters Initialized
INITAL	GEOM DATA	–	Initializes default values and calls initializing subroutines
INFORC	DATA	Force–structure	Force–structure parameters
INPSTR	STRUCT T F M	Thermal–structure prototype and location records	Thermal–structure parameters
ICTEMP	DATA	–	Boundary values of velocity, temperature, heat, density, and pressure
ICTUBE	TUBS	–	Values of velocity, temperature, and pressure for tube–side flow
BARIN	–	Boundary and initial–value records	Boundary and initial values of pressure, velocity, temperature, enthalpy, heat source, porosity, and surface area

The six major loops in subroutine TIMSTP are

- Shell–Side and Tube–Side Heat Transfer Coupling Loop: Heat transfer coefficients, heat transfer rates from steam to tube and from tube to cooling water, and steam condensation rate are calculated. Subroutine HSTRUC computes the heat transfer coefficients, subroutine QSTRUC computes the heat transfer rates both in shell side and tube side, and subroutine INMDOT computes the steam condensation rate.

- Mass–Momentum Loop: Mass and momentum equations are solved and new velocity and pressure values are computed. Subroutine MOLOOP calls the required subroutines in proper sequence to solve the mass and momentum equations.

- Turbulence Loop: Two subroutines, TKLOOP and TDLOOP, are called to calculate the turbulence parameters k (turbulence kinetic energy) and ε (rate of dissipation of k). Turbulent viscosity and conductivity are then calculated by subroutine TURV12.
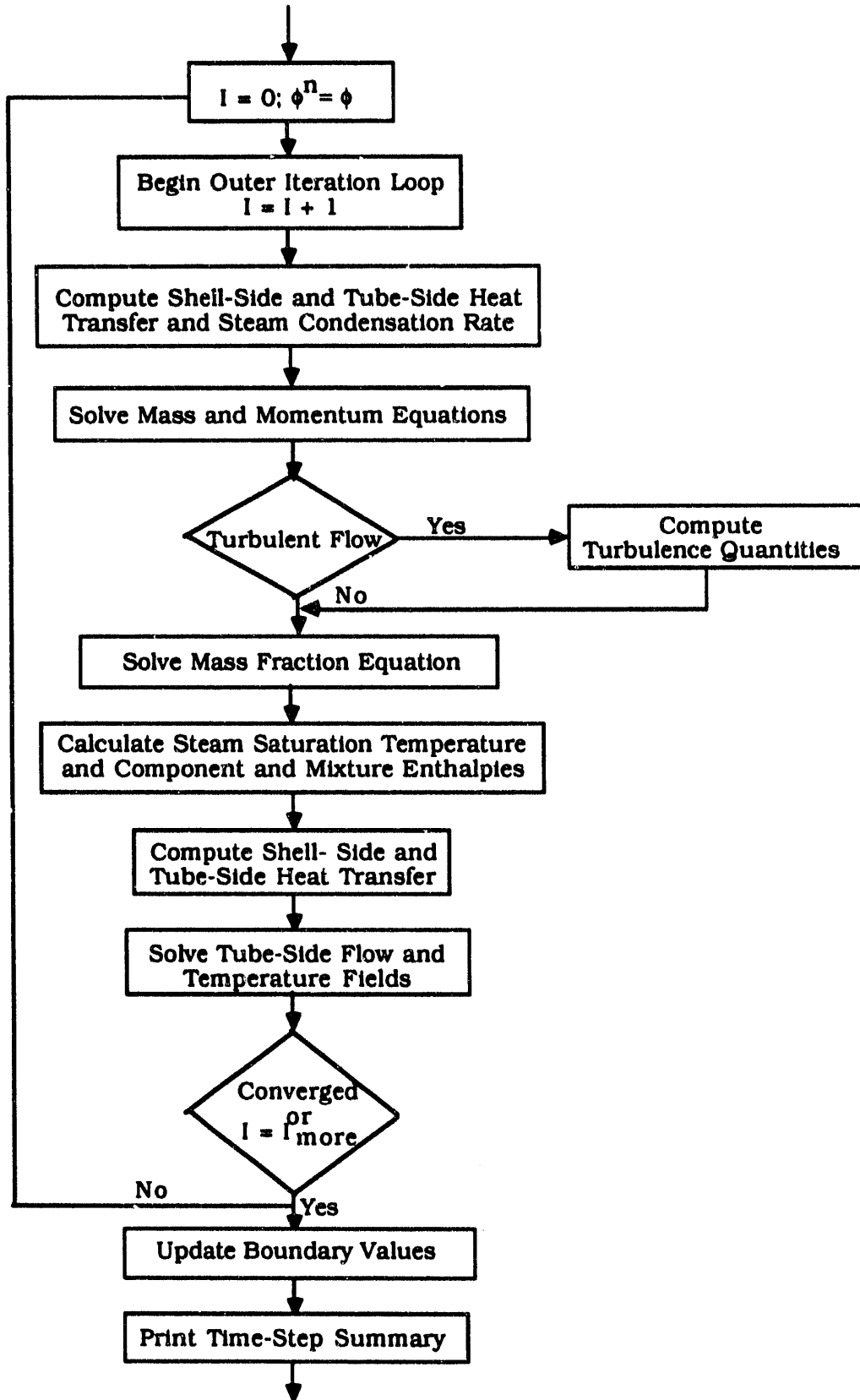
Fig. 2. Flow chart for solution sequence in subroutine TIMSTP

- Component Mass Fraction Loop: Component continuity equations are solved and new values of component mass fraction are calculated. Subroutine MALOOP calls the required subroutines in sequence to solve the component mass conservation equation.

- Energy Loop: The saturation temperature of steam is calculated from the steam partial pressure. Subroutine ENLOOP computes the saturation temperature of steam. New values of enthalpies of steam, air, and a steam-air mixture are computed.

- Tube–Side Flow and Temperature Loop: The one–dimensional tube–side flow and temperature fields are solved and new values are calculated for temperature, pressure, and velocity. Subroutine TBSIDE solves the one–dimensional continuity, momentum, and energy equations.

2.3 Shell– and Tube–Side Heat Transfer Coupling Loop

The flow chart for the shell– and tube–side heat transfer coupling loop is shown in Fig. 3. The calling sequence is as follows:

- First, calculate the heat transfer coefficients h_a, h_c, and h_{cw} according to Eqs. 9.3, 9.4, and 9.14 of Vol. I, respectively, and the fouling resistance R_f described in Eq. 9.35 also of Vol. I. These quantities are then used to compute the shell–side and tube–side heat transfer coefficients h_1 and h_2 according to Eqs. 9.32 and 9.41 of Vol. I, respectively. The calculations of h_a, h_c, h_{cw}, R_f, h_1, and h_2 are performed in subroutines HSTRUC, HTCOEF, HTCOND, and HTCTUB.

- Use heat transfer coefficients h_1 and h_2, tube geometrical information, material properties, and the steam/air temperature to calculate coefficients A_ℓ and C_ℓ for ℓ = 1–L, as described in Eqs. 9.51–9.54. Then, solve for temperature distribution $T_\ell(\ell = 1 \ldots L)$ from Eqs. 9.48–9.50, and compute the heat transfer rate $\dot{q}_1$ and $\dot{q}_{L+1}$ from Eqs. 9.55 and 9.56, all of Vol. I. These calculations are performed by subroutine QSTRUC.

- Use $\dot{q}_1$ and latent heat to calculate the steam condensation rate $\dot{m}$ by subroutine INMDOT.

The flow diagrams for the mass–momentum, component mass fraction, energy, and tube-side flow and temperature loops are presented in Secs. 2.4, 2.5, 2.6, and 2.7, respectively. The turbulence loop is discussed in Sec. 8.3.

2.4 Mass–Momentum Loop

The flow chart for the mass–momentum loop is shown in Fig. 4. The calling sequence is performed by subroutine MOLOOP.

```
                    ┌─────────────────────────────────────┐
                    │  Calculate Shell- and Tube-Side      │
                    │  Convective Heat Transfer            │
                    │  Coefficients in                     │
                    │  HSTRUC, HTCOEF, HTCOND, HTCTUB       │
                    └─────────────────────────────────────┘

                    ┌─────────────────────────────────────┐
                    │  Calculate Heat Transfer Rates in    │
                    │  Shell Side and Tube Side in         │
                    │  QSTRUC                               │
                    └─────────────────────────────────────┘

                    ┌─────────────────────────────────────┐
                    │  Compute Steam                        │
                    │  Condensation Rate in                 │
                    │  INMDOT                               │
                    └─────────────────────────────────────┘
```
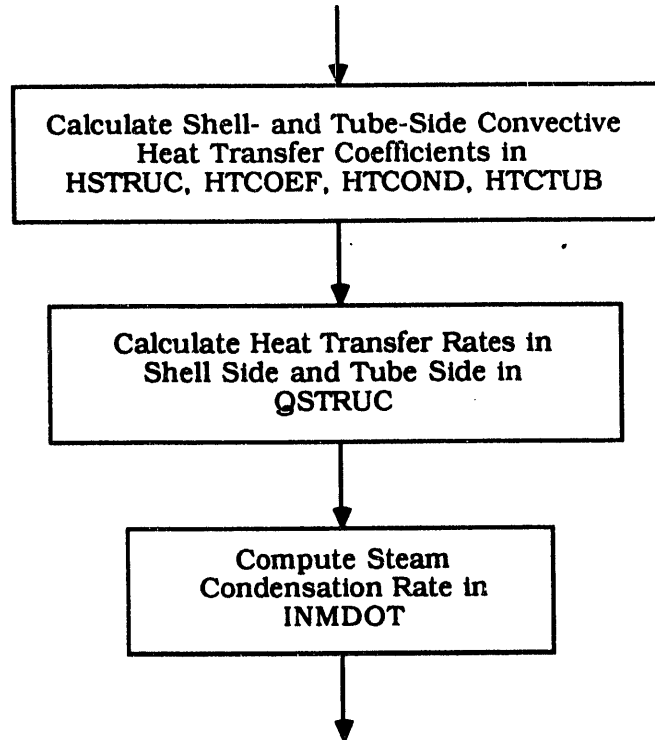
*Fig. 3. Flow diagram for shell- and tube-side
heat transfer coupling loop*

- First, calculate the coefficients $\hat{u}$, $\hat{v}$, $\hat{w}$, d^u, d^v, and d^w in the pressure-velocity relation described in Secs. 5 and 6 of Vol. I. These calculations are performed in subroutines XMOMI, YMOMI, and ZMOMI for x (or r), y (or θ), and z directions, respectively.

- Use these pressure–velocity–relation coefficients to calculate the coefficients a_0^r, a_1^r, ...a_6^r, b_0^r (see Table 12 of Vol. I) in the pressure equation. This is done by subroutine PEQN.

- The pressure equation is then solved in subroutine SOLVER by one of the matrix solvers (subroutine SOLVIT for the SOR method, subroutine DMIM for the DMIM, and subroutine CGRAD for the PCG method). If the SOR or PCG method is selected by the user, the solution is obtained by an iterative procedure.

  The iteration is continued until either the residue of the pressure equation is below the specified convergence criterion or the number of iterations has reached the specified maximum value, called ITMAXP. If the DMIM is selected, the solution is obtained by direct inversion and no iteration is involved.

- Velocities are then updated in subroutine MOMENI with the new pressure values and the following relations:

```
┌─────────────────────────────────────────┐
│   Velocity-Pressure -Relation Coefficients│
│        û, v̂, ŵ, d^u, d^v, d^w            │
│                  in                       │
│        XMOMI, YMOMI, ZMOMI                │
└─────────────────────────────────────────┘
```

Velocity-Pressure -Relation Coefficients

$\hat{u}, \hat{v}, \hat{w}, d^u, d^v, d^w$

in

XMOMI, YMOMI, ZMOMI

Pressure-Equation Coefficients

$a_0^P, a_1^P, a_2^P, \ldots , a_6^P, b_0^P$

in

PEQN

Solve Pressure Equation for
New-Time Pressure
in
DMIM/SOLVIT/CGRAD

Compute New-Time
u, v, w
in
MOMENI

Update Boundary Velocities
in
BCFLOW
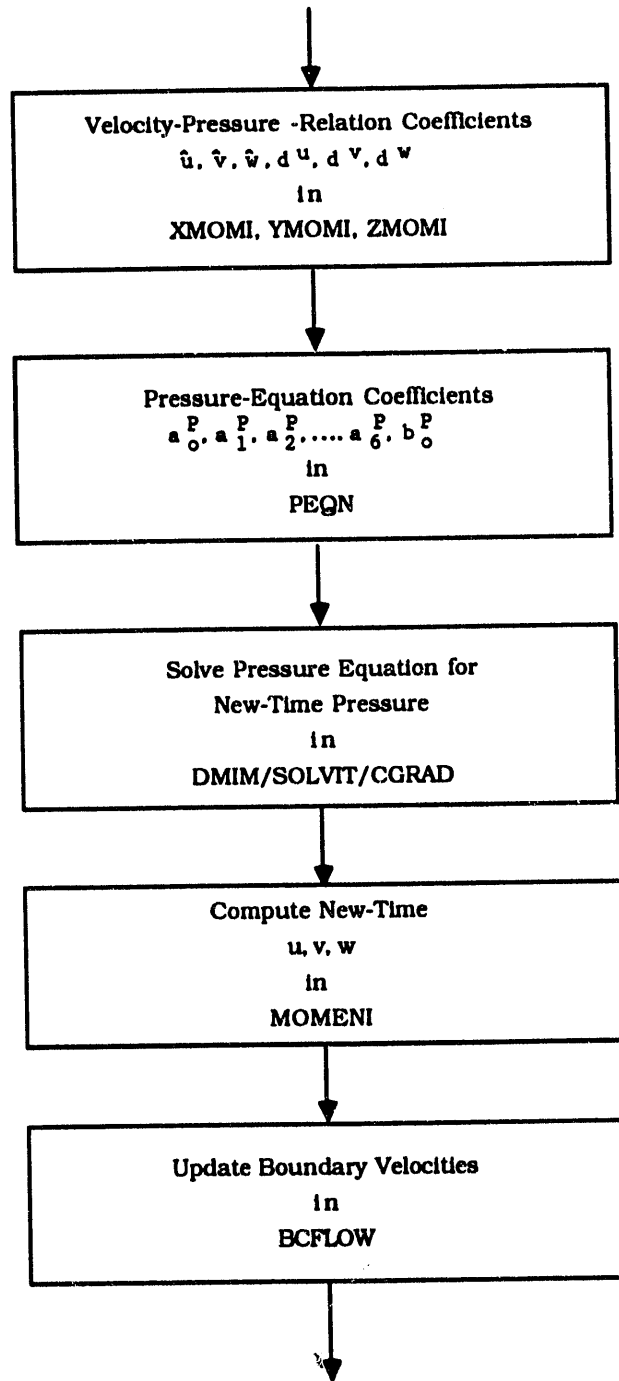
Fig. 4. Flow diagram for mass-momentum loop

$$u = \hat{u} - d^u(\delta p_2 - \delta p_0),$$

$$v = \hat{v} - d^v(\delta p_4 - \delta p_0),$$

and

$$w = \hat{w} - d^w(\delta p_6 - \delta p_0).$$

- Finally, update the velocity boundary values in subroutine BCFLOW.

This completes the mass–momentum loop.

2.5 Component Mass Fraction Loop

The sequence of computations in the component mass fraction loop (called by subroutine MALOOP) is shown in Fig. 5.

- Compute the convection terms in subroutine MACONØ.

- Compute the diffusion term in subroutine MADIFF.

- Compute the transient and source terms in subroutine MASSCO.

- Solve the mass fraction equations

$$\left(a_0^x x_0^{n+1}\right)_i = \sum_\ell \left(a_\ell^x x_\ell^{n+1}\right)_i + \left(b_0^x\right)_i \qquad (i = 2, 3, \ldots n)$$

by subroutine SOLVER for the new–time mass fractions by either the SOR method (subroutine SOLVIT) or the DMIM (subroutine DMIM). Note that i indicates the component number.

- Compute the mass fraction of the first component by the following relation:

$$x_1 = 1 - \sum_{i=2}^{n} x_i.$$

2.6 Energy Loop

The sequence of computations in the energy loop (called by subroutine ENLOOP) is shown in Fig. 6.

- Update all boundary values in subroutine BCTENT.

- Compute the steam partial pressure.

- Compute the steam saturation temperature based on steam partial pressure.

- Compute the enthalpies of steam, air, and steam and air mixture.
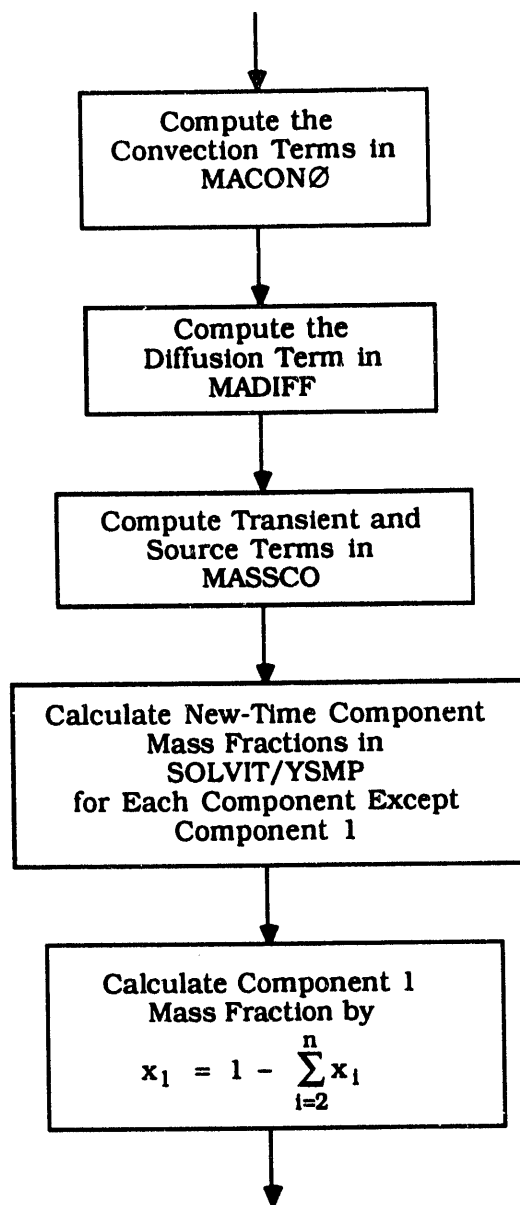
Fig. 5. Flow diagram for component mass fraction loop

2.7 Tube–Side Flow and Temperature Loop

The sequence of computations in the tube–side loop (called by subroutine TBSIDE) is shown in Fig. 7.

- Compute coefficients in the velocity–pressure relation.

- Compute coefficients in the pressure equation.

- Solve pressure equation for the new–time pressure.

- Compute new–time velocity.

```
           │
           ▼
┌─────────────────────────┐
│   Update Constant and   │
│ Transient Boundary Values in │
│          BCTEMT         │
└─────────────────────────┘
           │
           ▼
┌─────────────────────────┐
│  Compute Steam Partial  │
│        Pressure         │
│                         │
│          xₛPₜ           │
│   pₛ = ───────────      │
│        xₛ + 0.622xₐ     │
└─────────────────────────┘
           │
           ▼
┌─────────────────────────┐
│   Compute Saturation    │
│      Temperature        │
│          Ts             │
└─────────────────────────┘
           │
           ▼
┌─────────────────────────┐
│  Compute Enthalpies of  │
│ Steam, Air, and Steam and │
│       Air Mixture       │
└─────────────────────────┘
           │
           ▼
```

$$p_s = \frac{x_s P_t}{x_s + 0.622 x_a}$$
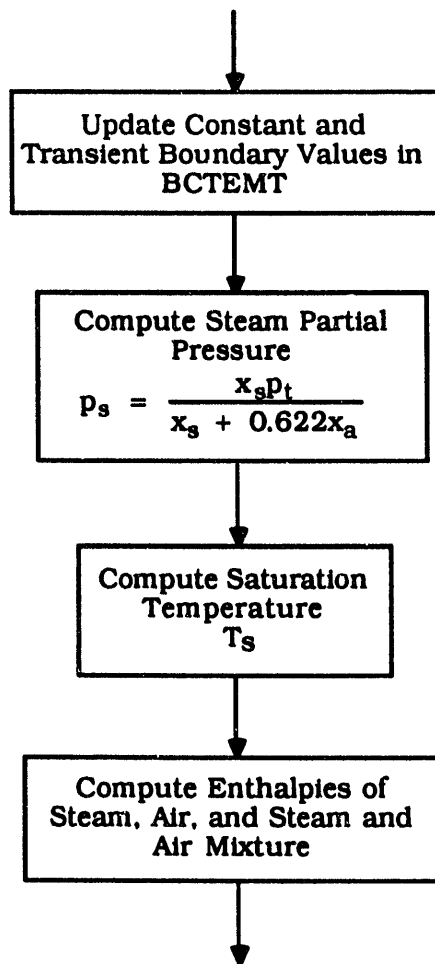
Fig. 6. Flow diagram for energy loop

- Solve energy equation for new-time temperature and enthalpy.

- Update boundary velocities and temperature.

3   Geometry Modeling

3.1   Introduction

In most cases, the first step is to model the geometry of the system to be simulated. The geometry concept of COMMIX is somewhat unique and is different from the conventional approach. We hope that, after using the COMMIX geometry package, the user will not only feel at ease with the COMMIX concept, but will begin to appreciate the benefits of the COMMIX approach. To make the introductory period as easy and smooth as possible, we suggest that all new users read this section with extra thoroughness.
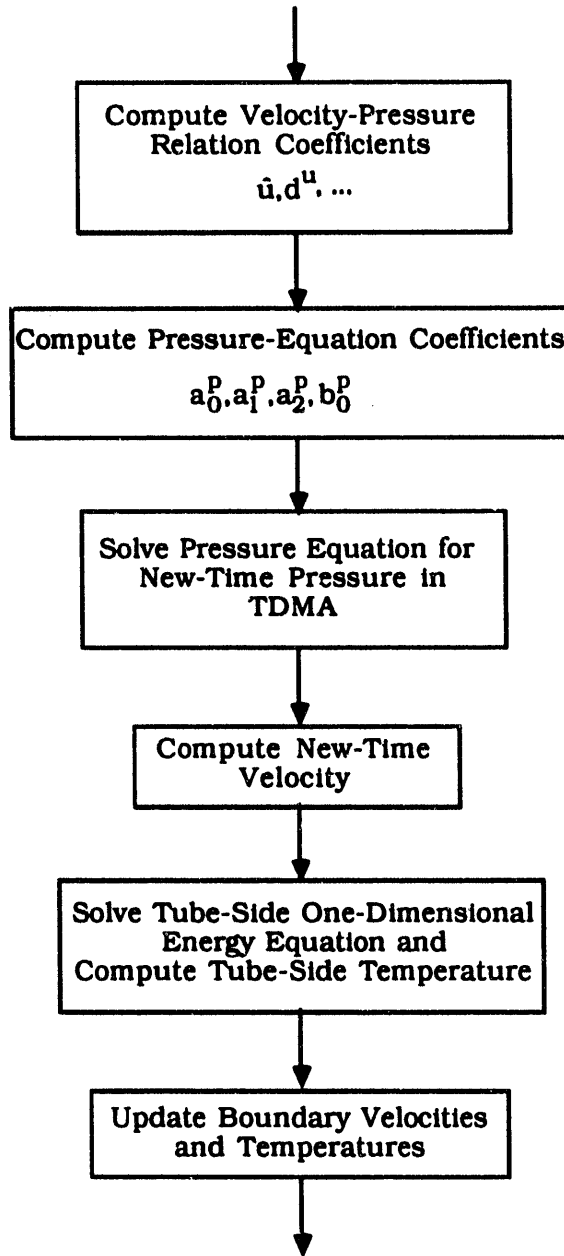
Fig. 7. Flow diagram for tube-side loop

3.2 Concept and Definitions

In numerical modeling, the computational flow domain is partitioned into several computational cells formed by x, y, and z grid planes in a Cartesian coordinate system or by r, θ, and z grid surfaces in a cylindrical system, as shown in Fig. 8. In COMMIX, the following convention is used to define the various elements of the flow domain. For the purpose of illustration, we consider a simple box geometry shown in Fig. 9.
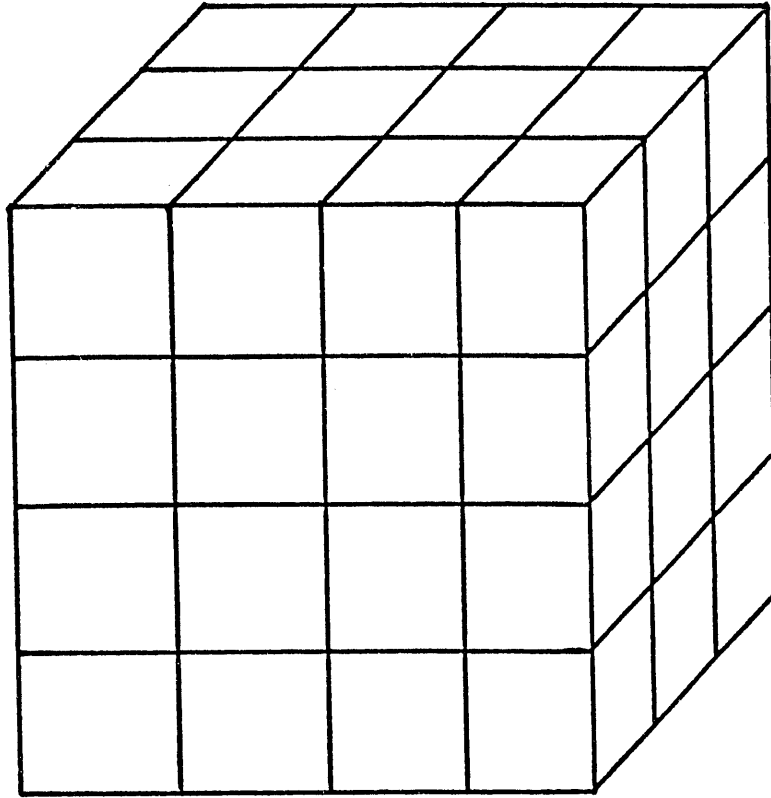
(a)
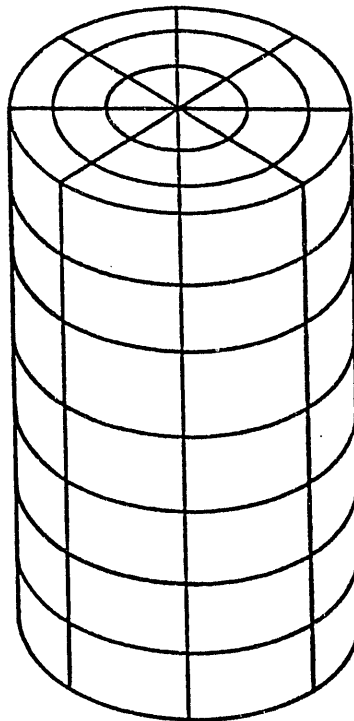
(b)

Fig. 8. Partitioning in (a) Cartesian and (b) cylindrical coordinate systems
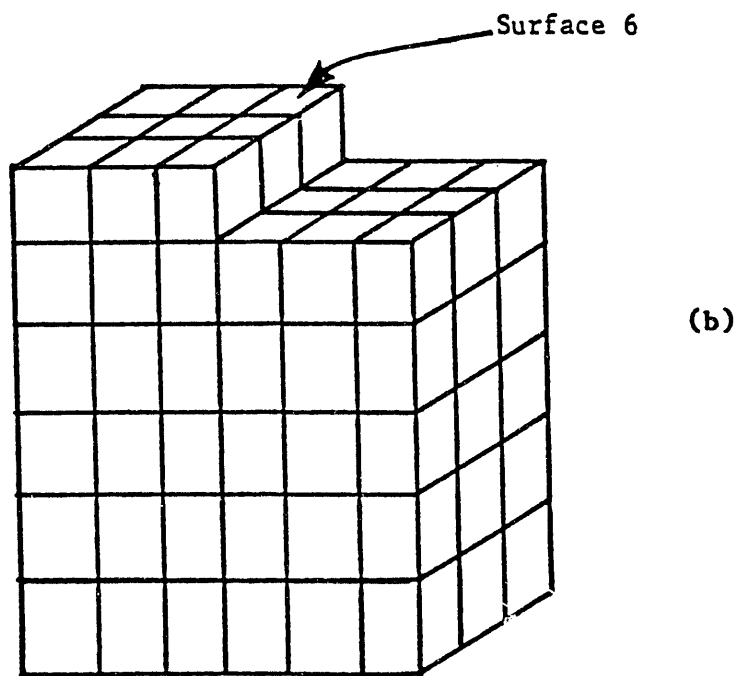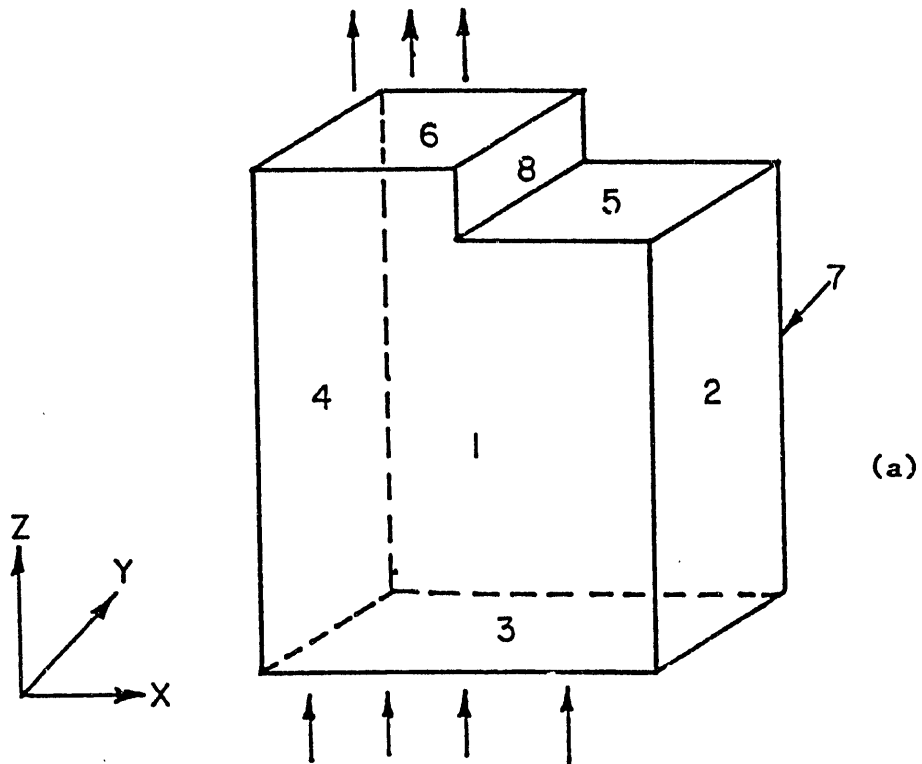
Fig. 9. *Model geometry showing (a) boundary surfaces and (b) partitioning of surface elements*

- **Computational Cell**

  In COMMIX, the computational cell is defined by the location of the grid point place: in the geometrical center of the cell. Cell sizes can be nonuniform. A computational cell surrounded only by other computational cells is called an internal cell. If one cell surface is a boundary surface, it is called a boundary cell. A user must specify the total number of computational cells required through the FORTRAN variable NM1.

- **Boundary Surface**

  The external boundaries enveloping the flow domain are called the boundary surfaces. These may be solid walls or planes through which fluid can flow. The geometry in Fig. 9a has eight boundary surfaces.

  A boundary surface is defined by its unit normal vector, always pointing into the fluid region. The x, y, and z components (XNORML, YNORML, and ZNORML) of a unit normal vector are specified by its direction cosines. For example, the unit normal vector of Surface 2 has components (-1,0,0). Table 2 lists the components of the unit normal vectors of the eight surfaces of the flow domain shown in Fig. 9a.

- **Regular Surface**

  A boundary surface coinciding with any one of the grid planes is called a regular surface. All surfaces of the geometry of Fig. 9 are regular surfaces.

Table 2. Components of unit normal vectors (direction cosines) of geometry in Fig. 9a

Surface	XNORML	YNORML	ZNORML
1	0	1	0
2	-1	0	0
3	0	0	1
4	1	0	0
5	0	0	-1
6	0	0	-1
7	0	-1	0
8	-1	0	0

- **Irregular Surface**

  A boundary surface that does not coincide with any one of the grid planes is called an irregular surface. In Fig. 10a, Surface 1 is an irregular surface. *Note that only regular surfaces can be specified as inlet and outlet planes, i.e., flow inlet and outlet planes cannot be irregular surfaces.*

- **Surface Number**

  A user must assign a number to each boundary surface. The same surface number can be assigned to boundary surfaces that have
  -the same unit normal vector, and
  -the same velocity, pressure, temperature, and heat flux boundary
    conditions.

  For example, although Surfaces 2 and 8 in Fig. 9a are in two different planes, they can be assigned the same surface number if their unit normal vector has the same direction cosines and the same boundary conditions, as illustrated in Fig. 11. However, they may also be defined as two different surfaces, if desired.

  Surfaces 3 and 8 lie in the same plane, as illustrated in Fig. 12, and they have the same unit vector. They must be considered as two different surfaces if they have different boundary conditions for velocity or pressure or temperature or heat flux.

  The variable NSURF is used to specify a total number of surfaces. *All irregular surfaces must be numbered before other regular surfaces are numbered.*

- **Irregular Cell**

  If one surface of a computational cell is an irregular surface, that cell is called an irregular cell. An irregular cell cannot be an interior cell because it contains an irregular surface that is part of a boundary surface. *A computational cell is permitted to have at most one irregular surface.*

- **Surface Element**

  A section of a surface between two pairs of consecutive grid lines is defined as a surface element. A surface can therefore have more than one surface element. For example, in Fig. 9b, Surface 6 has nine surface elements. The variable NL1 is used to specify the tot… number of surface elements.

- **Volume Porosity**

  The volume porosity γ is a geometrical parameter that is defined as the ratio of fluid volume in a cell to the total cell volume. The FORTRAN variable name for volume porosity is AL and its numerical value must lie between 0 and 1. This parameter is included to account for irregularity in geometry and the
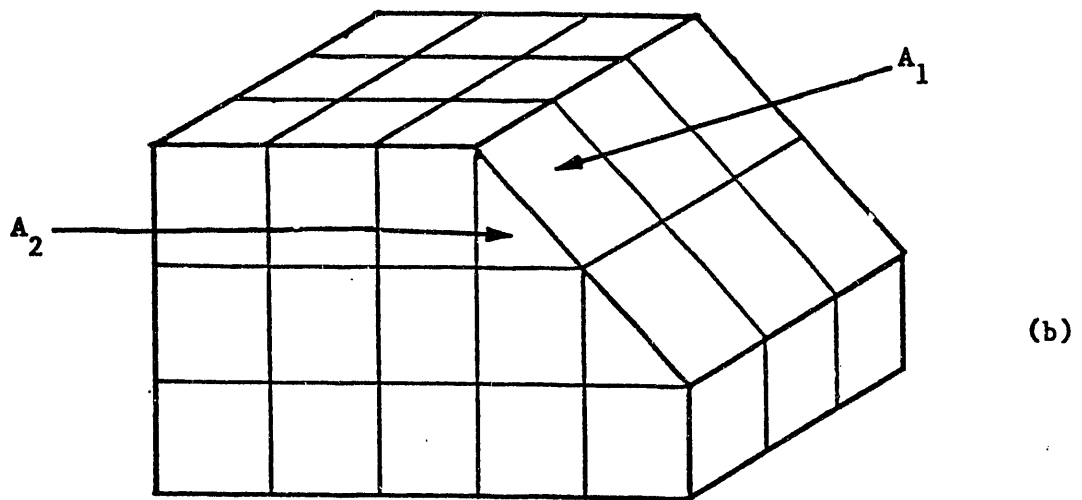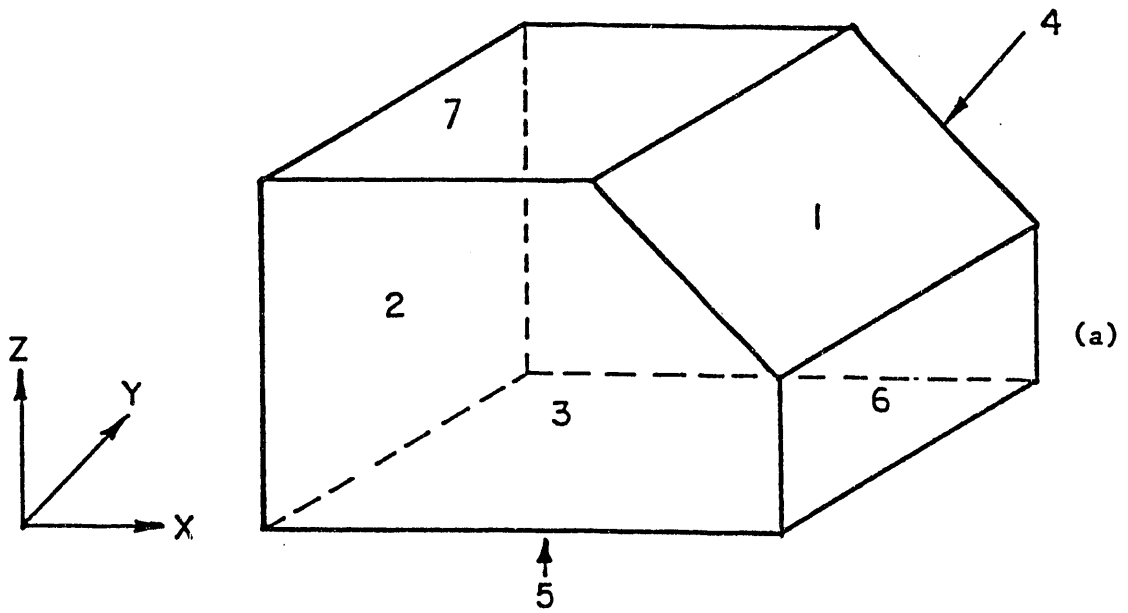
Fig. 10. Model geometry showing (a) irregular surface and
(b) partitioning of surface elements
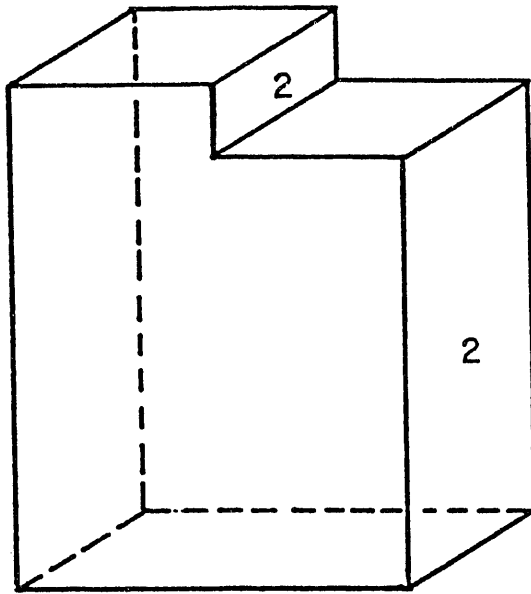
Fig. 11. *Two noncoincident surfaces with the same surface number*
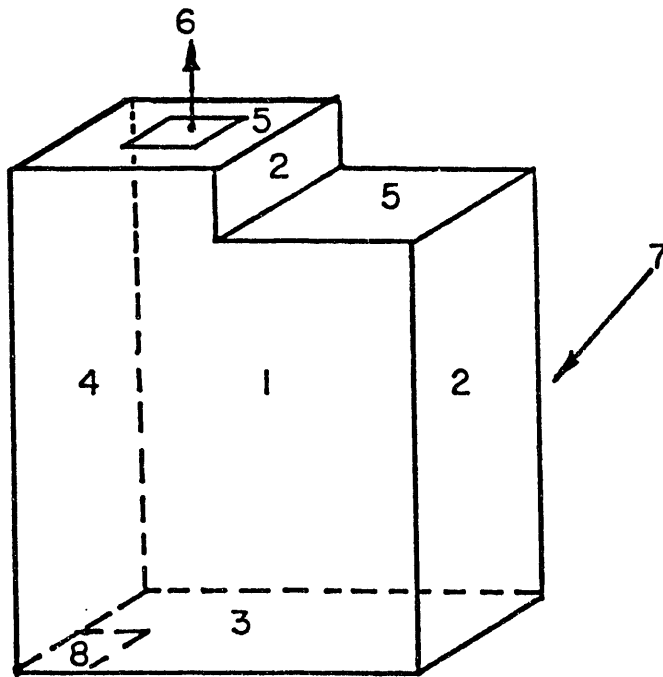
Fig. 12. *Two coincident surfaces with different surface numbers*

existence of internal solid structures. For example, the volume porosity of the computational cell due to irregular geometry (Fig. 13a) is

$$\gamma_v = AL = \frac{\Delta x \Delta y \Delta z - \text{volume of prism A}}{\Delta x \Delta y \Delta z}.$$

Similarly, the volume porosity due to an internal solid structure (Fig. 13b) is

$$\gamma_v = AL = \frac{\Delta x \Delta y \Delta z - \text{volume of the half solid cylinder}}{\Delta x \Delta y \Delta z}.$$

• Directional Surface Porosity

The directional surface porosity γ_x associated with a surface whose normal vector is in the x-direction is defined as the ratio of fluid flow area in that surface to total surface area. The directional surface porosity γ_y and γ_z can be similarly defined. The variable names are ALX, ALY, and ALZ for the x (or r), y (or θ), and z directions, respectively. Thus, in Fig. 13a,

$$\gamma_x(i+1/2,j,k) = ALX \ (\text{cell } ijk) = (\Delta y \Delta z - \text{area A1})/(\Delta y \Delta z),$$

$$\gamma_y(i,j+1/2,k) = ALY \ (\text{cell } ijk) = 1.0, \ \text{and}$$

$$\gamma_z(i,j,k+1/2) = ALZ \ (\text{cell } ijk) = (\Delta x \Delta y - \text{area A3})/(\Delta x \Delta y);$$

and in Fig. 13b,

$$\gamma_x(i+1/2,j,k) = ALX \ (\text{cell } ijk) = (\Delta y \Delta z - \text{area A5})/(\Delta y \Delta z),$$

$$\gamma_y(i,j+1/2,k) = ALY \ (\text{cell } ijk) = 1.0, \ \text{and}$$

$$\gamma_z(i,j,k+1/2) = ALZ \ (\text{cell } ijk) = (\Delta x \Delta y - \text{area A4})/(\Delta x \Delta y).$$

The directional surface porosity is considered a flow-variable parameter. In the staggered-grid arrangement, the flow-variable parameters are defined at the face of a cell. Therefore, when we describe γ_x, γ_y, and γ_z of cell (i,j,k), we mean γ_x at $(i+1/2,j,k)$, γ_y at $(i,j+1/2,k)$, and γ_z at $(i,j,k+1/2)$.

• Tube Channel

In COMMIX-PPC, a tube channel is defined as a series of computational cells that always contain the same group of condenser tubes. Each channel is assigned a channel number and may contain more than one tube. Thus, in Fig. 14, Channel 1 contains three condenser tubes and Channel 2 contains five condenser tubes.
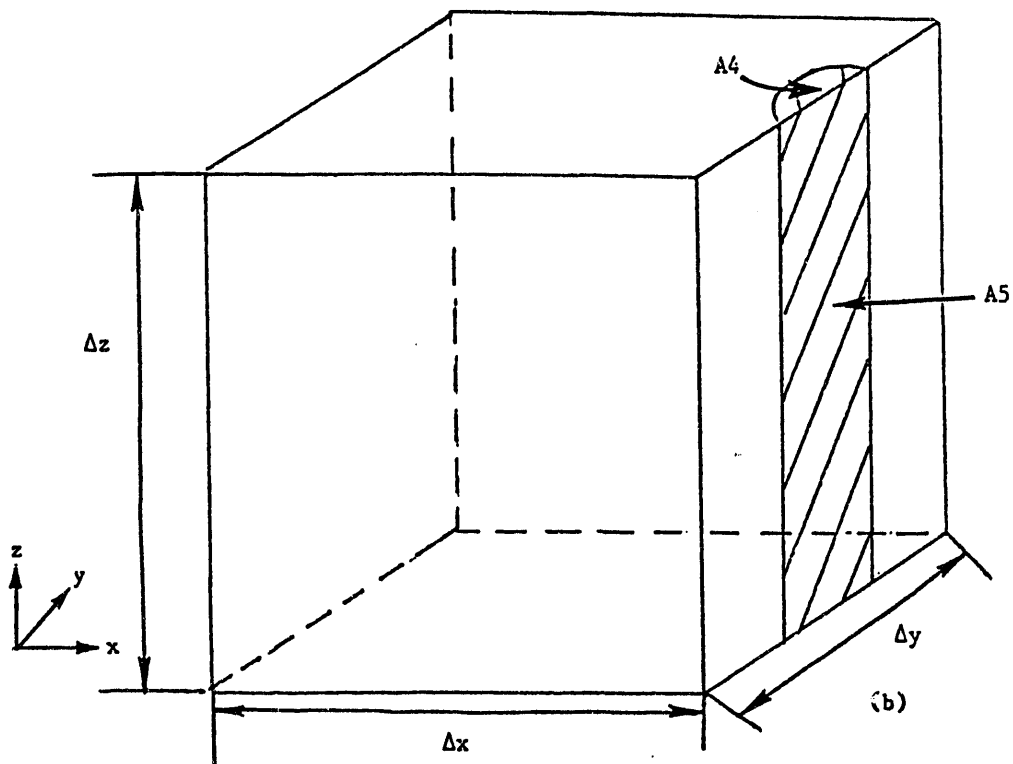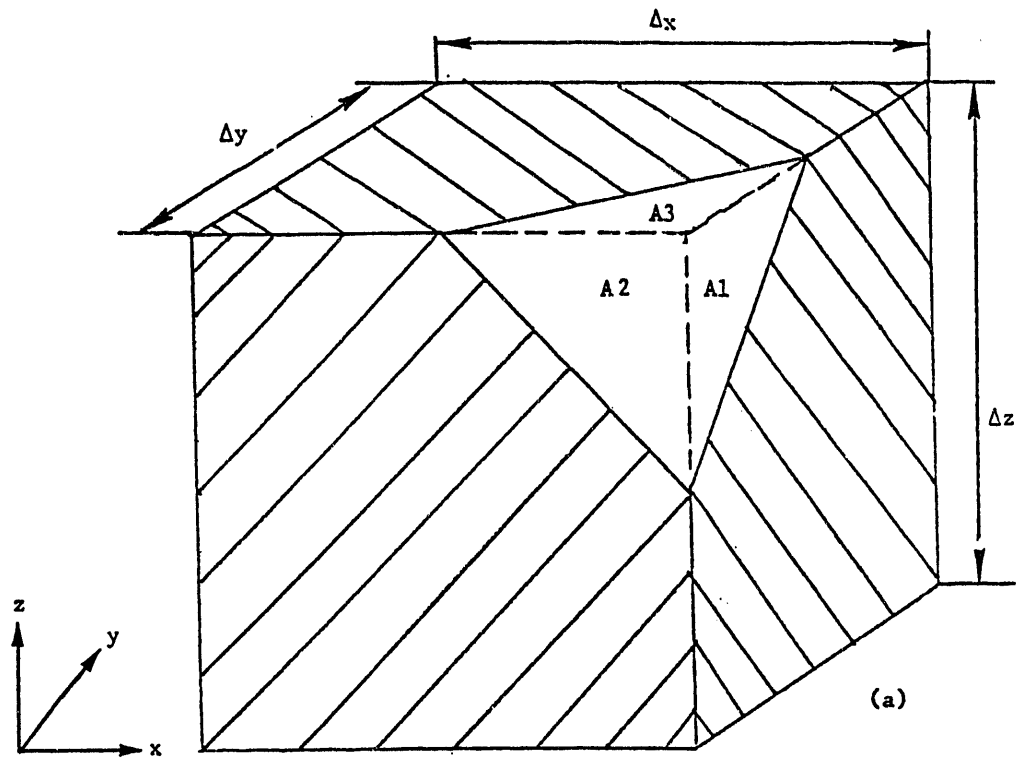
Fig. 13. Volume porosity due to (a) irregular geometry and
(b) internal solid structure
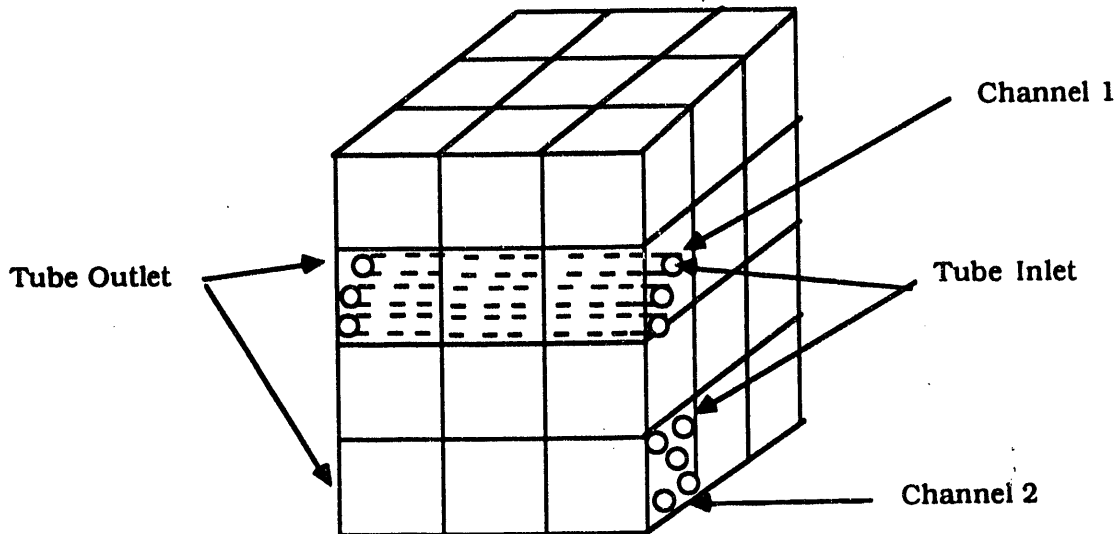
Fig. 14. Distribution of tube channels

3.3 Recommended Approach

The task of developing a geometrical model of a flow domain involves

- selection of an appropriate coordinate system,

- partitioning of a computational flow domain into several computational cells bounded by coordinate grid planes or grid surfaces, and

- computation of geometrical partition sizes.

The development of a geometrical model of a physical situation requires a judicious balance between attempting to represent the geometry as accurately as possible on the one hand, and minimizing the computational cost in terms of time and storage on the other. The computational cost generally places an upper limit on the number of computational cells; hence, the model should seek a proper balance between homogenization of the details and resolution and accuracy of the results.

Developing a model and preparing input for a complex geometry involve many decisions. There is no simple, rule-of-thumb procedure in modeling, because most of the decisions that must be made are problem-dependent. The user must seek his/her own intuition and judgment. The following are only a few broad suggestions:

- Select the appropriate coordinate system.

- Take advantage of symmetry and model the system with minimal required geometry.

- Use a relatively coarse mesh at the beginning to ensure that the input is correct and the results are reasonable. The mesh size should then be reduced to determine its effect on the accuracy of the solution.

- Use fine meshes only in those regions where large variations in parameters or properties are expected to occur.

3.4 Geometry Input

When all major elements of geometry modeling are decided, we can start the preparation of geometry input. The following is a recommended step-by-step procedure.

- Specify value of the variable IGEOM.

  IGEOM = 0   for Cartesian geometry and
      = -1   for cylindrical geometry.

- Partition the flow domain to be modeled by x, y, and z, or r, θ, and z grid surfaces. Two examples are illustrated in Fig. 15. The following must be specified:

  IMAX, JMAX, and KMAX: Maximum number of cells in x, y, and z (or r, θ, and z) directions.

  DX, DY, and DZ: Partitioning distances in x, y, and z directions.

  NSURF: Total number of surfaces.

  NM1:   Total number of computational cells.

  NL1:   Total number of surface elements.

- Be sure to take advantage of parameters IFX, IFY, and IFZ for one- and two-dimensional calculations. For example, if the system variables are independent of the x (or r for cylindrical coordinate) direction, set IFX = 0. The code will bypass all calculations that are x (or r) dependent.

- Assign surface numbers to all boundary surfaces. Compute and specify XNORML, YNORML, and ZNORML (the components of unit normal vectors) for all surfaces. *Number all irregular surfaces first.*

  Partitioning must be done so that each cell has a maximum of one irregular surface.

- Compute areas of (1) surface elements of all irregular surfaces (such as surface area A_1 in Fig. 10b), and (2) partially truncated regular surface elements of irregular cells (such as surface area A_2 in Fig. 10b). Prepare and supply all information about surface elements, as described in the section on Boundary Surface Identification Records in the Input Description.
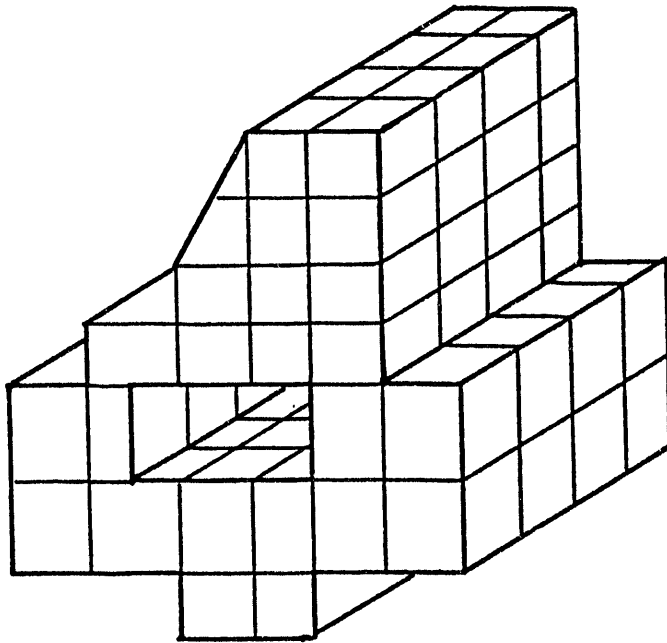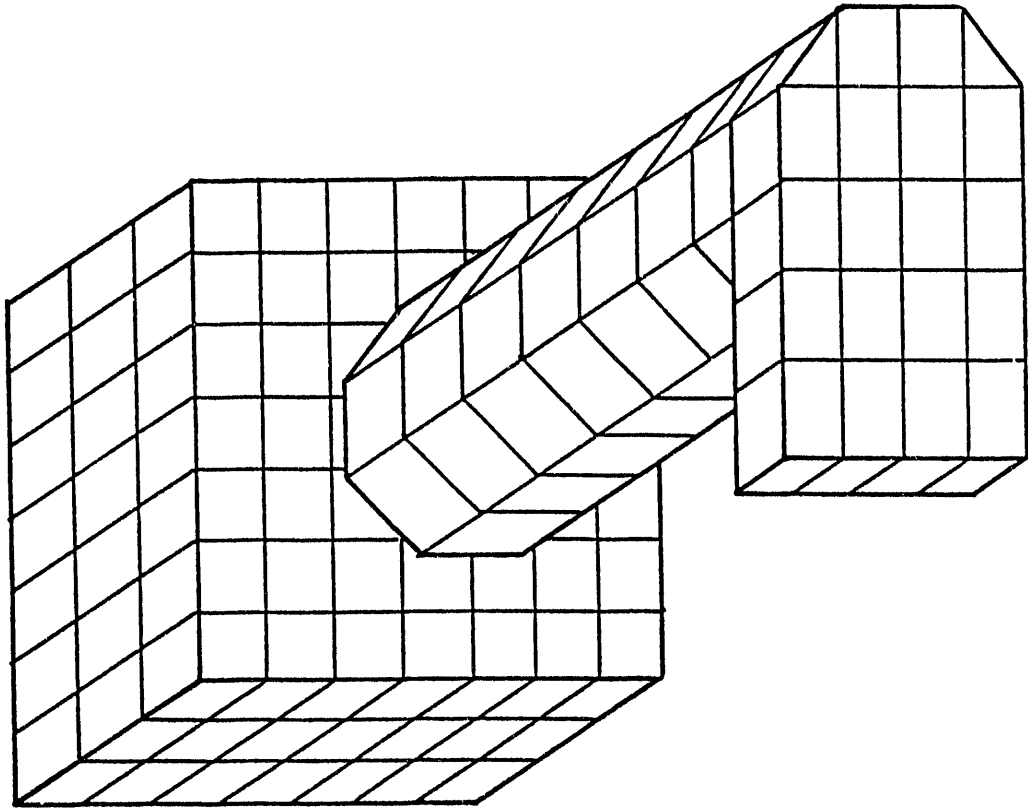
Fig. 15. Illustrations showing partitioning of sample geometries

- Compute volume porosity AL and directional surface porosities ALX, ALY, and ALZ and input this information according to the section on Cell Initialization Records in Appendix A (Input Description).

- Compute the condenser–tube numbers in each tube channel and specify the channel locations and flow direction according to the section on Tube Channel Location Records in Appendix A. Also specify:

  NTUBES: Total number of tube channels.

  NMCELL: Total number of computational cells in the tube side.

4 Initialization

4.1 Introduction

After completing the geometrical modeling, initial values of temperature, pressure, and velocity for all cells and surfaces are assigned. If one is continuing a previous run, initialization is performed through the restart capability of COMMIX.

The input of all initial and boundary values at the start of the first run can be very tedious. In COMMIX, several simplified input procedures for initialization are provided.

Lists of initialization variables for uniform and nonuniform conditions in the shell side are given in Tables 3 and 4, respectively. The variables for nonuniform initialization override those for uniform initialization. For tube–side flow, the list of initialization variables is given in Table 5. These variables are discussed in Sec. 4.2. More details can be found in Appendix A.

4.2 Simplified Procedures

Shell Side

- For the initial input, specify only pressure, temperature, and velocity. The values of enthalpy and density are not required; they are calculated in the code from the equation of state and the specified pressure and temperature distributions.

- Establish initial hydrostatic pressure distributions in the entire flow domain by specifying only

  –One pressure value (variable PRESØ) for all x, y, and z locations (variables are XPRESØ, YPRESØ, and ZPRESØ), and
  –The components of the gravity vector (variables are GRAVX, GRAVY, and GRAVZ).

  The program then calculates the entire hydrostatic–pressure field.

Table 3. Initialization variables for uniform shell-side conditions
(Input Section is DATA)

Variable	Variable Name	Initializing Region	Remarks
Temperature, °C	TEMPØ	Internal cell	One value for all cells
	TEMP(N)	Boundary surface	One value for each surface
Velocity, m/s	VELOC(N)	Boundary surface	One value for each surface
Pressure, Pa	PRESØ	Internal cell	Hydrostatic pressure distribution
	PRES(N)	Boundary surface	One value for each surface
Heat flux, W/m^2	TEMP(N)	Boundary surface	One value for each surface
Mass flux, $\dfrac{kg}{s-m^2}$	VELOC(N)	Boundary surface	One value for each surface

- Uniform temperature distribution in the entire flow domain is obtained by specifying only one temperature value (variable TEMPØ).

- Uniform temperature and hydrostatic pressure distributions can be overridden by using cell initialization records (CIR) for the desired (i,j,k) locations.

- Uniform normal velocity and temperature for each surface are prescribed by specifying the desired values for variables VELOC(N) and TEMP(N), respectively, where N is the surface number. Uniform pressure at cells adjacent to a surface is specified by PRES(N) and only needs to be specified for a surface with a uniform pressure boundary condition.

- Nonuniform velocity and temperature distributions for surface elements are specified by using the surface element initialization records (SEIR) with variables VELB and TLB. This overrides any VELOC(N) and TEMP(N) values. Nonuniform pressure distribution at cells adjacent to a surface with a specified pressure boundary condition is presented by using CIR, which override the PRES(N) specification.

- If the user wishes to initially prescribe surface heat flux instead of temperature, she/he can do so by specifying the desired value in W/m^2 to the

Table 4. Initialization variables for nonuniform shell-side conditions[a]

Variable	Variable Name	Initializing Region	Input Section	Remarks
Temperature, °C	TL	Internal cell	CIR[b]	Desired internal cells
	TLB	Surface element	SEIR[c]	Desired surface elements
Velocity, m/s	UL,VL,WL	Internal cell faces	CIR	Desired internal cell faces
	VELB	Surface element	SEIR	Desired surface elements
Pressure, Pa	POLD	Internal cell	CIR	Desired internal cells
Heat flux, W/m^2	QBN	Surface element	SEIR	Desired surface element
Enthalpy, J/kg	HL	Internal cell	CIR	Desired internal cells
	HLB	Surface element	SEIR	Desired surface elements
Density, kg/m^3	RLB	Surface	SEIR	Desired surface elements
Heat source, W/m^3	QSOU	Internal cell	CIR	Desired internal cells
Turbulence kinetic energy, J/kg	TK	Internal cell	CIR	Desired internal cells
	TKB	Surface element	SEIR	Desired surface elements
Turbulence dissipation rate, W/kg	TD	Internal cell	CIR	Desired internal cells
	TDB	Surface element	SEIR	Desired surface elements
Mass flow rate, kg/s	FLOW	Surface element	SEIR	Desired surface elements

[a]Variables listed in Table 4 override those listed in Table 3.
[b]CIR: Cell Initialization Records.
[c]SEIR: Surface Element Initialization Records.

variable TEMP(N). A nonuniform heat flux distribution can be specified by using the SEIR with variable QBN. This overrides any TEMP value.

- Initial values of density and enthalpy fields are computed by the code using the equation of state and the prescribed initial temperature and pressure fields.

- Turbulence parameters (k and ε) are specified for internal cells by using the CIR with variables TK and TD, and for surface elements by using the SEIR with variables TKB and TDB.

*Table 5. Variables for tube-side initialization
(Input Section is TUBS)*

Variable	Variable Name	Initializing Region	Remarks
Temperature, °C	TEMØTB	Internal cell	One value for all cells
	TLBTB1	Inlet boundary surface	One value for each tube channel
	TLBTB2	Outlet boundary surface	One value for each tube channel
Velocity, m/s	VELØTB	Internal cell	One value for all cells
	ULBTB1	Inlet boundary surface	One value for one tube channel
	ULBTB2	Outlet boundary surface	One value for one tube channel
Pressure, Pa	PREØTB	Internal cell	One value for all cells

- Mass flow rates corresponding to uniform mass flux are specified by VELOC(N).

- Mass flow rates for the boundary surfaces are specified using the SEIR with the variable FLOW. This overrides any value specified through VELOC.

- The format of the CIR and SEIR is

  NAME   RVAL   IB   IE   JB   JE   KB   KE   N*

An example of the CIR is

  TL   60.0   5   18   7   12   1   6,

meaning that we are specifying a cell temperature of 60°C for all internal cells in the region having an I value from 5 to 18, J value from 7 to 12, and K value from 1 to 6. Thus, in this example, 504 cells are initialized by one input card.

An example of the SEIR is

  TLB   60.0   5   18   7   12   1   1   5,

---

*N for SEIR only.

meaning that we are specifying a surface temperature of 60°C for all surface elements on computational cells having an I value from 5 to 18, J value from 7 to 12, and K value from 1 to 1 for surface number 5. We can see here that in this example one input card initializes the temperature value for 84 surface elements.

- Before a program reads the input data, all variables are set to zero. Consequently, only the values other than zero must be specified in the input data.

  The commonly occurring values of variables are provided as default values. If the default value for a given variable is acceptable, the input for that variable need not be specified.

Tube Side

- Just as for shell side, one need only specify temperature, pressure, and velocity for the initial input. The values of enthalpy and density are calculated in the code from the prescribed pressure and temperature distributions.

- Uniform temperature, velocity, and pressure distribution in the entire flow domain are obtained by specifying only one value for each of the variables TMP∅TB, VEL∅TB, and PRE∅TB, respectively.

- The inlet and outlet velocity for each tube channel are prescribed by specifying the desired values to the variables ULBTB1(N) and ULBTB2(N), respectively, where N is the tube channel number.

- The inlet and outlet temperatures for each tube channel are prescribed by specifying desired values for the variables TLBTB1(N) and TLBTB2(N), respectively

- The variables for tube-side initialization are listed in Table 5.

4.3 Input Preparation

4.3.1 Internal Cell Variables

Shell Side

In the input preparation of initial cell values, the following variables must be specified:

- Three velocity components, UL, VL, and WL in m/s,
- Temperature TL in °C,
- Pressure POLD in Pa, and
- Heat source QSOU in W/m^3.

As mentioned previously, only nonzero values need be specified. Also, simplified procedures described in Sec. 4.2 should be used for specifying uniform temperature and hydrostatic-pressure distributions at the start. Use TEMP∅ and PRES∅ in NAMELIST/DATA/.

hydrostatic-pressure distributions at the start. Use TEMPØ and PRESØ in NAMELIST/DATA/.

With regard to the heat source, the user has the option of either using the volumetric heat source QSOU or specifying it through thermal structure (see Sec. 5).

Tube Side

The following variables are assumed to be uniform throughout the tubes.

- Flow velocity ULTB in m/s,
- Temperature TLTB in °C, and
- Pressure POLDTB in Pa.

These three variables are calculated in the code by specifying VELØTB, TEMØTB, and PREØTB in NAMELIST/TUBS/.

4.3.2 Boundary Surface Variables

Shell Side

In the initialization of boundary variables, one must specify the type of boundary conditions and the boundary values. They are discussed separately below.

- Types of Boundary Conditions

    The variables used for defining the types of boundary conditions are

KFLOW:	for velocity,
KTEMP:	for temperature/heat flux, and
KPRES:	for pressure.

The options for the velocity, temperature/heat flux, and pressure boundary conditions are listed in Tables 6–8 respectively. Detailed descriptions of these options are given in Volume I and Appendix A.

- Boundary Values

    The variables VELOC(N), TEMP(N), and PRES(N) are used to initialize uniform values of velocity, temperature, and pressure. These values are specified in NAMELIST/DATA/.

    If nonuniform boundary conditions are required, the input is achieved through SEIR. Table 9 lists eight variables that can be specified through SEIR. In general, we need not specify all eight variables. Of course, one can always specify uniform boundary conditions by using the SEIR.

Tube Side

- Types of Boundary Conditions

    The variables used for defining the types of boundary conditions are

Table 6. Options for shell-side velocity boundary conditions

Parameter KFLOW(N)	Boundary Condition Type	Physical Boundary	Remarks[a]
-5	Continuative mass flow outlet	Outlet	$v_n^0 = \dfrac{(\rho Av)^{AI}}{(\rho A)^0}$ (one outlet surface element)
-4	Uniform velocity outlet	Outlet	$v_n^0 = \dfrac{\Sigma(\rho Av)^{AI}}{\Sigma(\rho A)^0}$ (several outlet surface elements)
-3	Free slip	Symmetry surface	$v_n^0 = 0; \dfrac{\partial v_t^0}{\partial n} = 0$ No momentum diffusion
-2	Continuative velocity outlet	Outlet	$v_n^0 = v_n^{AI}$ For constant density and area
-1	Continuative momentum outlet	Outlet	$v_n^0 = \dfrac{(\rho v)^{AI}}{\rho^0}$ For constant area
0	No slip	Stationary solid wall	$v_n^0 = 0; \; v_t^0 = 0$
1	Constant velocity	Inlet, solid wall	$v_n^i \neq 0, \; v_t^i = 0$ $v_n^0 = 0, \; v_t^0 = 0$
2	Constant mass flow rate	Inlet/ outlet	Mass flow rate specified by FLOW in the SEIR
100 + NF	Uniform transient velocity	Inlet	$v_n^i(t) = $ VELOC(N)f (t) f(t) = Dimensionless function number
200 + NF	Uniform transient mass flow rate	Inlet	FLOW(t) = VELOC(N) f (t)

[a]Superscripts: 0 = Outlet or boundary value; AI = adjacent internal cell; i = inlet value; n = normal to boundary surface; t = tangential to boundary surface.

Table 7. Options for shell-side temperature/heat flux boundary conditions

Parameter KTEMP(N)	Boundary Condition Type	Physical Boundary	Remarks
1	Constant temperature	Inlet, solid wall	T_W = constant, q_W is calculated
100 + NF	Transient temperature	Inlet, solid wall	$T_W(t)$ = $T_W(0)f(t)$, q_W is calculated
200	Constant heat flux	Solid wall	q_W = constant, T_W is calculated
300 + NF	Transient heat flux	Solid wall	$q_W(t)$ = $q_W(0)f(t)$, T_W is calculated
400	Adiabatic	Outlet, symmetry	q_W = 0.0

Table 8. Options for shell-side pressure boundary conditions

Parameter KPRES(N)	Boundary Condition	Physical Boundary	Remarks
0	–	–	No pressure boundary condition is applied
1	Constant pressure	Inlet-outlet	P_W = constant
100 + NF[a]	Transient pressure	Inlet-outlet	$P_W(t)$ = $P_W(0)$ F(NF)[a]

[a]NF is the transient function number; F(NF) is the NFth transient function.

Table 9. Shell-side variables that can be specified through SEIR

Variable	FORTRAN Input Names	Unit
Enthalpy	HLB	J/kg
Mass flow rate	FLOW	kg/s
Heat flux	QBN	W/m^2
Density	RLB	kg/m^3
Temperature	TLB	°C
Normal velocity	VELB	m/s
Turbulence kinetic energy	TKB	J/kg
Turbulence dissipation rate	TDB	W/kg

where I = 1 for the inlet boundary and I = 2 for the outlet boundary.

- Boundary Values

For flow inside the condenser tubes, the boundary values of velocity and temperature are specified in NAMELIST/TUBS/ by using the following variables:

ULBTB1(N):   for inlet velocity,
ULBTB2(N):   for outlet velocity,
TLBTB1(N):   for inlet temperature,
TLBTB2(N):   for outlet temperature,
where N is the tube channel number.

5 Thermal–Structure Modeling

5.1 Introduction

The purpose of incorporating a thermal–structure model in COMMIX–PPC is to facilitate consideration of heat–transfer interaction between fluid and structures. The model implemented in COMMIX solves one–dimensional heat conduction equations for all solid structures, including condenser tubes. It calculates temperature distribution in solids and heat transfer from solids to surrounding fluids. In general, the output from the thermal–structure model is a heat source/sink term for the fluid energy equation. However, because the energy equation is not used for condenser modeling, the heat source/sink term is used to calculate the steam condensation rate.

The basic equations, formulations, and features of the thermal–structure model of condenser tubes and other internal solid structures are described in Vol. I. Here, we describe only user–related aspects of the model in a general way.

5.2 Some Concepts and Definitions

A thermal structure is a solid structure, in a fluid–flow domain, that thermally interacts with the surrounding fluid. It can be planar, cylindrical, or spherical. The COMMIX-PPC model permits only structures with axes aligned with one of the three coordinate axes, as illustrated in Fig. 16. In a given flow domain, more than one thermal structure can be modeled if desired.

A thermal structure is identified by its geometric and physical features, i.e.,

- All solid structures having the same grid axis alignment, same geometric features, and same physical characteristics can be collectively modeled as one thermal structure, although they may be spread out physically in the fluid domain. Examples are fuel pins in a nuclear reactor, cooling tubes in a power plant condenser.
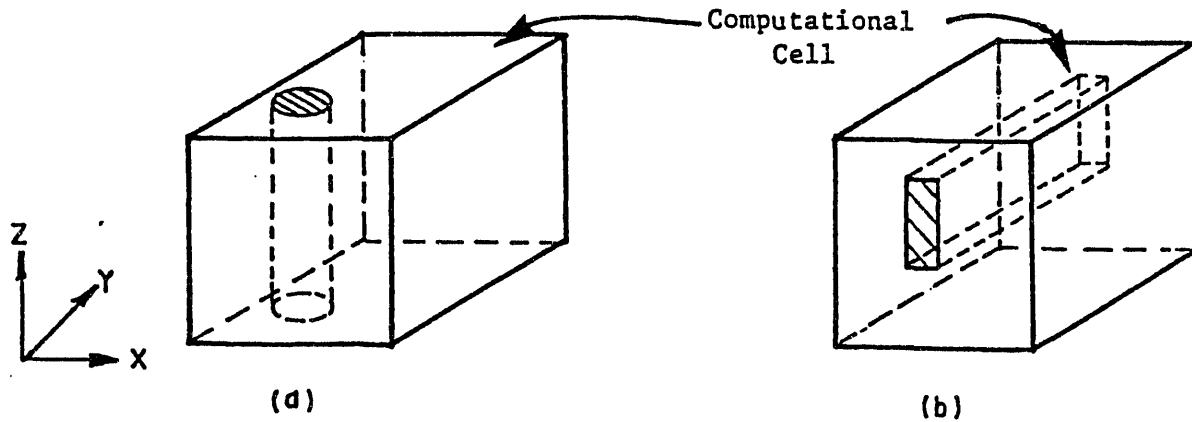
Fig. 16. Illustrations showing thermal–structure alignment:
(a) cylindrical structure aligned to z axis;
(b) planar structure aligned to y axis

- A solid structure with a single geometric feature but heterogeneous physical characteristics cannot be modeled as one thermal structure. An example is fuel pins with different material composition in different axial sections.

In COMMIX–PPC computations, each thermal structure is partitioned by grid planes normal to the structure axis to form several thermal structure elements, as shown in Fig. 17. Each element has its own internal temperature distribution because the heat conduction equation is solved for each element.

A thermal structure has two surfaces, outer and inner. These surfaces can be adiabatic or they can interact with fluid, as shown in Fig. 18. *Each structural-surface element is permitted to interact with only one fluid cell.* However, a fluid cell can interact with more than one structure surface. This can be seen in Figs. 19 and 20.

Each structure may be composed of several material segments. Figure 21 illustrates the cross section of a structure element having

- Outside and inside surfaces, numbered 1 and 2, respectively,

- Three different materials separated by gaps, and

- Each material region divided into several partitions.

5.3 Thermal–Structure Subroutines

Three major subroutines are related to the thermal–structure model:

- HSTRUC: Computes heat transfer coefficients for the outer and inner surfaces of all thermal–structure elements. It uses local velocities
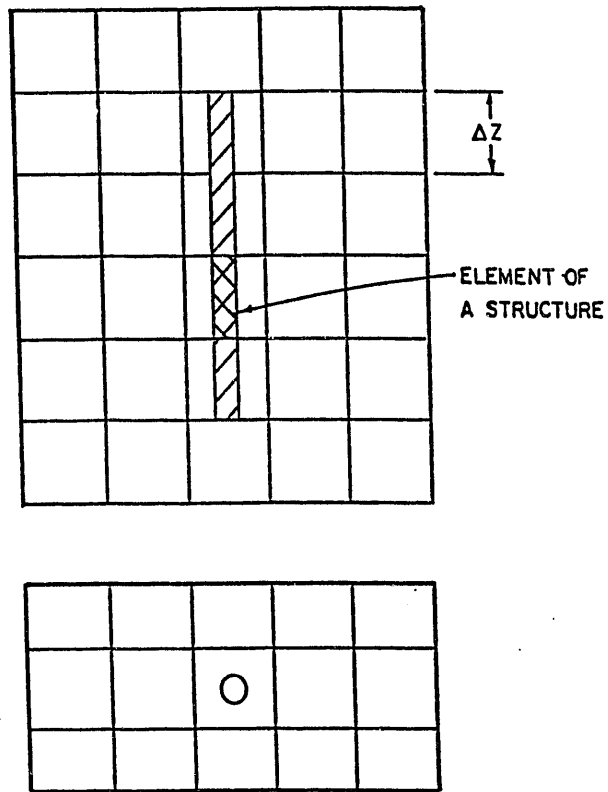
Fig. 17. An element of a thermal structure
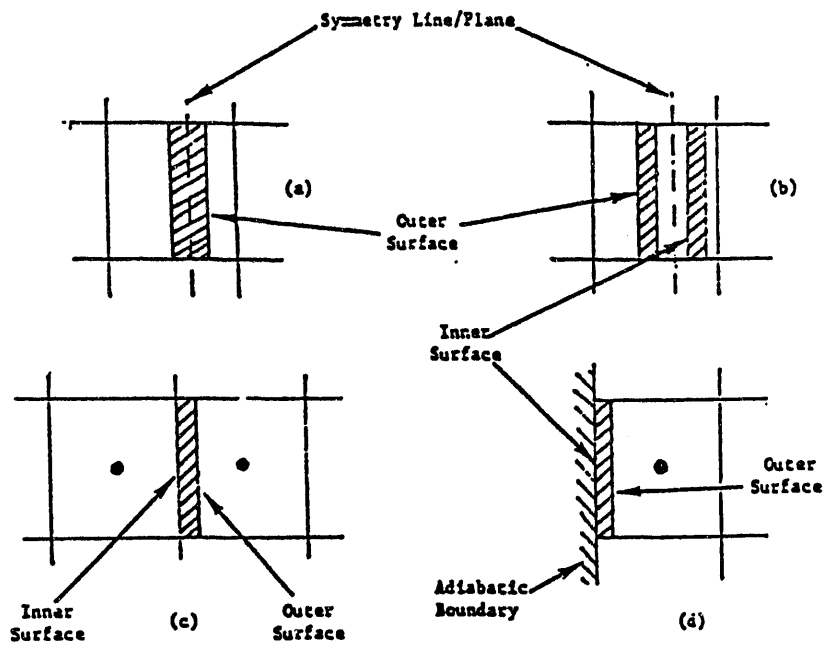
Fig. 18. Element of a thermal structure, showing outer and inner surfaces
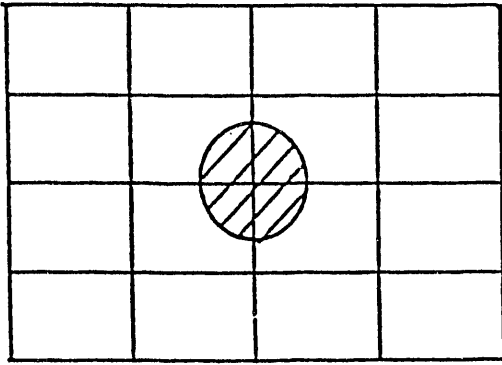
Fig. 19. *Four quarter-cylindrical structures, each interacting with one fluid cell*
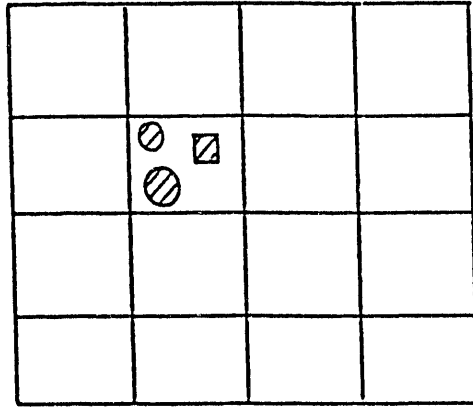
Fig. 20. *Multiple structures interacting with a single fluid cell*

CROSS SECTION A-A
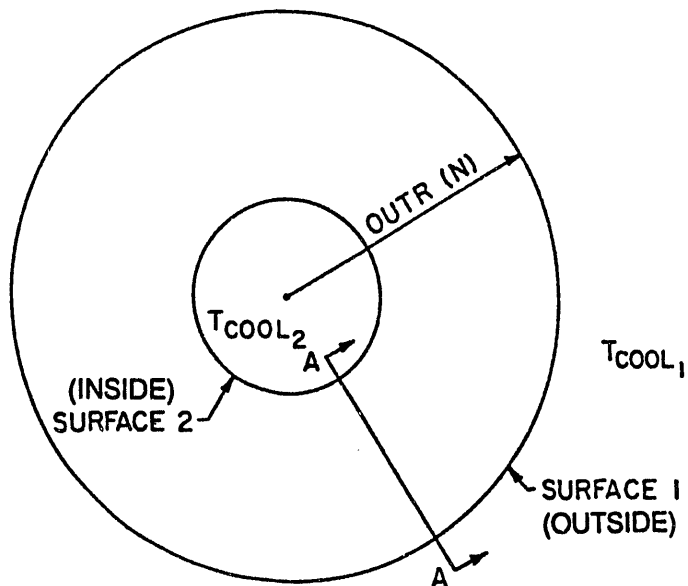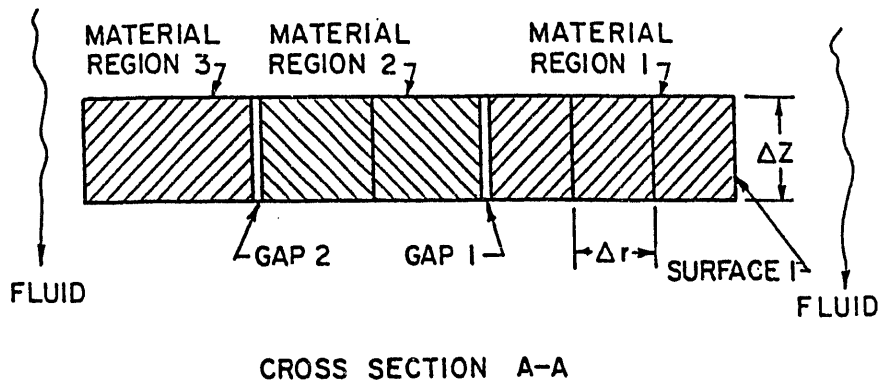
Fig. 21. *Typical structure element showing material regions and gaps*

and thermal properties to calculate Reynolds number and Prandtl number and appropriate user-specified heat transfer correlations to evaluate the heat transfer coefficient.

- QSTRUC: Solves the heat conduction equations for each element and computes the heat source term for the fluid energy equation.

- TSTRUC: Solves the heat conduction equations for each element and computes the temperature distribution of the thermal-structure element.

The other three subroutines for this model are TSCAN, INPSTR, and PSTRUC. The functions of TSCAN are to scan input and determine storage requirements; INPSTR reads thermal-structure input and assigns appropriate markers and pointers; and PSTRUC prints results related to thermal structures.

5.4 Modeling Recommendations

The following is a list of recommendations relating to thermal-structure modeling

- For steady-state analysis, one needs to model only those solid structures with heat sources.

- For transient analysis, all solid structures, with or without heat source, must be modeled.

- Only plane, cylindrical, or spherical shapes are permitted in COMMIX-PPC. If a structure does not conform to one of these shapes, the user should make some approximations.

- COMMIX-PPC permits modeling of any multiple or fraction of a structure as one thermal structure; e.g., if there are 10 condenser tubes passing through one computational cell, as shown in Fig. 22a, the group of condenser tubes is modeled as one thermal structure with surface area equal to 10 times the surface area of a single tube. On the other hand, the user may wish to model only a fraction of a tube as one thermal structure, as illustrated in Fig. 22b.

- A slab structure (Fig. 23) can be considered as either a
  - Two-sided thermal structure with surface area for each side $= \Delta y \Delta z$ and thickness $= t$, or
  - One-sided thermal structure of thickness $t/2$, with one adiabatic inner surface, with outer surface area of $2 \Delta y \Delta z$.

- In many cases, we find, for computational purposes, that the solid structures can be considered uniformly distributed, e.g., fuel pins in a reactor core, cooling tubes in power condensers. An alternative means has been provided for specifying the heat transfer surface area to model such uniformly distributed thermal structures. This is done through the variable RODFR, which has different meanings depending on what and how we specify. This can best be explained through examples.
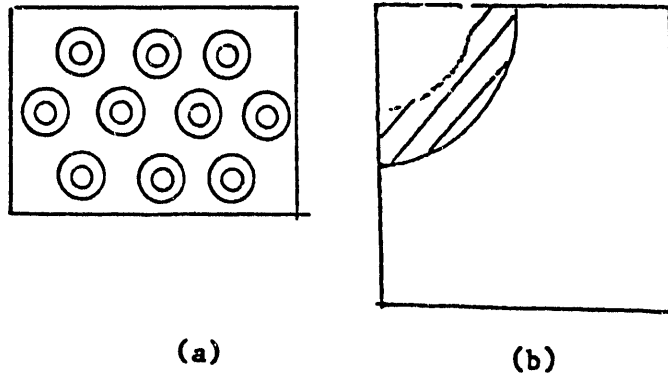
Fig. 22. *Modeling (a) multiple structures or (b) fraction of a structure as one thermal structure*
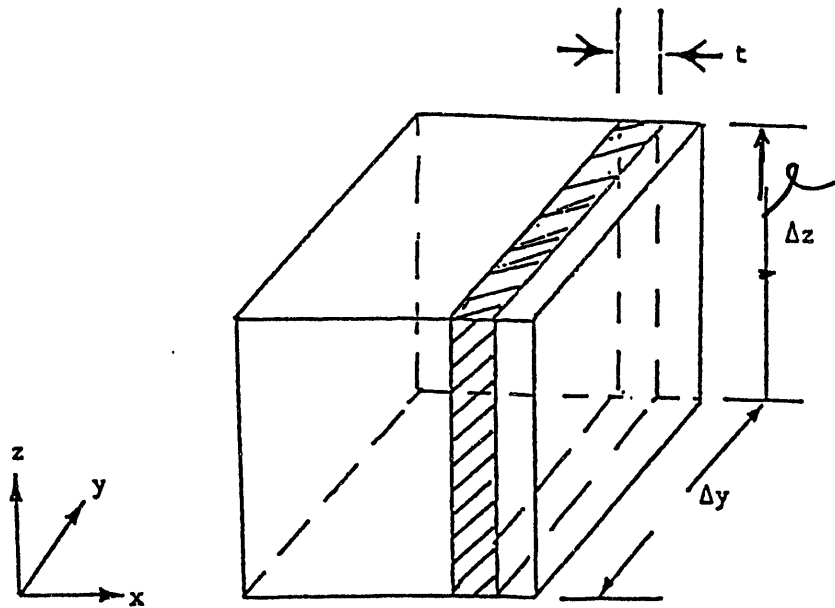
Fig. 23. *Slab structure element*

Positive RODFR: COMMIX -PPC computes heat transfer surface area using the following equations:

Cylindrical Structure

Surface Area = (2π r Δ Z$_i$) RODFR

Plane Structure

Surface Area = RODFR

Spherical Structure

Surface Area = 4πr^2 RODFR.

Here, r is the surface radius (either outer surface or inner surface) and Δ Z$_i$ is the axial length of the coolant cell. Therefore, the definition of RODFR is

RODFR = Number or fraction of rods interacting with the fluid cell, for a cylindrical or spherical structure, and

RODFR = Surface area, for a slab-type structure. Hence, for Fig. 22a, RODFR = 10, and for Fig. 22b, RODFR = 0.5.

Negative RODFR: COMMIX-PPC uses the following equations to compute the heat transfer surface area:

Cylindrical Structure

$$\text{Surface Area} = (2\pi\, r\, \Delta\, Z_1 |\text{RODFR}|)*\frac{\text{(Cell area normal to the}}{\text{structure axis).}}$$

Plane Structure

$$\text{Surface Area} = |\text{RODFR}|*\frac{\text{(Cell area parallel to the structure surface}}{\text{area).}}$$

Spherical Structure

$$\text{Surface Area} = 4\pi r^2\, |\text{RODFR}|*\text{Cell Volume.}$$

Therefore, negative RODFR means

$$|\text{RODFR}| = \frac{\text{number (or fraction of rods)}}{\text{cell cross-sectional area}} \quad \text{for cylindrical structures,}$$

or

$$|\text{RODFR}| = \frac{\text{slab heat transfer surface area}}{\text{cell cross-sectional area}} \quad \text{for slab-type structures,}$$

or

$$|\text{RODFR}| = \frac{\text{number of spheres}}{\text{cell volume}} \quad \text{for spherical structures.}$$

Hence,

$$\text{RODFR} = -2/ab$$

for the cell at the upper left corner in Fig. 24,

$$\text{RODFR} = -\frac{1}{\pi\left(r_2^2 - r_1^2\right)}$$

$$= -\frac{1}{\pi(r_1 + r_2)(r_2 - r_1)}$$

for the illustration in Fig. 25, and

$$\text{RODFR} = -1$$

for the illustration in Fig. 23.
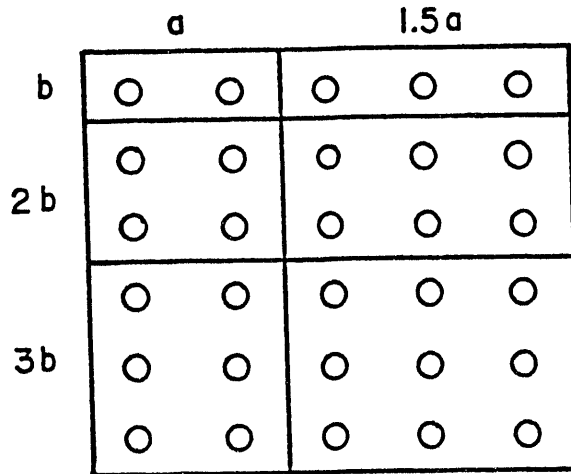
Fig. 24. Uniformly distributed rod bundles in a nonuniform grid
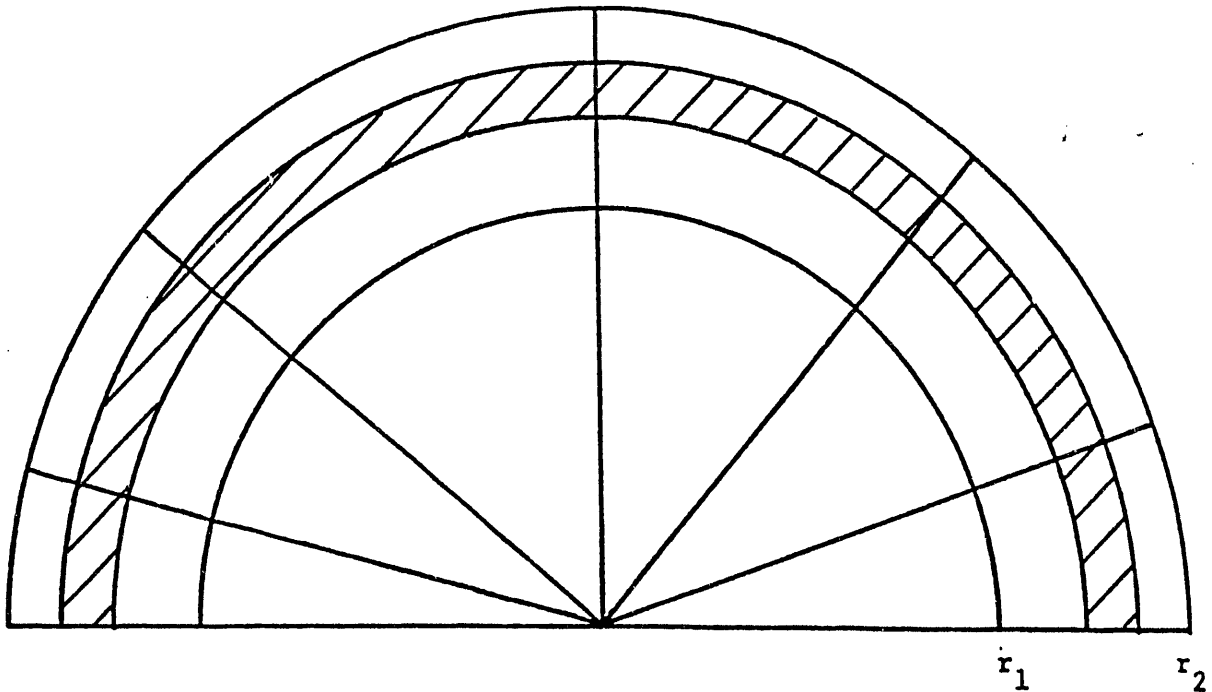
Fig. 25. Cylindrical shell with nonuniform azimuthal grid

5.5 Input Preparation

5.5.1 Introduction

There are four sections of COMMIX-PPC input where the specified information is directly related to the thermal structure. They are:

- NAMELIST/GEOM/.
- NAMELIST/DATA/.

- Thermal-Structure Prototype Records.
- Thermal-Structure Location Records.

The first two are described in Sec. 5.5.2, the third, in Sec. 5.5.3, and the fourth, in Sec. 5.5.4. In addition, the inputs must also include material properties and heat transfer correlations (described in Sec. 8).

5.5.2   NAMELIST-Input

- NAMELIST/GEOM/: Here, we input the variable ISTRUC=1, which commands that the thermal-structure-related input is to be read and computation is to be performed.

- NAMELIST/DATA/: Here, the TS-related variable is NEWTS, which we specify NEWTS = 1 only if we want to

  -Modify or update information related to thermal structure using the restart option, or
  -Input new information related to thermal structure

  at the start of either a steady-state run (ISTATE = 0) or a transient run (ISTATE = 2). This variable comes into operation only with ISTRUC = 1 and ISTATE = 0 or 2.

5.5.3   Prototype Records

The thermal-structure prototype records are records where we input all geometric and physical information for all thermal structures. A detailed description of this input is given in Appendix A. Some input-related rules are briefly described below.

- For each TS there is a set of input records.

- Each set contains several NAMELIST records. They are to be in the following order:

  &T   Information about thermal structure,

  &F   Information about outer surface fluid,

  &M   Information about Material 1 and Gap 1

  &M   Information about Material 2 and Gap 2
       •
       •(Include one NAMELIST/M/ for each material region in a thermal structure.)
       •

  &F   Information about inner-surface fluid. This record is included only if the TS is two-sided. If the inner surface is adiabatic or a symmetry boundary, this record is not required.

- The numbering of material regions begins as we traverse from outer surface to inner surface. To illustrate the ordering system, three examples are presented.

Example 1: Ordering sequence of records for TS shown in Fig. 26a:

&T N =, IXYZ =, NT =, RODFR =, OUTR =, &END

&F IHT =, &END

&M MI =, NP =, DR =, Q =, &END

&M MI =, NP =, DR =, Q =, SGAP =, HGAP =, &END

&F IHT =, &END

Example 2: Ordering sequence of records for TS shown in Fig. 26b:

&T N =, IXYZ =, NT =, RODFR =, OUTR =, &END

&F IHT =, &END

&M MI =, NP =, DR =, Q =, SGAP =, HGAP =, &END

&M MI =, NP =, DR =, Q =, SGAP =, HGAP =, &END

&F IHT =, &END

Example 3: Ordering sequence of records for TS shown in Fig. 26c:

&T N =, IXYZ =, NT =, RODFR =, OUTR =, &END

&F IHT =, &END

&M MI =, NP =, DR =, Q =, SGAP =, HGAP =, &END

&M MI =, NP =, DR =, Q =, SGAP =, HGAP =, &END

&M MI =, NP =, DR =, Q =, SGAP =, HGAP =, &END

&M MI =, NP =, DR =, Q =, SGAP =, HGAP =, &END

The meanings of all FORTRAN variables referred to in the TS prototype records are given in Table 10.

If a fluid or an adiabatic surface follows a material, the gap properties are ignored. The gap properties are used for a given material only when another material follows.

If there is no gap between two materials, we specify a high heat transfer coefficient, e.g.,

SGAP = 0.0, HGAP = 1.E30.
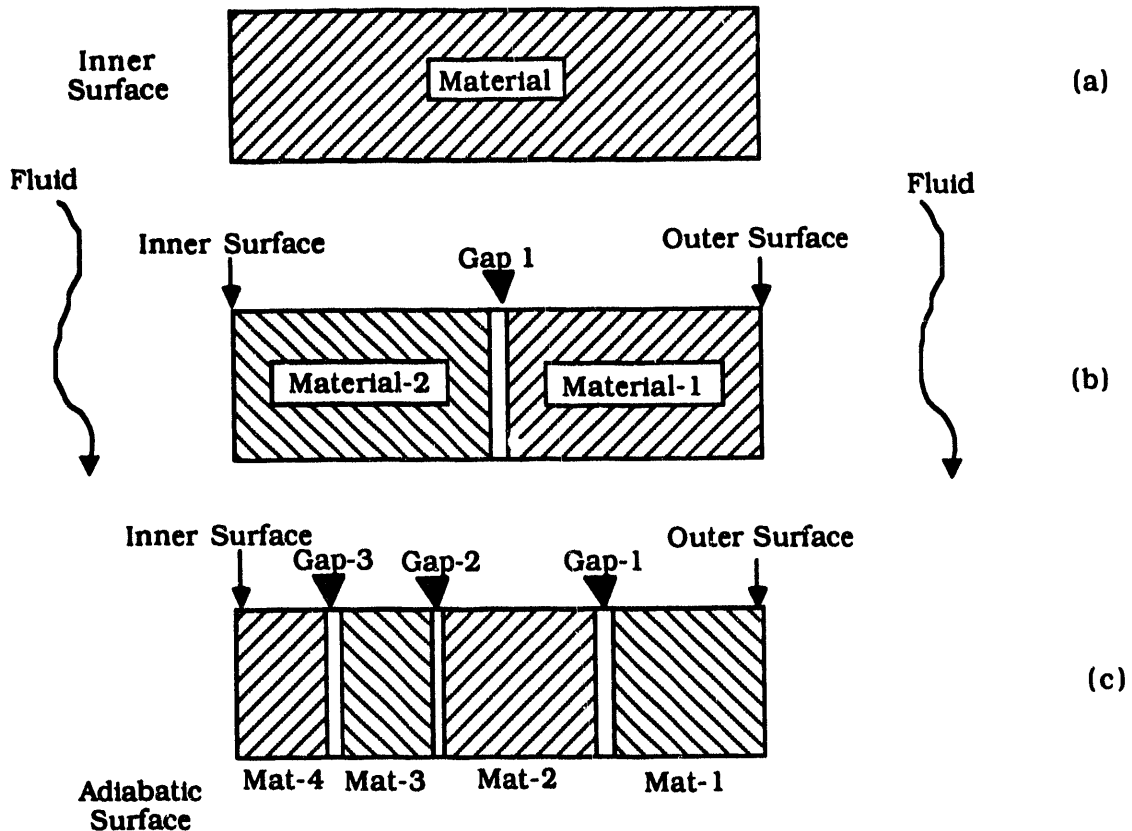
Fig. 26. Numbering system of thermal-structure material regions

Table 10. FORTRAN variables for TS prototype records

Variable	Description
N	TS#
IXYZ	Number to describe shape and axis alignment (see Appendix A for numbers)
NT	Transient function number for heat sources
RODFR	Rod fraction to specify surface area
OUTR	Outer-surface radius (m)
IHT	Heat-transfer correlation number
MI	Material number (see Sec. 8)
NP	Number of grid partitions in the material for finite-difference analysis
DR	Thickness of each partition (m)
Q	Volumetric heat source (W/m^3)
SGAP	Gap thickness (m)
HGAP	Gap heat transfer coefficient $(W/m^2{}^\circ C)$

5.5.4 Location Records

The purpose of the location records is to input TS–element location information. The format of specifying the location information is similar to that of boundary value and internal–cell initialization records. The FORMAT is (A4, 7I4):

```
    OUT  N  IB  IE  JB  JE  KB  KE
or
    IN   N  IB  IE  JB  JE  KB  KE
```

For a two–sided structure, we specify OUT to describe the locations of the outer–surface cells and IN to describe the locations of the inner–surface cells. For one–sided structures, we have either "IN" or "OUT" records only. The variable N stands for the TS number and IB ... KE stands for the beginning and ending of i, j, and k indices. For thermal–structure modeling of condensers, the locations of the outer– and inner–surface cells of the tubes are the same.

To illustrate the location input records, we consider the simple geometry shown in Fig. 27. The inputs for the thermal structures are as follows:

```
    OUT  1  2  2  1  4  4  9
    OUT  2  8  8  1  5  9  9
    OUT  2  6  6  1  5  9  9
    OUT  3  8  8  1  5  2  2
    IN   3  8  8  1  5  1  1
```

6 Force–Structure Modeling

6.1 Introduction

The purpose of force–structure modeling in COMMIX–PPC is to facilitate consideration of flow resistance due to irregular geometry and the presence of solid structures in a flow domain. In COMMIX–PPC, such resistances are accounted for by introducing an additional distributed–resistance source term in the momentum equation. To incorporate this distributed–resistance source term in the computation, certain information is needed.

6.2 Flow Resistance Correlation

In the literature, many different equations have been used to express pressure drop due to obstructions, e.g.,

$$\Delta p = 4 \frac{L}{D} \frac{1}{2} \rho v^2 f , \tag{6.1a}$$

$$= \frac{L}{D} \frac{1}{2} \rho v^2 C_D , \tag{6.1b}$$

$$= \frac{1}{2} \rho v^2 K . \tag{6.1c}$$
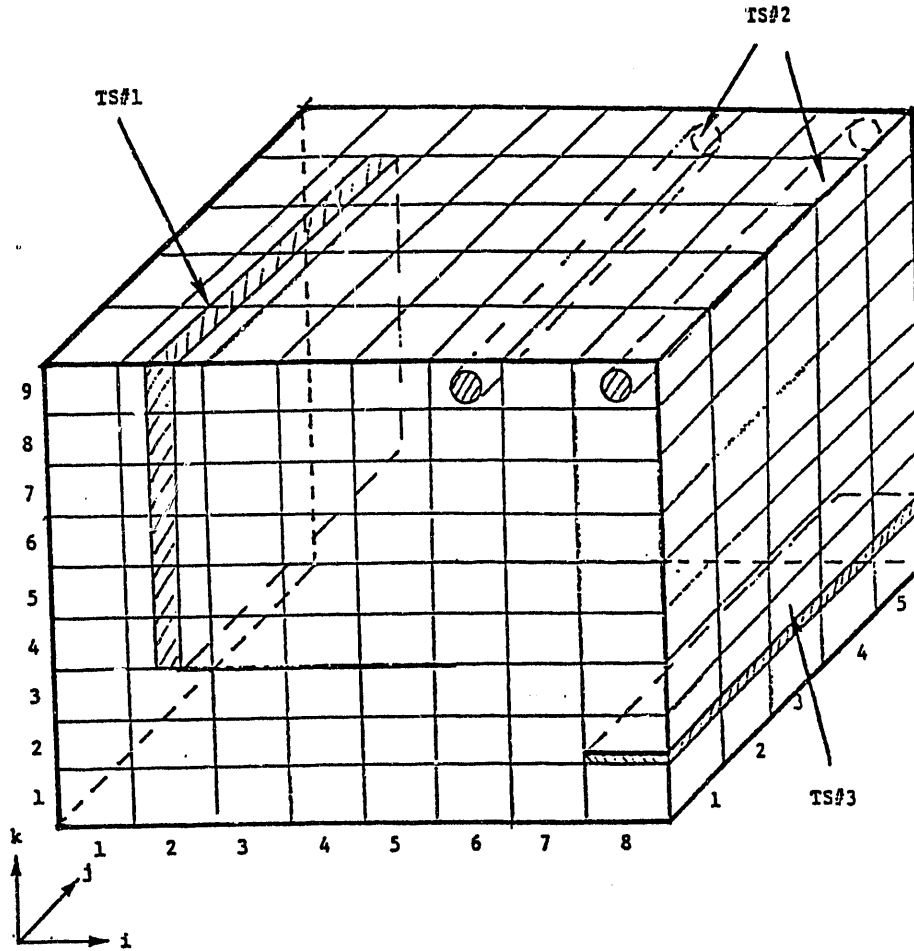
Fig. 27. TS location input

The coefficients f, C_D, K, etc. have been given different names, e.g., Fanning friction factor, Darcy friction factor, drag coefficient, loss coefficient, etc., depending on the equation.

In COMMIX-PPC, the following general forms are used:

$$\Delta p = C_1 \frac{L}{D} \rho v^2 f ,$$ (6.2)

which, in terms of distributed resistance R, is

$$R = \frac{\Delta p}{L} = C_1 \rho \frac{v|v|}{D} f.$$ (6.3)

Here, L[Δx (Δr), Δy ($r\Delta\theta$), or Δz] is the cell length of a momentum control volume, D is the hydraulic diameter or characteristic length, and C_1 is the coefficient that accounts for different definitions of friction factor f.

Friction factor f in Eqs. 6.2 and 6.3 is generally a function of the Reynolds number. In COMMIX-PPC, the following forms of the friction factor correlation are used:

$$f = a_\ell Re^{b_\ell} + c_\ell$$ (6.4a)

for laminar flow when the Reynolds number Re (= $\rho u d/\mu$) is less than a predefined transition Reynolds number Re_{tr}, and

$$f = a_t Re^{b_t} + c_t \qquad (6.4b)$$

for turbulent flow (Re > Re_{tr}). The subscripts l, t, and tr stand for laminar, turbulent, and transition, respectively.

6.3 Input Requirements

With reference to the form of the equations in the preceding section, the following inputs are required.

Shell Side

- Variables C_1 (FORCEF) and D(CLENTH) for the computation of the resistance-source term (Eqs. 6.2 and 6.3),

- Variables a_l (ACORRL), ..., c_t(CCORRT), and Re_{tr} (REYTRN) for the computation of the friction factor f (Eq. 6.4), and

- Reference length d (REYLEN) in Reynolds number Re.

Additional input requirements are

- NEWFOR   A signal to inform that new force-structure input must be read.

- NFORCE   Number of force structures.

- NCORR   Number of friction factor correlations.

- ICORR   Linkage between a force structure and a correlation number, e.g., ICORR(3) = 4 means that correlation 4 is to be used for Force Structure 3.

- Force-structure locations.

All input variables related to force structure are listed in Table 11.

Tube Side

- Tube diameter for computing Reynold number Re,

- Variables a_l (ATBL), ..., C_t(CTBT), and Re_{tr}(RETRN) for computing friction factor f (Eq. 6.4), and

- Variables C_1(FORCTB) for computing the resistance term (Eq. 6.3).

All input variables related to the tube-side force structure are listed in Table 12.

6.4 Force–Structure Locations

Information on force-structure location is provided through force-structure specification records. The FORMAT is (A4, 7I4):

Table 11. *Input variables related to shell-side force-structure modeling*

FORTRAN Name[a]	Description of Variable	COMMIX Input Section	Remarks
NFORCE	No. of force structures	NAMELIST/GEOM/	---
NEWFOR	Signal for new force-structure input	NAMELIST/DATA/	= 0 for no, = 1 for yes; applicable for ISTATE = 0 or ISTATE = 2
CLENTH(NF)	D (Eqs. 6.2 and 6.3)	NAMELIST/DATA/	Given a negative value if desire to use Eq. 6.1c; i.e., when L = D
FORCEF(NF)	C_1 (Eqs. 6.2 and 6.3)	NAMELIST/DATA/	---
NCORR	No. of correlations	NAMELIST/DATA/	---
ICORR(NF)	Correlation linkage	NAMELIST/DATA/	See Sec. 6.3
ACORRL(N)	a_ℓ (Eq. 6.4a)	NAMELIST/DATA/	---
BCORRL(NC)	b_ℓ (Eq. 6.4a)	NAMELIST/DATA/	---
CCORRL(NC)	c_ℓ (Eq. 6.4a)	NAMELIST/DATA/	---
ACORRT(NC)	a_t (Eq. 6.4b)	NAMELIST/DATA/	---
BCORRT(NC)	b_t (Eq. 6.4b)	NAMELIST/DATA/	---
CCORRT(NC)	c_t (Eq. 6.4b)	NAMELIST/DATA/	---
REYTRN(NC)	Re_{tr}	NAMELIST/DATA/	Reynolds no. for laminar/ turbulent transition
REYLEN	d	NAMELIST/DATA/	Reference length for Reynolds no.
XFOR YFOR ZFOR	Force-structure location	Force-structure specification records	For direction and location, see Sec. 6.4

[a]NF is a force-structure number; NC is a correlation number.

Table 12. Input variables related to tube-side force-structure modeling

FORTRAN Name	Description of Variable	COMMIX Input Section	Remarks
ATBL	a_ℓ (Eq. 6.4a)	NAMELIST/TUBS/	----
BTBL	b_ℓ (Eq. 6.4a)	NAMELIST/TUBS/	----
CTBL	c_ℓ (Eq. 6.4a)	NAMELIST/TUBS/	----
ATBT	a_t (Eq. 6.4b)	NAMELIST/TUBS/	----
BTBT	b_t (Eq. 6.4b)	NAMELIST/TUBS/	----
CTBT	c_t (Eq. 6.4b)	NAMELIST/TUBS/	----
RETRN	RETR	NAMELIST/TUBS/	----
DMTB	D_ℓ (Eq. 6.3)	NAMELIST/TUBS/	Tube inside surface
FORCTB	C_1 (Eq. 6.3)	NAMELIST/TUBS/	----

$$\begin{matrix} \text{XFOR} \\ \text{or} \quad \\ \text{YFOR} \\ \text{or} \quad \\ \text{ZFOR} \end{matrix} \right\} \quad \text{NF} \quad \text{IB} \quad \text{IE} \quad \text{JB} \quad \text{JE} \quad \text{KB} \quad \text{KE},$$

where XFOR, YFOR, or ZFOR are to input the direction of force. The variable NF stands for the force-structure number, and IB .... KE stands for the beginning and end of the i, j, k indices of the cell locations. For more details relating to force-structure location input, see Appendix A.

6.5 Modeling Recommendations

6.5.1 Staggered-Grid System

In the finite-volume formulation, the frictional resistance due to a solid structure in a flow domain is considered an additional source term in the momentum equation. Because a staggered-grid system is used in COMMIX-PPC, the control volumes for the momentum equations are displaced from the mass or energy cells, as illustrated in Fig. 28. Therefore, for modeling of the resistance term, it is important to remember that

- The distributed-resistance source term is for the staggered control volume, shown in Fig. 28, and

- The reference velocity used in the resistance source term equation is the velocity at the face of a cell.
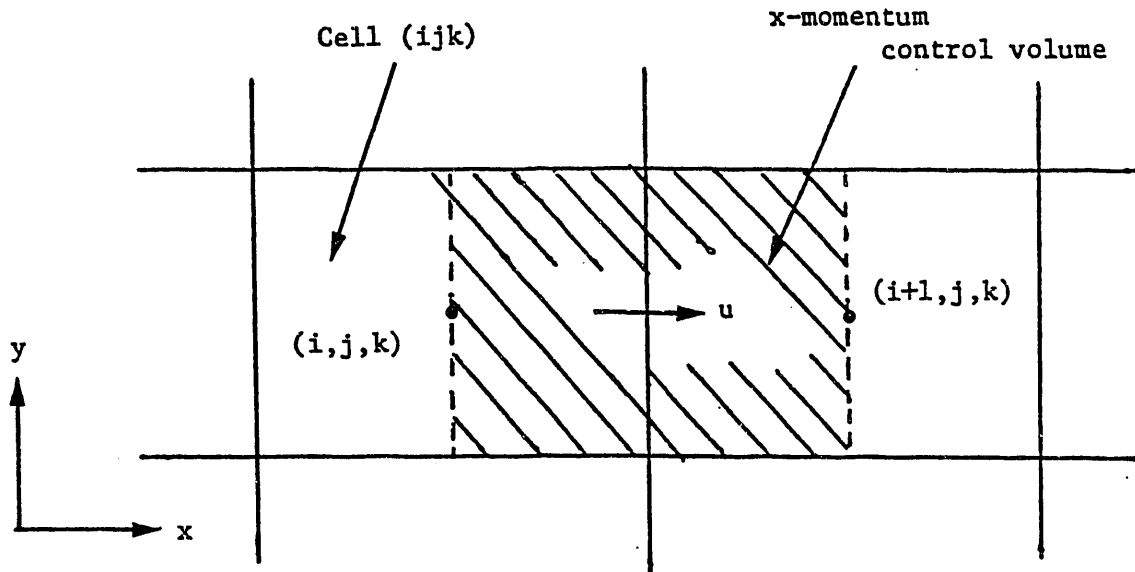
Fig. 28. x-Momentum control volume in a staggered-grid system

To illustrate this point, we consider the case of a sudden enlargement, as shown in Fig. 29. The pressure loss due to an abrupt change in area is generally expressed in terms of a loss coefficient K_1 or K_2, depending on which reference velocity is used,

$$\Delta p = K_1 \frac{1}{2} \rho V_1^2 ,$$

$$= K_2 \frac{1}{2} \rho V_2^2 ,$$

where subscripts 1 and 2 refer to smaller and larger cross sections, respectively. In such cases, the user must look at the location of abrupt expansion (see Fig. 29) and then prescribe a suitable correlation for the loss coeficient K_1 or K_2.

6.5.2 Friction-Factor Library

Occasionally, the COMMIX-PPC user may find that the desired correlation is not of the form prescribed in Sec. 6.2. When this occurs, the user may

- Approximate the correlation to conform with the input form, or

- Implement a new correlation in the code.

The user who wishes to implement a new correlation should first examine the subroutine FORCES to see what correlation numbers are free and available. Then, with other library correlations as a guide, a new correlation can be inserted appropriately in subroutine FORCES and recompiled.

6.5.3 List of Correlations

To save the user's time in searching the vast literature, a set of correlations commonly needed by COMMIX-PPC users has been compiled and listed in Appendix C. These correlations are not necessarily ideal; therefore, we welcome feedback and comments from all users so that an improved and expanded list can be prepared.
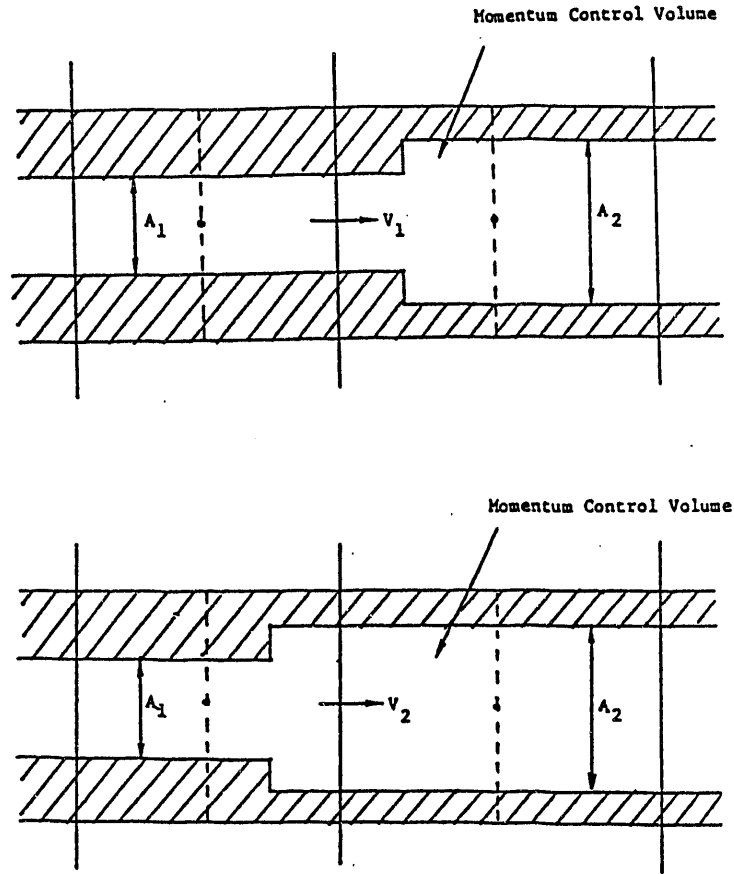
Fig. 29. Sudden enlargement

7 Solution Procedure

7.1 Introduction

As described in Vol. I, COMMIX-PPC employs the fully implicit scheme for the general finite-volume equations. Also available in COMMIX-PPC are the three matrix solvers for the scalar transport equations (energy, k, and ε) and the pressure equation. These options make the numerical computation more efficient for a given problem. In this section, we describe how to use these options and provide some guidance on the selection of the method that is suitable for a given application. Convergence and relaxation parameters are also discussed.

7.2 Solution Methods

Two variables in the solution procedure are given in Table 13. The user can choose one of the matrix solvers for the scalar transport equations and the pressure equation. The successive overrelaxation (SOR) method and the direct matrix inversion method (DMIM) are suitable for both the symmetric and nonsymmetric matrix and therefore can be selected

Table 13. Variables in the COMMIX NAMELIST/GEOM/ Input Section of the solution procedure

FORTRAN Name	Description	Remarks
ISOLVE	Flag to choose matrix solver for scalar transport equations (energy, k, ε, and mass fraction x)	= 0 for SOR[a] = 1 for DMIM[b]
ISOLVR	Flag to choose matrix solver for the pressure equation	= 0 for SOR = 1 for DMIM = 11 for PCG[c]

[a]SOR: successive overrelaxation method.
[b]DMIM: direct matrix inversion method.
[c]PCG: Preconditioned conjugate gradient method.

for both the scalar transport equations and the pressure equation. The preconditioned conjugate gradient (PCG) method is applicable to symmetric matrices and is therefore suitable for the pressure equation only. The FORTRAN name ISOLVE is the flag for choosing the matrix solver for the scalar transport equations. If ISOLVE = 0, SOR is selected; if ISOLVE = 1, DMIM is selected. The FORTRAN name ISOLVR is the flag for choosing the matrix solver for the pressure equation. ISOLVR = 0, 1, and 11 corresponds to matrix solvers SOR, DMIM, and PCG, respectively. If SOR is selected, the user should specify the convergence parameter epsilon and the relaxation parameter omega, which will be separately discussed in Secs. 7.3 and 7.4. If the DMIM is selected, the user should input the parameters NNZERO and NSPACE in the NAMELIST/GEOM/. The values of these two parameters are not known a priori. A common approach is to input some arbitrary values for NNZERO and NSPACE, and submit a job. The output will then indicate the proper values to use for NNZERO and NSPACE. This procedure may have to be repeated several times.

In general, DMIM is most efficient if the number of the computational cells is less than 1000. If the number of computational cells is greater than 2000, the SOR method should be selected for the scalar transport equations and the PCG method for the pressure equation. If the number of computational cells is between 1000 and 2000, there is no clear advantage in using one method over the others and the selection is problem-dependent.

7.3 Convergence Parameters

A list of convergence criteria employed in COMMIX-PPC is presented in Table 19 of Vol. I. The user must input these convergence parameters for the iterative solution schemes such as the SOR method and the PCG method. The list is repeated in Table 14 and all parameters shown are required as input. The default value for each parameter should be in the NAMELIST/DATA/ section of the input.

Table 14. Convergence parameters

FORTRAN Name	Symbol	Description	Default Value
EPS1	ε_1	Mass convergence for pressure equations	10^{-4}
EPS2	ε_2	Mass convergence for pressure equations	10^{-6}
EPS3	ε_3	All transport variables (h, k, e, u, v, and w)	5×10^{-5}
EPS6	ε_6	Turbulence parameters k and ε	10^{-5}

7.4 Relaxation Parameters

The finite-volume discretization equations in COMMIX-PPC have been so constructed that, in the absence of interlinkages and nonlinearities, convergence will be certain. However, because the equations of interest are nonlinear and interlinked, care must be exercised to prevent divergence. One simple strategy is to slow down the changes that occur from iteration to iteration. This is accomplished by underrelaxation.

7.4.1 Implicit Underrelaxation

The general finite-volume discretization equation of COMMIX-PPC can be expressed by

$$a_0^\phi \phi_0 = \sum_\ell a_\ell^\phi \phi_\ell + b_0^\phi , \qquad (7.1)$$

where the subscript ℓ denotes neighboring points.

We define

$$\phi_0^{new} = \omega \phi_0 + (1 - \omega) \phi_0^* , \qquad (7.2)$$

where w is the underrelaxation factor, ϕ_0 satisfies Eq. 7.1, and ϕ_0^* is the most recent iteration value of ϕ_0. Multiplying Eq. 7.2 by $\left(a_0^\phi / \omega \right)$ gives

$$\left(\frac{a_0^\phi}{\omega} \right) a_0^{new} = a_0^\phi \phi_0 + (1 - \omega) \left(\frac{a_0^\phi}{\omega} \right) \phi_0^* . \qquad (7.3)$$

Substituting Eq. 7.1 into Eq. 7.3 gives

$$\left(a_0^\phi / \omega \right) \phi_0^{new} = \sum_\ell a_\ell^\phi \phi_\ell + b_0^\phi + (1 - \omega) \left(a_0^\phi / \omega \right) \phi_0^* . \qquad (7.4)$$

$$\left(a_0^\phi/\omega\right)\phi_0^{new} = \sum_i a_i^\phi \phi_i + b_0^\phi + (1-\omega)\left(a_0^\phi/\omega\right)\dot{\phi}_0 \ . \tag{7.4}$$

When ϕ_0 tends to equal $\dot{\phi}_0$ (i.e., the iterations converge), Eq. 7.4 tends to become identical to Eq. 7.1. However, when the relaxation factor ω is less than 1, Eq. 7.4 will have a tendency to keep the resulting ϕ_0^{new} closer to $\dot{\phi}_0$ than would Eq. 7.1. A value of ω close to zero will result in very heavy underrelaxation.

For the velocity components, a conservative value of $\omega = 0.8$ may be used. Similar values may be used for turbulence kinetic energy and turbulence dissipation. A proper set of ω values can usually be obtained through working experience with a given class of problems. In COMMIX-PPC, the input parameters OMEGAV, OMEGAK, and OMEGAD are provided for implicit underrelaxtion for velocities u, v, and w, turbulence kinetic energy k, and turbulence dissipation rate ε, respectively. Table 15 lists the underrelaxation parameters and default values employed in COMMIX-PPC. It includes two additional underrelaxation parameters, OMEGAR for density and OMEGAT for turbulent viscosity. The default value for these two parameters is 1.0.

7.4.2 Successive Overrelaxation

When the SOR method is used for the pressure equation and/or the scalar transport equation, the recommended default values for these parameters are those given in Table 16.

Table 15. Underrelaxation parameters and default values employed in COMMIX-PPC

FORTRAN Name	Default Value	Remarks
OMEGAV	0.8	Velocity components
OMEGAK	0.7	Turbulence kinetic energy
OMEGAD	0.7	Rate of dissipation of turbulence kinetic energy
OMEGAR	1.0	Density
OMEGAT	1.0	Turbulent viscosity

Table 16. Relaxation parameters and default values when SOR method is employed in COMMIX-PPC

FORTRAN Name	Default Value	Remarks
OMEGA	1.5	Pressure
RELAXK	0.8	Turbulence kinetic energy

8 Auxiliary Input

In addition to geometry specification, initialization, and model input, several auxiliary inputs are required. These inputs are briefly described here; detailed information is presented in Appendix A.

8.1 Heat Transfer Correlation

Relevant heat transfer correlations are needed to calculate the surface heat transfer coefficient in thermal-structure models. Currently, three types of heat transfer correlations are available in COMMIX-PPC. The heat transfer coefficient is linked to the thermal-structure model through the variable IHT in the thermal-structure prototype records NAMELIST/F/. Three input parameters are associated with a particular IHT:

- IHTCOR(IHT)   Heat transfer correlation number,

- HTCLEN(IHT)   Characteristic length, and

- HTCMUL(IHT)   Heat transfer coefficient multiplier.

For example, if IHT = 2, then

IHTCOR(2) = 8,

HTCLEN(2) = 2.0,

HTCMUL(2) = 3.0,

meaning that heat transfer correlation number 8 will be used for this particular thermal structure, the characteristic length used in the calculation of the Reynolds and Nusselt numbers is 2.0 meters, and the calculated heat transfer coefficient is multiplied by a factor of three.

The three types of heat transfer correlations in COMMIX-PPC are

1. If IHTCOR = 1 - 10:

$$h = h_0 \times Nu \times k / d \qquad (8.1)$$

where h_0 = heat transfer coefficient multiplier (HTCMUL),
  Nu = $C_1 + C_2 Re^{C_3} Pr^{C_4}$, $\qquad (8.2)$
  Re = Reynolds number,
  Pr = Prandtl number,
  k = thermal conductivity, and
  d = characteristic length (HTCLEN)

2. If IHTCOR = 11 - 20:

$$h = h_0 \left(C_1 + C_2 Re^{C_3} Pr^{C_4} \right). \qquad (8.3)$$

The constants C_1, C_2, C_3, and C_4 are the user input coefficients, and the FORTRAN names for these coefficients are HEATC1, HEATC2, HEATC3, and HEATC4, respectively. All input parameters for the heat transfer coefficient calculations should be in the NAMELIST/DATA/ section.

3. If IHTCOR = 21 to 40, the condensation heat transfer correlations are used. Values of IHTCOR from 21 to 30 are reserved for shell-side heat transfer correlations and values of IHTCOR from 31 to 40 are reserved for tube-side heat transfer correlations.

   a) Shell-Side Heat Transfer Correlations

      At the present time, only one value of IHTCOR is available, i.e., IHTCOR = 21. The condensation correlations of Nusselt (Eq. 9.5 of Vol. I) and Berman and Fuks (Eq. 9.4 of Vol. I), which account for the effect of entrained air, are used. The effects due to inundation, subcooling, and vapor shear are specified by the variables INNUDA, ISBUC, and ISHEAR, respectively, in NAMELIST/GEOM/.

      INNUDA = 0   inundation is not considered
               1   Eq. 9.8 of Vol. I is used

      ISUBC = 0   subcooling is not considered
              1   Eq. 9.9 of Vol. I. is used
              2   Eq. 9.10 of Vol. I is used

      ISHEAR = 0   effect due to vapor shear is not considered
               1   Eq. 9.11 of Vol. I is used

   b) Tube-Side Heat Transfer Condition

      The heat transfer correlation for tube-side flow (single-phase) has the same form as in Eq. 8.1 for which the Nusselt number is given by Eq. 8.2. If IHTCOR = 31, the Dittus-Boelter correlation for Nu is used.

      The effect due to biofouling is specified by the variable IFOUL in NAMELIST/GEOM/.

      IFOUL = 0   biofouling effect is not considered
              1   biofouling effect is considered.

      When IFOUL = 1, the fouling resistance, FOUL, must be specified in NAMELIST/DATA/.

Other heat transfer correlations may be selected by the user if deemed appropriate. The new additions can be defined by using an IHTCOR number greater than 41. They should be inserted in the subroutine HTCOEF and recompiled.

8.2 Fluid and Material Properties

Fluid properties are determined by the variable MATYPE in the input section of NAMELIST/DATA/. The values of MATYPE may be any integer from 1 to 22. When the

value of MATYPE is from 1 to 20, the fluid properties are computed from the simplified equations. If MATYPE is 21 or 22, the fluid properties are calculated by rigorous subroutines for the following:

21   water liquid,
22   water vapor.

The simplified equations for enthalpy h, density ρ, thermal conductivity λ, viscosity μ, saturation pressure P_{sat}, and molecular diffusivity D are

$$h\left(\frac{J}{kg}\right) = C_0^h + C_1^h T + C_2^h T^2 + C_3^h P \ , \tag{8.4}$$

$$\rho\left(\frac{kg}{m^3}\right) = C_0^\rho + C_1^\rho T + C_2^\rho P/(T + 273.16) \ , \tag{8.5}$$

$$k\left(\frac{W}{m - {}^\circ C}\right) = C_0^k + C_1^k T + C_2^k T^2 \ , \tag{8.6}$$

$$\mu(Pa \bullet s) = C_0^\mu + C_1^\mu T + C_2^\mu/(T + 273.16) \ , \tag{8.7}$$

$$P_{sat}(Pa) = \exp\left(C_0^p + C_1^p T + C_2^p T^2\right) \tag{8.8}$$

$$D\left(\frac{m^2}{s}\right) = \left(C_0^d + \frac{C_1^d}{p}\right)(T + 273.15)^{C_2^d} \tag{8.9}$$

where T is in °C and P is in Pa. For each property, the user must input the constants C_0, C_1, etc. The FORTRAN names for these constants are

CØH, C1H, C2H, C3H	Coefficients in enthalpy equation,
CØRO, C1RO, C2R	Coefficients in density equation,
CØK, C1K, C2K	Coefficients in conductivity equation,
CØMU, C1MU, C2MU	Coefficients in viscosity equation,
CØP, C1P, C2P	Coefficients in saturation pressure equation, and
COD, C1D, C2D	Coefficients in molecular diffusivity equation.

Linkage of the material properties to the thermal-structure model is through the variable MI in the thermal-structure prototype records NAMELIST/M/. For example, if MI = 2 for a given material and

CØK = 20.0, 40.0, 60.0,

C1K = 10^{-3}, 10^{-4}, 10^{-5},

the thermal conductivity of the material is given by

k = 40 + 10^{-4} x T, in W/m-°C.

Similarly, if MATYPE = 1, the fluid properties are calculated by

k = 20 + 10^{-3} T, in W/m-°C.

8.3 Turbulence Modeling

In COMMIX-PPC, two options are provided to account for the effect of turbulent flow:

- Constant-diffusivity model, and
- k-ε two-equation turbulence model.

The theory and equations relating to these models are described in Vol. I. Here, we present only the information needed by the user.

8.3.1 Signal Parameter

The variable ITURKE in NAMELIST/GEOM/ specifies which turbulence model is to be used:

ITURKE = 0   Use the no-turbulence (laminar flow) or constant-diffusivity model,

= 12   Use the k-ε two-equation turbulence model.

8.3.2 Constant-Diffusivity Model

In the constant-diffusivity model (ITURKE = 0), the user must specify the values of the turbulent viscosity (μ_{tur}) and turbulent conductivity (k_{tur}) in NAMELIST/DATA/. The corresponding FORTRAN variables are TURBV and TURBC, respectively.

It is recommended that whenever possible, the prescribed values be based on experimental data. If experimental data are not available, a user can provide his/her own estimate or use the procedure suggested in Sec. 7.1 of Vol. I.

8.3.3 k-ε Two-Equation Turbulence Model

In the two-equation model (ITURKE = 12), the transport equations of the turbulence kinetic energy k and its dissipation rate are solved. As has been described in Vol. I, eight presumably constant coefficients are employed in the k-ε two-equation turbulence model. Table 17 is a list of the FORTRAN names and default values of these coefficients. These parameters are required only if the user wishes to use values different from the default values given in the table, in which case, the values desired by the user should be in the input section of NAMELIST/DATA/.

Table 18 lists additional inputs that the user may need for the k-ε two-equation turbulence model. These parameters have already been described in previous sections. For example, the relaxation parameters are explained in Sec. 7.4, and the boundary turbulence parameters (TKB and TDB) are explained in Sec. 4.2. They are presented here mainly for cross reference.

All parameters listed in Table 18, with the exception of TKB and TDB, should be in the input section of NAMELIST/DATA/. TKB and TDB should be in the surface-element initialization records.

Table 17. Coefficients employed in k-ε two-
equation turbulence model

FORTRAN Name	Symbols Used in Volume I	Default Value
PRNDLH	σ_h	0.9
PRNDLK	σ_k	1.0
PRNDLD	σ_ε	1.3
CT1	C_1	1.44
CT2	C_2	1.92
CDTURB	C_D	0.09
AKAPPA	K	0.42
EE	E	9.0

Table 18. Possible additional input for k-ε two-equation turbulence model

Variable	Function	Default Value
ITMAXK	Maximum number of iterations for k equation	29
OMEGAT	Relaxation factor for turbulent viscosity	1.0
OMEGAK	Relaxation factor used in the solution of k equation	0.7
OMEGAD	Relaxation factor used in the solution of ε equation	0.7
RELAXK	Relaxation factor for k	0.8
EPS6	Convergence criterion for the k and ε equations	10^{-5}
TKB	Boundary turbulence kinetic energy	10^{-16}
TDB	Dissipation rate of boundary turbulence kinetic energy	10^{-10}

8.4 Time–Step Size

COMMIX performs thermal–hydraulic calculations by marching in time. All values of the dependent variables at a given time t and the corresponding time step n are known. The values of the dependent variables at time t + Δt and time step n+1 are calculated. By repeating this procedure, the thermal–hydraulic conditions are determined for the desired time span.

For steady–state calculations, the same procedure is followed. We start with an initial state and continue the marching–in–time process until the values of all dependent variables slowly vary. The size of the time step for the implicit–steady–state calculation can be very large, e.g., as much as 10–20 times the Courant time–step criterion.

In COMMIX-PPC, there are two options for selecting the time-step size:

- The user can prescribe the desired time-step size as input; details of this option are given in Appendix A.

- The automatic time-step option can be used.

In the automatic time-step option, the time-step size is evaluated on the basis of the Courant condition:

$$\Delta t = C_1 \, \Delta t_C. \tag{8.10}$$

where C_1 is the user-prescribed coefficient and Δt_c is the time-step size evaluated from the Courant condition. The Courant time-step size is the minimum time required for fluid to be convected through a cell. The automatic time-step option does not provide an optimum time-step size for a given transient condition. Additional work is needed to develop an automatic time-step selection scheme, where an optimum time-step size is selected during the course of a transient calculation, as described in Vol. I.

The following input variables are related to time-step size:

IDTIME	Signals whether the time-step is user-specified or a Courant time-step.
DT(1) DT(2) LASTDT	DT(1) is the time-step size for Steps 1-LASTDT. DT(2) is the time-step size for steps after LASTDT.
RDTIME	Factor C_1 is used for multiplying the Courant time-step size (Eq. 8.10).

Several other time-related parameters are listed in Table 19. These parameters provide the user with additional flexibility in controlling how a particular run should be conducted. For example, if the user wants to run for just one time step (for debugging), the parameter NTMAX should be set to 1. If the user wants to run a particular problem for just 1 min, the parameter TIMAX should be set to 60.

8.5 Output

An input procedure, described in Appendix A, is provided for printing array values of a range of variables at given locations (specified plane) and at a given time or time step.

9 Steady-State Calculation

9.1 Introduction

In COMMIX-PPC, even when analyzing a transient problem, we must generate an initial condition for the transient analysis by first obtaining a steady-state solution.

Table 19. Time-related parameters

Name	Description	Default Value
NTMAX	Maximum time step for a given run	99999
TIMAX	Maximum time for a given run	3.6×10^7
ITEMER	= 0, no subroutine time information shown = 1, subroutine time information shown at the end of a run = 2, subroutine time information shown after every call	0
TREST	If the elapsed run time exceeds TREST, the run is terminated after optionally writing a restart file	3600
TSTART	This value should be reset to zero at the beginning of a transient run (STATE = 2)	0.0

To perform a steady-state calculation, the problem is treated as if it were a transient case. We prescribe an estimated distribution of the dependent variables as their initial values and continue marching in time until the distribution slowly varies and satisfies the prescribed convergence criteria.

9.2 Input Preparation

To start a steady-state calculation, we prescribe

- Control flag ISTATE = 0.

- Control flag IFRES = 1.

The control flag IFRES = 1 implies that we are starting a new case and that at the end of the run we want the results to be written on a restart file. If we do not desire a restart file to be written, we prescribe IFRES = 0. For continuation of a steady-state run, we specify

- ISTATE = 1 and

- IFRES = 3

  in the input of the continuation run.

- Geometrical information.

- Constant-value boundary conditions (use the surface-element initialization records if the boundary conditions are nonuniform).

- The best estimates for the initial values of all dependent variables; to save computer running time, it is recommended that prescribed initial estimated values be as close as possible to the expected solution.

- Number of iterations IT = 1. Because we are performing a steady-state simulation, each time step represents a steady-state iteration; therefore, more iterations per time step are not required.

- Time-step size DT can be large. We recommend starting with DT = 1000 s or larger. If this causes a convergence problem, it then can be reduced to, for example, 100 or 10 s or even less.

- Fluid and material properties.

- Other ancillary information, e.g., output printing desired.

- Force-structure input, if any.

- Thermal-structure modeling with heat source, if any. *For a steady-state calculation, only the thermal structures with heat sources need to be considered.*

- Turbulence-model input, if necessary.

9.3 Steady-State Convergence Criteria

We define a steady-state solution as having been achieved when the following criteria are satisfied simultaneously:

$$\left(\frac{|\Delta h|}{h}\right)_{max} < \varepsilon_3 ,$$

$$\left(\frac{|\Delta u|}{VELMAX}\right)_{max} < \varepsilon_3 ,$$

$$\left(\frac{|\Delta v|}{VELMAX}\right)_{max} < \varepsilon_3 ,$$

$$\left(\frac{|\Delta w|}{VELMAX}\right)_{max} < \varepsilon_3 , \text{ and}$$

$$|\delta|_{max} < DCONV .$$

Here Δh, Δu, ..., are the changes in enthalpy, velocity components, etc., between successive time steps, δ is the mass residue, ε_3 is the steady-state convergence criterion, VELMAX is the maximum of all velocity magnitudes, and DCONV is the mass convergence parameter calculated from

$$DCONV = \varepsilon_1 \left[\left(\frac{\rho \gamma_i u_i}{\gamma_v \Delta x_i}\right)_{max} + \varepsilon_2\right], \text{ in kg/m}^3\text{-s}, \tag{9.1}$$

where ε_1 and ε_2 are the input convergence constants, subscript i stands for the three coordinates, γ_i is the suface porosity, and γ_v is the volume porosity. The default values for ε_1, ε_2, and ε_3 are 10^{-4}, 10^{-6}, and 5×10^{-5}, respectively.

10 Transient Calculations

10.1 Introduction

In COMMIX-PPC, any one of the following conditions or their combination will result in a transient problem:

- Transient velocity boundary condition,

- Transient temperature and surface heat flux boundary conditions,

- Transient pressure boundary condition, and/or

- Transient heat source.

10.2 Procedure

The following procedure is recommended for running a transient problem:

- Obtain a steady–state solution using constant–value boundary conditions and guessed initial distributions of all dependent variables, and write the results on a restart file. The constant boundary values must be the values at time t = 0 of the transient problem.

- Run the transient problem, using the restart data and the following additional input in NAMELIST/DATA/.

  –ISTATE = 2.

  –TSTART = starting time of the transient.

  –KFLOW(N) = 100 + NF; this is for the transient velocity boundary condition. NF defines the transient function number to be used for the transient condition on surface N.

  –KTEMP(N) = 100 + NF or 300 + NF; this is for the transient temperature or heat flux boundary condition. NF defines the transient function number to be used for the transient condition on surface N.

  –KPRES(N) = 100 + NF; this is for the transient pressure boundary condition. NF defines the transient function number to be used for the transient condition on surface N.

–NOFQT is the number of the transient function used as a multiplier of the specified volumetric heat source (QSOU) distribution. For example, if NOFQT = 2,

$$Q(x, y, z, t) = f_2(t) \times QSOU (x, y, z),$$

where Q (x, y, z, t) is the transient volumetric heat source, f_2 is the transient function number 2, and QSOU (x, y, z) is the spatial heat source distribution in the fluid.

–TVAL represents the values of the independent variable (time) of the transient functions.

–FVAL represents the values of the dependent variable of the transient functions.

–NEND(N) is the number of points used to prescribe the transient function number N.

–Other ancillary information – time–step size, output, etc.

10.3 Transient Functions

In COMMIX–PPC, we use the relation

$$F(t) = F(0) * f(t) \tag{10.1}$$

to prescribe the desired variation of a function with time. Here, F(0) is the value of a function at time t = 0 and f(t) is a dimensionless transient function. The following is information relevant to the use of f(t) in COMMIX.

- A set of f and t values must be prescribed for each transient function. Cubic spline–fit coefficients are evaluated to approximate a transient function as a polynomial.

- Up to 25 functions, consisting of up to 100 points, can be defined.

- All transient functions should be normalized with respect to values at time t = 0.

- FVAL and TVAL are the names of FORTRAN variables that prescribe discrete values of f and t, respectively.

- NEND(NF) is the number of discrete f and t values prescribed for transient function #NF.

- FVAL and TVAL are one–dimensional arrays; the first value of the second transient function immediately follows the last value of the first function. The same pattern is followed for all subsequent transient functions.

- Discontinuities in a function can be indicated by specifying the same t value twice for the same or different f values.

11 Operating COMMIX–PPC

11.1 Creation of a Load Module

To ease the task of creating load modules (binary files) to fit the size of the problem being considered, a dynamic storage allocation scheme is implemented in COMMIX. Space for the geometry-dependent variables is allocated in the variable S of COMMON/SPACE/. The address of each variable is computed at the beginning of each run. These addresses are then passed into subroutines, where the variables are named and variably dimensioned.

11.2 Input/Output

11.2.1 Input Data File 5

The input for File 5 is described in Appendix A. The most recent version of the input description is generally distributed with the code. The input contains a mixture of NAMELIST and formatted data. It is rewound to allow for multiple passes through the file. The user may wish to change the file number of the read statements if the user's system does not provide for rewinding of File 5.

11.2.2 Printed Output File 6

The printed output from COMMIX-PPC is written into File 6. A 133-character line length is assumed, with Column 1 being the carriage control. The input data from File 5 and summary information, depending on the problem, are always printed. But the bulk of the output is user-specified and controlled by parameters such as ISTPR, NTHPR, NTPRNT, and TPRNT, which are described in Appendix A.

11.2.3 Restart Information Files 9 and 10

The restart capabilities of COMMIX-PPC are programmed in SUBROUTINE RESTAR. Blocks of information are written into File 10, which can be read by a subsequent job from File 9 to permit continued processing from the point at which the restart file was written.

Restart files are written optionally (see IFRES in Appendix A) in any of the following three events:

- Steady state is reached.

- The time specified for the job has elapsed.

- A specified time or time step has been reached.

The first event is indirectly controlled by the convergence parameters. The second and third events can be controlled by variables described in the "Restart Option" section under NAMELIST/GEOM/ and the "Time- and Time-Step-Related Parameters" section under NAMELIST/DATA/ in Appendix A.

After the restart information is written into File 10, several additional records are written. These records contain, in effect, a snapshot of the simulation as it existed when the restart was written. This information can then be used, by interfacing with the user's graphics programs, to obtain graphic plots, e.g., velocity vectors and isotherms.

11.2.4 Plot Tape File 76

Before reaching a steady state, it is generally adequate to obtain plots only for points in time at which restart files are written. However, once steady state has been reached and a driving transient has been turned on, it is often desirable to save the complete history of the flow and temperature fields. SUBROUTINE PLTAPE provides this optional capability (see NTPLOT in Appendix A). At the beginning of File 76, a group of records containing geometry and properties information is written. Then, at user-controlled time-steps, the entire velocity and temperature fields are written. This file can then be used to interface with the user's plotting routines. At the present time, the plotting routines for condenser modeling are available for shell-side flow only.

11.3 Error Detection and Diagnostics

It is generally impossible to anticipate all the potential error conditions that one might encounter while using COMMIX. However, an attempt has been made to provide information that will guide the user through abnormal terminations.

Key variables are tested for meaningful values in many places or where certain paths of a branch statement indicate error conditions. Some of these have been coded to call SUBROUTINES ERRORS and ERRCHK. These two subroutines print short error messages and determine whether processing can continue or must terminate.

The "Error Messages" section in Appendix A contains expanded explanations of the errors encountered.

12 Global Mass and Enthalpy Balances

12.1 Global Mass Balance

Shell side

The global balance equations for the mixture and for each component fluid are obtained by integrating Eqs. 2.1 and 2.2 of Vol. I over the entire flow domain; thus,

$$\int_V \frac{\partial(\gamma_v \rho)}{\partial t} dv + \int_A \gamma_A \rho \bar{v} \cdot \overline{dA} = \int_V \gamma_v \dot{m}''' dv \qquad (12.1)$$

for the mixture, and

$$\int_V \frac{\partial(\gamma_v \rho x_k)}{\partial t} dv + \int_A \gamma_A \rho x_k \bar{v} \cdot \overline{dA} = \int_V \gamma_v \dot{m}_k''' dv \qquad (12.2)$$

for the component fluid.

Equations 12.1 and 12.2 can be expressed as

$$\begin{bmatrix} \text{mass accumulation} \\ \text{rate} \end{bmatrix} = \begin{bmatrix} \text{net mass flow convected} \\ \text{into system} \end{bmatrix} + \begin{bmatrix} \text{mass generation} \\ \text{rate} \end{bmatrix}. \quad (12.3)$$

By denoting MDASDT = mass accumulation rate, kg/s, FLOSUM = net mass flow convected into the system, kg/s, and XSOURC = mass generation rate, kg/s, the global mass in balance can be calculated from

$$\Delta \dot{m} = \text{DMASDT} - \text{FLOSUM} - \text{XSOURC}. \quad (12.4)$$

Each term of the above equation is computed and printed in the shell-side global mass balance section of the printout when Subroutine OUTPUT is called.

Tube side

The global mass balance equation is obtained by integrating Eq. 8.1 over all the condenser tubes, i.e.,

$$\int_V \left[\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho u) \right] dv = 0 \quad (12.5)$$

or

$$\begin{bmatrix} \text{net mass} \\ \text{accumulation rate} \end{bmatrix} = \begin{bmatrix} \text{net mass flow convected} \\ \text{into condenser tubes} \end{bmatrix}. \quad (12.6)$$

By denoting DMASDT = mass accumulation rate and FLOSUM = net mass flow convected into condenser tubes, the global mass imbalance $\Delta \dot{m}$ for the tube-side flow is given by

$$\Delta \dot{m} = \text{DMASDT} - \text{FLOSUM}. \quad (12.7)$$

Each term of the above equation is computed and printed in the tube-side global mass balance section when Subroutine OUTPUT is called.

12.2 Global Enthalpy Balance

Shell side

The enthalpy imbalance can be determined from the following relation:

$$\begin{bmatrix} \text{net enthalpy} \\ \text{accumulation rate} \end{bmatrix} = \begin{bmatrix} \text{net enthalpy convected} \\ \text{into the system} \end{bmatrix} + \begin{bmatrix} \text{net heat conducted} \\ \text{into the system} \end{bmatrix}$$
$$+ \begin{bmatrix} \text{net latent heat released} \\ \text{within the system} \end{bmatrix} + [\text{pressure work}]. \quad (12.8)$$

In the COMMIX code, we define

DHNET = net enthalpy accumulation rate,

HINSUM = net enthalpy converted into the system,

QINSUM = net heat conducted into the system,

QSOURC = net latent heat released within the system, and

DPDT = pressure work.

Therefore, the enthalpy imbalance is calculated from

$$\Delta E = DHNET - HINSUM - QINSUM - QSOURC - DPDT. \tag{12.9}$$

Each term in the above equation is computed and printed in the shell-side global enthalpy balance section of the printout when Subroutine OUTPUT is called.

Tube side

The global balance equation is obtained by integrating Eq. 8.3 over all the tubes. It can be expressed as

$$\begin{bmatrix} \text{net enthalpy} \\ \text{accumulation rate} \end{bmatrix} = \begin{bmatrix} \text{net enthalpy convected} \\ \text{into condenser tubes} \end{bmatrix} + \begin{bmatrix} \text{net heat transferred} \\ \text{to the cooling water} \end{bmatrix} \tag{12.10}$$

In COMMIX-PPC, we define

dHdT = net enthalpy accumulation rate,

HINSUM = net enthalpy converted into condenser tubes,

QSOURC = net heat transferred to the cooling water,

and the energy imbalance is calculated from

$$\Delta E = dHdT - HINSUM - QSOURC. \tag{12.11}$$

Each term in the above expression is computed and printed in the tube-side global enthalpy balance section when Subroutine OUTPUT is called.

13 Concluding Remarks

The development of COMMIX began in 1976, with emphasis on the analysis of fuel assemblies in nuclear reactors, specifically under natural-circulation conditions. However, as application multiplied, demands increased, and the structure of COMMIX changed in response to users' needs, it became apparent that COMMIX could be made into a user-oriented general-purpose code with a wide range of capabilities and applicabilities.

The development of COMMIX has been a continuous, dynamic process. New modifications and improvements are implemented continuously in response to

- New development of physical models and solution procedures,

- Feedback from users, and

- A desire to streamline the code, i.e., make it more user-oriented, and increase its flexibility.

The first version of COMMIX, named COMMIX-1, was released in March 1978. Development continued and many features were added, e.g., thermal- and force-structure models, a cylindrical geometry option, semi- and fully implicit solution procedures, etc. In December 1983, COMMIX-1A was released. Further development led to COMMIX-1B, which was released in September 1985 and included new features such as turbulence models and a volume-weighted skew-upwind difference scheme. New matrix solvers, namely, DMIM and preconditioned conjugate gradient method, and modified finite volume formulation using the concept of volume averaged velocity, have been incorporated into COMMIX-1C, released in February 1990. Two more capabilities, namely, treating fluids of multicomponents and shell-tube thermal interaction, have been the most recent additions in COMMIX-PPC. These capabilities are introduced specifically for performance analysis of power plant condensers.

Since the inception of COMMIX, code verification has been performed in parallel with development. Extensive simulations have been performed to check and verify every step of the development. We believe that COMMIX is a very well-tested code. However, because COMMIX is large and versatile, some bugs might still have been overlooked. We certainly welcome feedback and comments from any user so the code can be further improved.

Within the constraints of available time and manpower, we have made very effort to make COMMIX a well-tested, user-oriented computer code. No doubt, many more improvements could be implemented to make it even more user-oriented. The following work is in progress:

- Implementation of more error detection and diagnostics to provide information that will guide the user through abnormal terminations.

- Development of a software package for computing all geometry-related information (e.g., mesh size, volume and directional surface porosity, and surface area) and generating input for COMMIX.

- Development of an interactive input processor for auxiliary input information, e.g., boundary conditions, thermal structures, and force structures.

- Development of a postprocessor for connecting COMMIX output to plot processors for generating vector and isotherm plots.

Acknowledgments

Appendix A: COMMIX-PPC Input Description

A.1 General Comments

The units used are meter, kilogram, second, and degrees Celsius. These and other derived units are indicated after the description of variables requiring them.

Default values are indicated either by an asterisk or a value in parentheses after the variable description.

Arrays are indicated by the use of a subscript following the variable name. The ranges of the subscripts are indicated in the following table. An asterisk in the 'Current Limit' column indicates that storage is allocated at execution time according to the value in the 'Range' column.

Index	Range		Current Limit
I	IMAX		99
IND	IMAX*JMAX	IND=I*(J-1)*IMAX	100
J	JMAX		99
K	KMAX		99
N	NSURF		399
NH	NHEATC		10
NM	Number of materials		24
NP			50
NF	NFORCE		*
NC	NCORR		20

A.2 Some Terminology

The computational area is partitioned into a number of computational cells, each bounded by consecutive X-, Y-, and Z- direction (or r- ,o, and z-direction) grid planes. Surface (portions of a plane or cylinder) may be defined both on the exterior, bounding the computational area, and in the interior. The intersection of a surface and consecutive grid planes outlines a surface element. Surfaces which coincide with a grid plane are called regular surfaces, otherwise, they are called irregular surfaces. A regular cell is one with all faces coinciding with grid planes. Irregular cells have one irregular surface element.

A.3 General Input Structure

The user input is read from a file associated with unit 5. This input consists of two required namelists, optional namelists, and several other record groups.

The user may specify unit 5 input in any order. One possible order follows:

Problem Description and Comments   (Optional)
NAMELIST/GEOM/
NAMELIST/DATA/

Boundary Surface Identification Records
Cell Initialization Records   (Optional)
Surface Element Initialization Records   (Optional)
Force Structure Specification Records   (Optional)
Thermal Structure Location Records   (Optional)
Tube Side Description and Comments   (Optional)
NAMELIST /TUBS/   (Optional)
Condenser Tube Location Records   (Optional)

A.4 Input

A.4.1 Problem Description and Comments

In order to sense the presence of optional input, columns 1-4 of each line of input is compared with the list of key words listed below. When a match is found, the line is reread in the appropriate format. If no match is found, the line is ignored or, in effect, treated as a comment. Thus any number of user comments can precede NAMELISTS or be interspersed between non-NAMELIST input as long as column 1-4 do not contain any of the following keywords.

REG	IREG	THL	THLB	XMS	XMSB
XFOR	YFOR	ZFOR	&T	&F	&M
OUT	IN	HLB	PB	QBN	RLB
TLB	VELBN	AL	ALX	ALY	ALZ
HL	P	QSOU	TL	UL	VL
WL	FLOW	TK	TD	TKB	TDB
AREA	EMDO	POLD	TUBE		

A.4.2 NAMELIST/GEOM/

The following variables are used to determine the amount of memory to be allocated for the run. It is important that they are specified correctly. The variables preceded by an asterisk can be approximated by a value larger than actually needed. The minimum values are printed after they are computed. Any of these variables that remain unchanged for a subsequent restart run need not be respecified since they are read from the restart file.

*NM1	*NL1	NSURF	IMAX	JMAX	KMAX
NFORCE	ISTRUC	ITURKE	IGEOM		
NNZERO	NSPACE				

The following three variables can be set to allow for more efficient computation when running one- or two-dimensional problems.

IFX   1 Perform all x-component calculations. (*)
        0 Bypass x-component calculations.

IFY   1 Perform all y-component calculations. (*)
        0 Bypass y-component calculations.

IFZ   1 Perform all z-component calculations. (*)
        0 Bypass z-component calculations.

IGEOM   0 Regular Box geometry (Cartesian coordinate) option. (*)

-1	Cylindrical geometry option using box geometry input.
	Note 1. A surface must be dedicated to R=0.0 when the origin is present. Set **KFLOW(N)=-3** and **KTEMP(N)=400** for that surface.
	Note 2. For full 2.0*PI radian geometries J=1 and J=JMAX are automatically linked thus no surfaces need be defined at Y=0.0 and Y=2.0*PI.
>0	INOPERATIVE

ISOLVE   Flag to determine the solution technique used to the transport equations. These include energy, turbulent kinetic energy and turbulent dissipation. (0)

0	Successive Over-Relaxation (SOR) solution scheme used. Values for eps1 and omega must also be specified when using this option.
1	The direct matrix inversion method (DMIM) solver is used. This option is recommended when the number of computational cells, nm1, is less than 1000. Values for nnzero and nspace are required when using this option. (*)

ISOLVR   Flag to determine the solution technique used to solve the pressure and component continuity equation. (0)

0	Successive Over-Relaxation (SOR) solution scheme used. Values for eps1 and omega must also be specified when using this option.
1	The direct matrix inversion method (DMIM) solver is used. This option is recommended when the number of computational cells, nm1, is less than 1000. Values for nnzero and nspace are required when using this option. (*)
11	A Pre-Conditioned Conjugate Gradient solver is used. This option is recommended when the number of computational cells, nm1, is greater than 1000.

MATOT(1)   Total number of components or materials.

NL1   Total number of surface elements. (0)

NM1   Total number of computational cells. (0)
Note. Both **NL1** and **NM1** can be approximated by values larger than actually required. However, if this is done they must not be included in **NAMELIST** **/GEOM/** when restarting (**ISTATE** >0). Storage will be allocated according to the values specified in the input rather than the minimum storage needed. The minimum values are printed when computed. If one desires to change **NM1** and/or **NL1**, it must be done only at the start a steady-state run (**ISTATE**=0).

IMAX   The maximum number of cells in the x-direction (R). (1)

JMAX   The maximum number of cells in the Y-direction (THETA). (1)

KMAX   The maximum number of cells in the z-direction. (1)

NSURF   The number of unique surfaces enclosing the computational domain. Unique surfaces are determined by a unique combination of the following three characteristics:
1. Velocity Boundary Condition
2. Temperature Boundary Condition
3. The unit normal vector to the surface.

DX(I)   The calculational cell sizes along the x-axis, m.

DY(J)   The calculational cell sizes along the Y-axis, m or rad.

DZ(K)   The calculational cell sizes along the z-axis, m.

The unit normal vectors referred to by the following three variables are those pointing into the computational domans.

XNORML(N)   The X-component of the unit normal vector to surface N.

YNORML(N)   The Y-component of the unit normal vector to surface N.

ZNORML(N)   The Z-component of the unit normal vector to surface N.

The required values for the following variables are internally computed during initialization for a problem. If the input values are too small, the run will terminate with a message indicating the proper size for these variables.

NNZERO   Number of matrix non-zeros when using DMIM.

NSPACE   Work space size when using DMIM.

ILMAX   Maximum number of surface elements on any surface.

ITURKE   In this version of COMMIX-PPC two turbulence models are included. For all of the details of input requirements for these options see the Turbulence Models in **NAMELIST/DATA/**.
    0   Constant Turbulent Viscosity Model (*).
    12   Two-Equation Turbulence Model.

LMPRNT 0   Cell number and surface number arrays are not printed. (*) Specifying **LMPRNT**=1 or **LMPRNT**=2 causes excessive geometry debugging information to be printed and execution to terminate. This information is of little use to the casual user and is not recommended.
    1   Cell number array is printed. Use **LMPRNT**=0.
    2   Cell number and surface number arrays are printed. Use **LMPRNT**=0.

NFORCE   Number of force structures. (0) When **NFORCE** > 0, both the Force Structures section of **NAMELIST/DATA/** and the FORCE STRUCTURE SPECIFICATION CARDS are required.

ISTRUC 0   No thermal structures are used. (*) Do not include Thermal Structure input, or Thermal Structure Location Records in the input.
    1   Thermal structures are used. NAMELIST/F/, /M/, and /T/, and Thermal Structure Location Cards are required in the input.

ISTBUG 0   The storage layout table is not printed. (*)
    1   The storage layout table is printed.
   -1   The input file listing is supressed.

IBSBUG 0   The BOUNDARY SURFACE SUMMARY is not printed. (*)
    1   The BOUNDARY SURFACE SUMMARY is printed, after which execution continues. For a description of the BOUNDARY SURFACE SUMMARY see the section entitled FINDING HOLES IN THE BOUNDARY in the appendix.
    2   The BOUNDARY SURFACE SUMMARY is printed, after which execution terminates.

ITIMER 0   No subroutine timing information is shown (*)
    1   Subroutine timing information summary.
    2   Subroutine timing information is show after every call.

ITUBE 0   By-pass the condenser calculation.
   -1   Condenser calculation via Option A.

1   Condenser calculation via option B. (*)

The following variables are related to the condenser calculation.

ISHELL   The index number in x-, y- or z- direction for separating the shell side and tube side geometrical location. It is used only when ITUBE   (10)

ISHEAR   0   Vapor shear model is not used.
        1   Berman's vapor shear model is used. (*)
        2   Berman and Tumanov's vapor shear model is used.

ISUBC   0   Subcooled model is not used.
        1   Subcooled model by Rohsenow is used. (*)
        2   Subcooled model by Chen is used.

INNUDA   0   Innudation is not considered.
        1   Innudation is considered. (*)

IFOUL   0   Biofouling is not considered.
        1   Biofouling is considered. (*)

A.4.2.1 Restart Option

There are two ways to force the code to write a restart file. The first is to allow the job to "max time". This is done by specifying large values for **NTMAX** and **TIMAX**. The amount of time remaining for the job is checked at the end of each iteration using the Argonne system routine **TLEFT**.

(See the appendix section entitled MACHING DEPENDENT ROUTINES.) If the amount of time remaining is greater than **TREST**, an input parameter in **NAMELIST/DATA/**, another iteration is performed. If not, a restart file is written.

The second way to obtain a restart file is to set **NTMAX** or **TIMAX** to a time step or time which will be reached before the CPU job time expires. A restart file will be written at this time step or time. After a restart file is written, execution terminates.

When restarting from a previous run make sure that **ISTATE** is set to the appropriate value. Also, it is advisable to delete all input for variables that one does not intend to change. In some cases variables will be reset back to their initial values if the input specification remains in the input stream. In short, the minimum input necessary is the correct input for restart cases.

IFRES   0   New case with no restart written. (*)
        1   New case with restart written to unit 10.
        2   Restart of previous run read from unit 9 with no restart written.
        3   Restart of previous run read from unit 9 with restart written to unit 10.

A.4.3 Boundary Surface Identification Records

These records must be present only at the start of stead-state runs (**ISTATE**=0). The purpose of this section is to specify a set of boundary surfaces which completely enclose the computational region and to define any other boundary surfaces inside the computational region. These interior boundary surfaces must completely surround a surface, a cell, or a

group of cells. To completely surround a surface one must specify two boundary surfaces with normals in opposite directions. A single sided boundary surface is not allowed in the interior of the calculational region. Also be sure that all surfaces specified bound calculational cells. Each boundary surface is defined by specifying one or more BOUNDARY SURFACE IDENTIFICATION CARDS, each of which contains the following variables in FORMAT (A4,F10.3,7I4):

> NAME   AREA IB IE JB JE KB KE N

NAME

> REG   The surface is a regular surface.
> Regular surfaces lie on grid planes.
>
> IREG   The surface is an irregular surface.
> Irregular surfaces do not lie on grid planes.

AREA   REGULAR SURFACES

> <0.0   The area of each surface element of cell (i,j,k) is set to the product of its actual geometrical value, either dx(i)*dy(j), dy(j)*dz(k), or dx(i)*dz(k), whichever is appropriate and absolute value of **AREA**.
>
> >0.0   The area of each surface element of cell (i,j,k) is set to **AREA**.

> IRREGULAR SURFACE
>
> <0.0   The absolute value is the slant length. The area of each surface element is set to slant length *DELT, where **DELT** corresponds to DX, DY, or DZ and is determined by the respective zero normal vector component.
>
> >0.0   The area of each surface element of cell (i,j,k) is set to **AREA**.

IB,IE   These six variables are the beginning and ending I-, J-, and K-indices that
JB,JE   define a rectangular solid composed of one or more cells. The rectangular
KB,KE   solid that defines or partially defines a surface is the one adjacent to and on the side pointed to by the surface normal. (Keep in mind that the surface normals **XNORML, YNORML**, and **ZNORML** always point into the computational region.) The intersection of each cell and the surface defines a surface element.

N   The surface number. All surfaces with the same combination of the following three characteristics can be assigned the same surface number:
> 1. Velocity boundary condition,
> 2. Temperature boundary condition,
> 3. Unit normal vector to the surface.

> Note 1. It is possible for two surface elements to lie in the same surface and have either the same or different surface numbers as well as for two surface elements to lie in different surfaces and have the same or different surface numbers.

> Note 2. The order of the BOUNDARY SURFACE IDENTIFICATION RECORDS must be as follows:
> 1. All IREG records (irregular surfaces) must precede all REG records (regular surfaces).
> 2. The surface numbers, N, of all IREG records and REG records must be in the order of increasing value.

> Note 3. When using cylindrical geometry (IGEOM=-1), a surface must be specified at the origin when computational cells are bounded by the origin. When an annular region is being modeled, a surface should not be defined at the origin but rather at the boundary of the first (counting from the center) computational cell. Set **KFLOW(N)=-3** and **KTEMP(N)=400** for surfaces defined at the origin.

> Note 4. When using cylindrical geometry (IGEOM=-1), with 2.0*PI radian geometries, J=1 and J=JMAX are automatically linked, thus, no

surfaces need be defined at Y=0.0 and Y=2.0*PI. the BOUNDARY VALUE INITIALIZATION CARDS.

A.4.4   NAMELIST/DATA/

ALPHA 0.0 Semi-implicit time advancement for both momentum and energy equations.
       1.0 Fully-implicit time advancement for both momentum and energy equations. (*)

IFMOM 0 No momentum calculation.
       1 Momentum calculation is performed. (*)

IFENER 0 No energy calculation.
       1 Energy calculation is performed. (*)

IFMASS 0 No component mass fraction calculation (*)
       1 Component mass fraction calculation is performed.
       2 Component mass equations solved with mass diffusion.

ISKEW   Two finite differencing options for energy equation are available.
       0 Pure Upwind Differencing scheme. (*)
       2 Flow Modulated Skew Upwind Differencing scheme. This option reduces numerical diffusion inaccuracies present in the Pure Upwind Differencing scheme when the predominate flow is not orthogonal to the computational mesh.

The two variables below give the user some control over the frequency that the momentum and energy calculations are performed. The need for this control might arise in cases when one of the two fields (velocity or energy) varies slowly compared to the other. The intent is to be able to perform one of the calculations (momentum or energy) every time step while performing the other only occasionally resulting in a savings of CPU time. Before the user activates these variables it is highly recommended that s/he understand the full implications of this approximation. The following combinations are allowed:

> **ISETMO**=1 and **ISETEN**=N where N is any nonzero integer.

> **ISETMO**=N and **ISETEN**=1 where N is any nonzero integer.

> **ISETMO**=M and **ISETEN**=N where one of the following conditions is satisfied: (1) M < 0 and N divides M or (2) N < 0 and M divides N.

ISETEN N When N is less than zero the energy calculation is turned off ever -Nth timestep.
       N When N is greater than zero the energy calculation is turned on only every Nth timestep. (1)

ISETMO N When N is less than zero the momentum calculation is turned off every -Nth timestep.
       N When N is greater than zero the momentum calculation is turned on only every Nth timestep. (1)

ISTATE 0 Start of steady-state run. Geometry, boundary conditions, and initial conditions are specified from the input stream. Other parameters take default values or zero. (*)
       1 Continuation of a steady-state run. Initial conditions are read from the restart file of a previous run in which steady-state has not yet been achieved. Some parameters may be changed in the input stream.

2 Beginning of a transient run. Initial conditions are read from the restart file of a previous run. It is desirable that this previous run has achieved steady-state although not necessary. Some parameters may be changed in the input stream.

3 Continuation of a transient run. Initial conditions are read from the restart file of a previous beginning-of-transient run or continuation-of-transient run. Limited changes may be made in the input stream.

ITIBUG 0 No convergence information is printed.
        1 Convergence information is printed every iteration.

The defaults for the following three values is 1 when ISTATE=0, and 0 when ISTATE=2. In other cases these variables are ignored.

NEWTS 0 No new thermal structure input is read.
       1 New thermal structure information is read if ISTRUC=1 and ISTATE=0 or ISTATE=2.

NEWFOR 0 No new force structure information is read.
        1 New force structure information is read if NFORCE>0 and ISTATE=0 or ISTATE=2.

A.4.4.1 Debugging Parameters

Several debugging flags exist in the code which are intended primarily for use in the developmental stages. One generally needs the source listing in order to determine exactly what values are printed and under what conditions. The default value of all debugging flags is zero which indicates that no debugging printout is activated.

IDLBUG

IENBUG

IMABUG

ITKBUG

ITLBUG

IXMBUG

IYMBUG

IZMBUG

A.4.4.2 Time and Time Step Related Parameters

DT(1) Time step size for time steps 1 through LASTDT, s. (0.1). This value is used only if IDTIME=0.

DT(2) Time step size for time steps after LASTDT, s. (0.1). This value is used only if IDTIME=0.

IDTIME 0 The time step size is taken from the user specified variable DT.

1	The time step size is computed internally as the product of the largest allowable time increment given the conditions (Courant time step size) and a user specified variable, **RDTIME**. (*)

LASTDT	This variable in combination with **DT** allows the user to change the time step size during a run. The time step size for all time steps through **LASTDT** is taken from **DT**(1). After step number **LASTDT**, the time step size is taken from **DT**(2). (99999) This value is used only if **IDTIME**=0.
NTHCON	Up to ten values to specify the time step numbers to call SUBROUTINE GDCONV to calculate convergence criteria and the allowable time step size. The following are acceptable values of **NTHCON**:
0	No further calls to **GDCONV**.
>0	Time step number for which **GDCONV** is called. After the Nth positive time step number in **NTHCON** has been processed, the N+1th value of **NTHCON** is used to determine subsequent calls to **GDCONV**.
<0	A value of -N indicates that **GDCONV** is to be called every Nth time step. No subsequent values of **NTHCON** are considered. (-1) See **NTPRNT** and **NTPLOT** for examples.

NTMAX	The maximum time step number for this run. Normal termination occurs after completion of this time step. (99999)

RDTIME	The time step size is computed internally as the product of the largest allowable time increment given the conditions and the variable, **RDTIME**. (0.8) This value is used only if **IDTIME**=1.

TIMAX	The maximum time of this run. Normal termination occurs after this time has been reached, s. (3.6E+7) **TIMAX** refers to the simulation or problem time and not the computer CPU time needed to run the problem.

TREST	The amount of time remaining for the job is checked at the end of each iteration. If the amount of time remaining is greater than **TREST** another iteration is performed. If not, the restart file is written. When running long jobs or jobs requiring several seconds per iteration, one might wish to choose a larger more conservative value of **TREST**, s. (20.0)

This implementation depends on the Argonne system routine **TLEFT** which returns the time left until the total job time as specified on the JOB card has elapsed.

Note.	In Sun work station, COMMIX-PPC calls the SUN FORTRAN Library Routine **DTIME** to obtain the elapsed frun time in seconds for the calling process. When at the end of an iteration this elapsed time exceeds **TREST**, the calling process is terminated after optionally writing restart file. (3600.0)

TSTART	Initial time, s. (0.0) This value should be reset to zero at the beginning of a transient run, **ISTATE**=2.

A.4.4.3   Iteration Control Parameters

The general definitions and default values of control parameters are given in this section. For a diagram showing the loop to which each variable relates, see the CONTROL PARAMETERS AT A GLANCE section in the appendix.

EPS1	Convergence criterion parameter. (1.0E-4)
EPS2	Convergence criterion parameter. (1.0E-6)

EPS3	Convergence criterion parameter. (5.0E-5)
EPS5	Convergence criterion parameter. (1.0E-5)
IT(1)	Number of iterations for time steps 1 through **LASTIT**. (10)
IT(2)	Number of iterations for time steps after **LASTIT**. (10)
ITMAXE	Number of iterations in the energy iteration loop. (99)
ITMAXP	Number of iterations in the pressure iteration loop. (99)
LASTIT	This variable in combination with **IT** allows the user to change the number of iterations per time step during a run. The number of iterations for all time steps through **LASTIT** is taken from **IT**(1). After step number **LASTIT**, the number of iterations is taken from **IT**(2). (99999)
OMEGA	Relaxation factor for pressure solution. (1.5)
OMEGAE	Under-relaxation factor for the energy equation coefficients. (0.8)
OMEGAR	Under-relaxation factor for the density. (1.0)
OMEGAV	Under-relaxation factor for the momentum equation coefficients. (0.8)
OMEGAX	Under-relaxation factor for the component continuity equation coefficients. (0.8)
RELAXE	Relaxation factor for ethe SOR energy solver. (0.95)
VCONV	Velocity used for convergence testing. (1.0e-3 m/s). For additional information, see the STEADY-STATE DEFINITION in Appendix.
DECONV	Enthalpy used for convergence testing. (1.0e3 J/kg). For additional information, see the STEADY-STATE DEFINITION in Appendix.

A.4.4.4 Boundary Condition Types

All external surfaces must have a velocity boundary condition type and a temperature or heat flux boundary condition type. Internal surfaces may also be assigned boundary condition types.

KFLOW(N)	Type of velocity boundary condition. (The default for all **NSURF** surfaces is 1)
-5	Continuative mass flow outlet.
-4	Uniform velocity outlet.
-3	Free slip boundary.
-2	Continuative velocity outlet.
-1	Continuative momentum outlet.
0	Solid Wall
1	Constant velocity boundary with normal velocity set from **VELOC(N)** or explicitly specified by the BOUNDARY VALUE INITIALIZATION CARDS. The tangential component is in effect zero. (*)
2	Constant mass flow. **FLOW = RLB * VELBN * AREA** specified by the BOUNDARY VALUE INITIALIZATION RECORDS.
100+NF	Uniform transient velocity boundary with normal velocity set from the product of the **NF**th transient function and **VELOC(N)**.
200+NF	Transient mass flow boundary with normal velocity set uniformly from **VELOC(N)**/SUM(RLB*AREA).

KPRES(N) Type of pressure boundary condition. Pressure boundary conditions are applied to the cells adjacent and interior to the boundary surface specified. (The default for all **NSURF** surfaces is 0)

    0 No pressure boundary condition is applied. (*)

    1 Uniform constant pressure boundary with pressure set from **PRES(N)**.

100+NF Uniform transient pressure boundary with pressure set from the product of the NFth transient function and **PRES(N)**.

KTEMP(N) Type of temperature or heat flux boundary condition. (The default for all **NSURF** surfaces is 1)

    1 Specified constant temperature boundary with temperature set from **TEMP(N)** or the BOUNDARY VALUE INITIALIZATION CARDS. (*) The surface heat flux is nominally computed considering the fluid conduction but not the presence of a wall. If one wishes to account for both the fluid convection and a wall conduction, the following four variables from the Wall Model section below must be specified: **IHTWAL(N), WALLDX(N)**, and **MATWAL(N)**.

100+NF Uniform transient temperature boundary with temperature set from the product of the NFth transient function and **TEMP(N)**. The surface heat flux is computed with the options as specified above for **KTEMP(N)=1**.

  200 Specified constant heat flux boundary with normal heat flux set from **TEMP(N)** or the BOUNDARY VALUE INITIALIZATION CARDS.

300+NF Uniform transient heat flux boundary with normal heat flux set from the product of the NFth transient function and **TEMP(N)**.

  400 Adiabatic or zero diffusive heat flux boundary.

KMASS(N) Type of mass fraction boundary condition. Each value of **KMASS** has an integer value of the form 'TSSCFF' which is coded according to the following rules:

  T 0 Continuative mass fraction outlet.

    1 Fixed specified mass frction.

    2 Fixed specified volume fraction.

    3 Transient mass fraction.

    4 Transient volume fraction.

  SS Surface number.

A.4.4.5 Wall Model

When specifying either a constant temperature boundary condition or a uniform transient temperature boundary condition (**KTEMP(N)=1** or **KTEMP(N)=100+NF**) a wall may be modeled by defining the following three variables.

WALLDX(N) Wall thickness, m. (1.0)

MATWAL(N) Material type for surface N. The value of this variable is used as the index NM in the Material Properties section below. (1)

IHTWAL(N) Heat-transfer coefficient number for the calculation of heat-transfer between coolant and wall. The value of this variable is used as the index NH in the Heat Transfer coefficient structure. (0)

        Note. If the default value is taken, then the coolant to wall heat-transfer coefficient, if used, is evaluated simply as the fluid conductivity divided by the fluid conduction length.

A.4.4.6 Uniform Boundary Initialization

The following three variables allow easy specification of uniform velocity, temperature or heat flux, and pressure values at boundaries. Nonuniform distributions can be specified by using the SURFACE ELEMENT INITIALIZATION RECORDS.

VELOC(N) Initial velocity at surface N in the direction indicated by **XNORML(N)**, **YNORML(N)**, and **ZNORML(N)**, m/s. (0.0)

TEMP(N) Initial temperature for surface N, C. (0.0). For a constant or transient heat flux boundary, **TEMP(N)** contains the heat flux, W/m**2. (0.0)

PRES(N) Initial pressure for surface N, Pa. (0.0)

A.4.4.7 Uniform Cell Initialization

The following variables allow easy specification of uniform cell temperature and pressure. Nonuniform distributions can be specified by using the CELL INITIALIZATION RECORDS.

TEMP0 Initial temperature of all internal cells, C. (0.0)

PRES0 Initial pressure at the pressure reference point located at (**XPRES0**, **YPRES0**, **ZPRES0**), Pa. (1.01353E+5). The default pressure initializaion computes the static head using the density based on component 1 properties evaluated at **TEMP0, PRES0**. The inital static head pressure at any point is computed with respect to the pressure reference point.

XPRES0 X-coordinate of the pressure reference point, m. (0.0)

YPRES0 Y-coordinate of the pressure reference point, m. (0.0)

ZPRES0 Z-coordinate of the pressure reference point, m. (0.0)

GRAVX X-component of gravity vector, m/s**2. (0.0)

GRAVY Y-component of gravity vector, m/s**2. (0.0)

GRAVZ Z-component of gravity vector, m/s**2. (0.0)

XMASS(N) Initial mass fraction for surface N.

A.4.4.8 Fluid-Structure Heat Transfer

Fluid-Structure heat transfer (q) is computed as follows:

$$q = A * h * (Ts - Tf)$$

where

A is the area,

h is the heat transfer coefficient,

Ts is the temperature of structure, and

Tf is the temperature of the fluid.

Heat transfer coefficient index, **NH**, which is specified by the input variables **IHTWAL(N)** in the WALL Model section and **IHT** in the Thermal Structure Fluid Namelist/F/, is defined by three input parameters:

IHTCOR(NH) Heat transfer coefficient correlation number.

HTCLEN(NH) Characteristic length.

HTCMUL(NH) heat transfer coefficient multiplier.

When the correlation number, **IHTCOR(NH)**, is in the range (1-10), then the heat transfer coefficient, h, is defined as follows:

$$h = \text{HTCMUL(NH)} * \text{Nu} * k / \text{HTCLEN(NH)} \tag{A}$$

where

$$\text{Nu} = \text{HEATC1(ic)} + \text{HEATC2(ic)} * \text{Re}^{**\text{HEATC3(ic)}} * \text{Pr}^{**\text{HEATC4(ic)}}$$

Re = the Reynolds number.

Pr = the Prandtl number.

ic = IHTCOR(NH)

HEATC1(ic) is Nusselt number coefficient.

Since the Nusselt number, Nu, must always be positive, **HEATC1(NH)** should be positive to accomodate a zero flow situation. (5.0)

HEATC2(ic) Nusselt number coefficient. (4.02E-4)

HEATC3(ic) Nusselt number coefficient. (0.8)

HEATC4(ic) Nusselt number coefficient. (0.0), and

k is the fluid conductivity.

When the correlation number, **IHTCOR(NH)**, is in the range (11-20), then the heat transfer coefficient, h, is defined as follows:

$$h = \text{HTCMUL(NH)} * \{\text{HEATC1(ic)} + \text{HEATC2(ic)} * \text{Re}^{**\text{HEATC3(ic)}}$$

$$*\text{Pr}^{**\text{HEATC4(ic)}}\} \tag{B}$$

where

ic=**IHTCOR(NH)**-10.

When Heat transfer correlation number, **IHTCOR(NH)**, is in the range (21-50), then it is referred to the condenser shell-side and tube-side heat transfer correlation. Details may be described as follows.

1. **IHTCOR(NH)=21-30** For shell-side heat transfer correlations. When **IHTCOR(NH)=21**, correlations by Nusselt's condensation on horizontal tubes and the effect due to non-condensable gas by Berman and Fuks are used.

2. **IHTCOR(NH)=31-40** For tube-side heat transfer correlations. The heat transfer coefficient, h, is calculated according to equation (A) with **ic=IHTCOR(NH)-30**.

When biofouling in inner tube wall is considered, the following variable must be specified in NAMELIST/DATA/.

      FOUL   Fouling resistance, m**2-K/kw. (1.0e-30)

A.4.4.9 Material Properties

Material Properties are needed when modeling the fluid in the computational cells **(MATYPE(K))** and optionally walls **(MATWAL(N))**. The values of **MATYPE(K)** and **MATWAL(N)** may be any integer from 1 to 22. When the value is in the range of 1 to 20, the material properties are computed from the fast running simplified straight-line approximations to the state equations. When the value is in the range of 21 to 22, the material propertites are computed from the rigorous equation-of-state subroutines.

MATYPE(K) Simplified material properties for compoment or material K (For value from 1 to 20).

Conductivity in W/(m-C):

      COND=C0K(MA)+C1K(MA)*TC+C2K(MA)*TC**2

Density in kg/m**3:

      DENSE=C0RO(MA)+C1RO(MA)*TC+C2RO(MA)*PA/TK

Enthalpy in J/kg:

      ENTH = C0H(MA) + C1H(MA)*TC + C2H(MA)*TC**2 + C3H(MA)*PA

Saturation pressure in Pa:

      PSAT=EXP(C0P(MA)+TC*C1P(MA)+TC*TC*C2P(MA))

Viscosity in Pa*s:

      VISC=C0MU(MA)+C1MU(MA)*TC+C2MU(MA)/TK

Molecular weight of material :

      MOLWT=WTMOL(MA)

Binary molecular diffusivity [m*m/s]:

      DIFFIM=(C0D(MA)+C1D(MA)/PA)*TK**C2D(MA)

Note. When COD(MA) < 0.0 and C1D(MA) < 0.0, DIFFIM is evaluated from the formula developed by Slattery and Bird.

where

TC is the temperature in degrees C,

TK is the temperature in degrees K,

PA is the pressure in Pascals, and

H is the enthalpy in J/kg.

DIFMUL The multiplier for the binary molecular diffusivity.

MATYPE(K) CODED VALUE OF MATERIAL TYPE FOR COMPONENT K. (For value from 21 to 22)

The following values of **MATYPE** are associated with rigorous equation-of-state subroutines. This list may be expanded with little difficulty by users having more accurate equation-of-state subroutines for their materials.

    21   Water liquid

    22   Water vapor

Note: In condenser application, **MATYPE(1)** and **MATYPE(2)** are reserved for steam and air respectively.

MATTAB(NM)
TABLOT(NM)
TABHIT(NM)

To allow the user to spot check property values, a small table is printed for each of the material types listed in the variable **MATTAB** with five temperature values ranging from the corresponding entries in **TABLOT** to **TABHIT** at a pressure of **PRESO**. For example, one could obtain a table of property values computed from the coefficients COK(1), C1K(1), C2K(1), CORO(1), C1RO(1), C2RO(1), COH(1), . . . etc., over a temperature range from 500.0 to 900.0 degrees C and a table of water liquid property values over the range from 20.0 to 90.0 degrees C by including the following input in NAMELIST/DATA/:

        MATTAB=1,21,

        TABLOT=500.0,20.0,

        TABHIT=900.0,90.0,

The default values for the above three variables are zero thus no property tables are printed unless these values are specified.

A.4.4.10   Transient Functions

All transient driving functions are input into the following three variables. They must be input at the beginning of the transient (**ISTATE**=2) even if they have been input previously. Each function is defined by a user specified set of points. Cubic spline fit coefficients are then generated in SUBROUTINE FITIT. Fifty equally spaced values are printed to allow the user to check the adequacy of the input distribution. Ten to fifteen values with points concentrated at rapidly changing Y-values should be adequate. Currently the total number of points allowed for the specification of transient functions is one hundred.

TVAL(NP) The independent variable, usually time, for the transient functions.

FVAL(NP) The dependent variable for the transient functions. The first value of the second function immediately follows the last value of the first function. The same pattern must be followed for all subsequent functions. Make sure that the entire range of the function used lies within the range input as the fitting routine does not extrapolate. Discontinuities are indicated by specifying the same X-coordinate twice with the same or different Y-coordinate values.

NEND(NF) The number of points in the NFth transient function

NTOTS In order to simplify thermal structure input in certain cases, the heat source transient function numbers can be overridden in NAMELIST/DATA/. These values are input into the variable NTOTS in the order in which the thermal structure prototypes were defined. Any values specified in NTOTS will override all other input and previous values. If no values of NTOTS are defined, no changes to the heat source transient function numbers are made.

NOFQT Number of the transient function which is used as a multiplier of the heat source for the coolant when thermal structures are present and as a multiplier of total heat source when no thermal structures are present. (0)

A.4.4.11 Plot Tape Option

NTPLOT Up to 25 values to specify when plotting information is to be written to unit 76. The following are acceptable values of NTPLOT:

  0 No more plotting information is written to unit 76. (*)

  >0 Time step number for which plotting information is written to unit 76. After the Nth positive time step in NTPLOT has been processed, the N+1th value of NTPLOT is used to determine subsequent writes to the plot file.

  <0 A value -N indicates that information is written to unit 76 every Nth time step. No subsequent values of NTPLOT are considered.

Example. NTPLOT=-5 indicates that every 5th step is to be processed. NTPLOT=5,10,-20 indicates that steps 5, 10, 20, 40, 60, etc., are to be processed. NTPLOT=10,20,0 indicates that only steps 10 and 20 are to be processed.

A.4.4.12 Printing Option

Calls to SUBROUTINE OUTPUT are controlled by the two variables, NTPRNT and TPRNT. They can be used individually or together. The information printed at each call to SUBROUTINE OUTPUT is determined by the variables ISTPR and NTHPR described below.

NTPRNT Up to 50 time step numbers at which SUBROUTINE OUTPUT is to be called. The following are acceptable values for NTPRNT:

  0 No more calls to SUBROUTINE OUTPUT. When restarting, previous specification of NTPRNT values may be overridden by specifying the desired new values followed by a zero in NTPRNT.

  >0 Time step number for which SUBROUTINE OUTPUT is to be called. After the Nth positive time step in NTPRNT has been processed the N+1th value of NTPRNT is used to determine subsequent calls to OUTPUT.

  <0 A value -N indicates that SUBROUTINE OUTPUT is called every Nth time step. No subsequent values of NTPRNT are considered. -9999..SUBROUTINE OUTPUT is called just before the run is terminated. (*)

Example. NTPRNT=0 indicates that after initialization, SUBROUTINE OUTPUT is never called. NTPRNT=5,10,-9999 indicates that SUBROUTINE OUTPUT is called at steps 5, 10, and just before termination.

TPRNT		Up to 50 times (problem time in seconds) at which SUBROUTINE OUTPUT is to be called. The following are acceptable values of TPRNT:
	0.0	No more call to SUBROUTINE OUTPUT. (*) When restarting, previous specification of TPRNT values may be overridden by specifying the desired new values followed by a zero in TPRNT.
	>0.0	Times at or after which SUBROUTINE OUTPUT is to be called. When or after the Nth positive time in TPRNT has been processed, the N+1th value of TPRNT is used to determine subsequent calls to OUTPUT.
	<0.0	A value of -T indicates that SUBROUTINE OUTPUT is to be called at T-second intervals. If the Nth value is negative, then the N+1th value stores the next time value at which OUTPUT is to be called. This is nominally set to zero but can be specified by the user. No subsequent values of TPRNT are considered.

Example. TPRNT=1.0,5.0,-10.0 indicates that OUTPUT is to be called at or after times 1.0, 5.0, 10.0, 20.0, . . etc.. TPRNT=-5.0,10.0 indicates that OUTPUT is to be calleu at times 10.0,15.0,20.0,. . . etc..

ISTPR		Up to fifty coded values which specify the arrays to be printed in the first call to SUBROUTINE OUTPUT. (0)

NTHPR		Up to fifty coded values which specify the arrays to be printed in all calls after the first call to OUTPUT. For internal arrays, each value of ISTPR and NTHPR is a signed seven digit integer of the form 'SCVVPLLL' which is coded according to the following rules:

C		Fluid component or phase number. (1)

S	+	Only the plane specified by 'PLLL' is printed. (*) A plus sign is assumed and need not be specified.
	-	All planes between the values of 'LLL' on the current and following values of ISTPR or NTHPR are printed.

VV	01	PSTATO	U-component of velocity,[m/s].
	02	VL	V-component of velocity,[m/s].
	03	WL	W-component of velocity,[m/s].
	04	HL	Enthalpy,[J/kg].
	05	TL	Temperature,[deg. C].
	06	AL	Volume porosity.
	07	RL	Density,[kg/s].
	08	P	Static Pressure,[Pa].
	09	DL	Residual mass,[kg].
	10	ALX	X-direction surface permeability.
	11	ALY	Y-direction surface permeability.
	12	ALZ	Z-direction surface permeability.
	13	RLOLD	Density at previous time step,[kg/m**3].
	14	TK	Turbulent kinetic energy,[J/kg].
	15	QSOUR	Volumetric heat source,[W/m**3].
	16	P-POLD	Pressure change from last time step,[Pa].
	17	P-PSTATO	Pressure minus static pressure,[Pa].
	18	THL	VOLUME fraction.
	19	P-PRES0	Pressure minus initial pressure,[Pa].
	20	TURCON	Turbulent conductivity,[W/m/C].
	21	TURVIS	Trubulent viscosity,[Pa-s].
	22	THLOLD	Volume fraction from previous time step.
	23	ULOLD	U-component of velocity at previous step,[m/s].
	24	VLOLD	V-component of velocity at previous step,[m/s].
	25	WLOLD	W-component of velocity at previous step,[m/s].
	26	HOLD	Enthalpy at previous step,[J/kg].
	27	POLD	Static pressure at previous step,[Pa].

28	XMS	Mass fraction.
29	VFLUID	Fluid cell volume,[m**3].
30	AFLUX	X-direction cell face area,[m**2].
31	AFLUY	Y-direction cell face area,[m**2].
32	AFLUZ	Z-direction cell face area,[m**2].
33	XMSOLD	Mass fraction at previous step.
37	TD	Dissipation of turbulent kinetic energy.[W/kg].
38	RTH	Density * Volume Fraction,[kg/m**3].
39	RTHOLD	Value of RTH at previous time step,[kg/m**3].
40	IFORCE	Coded entries of force strucures
41	DRDP	d(density)/d(pressure),[(kg/m**3)/Pa].
42	DRDH	d(density)/d(enthalpy),[(kg/m**3)/(J/kg)].
43	FLOWX	Mass flow across x-face,[kg/s].
44	FLOWY	Mass flow across y-face,[kg/s].
45	FLOWZ	Mass flow across z-face,[kg/s].
46	EKE	kinetic energy,[J/kg].
47	EKEOLD	kinetic energy at previous time step,[J/kg].
48		x-direction mass flux,[kg/m**2/s].
49		y-direction mass flux,[kg/m**2/s].
50		z-direction mass flux,[kg/m**2/s].
51	SMDOT	volumetric mass source,[kg/m**3/s].
52	DIFFU	molecular diffusivity,[m**2/s].
53	DIFFUT	turbulent diffusivity, [m**2/s].

P	1	An I-plane is printed.
	2	A J-plane is printed.
	3	A K-plane is printed.

LLL	Specific plane to be printed. If S is +, only one plane is indicated. If S is -, the 'LLL' values in the current and next values of ISTPR or NTHPR indicate the range of planes to be printed.

For thermal structure information, each value of ISTPR and NTHPR is a signed seven digit integer of the form 'SC8NNNNN' which is coded according to the following rules:

C		Fluid component or phase number. Values of 0 thru 9 correspond to components 1 thru 10. (0)
S	+	Only structure number 'NNNN' is printed. (*) A plus sign is assumed and need not be specified.
	-	All structure between the values of 'NNNN' in the current and following values of ISTPR and NTHPR are printed.
NNNNN		Specific structure to be printed. If S is '+', only one structure is indicated. If S is '-', the 'NNNNN' values in the current and next values of ISTPR or NTHPR indicate the range of surfaces to be printed.

For surface arrays, each value of ISTPR and NTHPR is a signed seven digit integer of the form 'SC9VVLLL' which is coded according to the following rules:

C		Fluid component or phase number. (1)
S	+	Only the surface number 'LLL' is printed. (*) A plus sign is assumed and need not be specified.
	-	All surfaces between the values of 'LLL' in the current and following values of ISTPR or NTHPR are printed.

VV	01	VELBN	Normal surface velocity,[m/s].
	02	QBN	Normal surface heat flux,[W/m**2].
	03	MB	Adjacent internal cell number.
	04	HLB	Surface enthalpy,[J/kg].
	05	TLB	Surface temperature,[deg. C].
	06	AREA	Surface element area,[m**2].
	07	RLB	Surface density,[kg/m**3].
	08	PB	Surface pressure,[Pa].

09	IJK	Adjacent internal cell indices. Each value is of the form 'IIJJKK' where II is the I index, JJ is the J index, and KK is the K index.
10	QBN/(TLB-TL)	Overall heat transfer coefficient from coolant to wall as used in duct wall model,[W/m**2/C].
11	XHSB	Boundary mass fraction.
12	FLOWB	Mass flow rate at boundary,[kg/s].
13	THLB	Volume Fraction at boundary.
14	RTHB	Density * Volume Fraction,[kg/m**3].
15	TKB	Turbulent kinetic energy,[J/kg].
16	TDB	Dissipation of Turbulent kinetic energy,[W/kg].

LLL   Specific surface to be printed. If S is +, only one surface is indicated. If S is -, the 'LLL' values in the current and next values of ISTPR or NTHPR indicate the range of surfaces to be printed.

Example. ISTPR=06105,-10301,-10305, NTHPR=01105,-02301,-02305,90101,-90501,-90505, indicates that the first call to OUTPUT will print the I=5 plane of volume porosity and K-planes 1 through 5 of the X-direction surface permeability. On all subsequent calls, to OUTPUT, the I=5 plane of the U component of velocity, K-planes 1 through 5 of the V component of velocity, the boundary velocity for surface 1, and surface temperature for surfaces 1 through 5.

NCOLUM   The number of columns to be written in the tabular output. Valid values for NCOLUM are 8, 9, 10, and 11. The formats used are 1PE13.6, 1PE11.4, 1PE10.3, and 1PE9.2 respectively. (10)

IJKRC   A three digit binary number which determines the row-column orientation of tabular output. The following table gives the acceptable values. (101)

	I-plane Indices		J-plane Indices		K-plane Indices	
	Row	Column	Row	Column	Row	Column
000	J	K	K	I	I	J
001	J	K	K	I	J	I
010	J	K	I	K	I	J
011	J	K	I	K	J	I
100	K	J	K	I	I	J
101	K	J	K		J	I
110	K	J	I	K	I	J
111	K	J	I	K	_ J	I

A.4.4.13   Force Structures

The force structure is a mechanism whereby a drag or resistance force in Pa/m can be applied to a fluid flow across a cell face between two calculational cells. The location of each force structure, NF, is specified in the FORCE STRUCTURE SPECIFICATION CARDS. The generic force structure applies a resistance of one of the following forms:

```
DPDX=-FORCEF(NF)*RL*ABS(UL)*UL*FCORR/CLENTH(NF)

DPDY=-FORCEF(NF)*RL*ABS(VL)*VL*FCORR/CLENTH(NF)

DPDZ=-FORCEF(NF)*RL*ABS(WL)*WL*FCORR/CLENTH(NF)
```

where   FCORR=ACORRL(NC)*RE**BCORRL(NC)+CCORRL(NC)

when   RE < REYTRN(NC),

and   FCORR=ACORRT(NC)*RE**BCORRT(NC)+CCORRT(NC)

when   RE >= REYTRN(NC),

and   RE=RL*SQRT(UL**2+VL**2+WL**2)*REYLEN(NF)/VIS,

and   **RL** is the local density,

       UL, VL, and **WL** are local velocities,

       VIS is the local viscosity, and

       NC is the correlation index, **ICORR(NF)**.

FORCEF(NF)   Force coefficient for force structure **NF**.

REYLEN(NF)   Length used to compute the Reynolds number for force structure **NF**, m.

CLENTH(NF)>0.0   The value input is used as the characteristic length in the above equation.

           <0.0   A characteristic length computed from either DX, DY, or DZ, whichever is appropriate, is used for **CLENTH(NF)** in the above equation.

ICORR(NF)   The correlation index of force structure **NF**. For the generic force structures the values of **ICORR** must be less than 21. These values are used as indices of the user specified correlation variables below.

                          Note. For the valve model **ICORR** is set by 100 * (the valve # NV) + **ICORR**.

NCORR   The number of correlation types available for force structures. This value must equal or exceed the maximum value specified in **ICORR** but be less than 21.

REYTRN(NC)   The transition Reynolds number. Correlation coefficients when the
ACORRL(NC)   Reynolds number above, RE, is in the laminar regime,
BCORRL(NC)   i.e., when **RE** < **REYTRN(NC)**. Correlation coefficients when the Reynolds
CCORRL(NC)   number above, **RE**, is in the turbulent regime, i.e., when **RE** >=
ACORRT(NC)   **REYTRN(NC)**.
BCORRT(NC)
CCORRT(NC)

A pressure relief valve can be modeled by specifying a force structure with a correlation index of the form 'VVCC' where 'VV' is the valve number, NV, ranging from 1 to 19, and 'CC' is the correlation index. Each valve, NV, has associated with it the following variables:

IVALVE(NV)   The state of valve NV. A value of 1 indicates that the valve is open and a value of 0 indicates that the valve is closed. (0)

DPOPEN(NV)   The pressure gradient between two cells at which a closed valve opens, Pa. (1.0E+20)

DPCLOS(NV)   The pressure gradient between two cells at which an open valve closes, Pa. (-1.0E+20)

                 Note. The pressure gradient between two cells is computed as P(I,J,K)-P(I+1,J,K) for x-direction valves, P(I,J,K)-P(I,J+1,K) for y-direction valves, and P(I,J,K)-P(I,J,K+1) for z-direction valves.

When a valve is closed a very high resistance is applied across the cell face. When a valve is open a resistance can be applied in one of two ways. By specifying a correlation index IC in the range of 1 through 20, a generic force structure as defined above can be applied. When choosing this option the user can specify **REYLEN(NF)**=1.0, **CLENTH(NF)**= **ALPHA**, the local volume porosity, **REYTRN(IC)**=1.0E+10, **ACORRL(IC)**=1/VIS, where VIS is the local viscosity, **BCORRL(IC)**=-1.0, and **CCORRL(IC)**=0.0, the resistance is then given by -**FORCEF(NF)** *WL, where **WL** is the local velocity. Alternatively, one can specify a force

correlation of 70 and the valve velocity will be automatically computed according to the valve velocity model.

Several other specific structures can be modeled by including a force structure with a correlation index listed below.

ICORR(NF) 50 dP/dx proportional to velocity (U).
60 dP/dx proportional to mass flux (RO*U).
61 Specified mass flux. RO*U = **FORCEF(NF)**.
90 CRBR fuel assembly
91 CRBR blanket assembly
92 DRHX (Direct Reactor Heat Exchanger)
93 CRBR chimney assembly
94 FFTF pin bundles
95 CRBR control assembly
96 Axial flow through vertical rod bundles.

FORCEF(NF) Force coefficient multiplying the resistance computed for the specific structure.

REYLEN(NF) When modeling axial flow through vertical rods, correlation index 96, this value defines the length used to compute the Reynolds number.

A precise description of the resistance being modeled can be found in the source code for SUBROUTINE FORCES or in the doccument entitled "Some Resistance Correlations for COMMIX Users" by Sha and Shah, ATHRP-13, (April 1983).

A.4.4.14 Turbulence Modeling

In all of the following turbulence models an effective viscosity is used in the diffusion term of the momentum equation. This effective viscosity is the sum of the turbulent viscosity and the the molecular viscosity. Similarly an effective thermal conductivity is used in the diffusion term of the energy equation which is likewise the sum of the turbulent thermal conductivity and the molecular thermal conductivity.

A.4.4.14.1 Constant Turbulent Diffusivity Model

The turbulent viscosity and turbulent conductivity are assumed constant everywhere.

ITURKE 0 Turbulent kinetic energy flag must be zero. (*) The variable **ITURKE** must be input in NAMELIST/GEOM/.

TURBV Turbulent viscosity, Pa-s. (0.0) This must be set to some non-negative value.

TURBC Turbulent conductivity, W/(m-C). (0.0)

A.4.4.14.2 Two-Equation Turbulence Model

This is the most rigorous turbulence model for practical engineering problems. Both the equation for turbulent kinetic energy (TK) and the equation for dissipation of turbulent kinetic energy (TD) are solved. Wall function corrections are applied to cells adjacent to solid walls for both the turbulent kinetic energy equation and momentum equations. The turbulent viscosity is computed using the following equation:

TURVIS=CDTURB*RO*TK**2/TD

where   **CDTURB** is the coefficient for computation of shear stress near the wall,

RO is the local density,

TK is the local turbulent kinetic energy, and

TD is the dissipation of turbulent kinetic energy.

Note: Values are initialized only when **ISTATE**=0 or **ISTATE**=2.

For this option the following input must be specified:

ITURKE 12   Turbulent kinetic energy flag must be 12. The variable **ITURKE** must be input in NAMELIST/GEOM/.

AKAPPA   Wall constant. (0.42)

CDTURB   Coefficient for computation of shear stress near the wall. (0.09)

CT1   Empirical constant used in the equation to compute turbulent kinetic energy. (1.44)

CT2   Empirical constant used in the equation to compute the dissipation of turbulent kinetic energy. (1.92)

EE   Wall constant. (9.0)

EPS6   Convergence criterion parameter for turbulent kinetic energy equation. (1.0E-5)

ITMAXK   Maximum number of iterations for turbulent kinetic energy equations. (29)

OMEGAD   Relaxation factor for equation to compute dissipation of turbulent kinetic energy. (0.7)

OMEGAK   Relaxation factor for equation to compute the turbulent kinetic energy. (0.7)

OMEGAT   Relaxation factor for turbulent viscosity. (0.7)

PRNDLD   Turbulence Prandtl number for dissipation of turbulent kinetic energy. (1.3)

PRNDLH   Turbulence Prandtl number for thermal energy transfer. (0.9)

PRNDLK   Turbulence Prandtl number for turbulent kinetic energy (1.0)

RELAXK   Relaxation factor for turbulent kinetic energy solution (0.8).

TDMIN   The smallest value allowed for turbulence dissipation. All values of turbulence dissipation computed to be less than **TDMIN** will be set to **TDMIN**. (1.0e-10)

TKMIN   The smallest value allowed for turbulence kinetic energy. All values of turbulence kinetic energy computed to be less than **TKMIN** will be set to **TKMIN**. (1.0e-16)

A.4.5 Force Structure Specification Records

These records must be included only when **NFORCE>0** and **NEWFOR=1** in NAMELIST /GEOM/. These records are used to locate the force structures described in the Force Structure section of NAMELIST/DATA/. These forces can be applied at cell faces between two computational cells. The locations therefore correspond to portion of grid planes. Each card in this section contains the following variables in the FORMAT (A4,7I4).

        NAME N IB IE JB JE KB KE

NAME   XFOR   X-direction force.
       YFOR   Y-direction force.
       ZFOR   Z-direction force.

N   Force structure number.

IB,IE   These six variables are the beginning and ending I-, J-, and K-indices used to
JB,JE   define a plane of cells. The cell face defined by cell (I,J,K) for an X-direction
KB,KE   force is that one between cells (I,J,K) and (I+1,J,K). For a Y-direction force,
                it is the one between cells (I,J,K) and (I,J+1,K), and for a Z-direction force,
                it is the one between cells (I,J,K) and (I,J,K+1).

A.4.6 Thermal Structure Records

This set of records is included if and only if **ISTRUC=1** and **NEWTS=1** in NAMELIST/GEOM/.

A thermal structure is a collection of thermal structure elements each of which has the same characteristics as specified by a thermal structure prototype. Thermal structure prototypes are defined using **TYPE**, **FLUID**, and **MATERIAL** namelists with the names T, F, and M respectively. The order in which these namelists are input indicates the the construction of the thermal structures and must conform to the following rules:

1. A TYPE namelist must begin the definition of each thermal structure prototype.

2. If fluid interacts with surface one, a **FLUID** namelist must be present after the **TYPE** namelist (before the first **MATERIAL** namelist). If, in addition, fluid interacts with surface two, a **FLUID** namelist must also be present after the last **MATERIAL** namelist.

3. A gap exists after each material except the last. The gap parameters are specified in the **MATERIAL** namelist.

4. The initial default for all namelist variables is zero. Subsequent defaults are the values in effect after reading the previous namelist. If, for example, the geometrical type is the same for all thermal structure prototypes, **IXYZ** need be specified only on the first **TYPE** namelist.

5. The definition of thermal structure prototype N+1 must follow the definition of thermal structure prototype N.

6. Blank cards or cards with blanks in columns 1 through 4 may be interspersed as desired.

The precise definition of each card is as follows:

A.4.6.1 TYPE NAMELIST/T/

N	Thermal structure prototype number. This number does not need to correspond to its index or ordinal number.

IXYZ   Geometrical type or characteristic.

1	Rods (cylinders) with axis aligned in the I-direction.
2	Rods (cylinders) with axis aligned in the J-direction.
3	Rods (cylinders) with axis aligned in the K-direction.
11	Slab with the normal aligned in the I-direction.
12	Slab with the normal aligned in the J-direction.
13	Slab with the normal aligned in the K-direction.
101	Sphere aligned in the I-direction.
102	Sphere aligned in the J-direction.
103	Sphere aligned in the K-direction. The alignment specification is included in the spherical option to allow the normalized axial power

NT	The number of the transient function to be used as a multiplier for the heat source.

RODFR   Rods or cylindrical thermal structures:

>0	Number or fraction of actual rods interacting with each associated coolant cell.
<0	The absolute value is the number or fraction of rods per unit area (m**2) interacting with each associated coolant cell.

Slab thermal structures:

>0	Slab area in each associated coolant cell, m**2.
<0	The absolute value is the slab area divided by the cell area. In the case of two sided thermal structures this value is equivalent to a solid permeability for the structure.

Spherical thermal structures:

>0	Number or fraction of spheres interacting with each associated coolant cell.
<0	The absolute value is the number or fraction of spheres per unit volume (m**3) interacting with each associated coolant cell.

OUTR	Thermal structure outer radius, m. This is not used for slab type thermal structures.

A.4.6.2 Fluid NAMELIST/F/

IHT	Heat transfer correlation index. This value is used as the index, **NH**, of the variables **HEATC1, HEATC2, HEATC3,** and **HEAT4** described in the Fluid-Structure Heat Transfer section of NAMELIST/DATA/.
HYD	Hydraulic diameter or reference length. this value is used as D, the reference length, as described in the Fluid-Structure Heat Transfer Section of NAMELIST/DATA/.

A.4.6.3 Material NAMELIST/M/

MI	Material type index. This value is used as the index NM described in the Material Properties (Solids) Section of NAMELIST/DATA/.

NP   Number of partitions in the material. A thermal structure temperature will be computed for each material partition.

DR   Partition size, m.

Q   Volumetric heat source for the material region, W/m**3.

The following gap properties must be correctly specified or defaulted only when another material follows. If a fluid follows, the gap properties are ignored.

SGAP Gap size, m. (0.0)

HGAP Gap heat transfer coefficient, W/(m**2-C). (1.0)

A.4.7 Thermal Structure Location Records

This set of records is included if and only if **ISTRUC**=1 and **NEWTS**=1 in NAMELIST /GEOM/.

Once the thermal structure prototypes have been defined the location of the thermal structure elements are specified by the THERMAL STRUCTURE LOCATION CARDS. These cards contain the following variables in FORMAT (A4,7I4)

LOC NUM IB IE JB JE KB KE

LOC   **OUT** The cells specified interact with the outside or surface 1.
         IN   The cells specified interact with the inside or surface 2.

NUM   Thermal structure prototype number.

IB,IE These six variables are the beginning and ending I-, J-, and K-indices that
JB,JE define a rectangular (cylindrical) solid composed of one or more cells which
KB,KE are to interact with thermal structure **NUM**.

Note 1. A cell should not be specified twice by the indices unless the true intention is to have two occurrences of the thermal structure prototype **NUM**.

Note 2. Many THERMAL STRUCTURE LOCATION CARDS may be needed to define all the cells interacting with a given thermal structure prototype.

Note 3. The order in which cells are specified is arbitrary except when the thermal structure prototype has fluid cells interacting with both surfaces. In this case cells are paired off in the order in which they are specified. The number of cells interacting with one surface must equal the number of cells interacting with the other surface.

A.4.8 Cell Initialization Records

The purpose of this set of records is to permit initialization of internal cell values of any of the array listed below. Uniform temperature can be more easily specified using the

variable **TEMP** in NAMELIST/DATA/. Each line in this section contain the following variables in the FORMAT (A4,F10.3,9I4).

NAME   RVAL IB IE JB JE KB KE   N   NCOM

NAME

AL	Volume porosity, the dimensionless ratio of fluid volume in a cell to total cell volume. (1.0)
EMDO	Volumetric mass source per geometric cell volume (eg. DX*DY*DZ) [kg/m**3/s]
HL	Enthalpy, J/kg.
P	Pressure [Pa] (see **PRESO** in namelist **DATA** for default)
POLD	use **P** & **POLD** to set pressure having a large number of significant digits as **P+POLD**
QSOU	Volumetric heat source per computational cell volume DX(I)*DY(J)*DZ(K), W/m**3. (0.0)
TD	Dissipation of turbulent kinetic energy. (J/kg)
TK	Turbulent kinetic energy. (J/kg)
TL	Temperature, C. (0.0)
THL	Void fraction of component **NCOM**.
XMS	Mass fraction of component **NCOM**.

RVAL   The value to be assigned to the variable named.

IB,IE
JB,JE   These six variables are the beginning and endingI-, J-, and K-indices that define a rectangularsolid composed of one or more cells.
KB,KE

N   The surface number of the boundary being set. (It should be ignored)

NCOM   Fluid component or phase number. (1) (It should be ignored except for THL and XMS)

A.4.9 Cell Surface Initialization Records

The purpose of this set of records is to permit initialization of internal cell surface values of any of the arrays listed below. Each card in this section contains the following variables in the FORMAT (A4,F10.3,9I4).

NAME   RVAL IB IE JB JE KB KE

NAME

ALX	Surface permeability, the dimensionless ratio of free flow area to the total surface element area, between cell (I,J,K) and cell (I+1,J,K). (1.0)
ALY	Surface permeability, the dimensionless ratio of free flow area to the total surface element area, between cell (I,J,K) and cell (I,J+1,K). (1.0)
ALZ	Surface permeability, the dimensionless ratio of free flow area to the total surface element area, between cell (I,J,K) and cell (I,J,K+1). (1.0)
UL	U-component of velocity, m/s. (0.0)
VL	V-component of velocity, m/s. (0.0)
WL	W-component of velocity, m/s. (0.0)

RVAL   The value to be assigned to the variable named.

IB,IE
JB,JE   These six variables are the beginning and ending I-, J-, and K-indices that define a rectangular solid composed of one or more cells.
KB,KE

Note. When the location of ALX(i,j,k), ALY(i,j,k), or ALZ(i,j,k) coincides with the location of AREA(L), then the operative variable is AREA(L). Similarly, when the location of UL(i,j,k), VL(i,j,k), or WL(i,j,k) coincides with the location of VELB(L), then the operative variable is VELR(L).

A.4.10 Surface Element Initialization Records

The purpose of this set of records is to permit initialization of surface values of any of the arrays listed below. Velocity boundary condition can be more easily specified using the variable VELOC in NAMELIST/DATA/. Each record in this section contains the following variables in the FORMAT (A4,F10.3,9I4).

NAME   RVAL IB IE JB JE KB KE N NCOM

NAME
AREA	Boundary surface permeability, the dimensionless ratio of free flow area to the total surface element area.
FLOW	Mass flow through boundary surface element. [kg/s]
HLB	Boundary enthalpy,[J/kg].
RLB	Boundary density,[kg/m**3].
TLB	Boundary temperature,[C].
TKB	Boundary turbulent kinetic energy,[J/kg].
TDB	Dissipation of boundary turbulent kinetic energy,[W/kg].
VELB	Magnitude of the velocity normal to the surface in the direction indicated by XNORML(N), YNORML(N), and ZNORML(N),[m/s].
THLB	Boundary void fraction for component NCOM.
XMSB	Boundary mass fraction for component NCOM.

RVAL   The value to be assigned to the variable named.

IB,IE
JB,JE
KB,KE   These six variables are the beginning and ending I-, J-, and K-indices that define a rectangular solid composed of one or more cells. The rectangular solid that defines or partially defines a surface is the one which is totally interior and adjacent to, or partially interior to and intersecting that surface.

N   The surface number of the boundary being set.
NCOM   Fluid component or phase number. (1) (It should be ingorned except for XMSB and THLB)

Note. The scheme to indicate surfaces in the BOUNDARY SURFACE IDENTIFICATION CARDS is the same as that used to indicate surfaces in the BOUNDARY VALUE INITIALIZATION CARDS. This, however, is different from the scheme used to indicate surfaces in the INTERNAL CELL INITIALIZATION CARDS. In the former case, surface elements are indicated by the cell which is adjacent to and on the side pointed to by the surface normal. In the latter case, cell (I,J,K) indicates the surface between cell (I,J,K) and either cell (I+1,J,K), cell (I,J+1,K), or cell (I,J,K+1), whichever is appropriate for the variable being initialized. Surfaces lying on boundaries must not be initialized using the INTERNAL CELL INITIALIZATION CARDS but rather the BOUNDARY VALUE INITIALIZATION CARDS.

A.4.11 Tube Side Condenser Model

This section defines the variables used in the COMMIX condenser calculation when ITUBE=1.

A.4.12 NAMELIST/TUBS/

NTUBS	Total number of the tube channel.
NMCELL	Total number of computational cells in tube side.
DMTB(N)	Diameter of tube in tube channel. Where N is the tube channel number.

TUBENO(N)   Number of tubes in tube channel N.
     >0   Number of tubes in tube channel N interacting with the associated fluid cell in steam side.
     <0   The absolute value is the tube number per unit area within the tube channel N.

IMATB   Index for computing the fluid properties of the coolant. The value of this index may be any interger from 1 to 22. For IMATB from 1 to 20, the fluid properties are computed from the fast running simplified straight-line approximation to the state equations. When the value is 21 or 22, the fluid properties are computed from the rigorous equation-of-state subroutines. It is similar to MATYPE(K) and MATWAL(K) as described in MATERIAL PROPERTIES section. For value of 1 to 20, the following coefficients must be specified in NAMELIST/DATA/.

COK(IMATB)	C1K(IMATB)	C2K(IMATB)	
CORO(IMATB)	C1RO(IMATB)	C2RO(IMATB)	
COD(IMATB)	C1D(IMATB)	C2D(IMATB)	
COH(IMATB)	C1H(IMATB)	C2H(IMATB)	C3H(IMATB)
COP(IMATB)	C1P(IMATB)	C2P(IMATB)	
COMU(IMATB)	C1MU(IMATB)	C2MU(IMATB)	

A.4.12.1 Iteration Parameters

ITERTB	Iteration number betweem momentum and energy equation. (1)
EPSTB6	Convergence criterion. (1.0e-5)

A.4.12.2 Resistance Coefficients

The pressure drop along the tube is expressed in the the following forms:

DPDX=-FORCTB*RL*ABS(UL)*UL*FTB/DMTB

where   FTB=ATBL*RE**BTBL+CTBL
when   RE < REYTRN, and
           FTB=ATBT*RE**BTBT+CTBT
when   RE >= REYTRN, and
           RE=RL*UL*DMTB/VIS, and
           RL is the local density,

UL is local velocity, and
VIS is the local viscosity.

FORCTB	Force coefficient.
REYTRN	The transition Reynolds number.
ATBL	Correlation coefficients when the Reynolds number above,
BTBL	RE, is in the laminar regime,
CTBL	i.e., when RE < REYTRN.
ATBT	Correlation coefficients when the Reynolds number above,
BTBT	RE, is in the turbulent regime,
CTBT	i.e., when RE >= REYTRN.

A.4.12.3 BoundaryCondition Type

Inlet and outlet of condenser tubes must have a velocity boundary condition type and a temperature or heat flux boundary condition type.

N	1	Inlet surface
	2	Outlet surface

KFLOTB(N)		Type of velocity boundary condition. (The default for inlet plane is 1 and outlet is -5)
	-5	Continuative mass flow outlet.
	-2	Continuative velocity outlet.
	-1	Continuative momentum outlet.
	1	Constant velocity boundary with velocity set from VELOTB(N).
	2	Constant mass flow. FLOW = RLBTB(N) * VELOTB(N) * AREA
	100+NF	Uniform transient velocity boundary with normal velocity set from the product of the NFth transient function and VELOTB(N).
	200+NF	Transient mass flow boundary with normal velocity set uniformly from VELOTB(N)/(RLBTB(N)*AREA).

KPRETB(N)		Type of pressure boundary condition. Pressure boundary conditions are applied to the cells adjacent and interior to the boundary surface specified. (The default for inlet plane is 0 and outlet plane is 1)
	0	No pressure boundary condition is applied.
	1	Uniform constant pressure boundary with pressure set from PRESTB(N).
	100+NF	Uniform transient pressure boundary with pressure set from the product of the NFth transient function and PRESTB(N).

KTEMTB(N)		Type of temperature or heat flux boundary condition. (The default for inlet is 1 and outlet is 400)
	1	Specified constant temperature boundary with temperature set from TEMPTB(N)
	100+NF	Uniform transient temperature boundary with temperature set from the product of the NFth transient function and TEMPTB(N).
	400	Adiabatic or zero diffusive heat flux boundary.

A.4.12.4 Printing Option

IOPT(I)		Printing option for tube-side variables.
	0	No printing for IOPT(I).
	1	Value for IOPT(I) is printed.

Where I is the index from 1 to 16 for the following variables:

1	ULTB	Velocity,[m/s].

Note. The boundary velocities at I-minus side (ULBTBM) and I-plus side (ULBTBP) are also printed.

2	TLB	Fluid temperature,[deg. C].

Note. The boundary temperatures at I-minus side (TLBTBM) and I-plus side (TLBTBP) are also printed.

3	HLTB	Enthalpy,[J/kg].

Note. The boundary enthalpies at I-minus side (HLBTBM) and I-plus side (HLBTBP) are also printed.

4	ROLTB	Density,[kg/m**3]

Note. The boundary densities at I-minus side (RLBTBM) and I-plus side (RLBTBP) are also printed.

5	PTB	Pressure,[Pa].
6	PTB-POLDTB	Pressure change from last time step,[Pa].
7	RMUTB	Viscosity,[Pa-s].
8	QTB	Heat Flux,[W/m**2].
9	VFLDTB	Volume of tube cell,[m**3].
10	IJKTB	Cell index.
11	UOLDTB	Velocity at previous step,[m/s].
12	TOLDTB	Temperature at previous step,[deg. C].
13	HOLDTB	Enthalpy at previous step,[J/kg].
14	ROLDTB	Density at previous step,[kg/m**3].
15	POLDTB	Pressure at previous step,[Pa].
16	HCTUBE	Tube side heat transfer coefficient,[W/m**2/C].

A.4.13 Tube Channel Location Records

The tube channel location records contain the following variables in FORMAT (A4,8I4)

NAM NUM IB IE JB JE KB KE NFD

NAM	TUBE	It indicates the condenser tube channel.
NUM		Tube channel number.
IB,IE JB,JE KB,KE		These six variables are the beginning and ending I-, J-, and K-indices of tube channel NUM.

NFD		The flow direction in the condenser tube.
	-1	The flow direction is from +x to -x.
	1	The flow direction is from -x to +x.
	-2	The flow direction is from +y to -y.
	2	The flow direction is from -y to +y.
	-3	The flow direction is from +z to -z.
	3	The flow direction is from -z to +z.

A.5 Control Parameters at a Glance

The table below is included to clarify the role of some of the control parameters. The values indicated, while not guaranteed, are ones that have been found to work in many applications. The user is encouraged to optimize these parameters according to application. A single asterisk indicates that the parameter is used. A double asterisk indicates that the parameter is not used. A value enclosed in brackets '[]' indicates that the default value is different and that this value must be explicitly specified in the input.

IMPLICIT TIME ADVANCEMENT   Solver

```
+---Time Step Loop     Default
|  NTMAX               99999
|  TIMAX               3.6E+7
|  IDTIME              1
|  TSTART              0.0
|  DT(1)               0.1
|  DT(2)               0.1
|  LASTDT              99999
|  RDTIME              [10.0]
|  NTHCON              -1
|
|  +---Outer Iteration Loop
|  |  IT(1)               [1]
|  |  IT(2)               [1]
|  |  LASTIT              99999
|  |
```

		Pressure Iteration Loop		SOR	DMIM	CG
		OMEGAV	0.8			
		ITMAXP	99	*	**	*
		OMEGA	1.5	*	**	**
		EPS1	1.0E-4	*	**	*
		EPS2	1.0E-6	*	**	*

```
|  |  +---End of Pressure Iteration Loop
|  |
```

		Mass fraction Iteration Loop		SOR	DMIM
		ITMAXX	99	*	**
		OMEGAX	1.0	*	**
		EPS1	1.0E-4	*	**
		EPS2	1.0E-6	*	**

```
|  |  +---Pressure
|  |
```

		Energy Iteration Loop		SOR	DMIM
		OMEGAE	0.8		
		ITMAXE	99	*	**
		RELAXE	0.95	*	**
		EPS5	1.0E-5	*	**

```
|  |  |--Energy
|  |
```

		Turbulent Energy Loop		SOR	DMIM
		OMEGAK	0.7		
		ITMAXK	29	*	**
		RELAXK	0.80	*	**
		EPS6	1.0E-5	*	**

```
|  |  |--Turbulent Kinetic Energy
|  |
```

		Turbulence Dissipation Loop	SOR	DMIM

```
|  |  | OMEGAD        0.7
|  |  | ITMAXK        29          •      • •
|  |  | RELAXK        0.80        •      • •
|  |  | EPS6          1.0E-5       •      • •
|  |  |--Turbulent Dissipation
|  |  EPS3            5.0e-5
|  +--End of Outer Iteration Loop
|
+--End of Time Step Loop
```

A.6 Steady-State Definition

Steady-state is reached when the following conditions are met:

1. DL < 1.0 where
   DL=maximum cell residue/DCONV,
   DCONV=EPS1*(UVWMAX+EPS2), and
   UVWMAX is computed in SUBROUTINE GDCONV.

2. ABS (DUMAX/ (VELMAX*OMEGAV))<EPS3 where
   DUMAX is the maximum change of u-velocity component
   VELMAX is MAX(VCONV,maximum u-velocity component).

3. ABS (DVMAX/ (VELMAX*OMEGAV))<EPS3 where
   DVMAX is the maximum change of v-velocity component
   VELMAX is MAX(VCONV,maximum v-velocity component).

4. ABS (DWMAX/ (VELMAX*OMEGAV))<EPS3 where
   DWMAX is the maximum change of w-velocity component
   VELMAX is MAX(VCONV,maximum w-velocity component).

5. ABS (DH/ (DELTAH*OMEGAH))<EPS3 where
   DH is the maximum change in enthalpy over two consecutive steps, and
   DELTAH is MAX(DHCONV, maximum current enthalpy variation).

A.7 Error Messages

The following table gives a listing of the error messages processed by SUBROUTINE ERRCHK. It is intended that this section will be ever expanding thus making the running of this code easier. In many cases, relevant information is printed out in the line(s) before the error message block. When appropriate, the error messages below refer to the variables in this information line. Variables are identified by their type (R for real, I for integer, and A for literal) and their relative position (1 through 12) in the line. For example, A1,R2,I3,I4,I5,I6,I7,I8,I9 would be used to refer to variables printed in the following line:

```
ALX      1.0  3  4  2  8  1  9  6
```

IER SUBROUTINE   ERROR DESCRIPTION

1	**RESTAR**	In reading the restart file, a block from COMMON /SPACE/ was found to have a length different from that specified on the restart file.
2	**HTCTUB**	Invalid heat transfer correlation index. Check the index. The correct index should be from 1 to 10.
3	**HTCTUB**	Invalid heat transfer correlation number was used. The correct number must be in the range of 71-90.
4	**BARIN**	An invalid input parameter has been encountered while initializing cell or surface element values. There are numerous conditions which may cause such an error. Some of them are listed below. One of the following necessary conditions has not been satisfied:

$$1 <= IB <= IMAX, \qquad 1 <= IE <= IMAX,$$
$$1 <= JB <= JMAX, \qquad 1 <= JE <= JMAX,$$
$$1 <= KB <= KMAX, \qquad 1 <= KE <= KMAX,$$
$$1 <= N <= NSURF,$$
$$0 <= NCOM <= NCOMP,$$
$$IB <= IE, \qquad JB <= JE, \qquad KB <= KE,$$
$$0.0 < \text{volume porosity (AL)} <= 1.0, \text{ or}$$
$$0.0 <= \text{surface permeability (ALX, ALY, ALZ)} <= 1.0.$$

The offending line is either printed above the error message box or is indicated with the following string printed at the right of the line: '<--**ERROR**'. In both cases the input line is ignored.

5	**HTCOEF**	Invalid heat transfer correlation index,ih,was used. The corret index is from 1 to 10.
6	**HTCOEF**	Invalid heat transfer correlation number,ic,was used. The correlation numbers greater than 50 are not available.
7	**TBSIDE**	The number of cells in tube side has exceeded the value NMCELL as specified in NAMELIST/TUBS/. If the input value is correct check the BOUNDARY SURFACE IDENTIFICATION RECORDS for possible errors.
8	**TBSIDE**	Errors have been found in the order of the TUBE-CHANNEL LOCATION RECORD. These must be resolved before execution can continue.
9	**TBSIDE**	An invalid TUBE-CHANNEL LOCATION RECORD has been found. Either an index is out of range, or NFD does not equal to 1, 2, 3, -1, -2, or -3.
10	**HTCOND**	Invalid heat transfer correlation number was used.
11	**BOXES**	One of the indices of the above BOUNDARY SURFACE SPECIFICATION CARD is outside of one of the following ranges:

$$I=1,IMAX \qquad J=1,JMAX \qquad K=1,KMAX \qquad N=1,NSURF,$$

or one or more of the beginning indices is greater than the corresponding ending index.

$$\text{I.e., } IB > IE \text{ or } JB > JE \text{ or } KB > KE.$$

| 12 | **BOXES** | While processing the card printed above the error box a surface element was found to be specified as being contained in two |

surfaces. The cell and surface identifiers are (I1,I2,I3) and I4 and I5 on the second line.

13	**BOXES**	On BOUNDARY SURFACE IDENTIFICATION CARDS, surfaces must be specified so that surface numbers are in increasing sequential order with all irregular surfaces preceding regular surfaces.
14	**ERRCHK**	Only fifteen calls to **ERRCHK** are allowed before termination. This number can be increased by changing the value of **NCALLS** in SUBROUTINE ERRCHK.
15	**FILLM**	One of the indices I, J, or K is outside of its expected range 1-IMAX, 1-JMAX, or 1-KMAX respectively. This error usually occurs when the BOUNDARY SURFACE IDENTIFICATION CARDS have left a hole in the boundary. Recheck the BOUNDARY SURFACE IDENTIFICATION CARDS for an undefined or incorrectly defined surface and see the appendix section entitled FINDING HOLES IN THE BOUNDARY.
16	**GEOM3D**	**LMPRNT** caused termination. Error is caused from error No. 15,17, or 18 in Subroutine **FILLM**.
17	**FILLM**	The total number of cells counted in **FILLM** has exceeded the upper bound of IMAX*JMAX*KMAX. Recheck the BOUNDARY SURFACE IDENTIFICATION CARDS.
18	**FILLM**	Excessive wrap around in the THETA direction. Recheck the BOUNDARY SURFACE IDENTIFICATION CARDS. Also assure that all surface normals are pointing into the calculational area.
19	**FILLM**	Time has run out while attempting to number the cells in **FILLM**. This probably has been caused by an input error in the BOUNDARY SURFACE IDENTIFICATION CARDS.
20	**BOXES**	The number of surface elements has exceeded the value of NL1 as specified in NAMELIST/DATA/. If the input value is correct check the BOUNDARY SURFACE IDENTIFICATION RECORDS for possible errors.
21	**BOXES**	The number of cells has exceeded the value of NM1 as specified in NAMELIST/DATA/. If the input value is correct check the BOUNDARY SURFACE IDENTIFICATION RECORDS for possible errors.
22	**FILLM**	The number of cells has exceeded the value of NM1 as specified in NAMELIST/DATA/. If the input value is correct check the BOUNDARY SURFACE IDENTIFICATION RECORDS for possible errors.
23	**ALLOC**	Changes in NM1, NL1, IMAX, JMAX, and KMAX are not allowed when restarting (**IFRES**=2 or **IFRES**=3).
24	**ZSUM**	When using the Simplified Properties Option you must input nonzero values for FOH, C1H, CORO, and COK. Be aware that the Simplified Properties Option computes properties as a linear function of temperature only and as such must be used with extreme caution!
25	**INITAL**	The duct wall model is not available in this version. Use **KTEMP(N)**=400 and Thermal Structure to model the equivalent thermal effects.
26	**INITAL**	A nonpositive value of **TEMPO** has been found in **INITAL**. Set **TEMPO** to some positive value in NAMELIST/DATA/.

27   **INFORC**   An invalid input card has been encountered in SUBROUTINE INFORC while reading the FORCE STRUCTURE SPECIFICATION RECORDS. The first field must contain either 'XFOR', 'YFOR', or 'ZFOR'. The indices IB and IE, JB and JE, and KB and KE must be in the ranges 1 through IMAX, 1 through JMAX, and 1 through KMAX respectively. The invalid card printed above the message is ignored and execution continues.

28   **ENLOOP**   Set **ISKEW**=0 or 2.

29   **FORCES**   An invalid correlation was specified for a force structure. Execution continues after setting **ZFORCE**=-1.0e+20.

30   **FORCES**   A Negative velocity was returned from the subroutine to to determine the velocity through a valve. Execution terminates.

31   **FORCES**   An invalid valve position was specified in the variable **IVALVE**. Execution continued after setting **IVALVE**=0 and **FORCE**=-1.0E+20.

32   **INITAL**   **ISTATE** has been found to be 0 while attempting to restart from a previous run. It has been reset by the code to 1. Verify that this is an acceptable fix. Execution continues.

33   **TSAREA**   **RODF** has a value of zero in the thermal structure prototype input.

34   **INITAL**   **NL1** and **NM1** must not be specified in NAMELIST /GEOM/ when restarting from a previous run with **ISTATE**>0. Remove **NL1** and **NM1** from NAMELIST/GEOM/ and rerun.

35   **OUTPUT**   The value 11 is an invalid value of **ISTPR** or **NTHPR**. specifically, the **vv** field is not defined. The value is ignored and processing continues.

36   **TSAREA**   The value of **IGEOM** is invalid. Set **IGEOM** to 0 or -1 and   rerun.

37   **TSAREA**   A negative material value has been found in the thermal structure input.

38   **WAL**   The liquid water property function **WALTSA** has been encountered a negative pressure when attempting to compute the saturation temperature.

39   **WAL**   The liquid water property function **WALTSA** has been computed a negative saturation temperature.

43   **TSCAN**   On of the following input rules for thermal structures has been violated: **TYPE** namelists can only appear first, after **FLUID** namelist and after **MATERIAL** namelists. The geometrical characteristics, **IXYZ**, must be one of the following values: 1, 2, 3, 11, 12, 13, 101, 102, 103. **FLUID** namelists can only appear after **TYPE** and **MATERIAL** namelists. Each thermal structure must have at least one material region.

44   **INPSTR**   When computing areas and volumes of the partitions of the thermal structure material regions an inner radius was found to be less than -1.0E+4***OUTR**, where **OUTR** was te outer radius as specified on the **TYPE** card. Check the thermal structure input for **OUTR**, **DRPAR**, and **NMPAR**. If no errors are found here check the entire thermal structure prototype input. The negative radius is reset to zero and execution continues. See error number 45 for a list of the variables printed above the error block.

45   **INPSTR**   When computing areas and volumes of the partitions of the thermal structure material regions an inner radius was found to be larger than the outer radius. Check the thermal structure input. The inner radius is reset to the outer radius end execution continues.

The parameters printed above the error block are: N - structure number, IREG - region number, IPAR - partition number, OUTR(N) - outer radius, DR - region size, ROUT - outside radius, RIN - inner radius.

46	TSCAN	An invalid THERMAL STRUCTURE LOCATION card has been found. Either an index is out of range, or the LOC value is invalid (must be either 'OUT' or 'IN'), or the NUM value does not match the number of any THERMAL STRUCTURE PROTOTYPE.
47	TSCAN	A THERMAL STRUCTURE PROTOTYPE has been encountered which has fluid cells interacting at both outside and and inside surfaces, however, the number of cells interacting with the outside surface does not equal the number of cells interacting with the inside surface. I1, I2, I3, and I4 are the structure number, surface interaction code, number of cells interacting with surface 1, and number of cells interacting with surface 2.
48	TSCAN	THERMAL STRUCTURE PROTOTYPE RECORDS are inconsistent with the THERMAL STRUCTURE LOCATION RECORDS. Either the · TSP records specify only cells interacting with the outside surface and the TSL records specify some cells interacting with the inside surface, or the TSP records specify only cells interacting with the inside surface and the TSL records specify some cells interacting with the outside surface. The values printed above the error message are the same as those identified in error 47.
49	INPSTR	The THERMAL STRUCTURE LOCATION RECORD printed above the error message box indicates a cell within the ranges of the indices which is not a valid calculational cell. The specific I, J, and K indices are printed out as I9, I10, and I11. This cell is ignored and execution continues. The results which follow are likely incorrect.
50	PRINRC	An invalid value of NCOLUM has been encountered. NCOLUM must have a value of 8, 9, 10, or 11. Execution continues without printing this table.
51	FILLM	The BOUNDARY SURFACE IDENTIFICATION CARDS have defined a single sided interior boundary surface between cells I1 and I2. Check to see that all surfaces you have defined bound calculational cells. Also be sure that any interior surface has calculational cells on both sides of it. Reread the BOUNDARY SURFACE IDENTIFICATION CARD input section and check your input. Execution continues however subsequent results are questionable.
52	TSAREA	An invalid value of IXYZ has been found in the thermal structure prototype input.
53	TSCAN	Currently only 100 thermal structure prototypes are allowed. If more is needed, changes must be made in COMMON /REBALS/ in subroutine ALLOC and INPSTR. Execution terminates.
54	TSCAN	Errors have been found in the order of the thermal structure prototype input. These must be resolved before execution can continue.
55	ZSUM	Invalid material number is specified in MATTAB.
56	ZSUM	The temperature range for indicated material number has been set to 50.0 - 90.0 degrees. This can be specified by the user in variables TABLOT and TABHIT.
57	ZPROPS	Invalid material number is used.

58	INITAL	Irregular surfaces must have no flow or pressure boundary condition applied across them. That is, KFLOW(N)=1, VELOC(N)=0.0, AND KPRES(N)=0 for all irregular surfaces N. When specifying transient boundary conditions, the transient function number, NF, must be nonzero. That is, KFLOW(N)=100, KTEMP(N)=100, KTEMP(N)=300, and KPRES(N)=100 are all invalid boundary condition types. Valid types, assuming properly defined transient functions, would be, for example, KFLOW(N)=101 and KTEMP(N)=102.
59	GEOM3D	DX(I), DY(J), and DZ(K) must be nonzero for I=1 through IMAX, J=1 through JMAX, and K=1 through KMAX.
60	GEOM3D	The length of the normal vectors defined by XNORML(N), YNORML(N), and ZNORML(N) must be within one percent of 1.0.
61	INFORC	A previously defined force structure location has been overwritten. In the preceding lines, A1 shows the cell face on which the force structure was being defined, I2 is the force structure number, and I3, I4, and I5 give the cell indices. The last force structure defined at a cell face will be the one which is used.
62	INITAL	Incorrect values have been specified for ISETEN and/or ISETMO. See NAMELIST/DATA/ for a description.
63	INITAL	New thermal structure input will be read. All previous thermal structure information from previous runs will be ignored.
64	INITAL	New force structure information will be read. All previous force structure information from previous runs will be ignored.

A.8 Storage Allocation

In order to ease the task of creating load modules (binary files) to fit the size of the problem being considered, a quasi-dynamic storage allocation scheme has been implemented. Space for most of the geometry dependent variables is allocated in the variable S of COMMON /SPACE/. The address of each variable is computed at the beginning of each run. These addresses are then passed into called subroutines where the variables are named and variably dimensioned.

The following table shows a list of the variables with space allocated in variable S of COMMON /SPACE/. The dimension of each variable is indicated as is the index of variable IS which contains the S offset address of the variables. If any changes are made in this area, one must assure that consistency is maintained.

VARIABLE DIMENSION	VARIABLE NAME	INDEX	VARIABLE NAME	INDEX	VARIABLE NAME	INDEX
PRIMARY	MIP	1	MIM	2	MJP	3
GEOMETRY	MJM	4	MKP	5	MKM	6
NM1	IJK	7				
	ALX	13	ALY	14	ALZ	15
	AL	16				
	VFLUID	111	AFLUX	112	AFLUY	113
	AFLUZ	114				
NL1	MB	42	ISURF	43	AREA	44

PRIMARY	HOLD	10	RL	17	UL	18
FLUID	VL	19	WL	20	EMDOT	115
NMFT	FLOWX	171	FLOWY	172	FLOWZ	173
	HL	22	TL	23	RLOLD	24
	ULOLD	28	QSOUR	29	VLOLD	30
	WLOLD	31	POLD	35	P	41
	EKE	177	EKEOLD	178	SOLD(HLT, TKT,TDT)	108
	DIFF,DIFFH	116				
NLFT	VELBN	46	HLB	48	RLB	45
	QBN	47	TLB	49		
	FLOWB	176	EKEB	179		

- -

SECONDARY	UHATL	25	VHATL	26	WHATL	27
FLUID	DUOL	32	DVOL	33	DWOL	34
NMFT	AUOL	38	AVOL	39	AWOL	40
	AC1	67	AC2	68	AC3	69
	AC4	70	AC5	71	AC6	72
	AC0	73	BC0	74	SPHEAT	120

- -

TERTIARY	RMU	8	DL	21	BHOLD	98
FLUID	BUOLD	99	BVOLD	100	BWOLD	101
NMFT	DRDP	102	DRDH	103	DHDP	164
	SCHL	104	SPHL	105	CK	50

- -

NMCT	XMS	109	XMSOLD	110		
	THL	78	THLOLD	79		
	RTH	152	RTHOLD	153		
NLCT	XMSB	81	THLB	150	RTHB	151

- -

TURBULENCE MODEL

NM1	TKOLD	12	TK	36	TURVIS	37
	TURCON	76	TD	80		
	TDOLD	137	BKOLD	138	BDOLD	139
	SCKL	106	SPKL	107		
NL1	TKB	51	TDB	136		

- -

SKEW UPWIND MODEL

NM1	BOSKE	155				

- -

FORCE

NFORCE	ICORR	60	CLENTH	61	REYLEN	62
	IFORCE	9	FORCEF	63		
NTSEP	ITSCB	52	HYDRA1	53	HYDRA2	54
	RODFR	55	NROW	117	RODDM	118
NPAR	STAREA	56	STVOL	7		
NREG	MATERL	58	HEAT	59	SIZE	64
NSUR	ICEL	65	HSTREL	66	HCTUBE	119
NTTS	TTS	77				
	TSTW	83	TCS	84	QFX	85

	HTGS	86	HTSS	87	NROW	117
	RODDM	118	DIFFU	122	PSAT	123
	HFG12	124	EKDOT	79		
SOR	MREB	11	MSWEEP	82		
YSMP	IA	127	MPERM	128	MPINV	129
	JA	130	MWHAT	131	A	132
	RSP	133	IIAF	134	IJAF	135
PCG	KA	88	KD	89	JA	90
	MWHAT	91	R	92	JA	93
	AP	94	P	95	QR	96
	AQR	97	A	125	L	126

| - | - | - | - | - | - | - |

MIJK	DUMMY1	75
MILIJK	IDUM1	140
ILMAX	IDUM2	141
MIJK	IDUM3	142
NL1	IDUM4	143
MAX1	RDUM1	144
MAX2	RDUM2	145

| - | - | - | - | - | - | - |

NMCELL	ULTB	180	PTB	181	TLTB	182
	HLTB	183	ROLTB	184	RMUTB	185
	QTB	186	VFLDTB	187	ROLDTB	188
	UOLDTB	189	POLDTB	190	HOLDTB	191
	DPTB	192	IJKTB	193	TOLDTB	194
NTUBES	LFDTB	195				

| - | - | - | - | - | - | - |

A.9 Calling Sequence

The following table indicates the code structure by showing the calling sequence of the subroutines. Calls to the properties routines and function are not indicated. Also multiple calls may not be indicated.

```
MAIN|--RUNID
    |--NAMELS
    |--CLEAR
    |--ERRCHK |--OUTPUT |--GLOBAL            |--RUNID
    |                   |        |--IJKGET
    |                   |        |--SUMRE1 |--IJKGET
    |                   |        |--TSQ    |--IJKGET
    |                   |        |         |--ERRMES
    |                   |--ERRMES
    |                   |--OUT2 |--OUTIU
    |                   |       |--OUTJU
    |                   |       |--OUTKU
    |                   |       |--CHOP
    |                   |       |--PRINRC |---  ERRMES
    |                   |--OUTR1
```

```
|                              |--OUT1   |--OUFIE
|                              |         |--CHOP
|                              |         |--PRINRC |--ERRMES
|                              |--IJKGET
|                              |--OUT1I  |--OUFII
|                              |         |--CHOP
|                              |         |--PRINRC |--ERRMES
|                              |--ERP.CHK
|                              |--RSURFO
|                              |--ISURFO            |--IJKGET
|                              |--PSTRUC
|                              |--OUTTB1 |--OUTPTB
|
|--GETMEM
|--STOSUM
|--TSCAN
|--TBSCAN
|--AMAIN  |--TMINGI
          |--TMINGB
          |--GEOM3D |--NAMELS
          |         |--BOXES |--ERRCHK
          |         |        |--IJKSET
          |         |        |--IJKGET
          |         |        |--FILLM  |--SHOME
          |         |        |         |--IJKGET
          |         |        |         |--IJKSET
          |         |        |         |--ERRCHK
          |         |        |         |--TLEFT
          |         |--TLEFT
          |         |--ERRCHK
          |         |--MARRAY
          |         |--IARRAY
          |         |--RARRAY
          |
          |--INITAL |--RESTAR              |--PLTAPE
          |         |            |--LOCF
          |         |            |--ERRCHK
          |         |--NAMELS
          |         |--ERRCHK
          |         |--ERRMES
          |         |--ZSUM   |--ERRCHK
          |         |--FITIT  |--ICSSCU
          |         |--INFORC              |--ERRCHK
          |         |--TBINPR
          |         |--ICTUBE
          |         |--UPDATB
          |         |--INPSTR              |--ERRCHK
          |         |            |--TSAREA
          |         |--ICTEMP
```

```
|                  |--INITPR              |--IJKGET
|                  |--BARIN |--ERRCHK
|                  |        |--SETRM
|                  |        |--SETRL
|                  |        |--REDEF
|                  |
|                  |--GEOVAR|--IJKGET
|                  |--INITFL              |--BCPRES              |--GETF
|                  |        |--ROTEMP |--TMINGB
|                  |        |         |--PROPF |--THUMID
|                  |        |         |--TMINGE
|                  |        |--GETFLO
|                  |        |--BCTEMP |--IJKGET
|                  |        |--BCTEMO |--TMINGB
|                  |        |         |--IJKGET
|                  |        |         |--TMINGE
|                  |        |--GETREC
|                  |        |--BCMASS |--IJKGET
|                  |        |--GETREM
|                  |        |--BCCONT
|                  |        |--BCTEMT |--IJKGET
|                  |        |--BCFLOW
|                  |        |--BCFLOT
|                  |        |--UPDATE
|                  |
|                  |--GIAJA              |--ORDV |--MD       |--MDI
|                  |        |            |       |--MDM
|                  |        |            |       |--MDP
|                  |        |            |       |--MDU
|                  |        |            |--SRO
|                  |        |
|                  |        |--CDRV |--NROC
|                  |        |--NSFC
|                  |        |--NNFC
|                  |        |--NNSC
|                  |        |--NNTC
|                  |--INITUR              |--TURV12
|
|--HSTRUC |--TMINGB
|         |--IJKGET|
|         |--HTCOEF  |--TMINGB
|         |          |--ERRMES
|         |          |--HTCOND |--TMINGB
|         |          |         |--ERRMES
|         |          |         |--TMINGE
|         |          |--TMINGE
|         |
|         |--HTCTUB|--TMINGB
|         |        |--ERRMES
```

```
|                   |                   |--TMINGE
|                   |--TMINGE
|
|--TSTRUC |--TMINGB
|                   |--IJKGET
|                   |--TMINGE
|
|--QSTRUC |--TMINGB
|                   |--IJKGET
|                   |--TMINGE
|
|--GDCONV |--IJKGET
|                   |--SETDT
|--PLTAPE |--RUNID
|--SUMRE2
|--OUTPUT
|--WATSTP
|--SETDT   |--ERRMES
|--TIMSTP  |--TMINGB
|                   |--UPDATE
|                   |--UPDATB
|                   |--BCPRES                 |--GETF
|                   |--BCTEMO
|                   |--GETRHC
|                   |--BCMASS
|                   |--GETRHM
|                   |--MOLOOP                 |--TMINGB
|                   |          |--BCFLOT |--GETF
|                   |          |--GETVIS
|                   |          |--XMOMI   |--TMINGB
|                   |          |          |--IJKGET
|                   |          |          |--ZMOMZ
|                   |          |          |--ZMOMX |--WLFNCV
|                   |          |          |--FORCES|--ERRMES
|                   |          |          |              |--VSTARO
|                   |          |          |              |--ERRCHK
|                   |          |          |--TMINGE
|                   |          |
|                   |          |--YMOMI   |--TMINGB
|                   |          |          |--IJKGET
|                   |          |          |--ZMOMZ
|                   |          |          |--ZMOMX |--WLFNCV
|                   |          |          |--FORCES|--ERRMES
|                   |          |          |              |--VSTARO
|                   |          |          |              |--ERRCHK
|                   |          |          |--TMINGE
|                   |          |--ZMOMI   |--TMINGB
|                   |          |          |--IJKGET
|                   |          |          |--ZMOMZ
```

```
|              |              |                        |--ZMOMX |--WLFNCV
|              |              |                        |--FORCES|--ERRMES
|              |              |                        |               |--VSTARO
|              |              |                        |               |--ERRCHK
|              |              |                        |--TMINGE
|              |              |
|              |              |--PEQN    |--TMINGB
|              |              |          |--IJKGET
|              |              |          |--TMINGE
|              |              |
|              |              |--SOLVER  |--TMINGB
|              |              |          |--SOLVIT|--TMINGB
|              |              |          |               |--TMINGE
|              |              |          |
|              |              |          |--DMIM
|              |              |          |
|              |              |          |--CGRAD |--TMINGB
|              |              |          |               |--GNZERO
|              |              |          |               |--GETKA
|              |              |          |               |--LOADA
|              |              |          |               |--CGSOLV
|              |              |          |               |--TMINGE
|              |              |          |--TMINGE
|              |              |
|              |              |--MOMENI |--TMINGB
|              |              |         |--TMINGE
|              |              |--GETFLO
|              |              |--BCFLOW
|              |              |--TMINGE
|              |--BCTURB
|              |--TKLOOP              |--TMINGB
|              |         |--TKSORC |--TMINGB
|              |         |         |--IJKGET
|              |         |         |--VELCEN
|              |         |         |--TKGRAD   |--VELCEN
|              |         |         |--TMINGE
|              |         |
|              |         |--ENCON0 |--IJKGET
|              |         |
|              |         |--TKENER |--TMINGB
|              |         |         |--IJKGET
|              |         |         |--DIFFX1
|              |         |         |--TMINGE
|              |         |--SOLVER
|              |         |--TMINGE
|              |
|              |--TDLOOP              |--TMINGB
|              |         |--ENCON0 |--IJKGET
|              |         |--TDENER |--TMINGB
```

```
|              |              |                    |--IJKGET
|              |              |                    |--DIFFX1
|              |              |                    |--TMINGE
|              |              |--SOLVER
|              |              |--TMINGE
|              |
|              |--TURV12                  |--TMINGB
|              |              |--TMINGE
|              |
|              |--MALOOP  |--TMINGB
|              |              |--MACON0  |--IJKGET
|              |              |--MADIFF  |--IJKGET
|              |              |--MASSCO  |--IJKGET
|              |              |--SOLVER
|              |              |--TMINGE
|              |              |
|              |--ENLOOP  |--TMINGB
|              |              |--GETEKE  |--IJKGET
|              |              |--BCTEMT  |--GETF
|              |              |--HSTRUC  |--TMINGB
|              |              |              |--IJKGET
|              |              |              |--HTCOEF|--TMINGB
|              |              |              |              |--ERRMES
|              |              |              |              |--HTCOND|-TMINGB
|              |              |              |              |              |-ERRMES
|              |              |              |              |              |-TMINGE
|              |              |              |              |--TMINGE
|              |              |              |
|              |              |              |--HTCTUB|--TMINGB
|              |              |              |              |--ERRMES
|              |              |              |              |--TMINGE
|              |              |              |--TMINGE
|              |              |
|              |              |--ESORCE  |--TMINGB
|              |              |              |--GETF
|              |              |              |--QSTRUC
|              |              |              |--IJKGET
|              |              |              |--TMINGE
|              |              |--GETCON
|              |              |--ENCON0
|              |              |--ENCON2  |--ENCX2  |- ENCFY
|              |              |              |              |--ENCOR3
|              |              |              |--IJKGET
|              |              |--ERRMES
|              |              |--ENERGI  |--TMINGB
|              |              |              |--IJKGET
|              |              |              |--ECONDX
|              |              |              |--TMINGE
|              |              |--GETHL
```

```
    |                |               |--SOLVER
    |                |               |--TMINGE
    |                |
    |                |--TBSIDE  |--TMINGB
    |                |               |--IJKGET
    |                |               |--- TDMA
    |                |               |--TDMA2
    |                |               |--BCTUBE
    |                |               |--TMINGE
    |                |
    |                |--ROTEMP  |--TMINGB
    |                |               |--PROPF
    |                |               |--TMINGE
    |                |--GETVEL
    |                |--BCCONT
    |                |--BCTEMP                |--IJKGET
    |                |--BCFLOW
    |                |--BCMAS  |--IJKGET
    |                |--TSTRUC
    |                |--TMINGE
    |--WATSTP
    |--PLTAPE
    |--WATTIM
    |--OUTPUT
    |--RESTAR
    |--TMINGE
```

A.10 Overlay Structure

This section gives one possible overlay structure. If this is found to be insufficient one can use the preceding section to help redesign an alternative scheme. When using a virtual memory operating system, user defined overlays are probably undesirable.

INSERT MAIN,ERRCHK,LOCF

INSERT I4VAR,R4VAR,I4ARY,R4ARY,SPACE

INSERT MACHIN,REBALS,CCORR,CHEATC,ADDCON

OVERLAY ONE

INSERT CLEAR,TSCAN,TBSCAN

OVERLAY ONE

INSERT AMAIN,TLEFT,RARRAY,RESTAR,PLTAPE

INSERT BCFLOT,BCFLOW,BCPRES,BCTEMP,BCTEMT,BCTEMO,BCTUBE

INSERT GETF,GDCONV,WATTIM,WATSTP

INSERT HSTRUC,QSTRUC,TSTRUC,HTCOND,HTCTUB

OVERLAY TWO

    INSERT GEOM3D,FILLM,MARRAY,IARRAY,SHOME

    OVERLAY THREE

    INSERT BOXES

  OVERLAY TWO

    INSERT INITAL,FITIT,ICSSCU

    INSERT ICTEMP,BARIN,RSET3,RSET2,REDEF,ICTUBE

    OVERLAY THREE

    INSERT INFORC

  OVERLAY THREE

    INSERT INPSTR,TBINPR

OVERLAY TWO

    INSERT INITZ1

OVERLAY TWO

    INSERT TIMSTP,FORCES

    INSERT TKLOOP,TSHEAR,TKSORC,TKENER,SOLVEN,BCTURB

  OVERLAY THREE

    INSERT MOLOOP,XMOMI,YMOMI,ZMOMI,PEQN,GETDL,TDMA,WLFNCV

    INSERT SOLVIT,MOMENI,ENLOOP,ESORCE,ENERGI

  OVERLAY THREE

    INSERT MALOOP,TBSIDE

  OVERLAY THREE

    INSERT OUTPUT,RSURFO,ISURFO,PSTRUC

  OVERLAY THREE

    INSERT INTURB

ENTRY MAIN

NAME G

A.11 Machine Dependent Routines

Two machine dependent functions are used in this package.

1. LOCF

· This function returns the absolute address of the variable which is passed as the argument. It is used both in determining the length of blocks to be written to the restart file and in performing initialization. This function is used extensively in the code and thus its functional equivalent must be supplied when implemented on other systems. An assembly language listing of LOCF for the IBM maching is given below.

```
 ·                    Return location of a variable as 32 big integer.
 ·
                      I=LOCF(X)
 ·
LOCF  CSECT
      SAVE    (14,12),,LOCF
      L       0,0(1)              Load the address.
      SLL     0,1                 Remove the sign bit.
      SRL     0,1
      MVI     12(13),X'FF'        Signal return.
      SR      15,15               Return code.
      BR      14                  Return.
      END
```

2. TLEFT

This function returns the CPU time left in the current run in units of 0.01 seconds. This time starts at the time specified on the JOB card and ends at zero when the job is terminated by the system. It is used for timing and to determine when to terminate and write a restart file. For interactive systems the following function may be substituted. This will eliminate meaningful timing measures and the MAXTIME restart capabilities; however it will not effect the codes results.

```
FUNCTION TLEFT (TIME)
DATA T /100000.0/
T=T-2.0
TLEFT=T
RETURN
END
```

A.11. Finding Holes in the Boundary

The BOUNDARY SURFACE SUMMARY is intended to aid the user in finding holes in the boundary surfaces. It is obtained by setting IBSBUG in NAMELIST/GEOM/. The boundary surface summary consists of two parts. First is a table of binary strings and their

corresponding printed character. Following this table are JMAX planes with each calculational cell being represented by one of the characters from the first table. The binary string associated with each character indicates the location of the surface elements in the following way. Each bit in the binary string corresponds to a face of the calculational cell. The first bit corresponds to the face in the I minus (I-) direction. This is the surface between cell (I,J,K) and cell (I-1,J,K). The second bit corresponds to the face in the I+ direction, the third in the J-, the fourth in the J+, the fifth in the K-, and the sixth in the K+ direction. A surface element is defined at a cell face if the bit corresponding to that face has a value of 1.

For example, suppose "F" is printed at the location for cell (I,J,K). "F" corresponds to the binary string "011000". This indicates that a surface element has been defined in the I+ and J-directions, that is, between cells (I,J,K) and (I+1,J,K) and between cells (I,J,K) and (I,J-1,K).

In order for this scheme to be effective the table should contain 62 different printable characters. A blank corresponds to string "000000" and string "111111" should never occur. While we have a laser printer with both upper and lower case at ANL, the printers usually used are impact printers with only about 58 different characters. Therefore, the current implementation uses the character "?" to correspond to all of the following binary strings: "111110", "111101", "111011", "110111", "101111", "011111", and "111111". This does introduce some ambiguity however the impact is probably not serious. For those users who wish to eliminate these duplications, changes must be made in SUBROUTINE SHOME.

Appendix B: List of COMMIX–PPC Subroutines

Subroutine	Calling Subroutine	Description
MAIN	–	Writes the title and computes addresses of variables according to the key variables read from input.
AMAIN	MAIN	Main calling program. See overall flow chart, Fig. 1.
BARIN	INITAL	Reads the boundary and internal cell initialization cards.
BCCONT	INITFL TIMSTP	Updates boundary values on continuative exits.
BCFLOT	INITFL MOLOOP	Updates boundary velocities on surfaces with transient flow boundary condition.
BCFLOW	INITFL TIMSTP MOLOOP	Updates boundary velocities during iterations.
BCMAS	TIMSTP	Sets continued mass and volume fraction boundary values.
BCMASS	INITFL TIMSTP	Sets continued mass and volume fraction boundary values per KMASS.
BCPRES	INITFL TIMSTP	Sets specified pressure values at cells adjacent to surface having pressure boundary conditions.
BCTEMP	INITFL TIMSTP	Updates boundary values of heat flux, temperature, density, and enthalpy.
BCTEMT	INITFL ENLOOP	Updates boundary values of temperature, pressure, and density for constant and transient heat flux boundary conditions.
BCTEMØ	INITFL TIMSTP	Computes boundary values of pressure, heat flux, and density for constant or transient temperature boundary conditions.
BCTUBE	TIMSTP	Updates boundary values of pressure, heat flux, and density for constant or transient temperature boundary conditions on tube side.
BCTURB	TIMSTP	Updates boundary values of turbulence kinetic energy.
BOXES	GEOM3D	Reads surface specification cards input for the box geometry option.

Subroutine	Calling Subroutine	Description
CGRAD	SOLVER	Solves matrix equation by preconditioned conjugate gradient method.
CHOP	OUT2 OUT1 OUT1I	Resets the beginning and end row and column markers to print out only rows and columns containing cell or boundary values.
CLEAR	MAIN	Zeros out the values of all variables between the two arguments passed.
DIFFX1	TDENER TKENER	Computes diffusion between two adjacent cells for k and ε equations.
DMIM	SOLVER	Solves the matrix equation with the direct matrix inversion method.
ECONDX	ENERGI	Computes conduction between two adjacent cells.
ENCFY	ENCX2	Computes y direction weighting factors for flow-modulated skew-upwind difference scheme.
ENCONØ	TKLOOP TDLOOP ENLOOP	Computes upwind convective terms.
ENCON2	ENLOOP	Computes convective flux for flow-modulated skew-wind difference scheme.
ENCOR3	ENCX2	Computes corner weighting factors for flow-modulated skew-upwind difference scheme.
ENCX2	ENCON2	Computes coefficients due to positive x direction for flow-modulated skew-upwind difference scheme.
ENERGI	ENLOOP	Computes coefficients of the energy equation.
ENLOOP	TIMSTP	Calls required subroutines in sequence for solution of energy equation.
ERRCHK	Several	Processes error conditions and prints error messages.
ERRMES	Several	Similar to ERRCHK
ESORCE	ENLOOP	Computes the source term for energy equation.
FILLM	BOXES	Initializes the cell and adjacent cell pointers.
FITIT	INITAL	Computes the coefficients of cubic spline fit for input transient functions.

Subroutine	Calling Subroutine	Description
FORCES	XMOMI YMOMI ZMOMI	Computes user-imposed drag forces.
GDCONV	AMAIN	Computes DCONV, the convergence criteria based on maximum velocity in the region.
GEOM3D	AMAIN	Determines essential geometric information.
GEOVAR	INITAL	Computes cell volumes and surface areas, which remain constant throughout a calculation.
GETCON	ENLOOP	Computes effective thermal conductivity.
GETEKE	ENLOOP	Computes flow kinetic energy.
GETF	several	Determines the value of transient function NF at the current time.
GETFLO	MOLOOP INITFL	Computes mass flow.
GETHL	ENLOOP	Computes enthalpy.
GETMEM	MAIN	Allocates memory dynamically.
GETRHC	INITFL TIMSTP	Computes boundary density and enthalpy.
GETRHM	INITFL TIMSTP	Evaluates mixture density and enthalpy, and product of density and volume fraction at boundary.
GETVEL	TIMSTP	Adjusts velocity after density change.
GETVIS	MOLOOP	Computes effective viscosity for all cells.
GLOBAL	OUTPUT	Prints global balances.
HSTRUC	AMAIN ENLOOP	Computes heat transfer coefficients for thermal-structure elements.
HTCOEF	HSTRUC BCTEMØ	Computes heat transfer coefficient.
HTCOND	HTCOEF	Computes heat transfer coefficient for condenser model.
HTCTUB	HSATRUC	Computes tube-side heat transfer coefficient.

Subroutine	Calling Subroutine	Description
ICTEMP	INITAL	Initializes default boundary temperature and boundary velocity (or mass flow).
ICTUBE	INITAL	Initializes tube-side flow conditions.
INFORC	INITAL	Reads input related to force structure and prints corresponding input summary.
INITAL	AMAIN	Calls required subroutines in sequence to initialize internal-cell and boundary values of all variables.
INITFL	INITAL	Initializes all fluid variables.
INITPR	INITAL	Sets default static pressure.
INITUR	INITAL	Initializes turbulence model.
INPSTR	INITAL	Reads thermal structure input data, computes required geometrical and physical information, and prints thermal-structure input summary.
ISURFO	OUTPUT	Prints surface array IVAR for surface number NSUR.
MACONØ	MALOOP	Computes the convective terms for component mass continuity equation.
MADIFF	MALOOP	Computes the diffusion terms for component mass continuity equation.
MALOOP	TIMSTP	Calls required subroutines in sequence to solve component mass continuity equation.
MASSCO	MALOOP	Computes transient and source terms for component mass continuity equation.
MOLOOP	TIMSTP	Calls required subroutines in sequence to solve mass-momentum equations.
MOMENI	MOLOOP	Calculates new-time velocity using new-time values of pressure.
NAMELS	GEO3D INITAL ADRIVE	Reads NAMELIST information.
OUT1	OUTPUT	Writes a plane of values for cell-centered variables.

Subroutine	Calling Subroutine	Description
OUT1I	OUTPUT	Writes a plane of integer values for cell-centered variables.
OUT2	OUTPUT	Writes a plane of values for face-centered variables.
OUTFIE	OUT1	Sets up two arrays, VAL and MARK, of the size NRMAX and NCMAX for cell-centered variables.
OUTFII	OUT1I	Sets up two arrays, VAL and MARK, of the size NRMAX and NCMAX for cell-centered variables.
OUTIU OUTJU OUTKU	OUT2	Similar to OUTFIE for face-centered variables.
OUTPTB	OUTTBI	Prints tube-side flow information.
OUTPUT	AMAIN ERRCHK	Prints array information.
OUTTBI	OUTPUT	Sets up tube-side variable storage information.
PEQN	MOLOOP	Computes coefficients of pressure equations.
PLTAPE	AMAIN RESTAR	Writes plotting information.
PRINRC	OUT1 OUT2	Writes out the incoming array.
PRINRI	OUT1I	Writes out the incoming integer array.
PROPF	ROTEMP	Computes properties.
PSTRUC	OUTPUT	Prints temperature fields and heat transfer information relating to thermal structures.
QSTRUC	AMAIN ESORCE	Solves heat conduction equations and computes effective heat source from thermal structures to the coolant.
REDEF	BARIN	Redefines porosities and permeabilities that are R dependent for cylindrical geometry.
RESTAR	INITAL AMAIN	Writes or reads a restart dataset.
ROTEMP	TIMSTP INITFL	Determines the state of each cell by updating the properties.

Subroutine	Calling Subroutine	Description
RSURFO	OUTPUT	Prints a specified surface array.
RUNID	MAIN GLOBAL PLTAPE	Returns time and version information.
SETDT	AMAIN GDCONV	Sets a nonzero time–step size (0.001).
SETRL	BARIN	Performs boundary value initialization.
SETRM	BARIN	Performs interior-cell value initialization.
SHOME	FILLM	Prints graphical representation of the boundary surface identification cards.
SOLVER	MALOOP MOLOOP TKLOOP TDLOOP ENLOOP	Calls one of the three matrix solvers to solve the discretized pressure equation and the scalar transport equations.
SOLVIT	SOLVER	Solves the matrix equation by the SOR method.
STOSUM	ADRIVE	Computes the lengths of variables and prints storage summaries.
SUMRE1	GLOBAL	Reads and stores a set of input.
SUMRE2	AMAIN	Writes the control variable summary.
TBINPR	INITAL	Reads the tube-side input to set up the storage for tube-side variables.
TBSCAN	MAIN	Scans tube-side input to determine amount of storage needed to run a condenser problem.
TBSIDE	TIMSTP	Solves one-dimensional Navier-Stoke's equation for tube-side flow.
TDENER	TDLOOP	Computes coefficients of the ε (dissipation of turbulence kinetic energy) equation.
TDLOOP	TIMSTP	Computes the dissipation of turbulence kinetic energy ε for the two-equation models.
TDMA	TBSIDE	Tri-diagonal matrix algorithm.

Subroutine	Calling Subroutine	Description
TIMSTP	AMAIN	Calls required subroutines in sequence to bring variable values from time t to time t + Δt.
TKENER	TKLOOP	Calculates the coefficients of the turbulence kinetic energy equation.
TKGRAD	TKSORC	Computes gradients used in the source terms in the turbulence equations.
TKLOOP	TIMSTP	Computes turbulence kinetic energy k.
TKSORC	TKLOOP	Computes the source terms in the turbulence kinetic energy (k) equation.
TSAREA	INPSTR	Computes the total heat transfer area between thermal structures and fluids.
TSCAN	MAIN	Scans the thermal-structure input to determine the amount of storage needed to run a problem.
TSQ	GLOBAL	Computes the total heat for each thermal structure.
TSTRUC	AMAIN TIMSTP	Solves the heat conduction equation and computes thermal-structure temperature, TTS.
TURV12	INITFL TIMSTP	Computes turbulent viscosity and thermal conductivity for the k-ε two-equation turbulence model.
UPDATB	INITAL TIMSTP	Restores previous time-step values to current time-step values on the tube side.
UPDATE	INITFL TIMSTP	Restores the previous time-step values to the current time-step values.
VELCEN	TKSORC TKGRAD	Computes cell-centered velocity.
VSTARØ	FORCES	Computes local critical velocity for superheated steam.
WLFNCV	ZMOMX	Modifies the wall shear stress to account for frictional force.
XMOMI	MOLOOP	Computes coefficients of x-momentum equations.
YMOMI	MOLOOP	Computes coefficients of y-momentum equations.
ZMOMI	MOLOOP	Computes coefficients of z-momentum equations.

Subroutine	Calling Subroutine	Description
ZMOMX	XMOMI YMOMI ZMOMI	Computes the z-x convective and viscous terms of the momentum equation.
ZMOMZ	XMOMI YMOMI ZMOMI	Computes the z-z convective and viscous terms of the momentum equation.
ZSUM	INITAL	Prints the property summaries.

Appendix C. Flow–Resistance Correlations

C.1 Introduction

This appendix, which contains a convenient collection of flow–resistance correlations that are commonly needed by COMMIX users, is written with hope that it will save the user from the need to search a vast literature. We also hope that this appendix will serve as a starting reference for new users.

We caution here that the correlations presented are not necessarily the only and final relations. We welcome feedback and comments from all users so that we can add other correlations, update the existing relations, and improve the information presented here.

C.2 Crossflow Over Tubes

The pressure drop for flow over a bank of tubes can be estimated with the equation

$$\Delta P = \frac{2 f' G_{max}^2 \, N}{\rho} \left(\frac{\mu_w}{\mu_b} \right)^{0.14} , \qquad (C.1)$$

where

ΔP = pressure drop, Pa,

G_{max} = mass velocity at minimum flow area, $kg/m^2 \cdot sec$,

ρ = density of fluid, kg/m^3,

N = total number of transverse flows in the main flow direction,

μ_w = viscosity evaluated at wall temperature, $kg/m \cdot s$,

μ_b = viscosity evaluated at bulk temperature, $kg/m \cdot s$, and

f = an empirical friction factor given by Jakob[C.1] as

$$f' = \left[0.25 + \frac{0.118}{\left(\frac{S_T - D_0}{D_0} \right)^{1.08}} \right] \left(\frac{G_{max} D_0}{\mu_b} \right)^{-0.16} \qquad (C.2)$$

for staggered tube arrangement (Fig. C.1), and

$$f' = \left[0.044 + \frac{0.08 S_L/D_0}{\left(\frac{S_T - D_0}{D_0} \right)^{0.43+1.13 D_0/S_L}} \right] \left(\frac{G_{max} D_0}{\mu_b} \right)^{-0.15} \qquad (C.3)$$

for in-line tube arrangements (Fig. C.2).
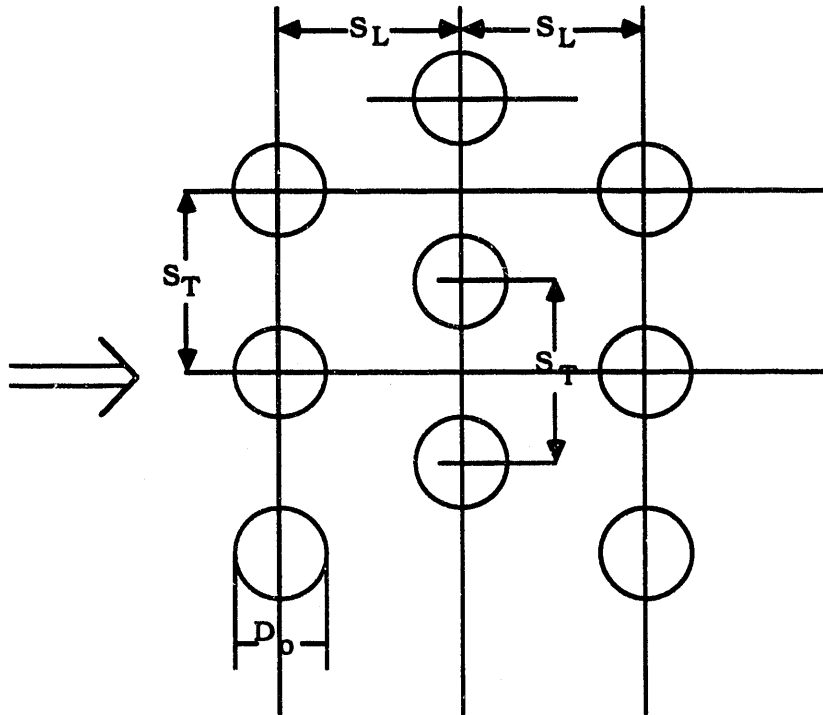
Fig. C.1. Nomenclature for a staggered tube arrangement
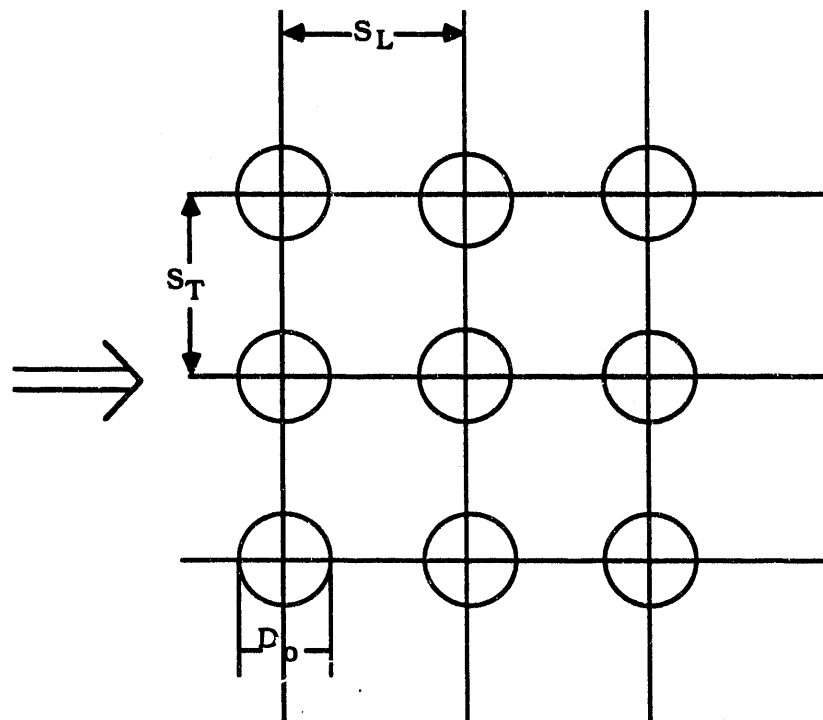
Fig. C2. Nomenclature for in-line tube arrangement

In Eqs. C.2 and C.3,

D_0 = outside diameter of tube, m,

S_T = transverse pitch, m, and

S_L = longitudinal pitch, m.

C.3 Sudden Enlargement and Contraction

Pressure loss due to abrupt change in a flow area is generally expressed in terms of the loss coefficient K.

$$\Delta p = K_1 \frac{1}{2}\rho v_1^2 \tag{C.4}$$

$$= K_2 \frac{1}{2}\rho v_2^2 . \tag{C.5}$$

where K_1 and K_2 are the pressure loss coefficients, and v_1 and v_2 refer to the velocity in smaller and larger cross sec ions, respectively.

For abrupt expansion, the loss coefficient K is given by the expression[C.2-C.3]

$$K_1 = \left(1 - \frac{A_1}{A_2}\right)^2 . \tag{C.6}$$

where A_1 and A_2 are the small and large areas, as shown in Fig. C.3. If the abrupt expansion is modeled as shown in Fig. C.4, the reference velocity used in COMMIX to evaluate pressure drop corresponds to the velocity in the larger cross section. Therefore, we must use Eq. C.5 with the loss coefficient K_2, given by

$$K_2 = \left(\frac{A_2}{A_1} - 1\right)^2 . \tag{C.7}$$

For abrupt contraction, as shown in Figs. C.5 and C.6, the values of the loss coefficient are presented in Table C.1, which is taken from Ref. C.4.

C.4 Venturi, Nozzle, and Orifice

C.4.1 Venturi

For flow through venturi, the pressure loss can be determined from

$$\Delta p_{loss} = K_1 \frac{1}{2}\rho v_1^2 \tag{C.8}$$

$$= K_2 \frac{1}{2}\rho v_2^2 . \tag{C.9}$$

where K_1 and K_2 are the loss coefficients of kinetic energy in the small and large cross sections, respectively.

The loss coefficients for venturi, shown in Figs. C.7 and C.8, are given respectively by
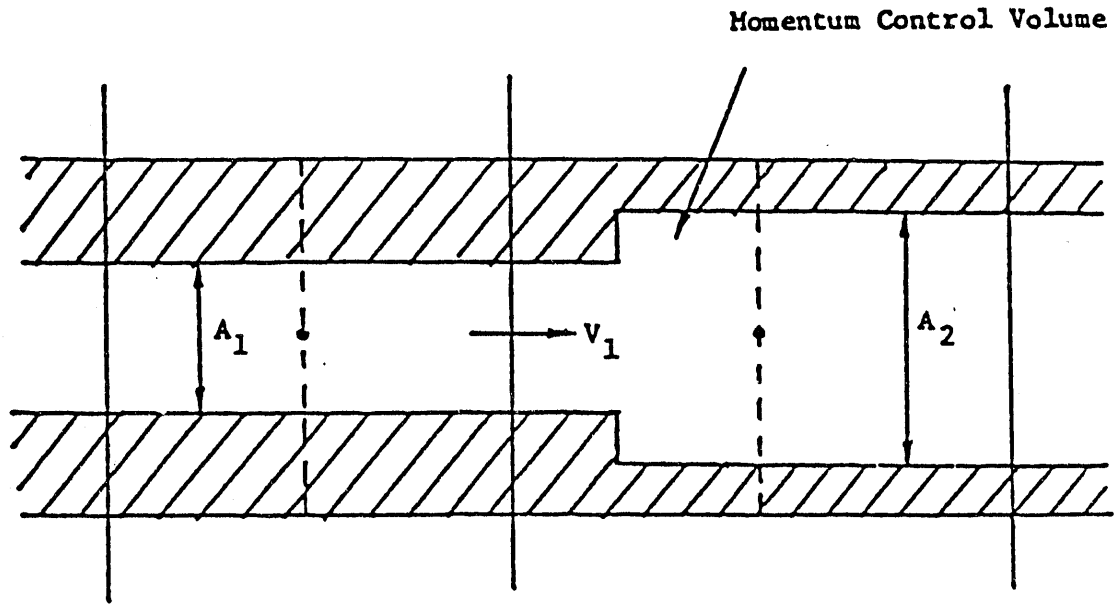
Fig. C.3. Sudden enlargement with reference velocity V_1
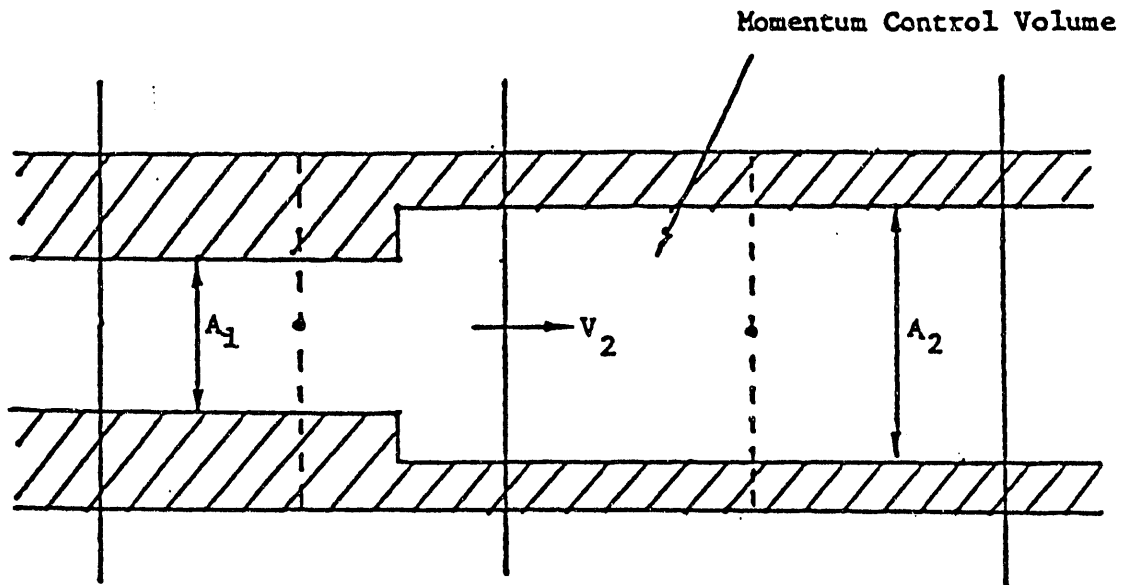
Fig. C.4. Sudden enlargement with reference velocity V_2
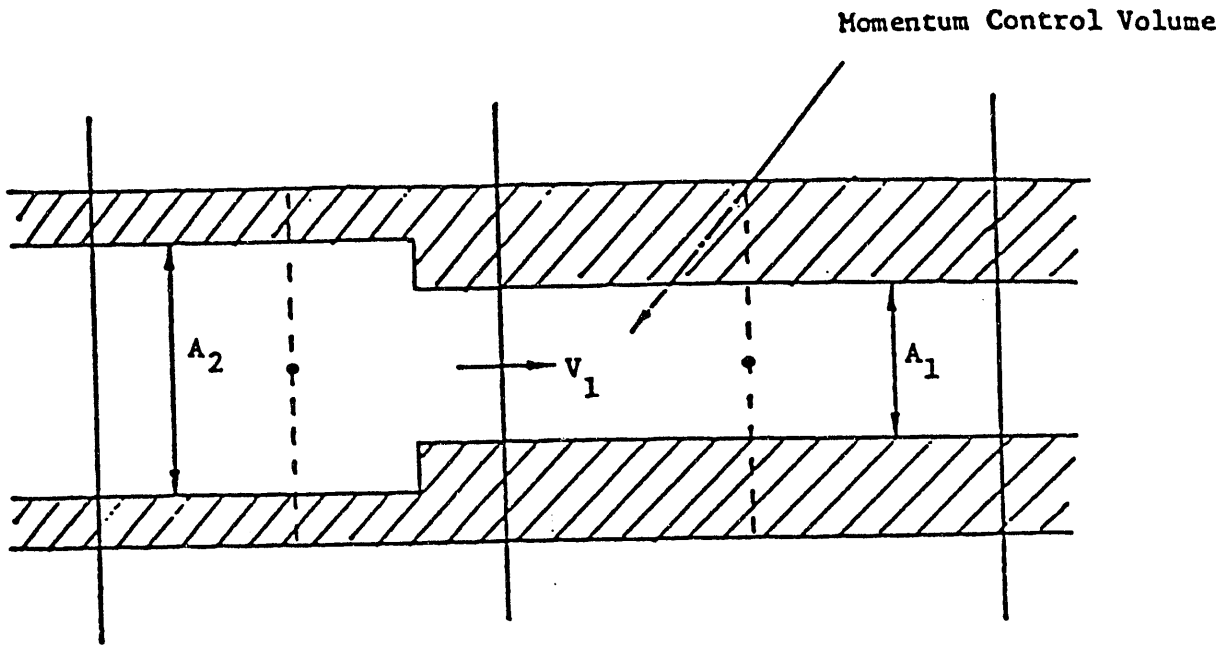
Fig. C.5. Sudden contraction with reference velocity V_1
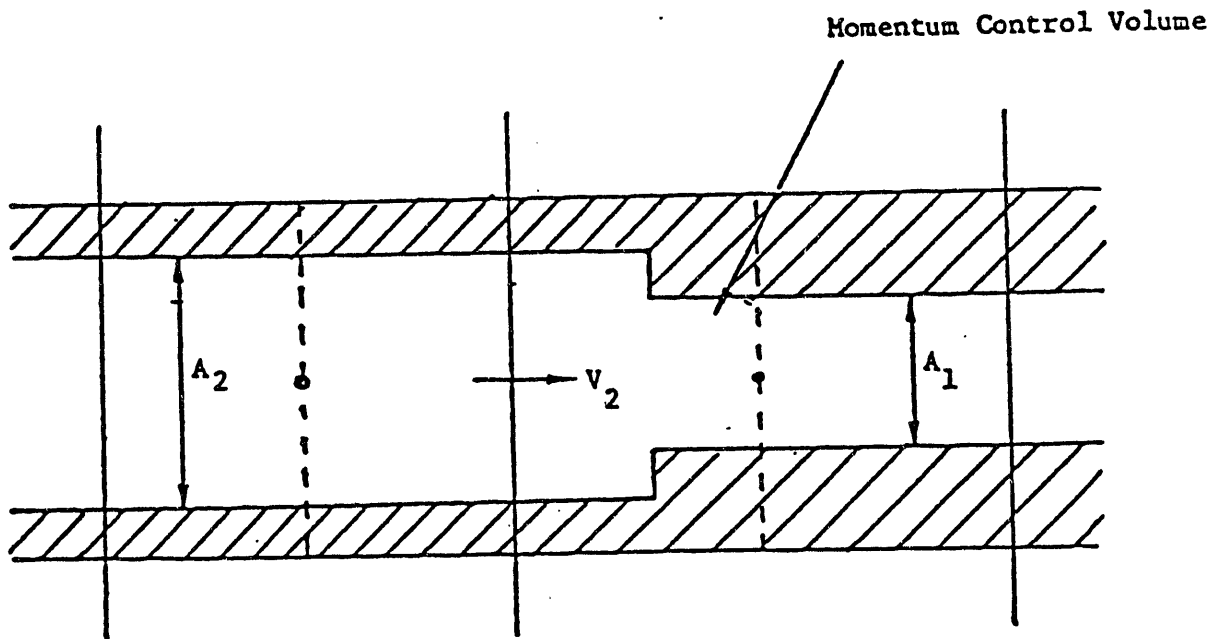
Fig. C.6. Sudden contraction with reference velocity V_2

Table C.1. Loss coefficients for sudden contraction[a]

A_1/A_2	C_c	K_1	K_2
0.1	0.624	0.363	36.375
0.2	0.632	0.339	8.475
0.3	0.643	0.308	3.422
0.4	0.659	0.268	1.675
0.5	0.681	0.219	0.876
0.6	0.712	0.164	0.456
0.7	0.755	0.105	0.214
0.8	0.813	0.053	0.083
0.9	0.892	0.015	0.019
1.0	1.0	0	0

[a]Source: Ref. C.4

$$K_1 = \left[1 - \left(\frac{A_1}{A_2} \right)^2 \right] \left(\frac{1}{C_V^2} - 1 \right) \tag{C.10}$$

and

$$K_2 = \left[\left(\frac{A_2}{A_1} \right)^2 - 1 \right] \left(\frac{1}{C_V^2} - 1 \right), \tag{C.11}$$

where the velocity coefficient c_V is a function of Reynolds number $(\rho v_1 D_1 / \mu)$, as listed in Table C.2. The Reynolds number is based on the velocity and diameter of the small cross section.

C.4.2 Nozzle and Orifice

For flow through a nozzle and orifice, shown in Figs. C.9 and C.10, the pressure loss is determined from

$$\Delta p = K \frac{1}{2} \rho v^2 , \tag{C.12}$$

where

$$K = \frac{1}{C^2} \left(\frac{A_2}{A_1} \right)^2 . \tag{C.13}$$
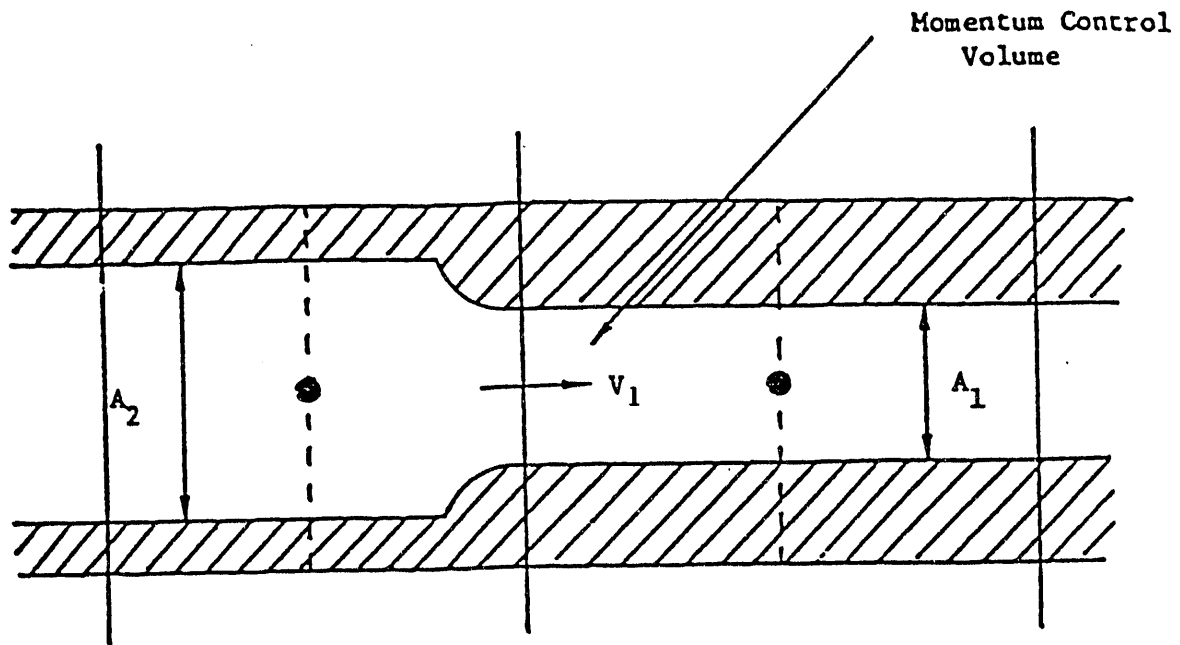
Fig. C.7. Venturi in a momentum control volume, where the loss
coefficient is defined by Eq. C.10
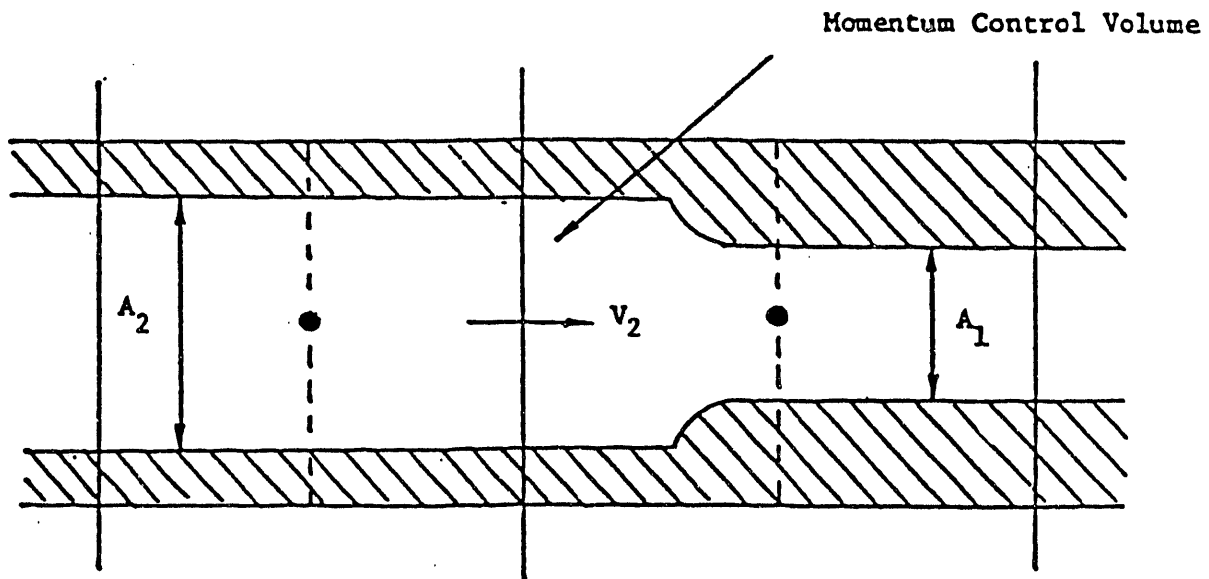
Fig. C.8. Venturi in a momentum control volume, where the loss
coefficient is defined by Eq. C.11

Table C.2. Velocity coefficients c_v for venturi[a]

$Log_{10}Re$	c_v
3.2	0.9
3.5	0.925
4.0	0.950
4.5	0.966
5.0	0.977
5.5	0.985
6.0	0.989
6.5	0.992

[a]Source: Ref. C5
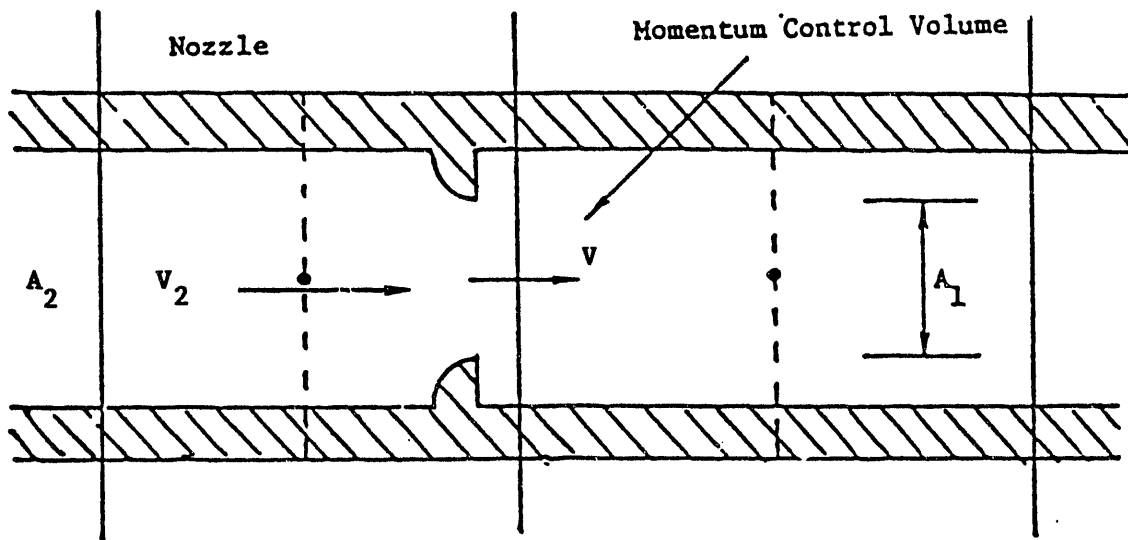
Fig. C.9. Nozzle in a momentum control volume
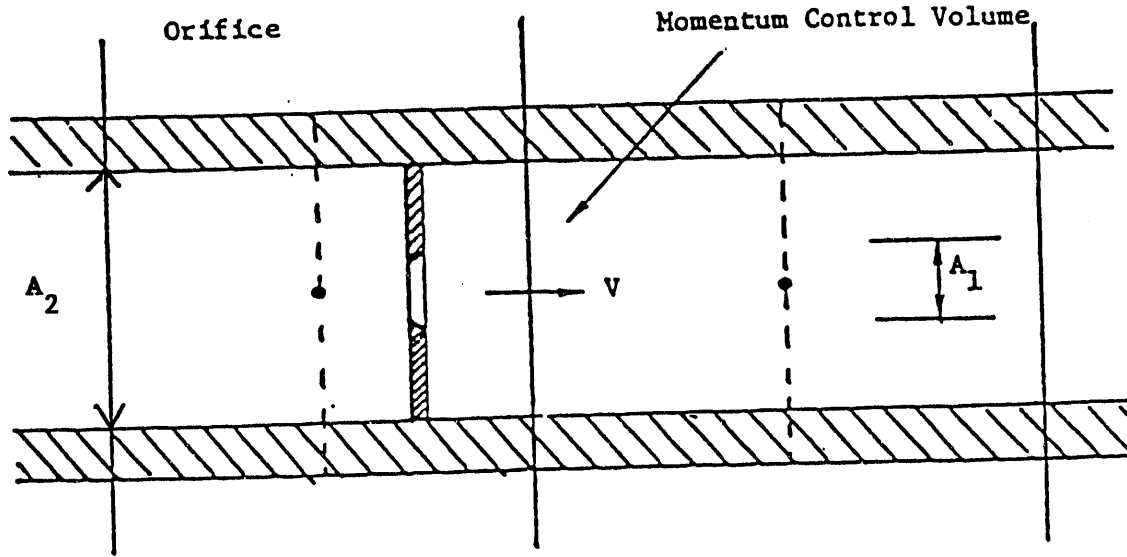
Fig. C.10. Orifice in a momentum control volume

Here, the discharge coefficient C is a function of the area ratio and Reynolds number. The Verein Deutsche Ingeniere (VDI) has published curves for C for the German standard nozzles and orifices. They are shown in Figs. C.11 and C.12. Note that the Reynolds numbers in both figures are based on the diameter and undisturbed velocity upstream of the nozzle or orifice.

C.5 Submerged Body

The pressure loss due to a submerged object, shown in Fig. C.13, is given by

$$\Delta p = C_D \frac{A_p}{A_o}\left(\frac{1}{2}\rho v^2\right).$$

(C.14)

Here, A_p is the projected area of a submerged object in a plane normal to the flow direction, A_o is the flow area, and C_D, the drag coefficient, is a function of Reynolds number based on the undisturbed velocity v_∞ and the object diameter D. Figure C.14 gives the variation of C_D with Reynolds number for several common shapes.
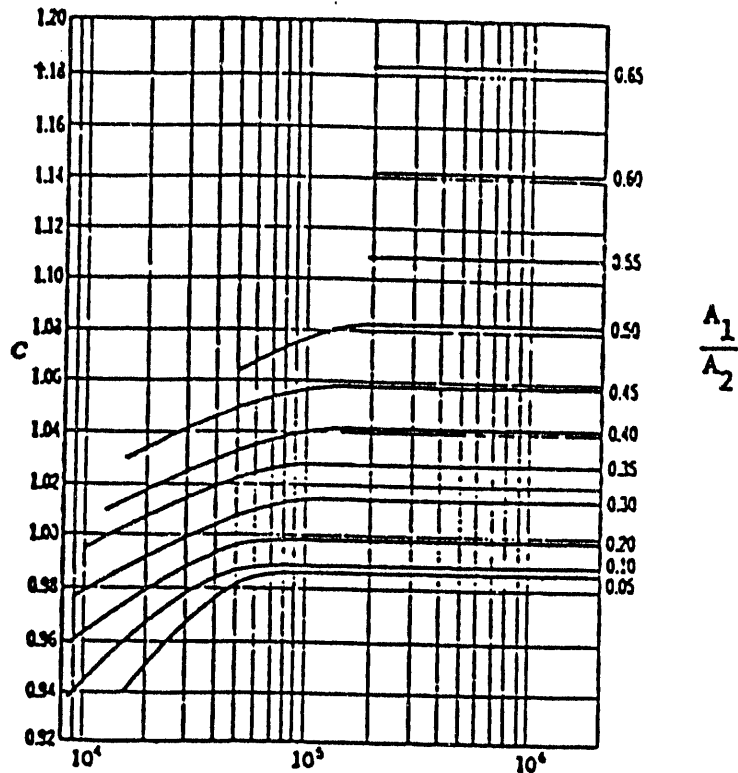
$$Re = \rho v_2 D_2 / \mu, \quad D_2 = \left(\frac{4A_2}{\pi}\right)$$

Fig. C.11. *Discharge coefficient for VDI nozzle*
(Source: Ref. C.4)
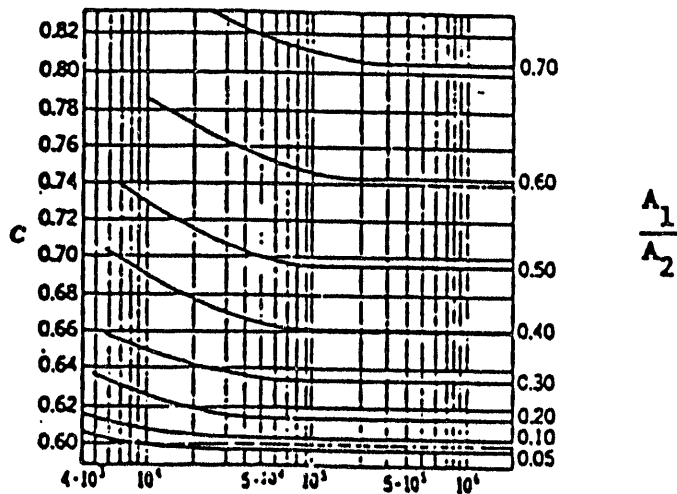
$$Re = \frac{\rho v_2 D_2}{\mu}$$

Fig. C.12. *Discharge coefficient for VDI orifice*
(Source: Ref. C.4)
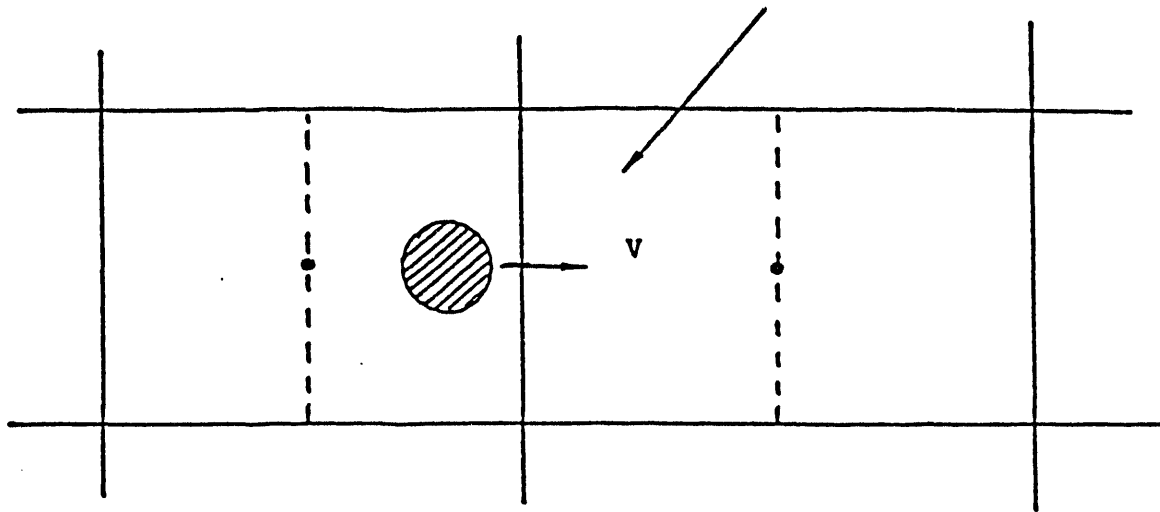
Fig. C.13. Submerged object in a momentum control volume
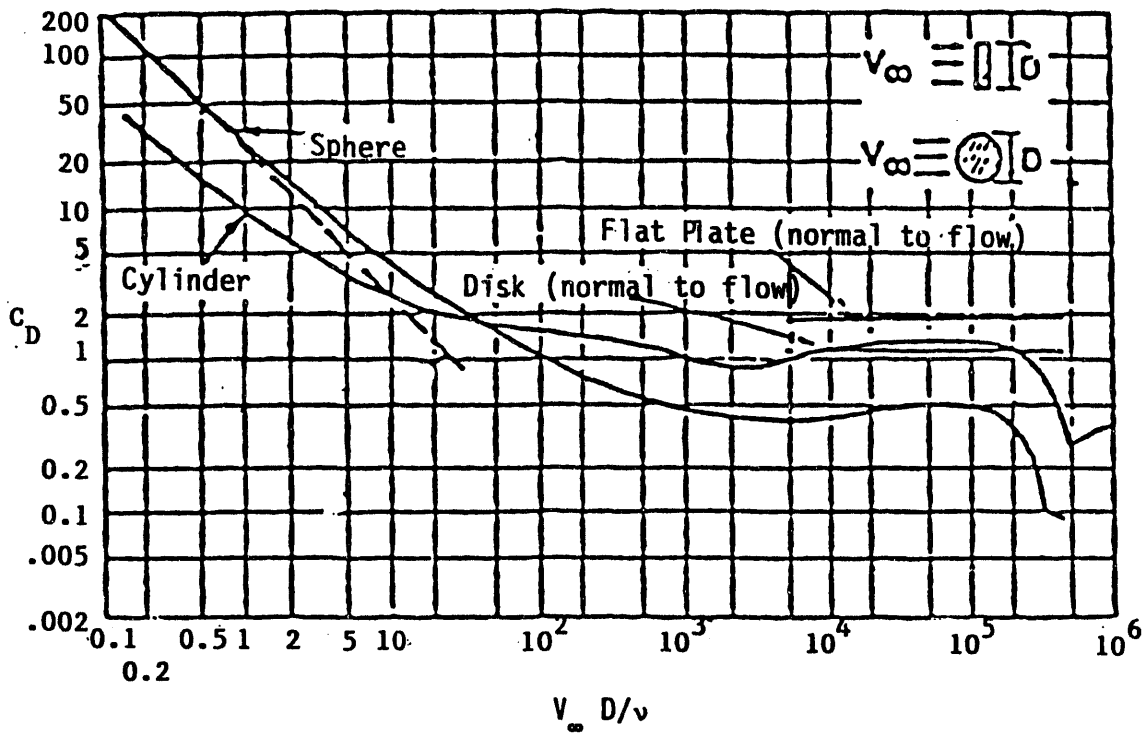
Fig. C.14. Drag coefficient for several simple shapes
(Source: Ref. C.4)

C.6 Straight Duct

For flow through a straight duct, Fig. C.15, the pressure loss is expressed as

$$\Delta p = \frac{L}{d_h}\left(\frac{1}{2}\rho v^2\right) f .$$
(C.15)

Here, L is the length of the control volume, d_h is the hydraulic diameter, and the friction factor f is a function of Reynolds number.

- **Laminar Flow**

  For a circular duct, the fully developed friction factor is given by

$$f = \frac{64}{Re} .$$
(C.16)

  The fully developed friction factor for a family of rectangular ducts ranging from a square to flow between two parallel plates is plotted in Fig. C.16.

- **Turbulent Flow**

  For turbulent flow in a straight duct, the friction factor given by Blasius[C.7] is

$$f = \frac{0.3164}{Re^{0.25}} ,$$
(C.17)

where

$$Re = \rho v f_h/\mu .$$
(C.18)

The Blasius formula is valid for $Re < 2 \times 10^5$.

C.7 Pipe Fittings

The pressure loss due to pipe fittings is commonly expressed by

$$\Delta p = K \frac{1}{2}\rho v^2 .$$
(C.19)

The head loss coefficients K for typical fittings, published by Crane Company,[C.8] are listed in Table C.3.

C.8 Concluding Remarks

In Appendix C, we have presented a set of pressure loss correlations for the convenience of COMMIX users. For geometries not included here, Refs. C.9 and C.10 may be consulted.

If experimental data are available for any special geometry under consideration, it is preferable to use the data rather than the correlations.
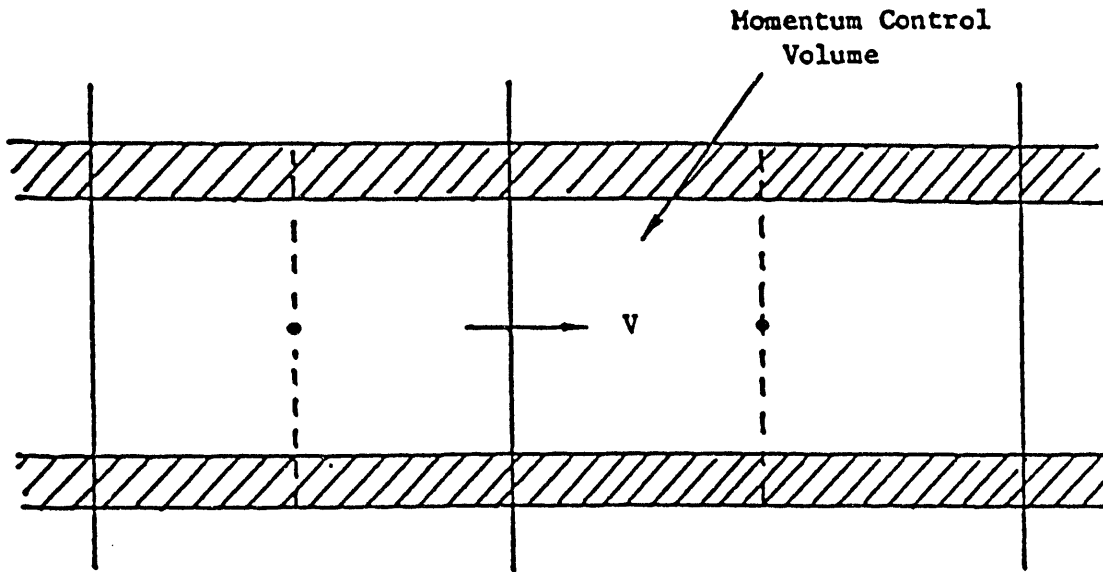
Fig. C.15   Straight duct in a momentum control volume
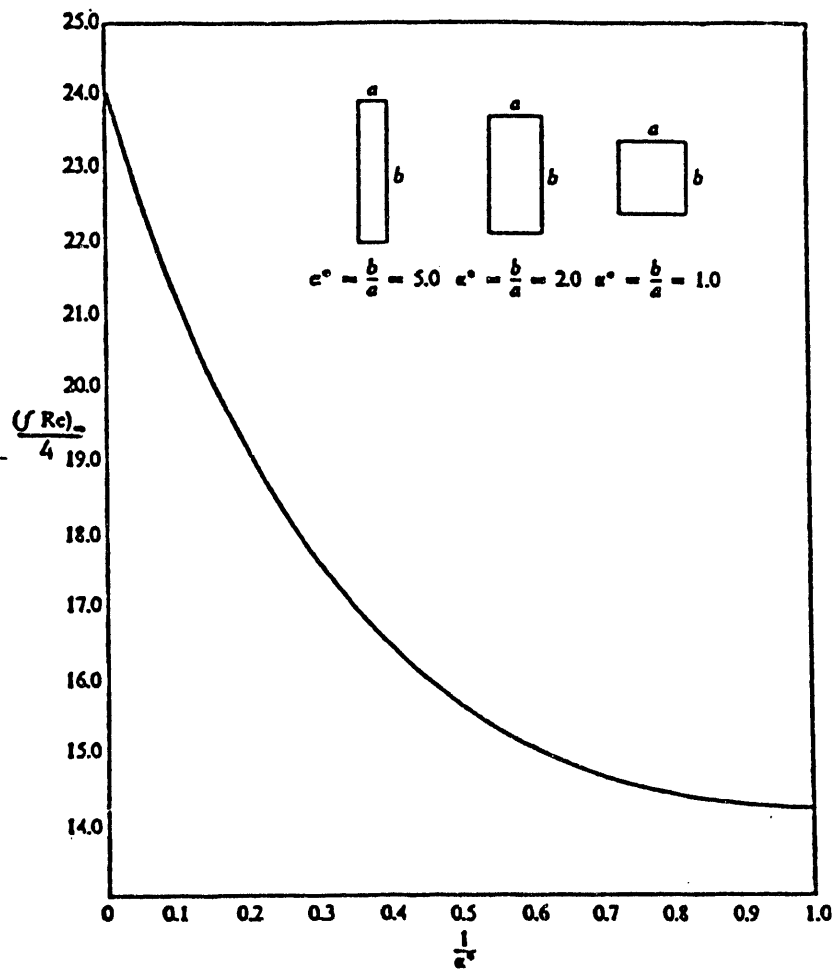
Fig. C.16. Friction coefficients for fully developed laminar
flow in rectangular tubes (Source: Ref. C.6)

Table C.3. Head loss coefficients K for various fittings

Fitting	K
Globe valve (fully open)	10.0
Angle valve (fully open)	5.0
Swing check valve (fully open)	2.5
Gate valve (fully open)	0.19
Close return bend	2.2
Standard tee	1.8
Standard elbow	0.9
Medium sweep elbow	0.75
Long sweep elbow	0.60

References for Appendix C

C.1. M. Jakob, *Heat Transfer and Flow Resistance in Cross Flow of Gases over Tube Banks*, Trans. ASME, **60**, 384 (1938).

C.2 Y. S. Tang, R. D. Coffield, Jr., and R. A. Markley, *Thermal Analysis of Liquid Metal Fast Breeder Reactors*, Published by American Nuclear Society (1978).

C.3 A. K. Agrawal and M. Khatib-Rahbar, *Dynamic Simulation of LMFBR Systems*, Atomic Energy Review 18(2):329–552 (1980).

C.4. V. L. Streeter and E. B. Wylie, *Fluid Mechanics*, McGraw Hill, New York (1975).

C.5. J. C. Hunsaker and B. G. Rightmire, *Engineering Applications of Fluid Mechanics*, McGraw Hill, New York (1947).

C.6. W. M. Kays, *Convective Heat and Mass Transfer*, McGraw Hill, New York (1966).

C.7. H. Blasius, *Das Ahnlichkeitsgesetz bei Reibungsvorgängen in Flüssigkeiten*, Forschg. Arb. Ing.-Wes. No. 134, Berlin (1913).

C.8 Crane Company, *Flow of Fluids*, Tech. Paper 409, Chicago (May 1942).

C.9. I. E. Idelchik, *Handbook of Hydraulic Resistance*, Hemisphere Publishing Corp., New York (1986).

C.10. *Applied Fluid Dynamics Handbook*, Van Nostrand Company, Inc., New York (1984).

Appendix D. Sample Problem: Steady-State Performance of a Power Plant Condenser in the Presence of Noncondensible Air

D.1 Purpose

The purpose of this appendix is to familiarize readers with the input/output structure of the code.

D.2 Problem Description

The simple problem presented here is a 1/2 shell of a typical nuclear power plant condenser. Figure D.1 shows the grid structures in the x, y, and z directions for the present coarse model. The J = 10 plane is a symmetrical plane. Figures D.2-D.4 show the grid layout at the I = 4, J = 7, and J = 9 planes, respectively. A steam/air mixture enters at the condenser top, i.e., K = 2 plane. It is explicitly assumed here that all the air leaked into the condenser is lumped and accounted for through the condenser inlet boundary condition. The steam from the feed pump turbine exhaust enters into the lower portion of the condenser at cells (2, 9, 4) and (2, 10, 4). The noncondensible air, with some steam, is extracted out of the condenser through the air extractor pipes.

All the condenser tubes are appropriately distributed over 38 tube channels as shown in Fig. D.2. Each tube channel is modeled into 5 nodes along the x-direction (I = 2 to I = 6). The cooling water enters at cell J = 6 and exits at cell I = 2.

D.3 Input

D.3.1 Working Fluids

Shell side: steam and air

Tube side: sea water

D.3.2 Condenser Tubes

Number of tubes: 10,734

Tube material: Titanium

Outside diameter: 0.02540 m (1.0 in.)

Inside diameter: 0.02398 m (0.944 in.)

Tube arrangement: staggered with pitch = 0.03175 m (1.25 in.)
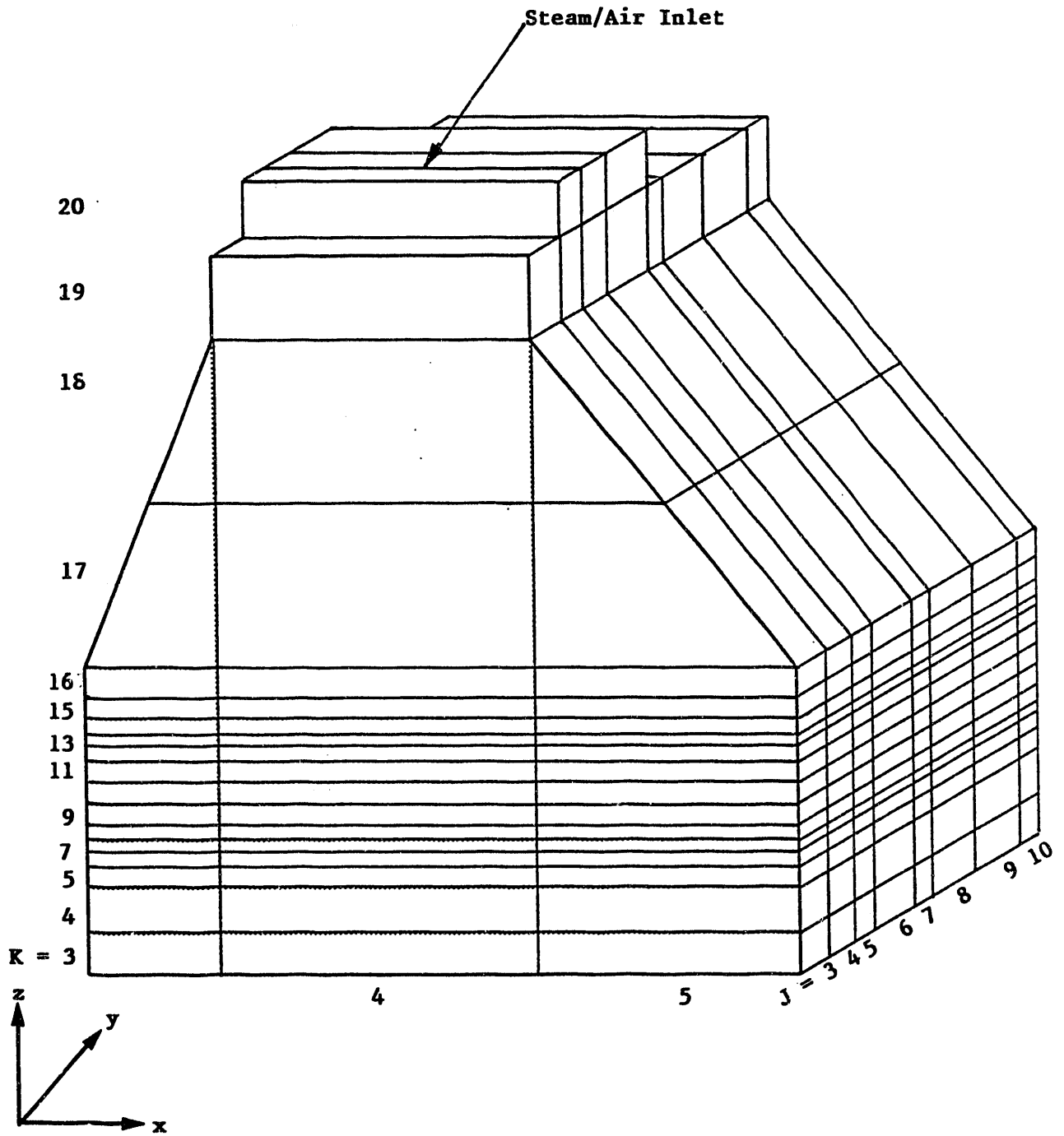
Fig. D.1. Grid structure of the sample problem
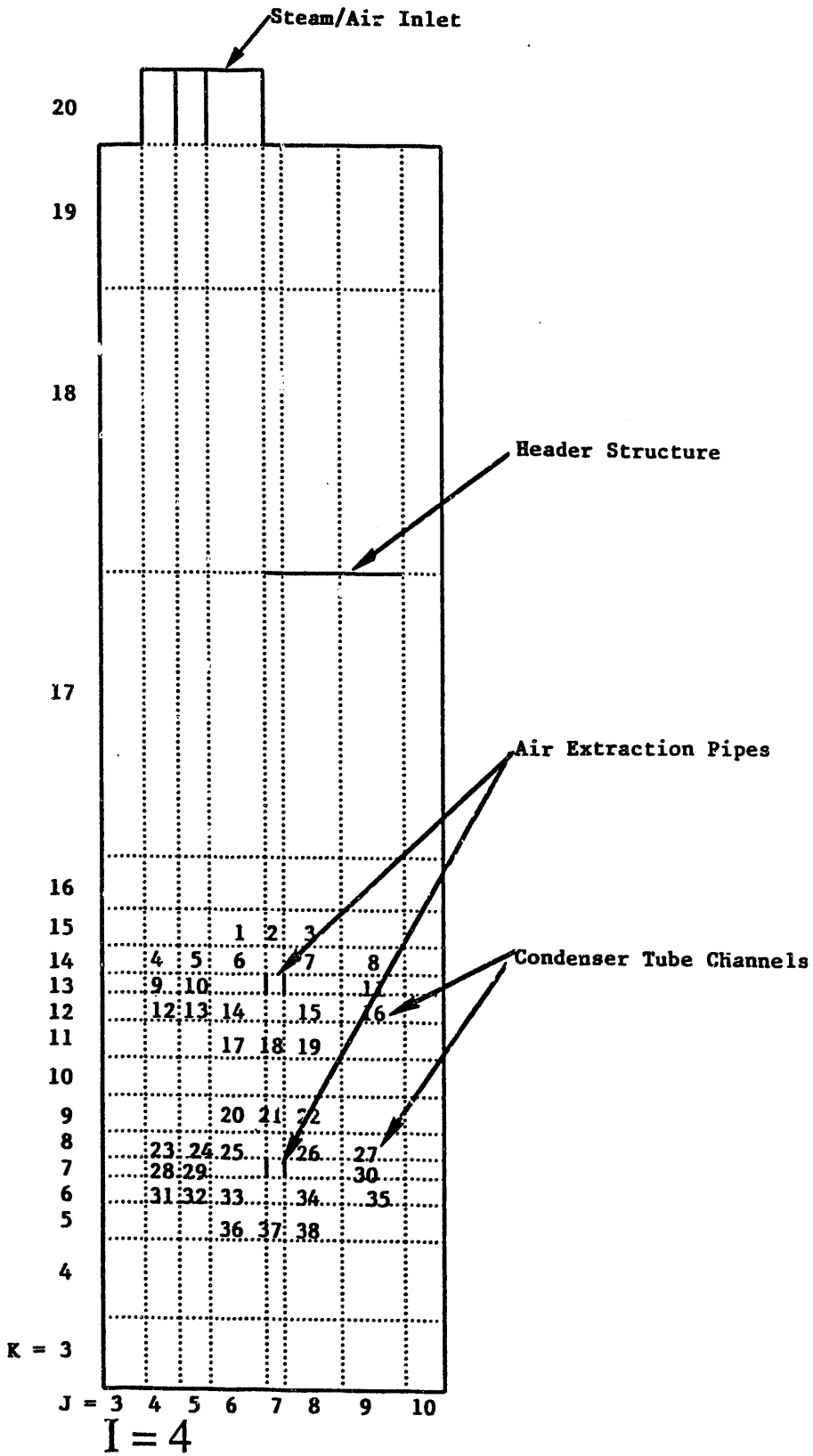
Fig. D.2. Grid layout at the I = 4 plane
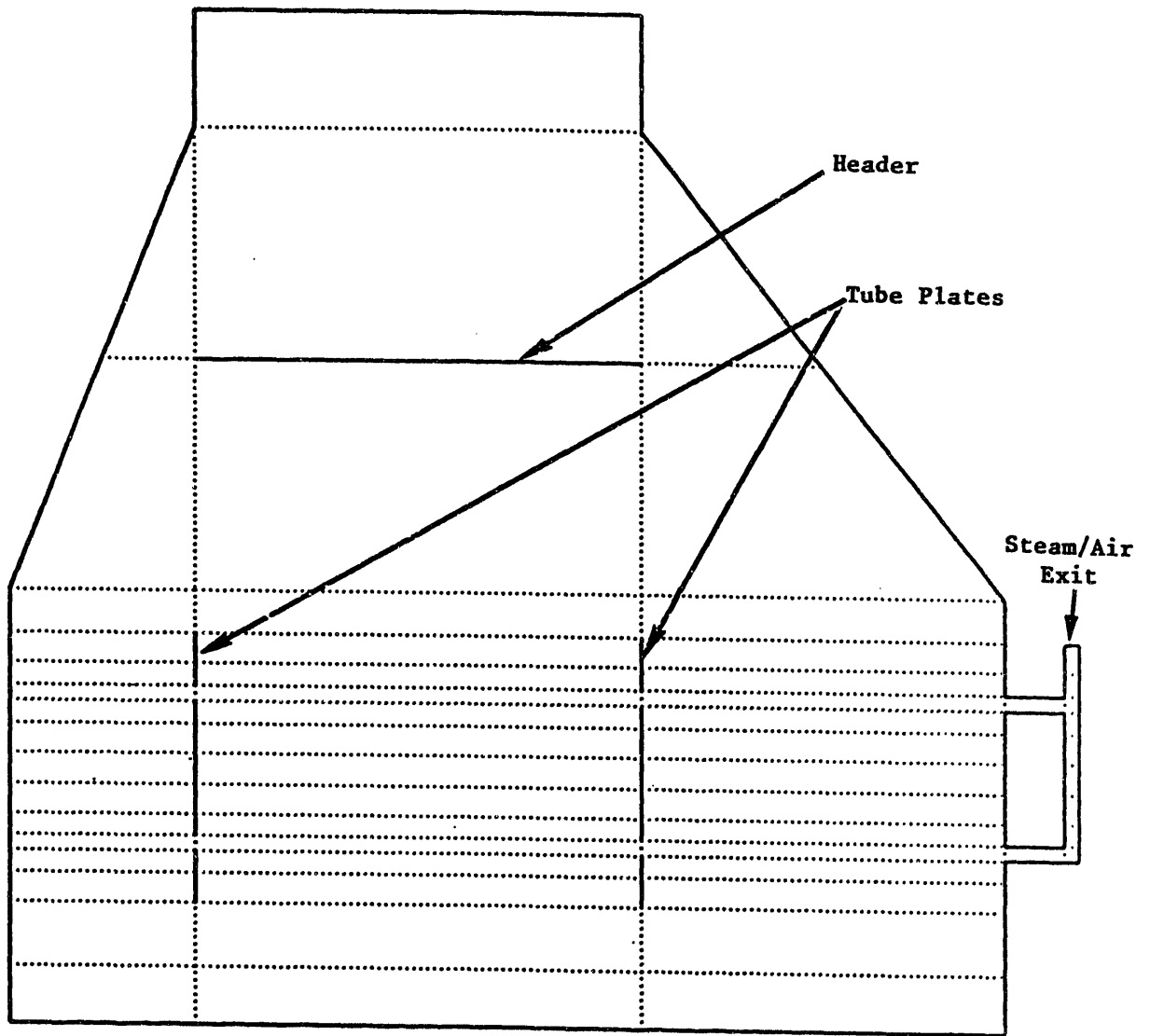
Fig. D.3. Grid layout at the J = 7 plane

Header Structure

Tube Plates

Inlet for Feed-
Water Pump
Turbine
Exhaust Flow

J = 9
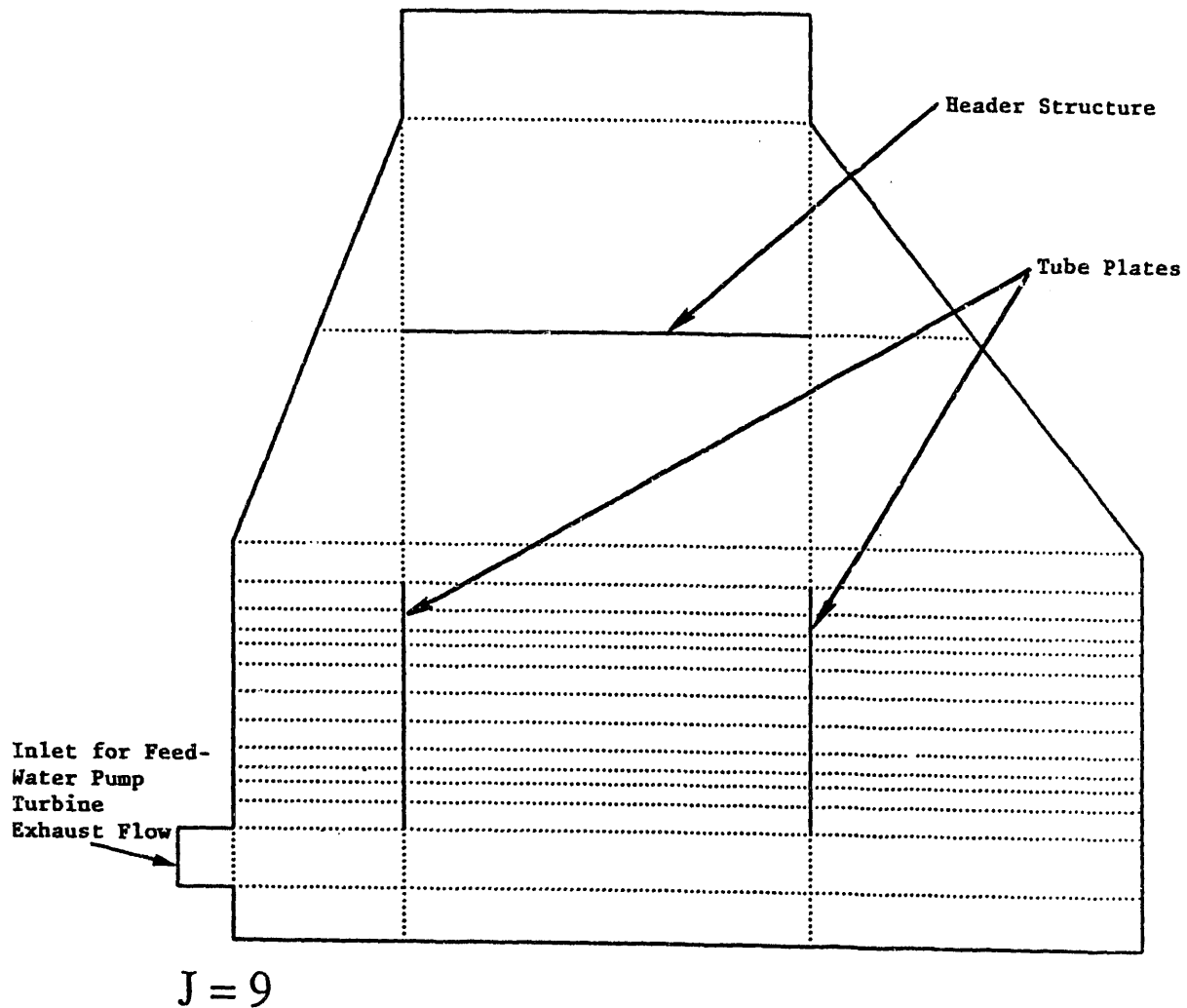
Fig. D.4. Grid layout at the J = 9 plane

D.3.3 Flow Boundary Conditions

Shell side

Inlet: Uniform steam and air mixture flow with air mass fraction equal to
4.105 x 10^{-5} enters through the top; constant steam mass flow
equal to 5.6 kg/s enters through the lower portion of the condenser.

Outlet: Constant mass flow of steam/air mixture, 0.0505 kg/s.

Walls: No slip.

Symmetric plane: Free slip.

Tube side

> Inlet: Constant velocity, 2.0028 m/s.

> Outlet: Continuity mass flow.

D.3.4 Thermal Boundary Conditions

Shell side

> Inlet: Constant temperature, 46.983°C at the top and 46.22°C at lower portion of the condenser.

> Outlet and Other Walls: Adiabatic.

Tube side

> Inlet: Constant temperature, 29°C.

> Outlet: Adiabatic.

D.3.5 Pressure Boundary Condition

Shell side

> Inlet: Constant pressure at top, 10,577 Pa.

Tube side

> Constant pressure at inlet, 94,006 Pa.

D.3.6 Force Resistance Correlations

Shell side

> Tube Bundle: Crossflow over staggered tubes by Jakob,[C.1] Eq. C.2.

> Steam/Air to Air Extraction Pipe: Sharp edge orifice, Eq. C.13.

> Flow in Air Extraction Pipe: Flow inside straight duct, Eqs. C.16 and C.17.

Tube side

> Flow inside straight duct, Eqs. C.16 and C.17.

D.3.7 Other Options

Shell Side

> Constant turbulence diffusivity model.

> DMIM (Direct matrix inversion method) solver.

D.4 Output

```
3-d power plant condenser
sample problem (with air)
inlet air mass fraction = 0.00004105
exit mass flow rate= 0.0505 kg/sec
```

```
&geom
itimer=1,
itube=1, ishear=1, ifoul=0, isubc=0, innuda=0,
nl1=460, nm1=408, nsurf=25,
imax= 7, jmax= 10, kmax= 20,
itres=1,
nforce=7,
istruc=1,

matot=2,
isolvr=1, nnzero= 2600, nspace= 17300, isolve=1,

dx=
 1.00000, 1.00000, 3.07658, 7.4549, 6.12458,
 1.00000, 0.25092,

dy=
 1.00000, 1.00000, 0.57468, 0.46774, 0.40559, 0.79529,
 0.25092, 0.79529, 0.87313, 0.54293,

dz=
 1.00000, 1.00000, 0.93138, 1.04363, 0.48919,
 0.34503, 0.25092, 0.34503, 0.48919, 0.50000,
 0.48516, 0.36971, 0.25092, 0.36971, 0.48516,
 0.70000, 3.79096, 3.79096, 1.92405, 1.00000,

xnorml= +0.9266189,-0.7779050,   +1.0,   -1.0,   0.0,
                     0.0,   0.0,   0.0,   0.0,   +1.0,
                     0.0,   0.0,   0.0,   0.0,   0.0,
                    -1.0,   1.0,   1.0,   0.0,   0.0,

ynorml=   0.0,   0.0,   0.0,   0.0,   0.0,
         +1.0,  -1.0,   0.0,   0.0,   0.0,
         +1.0,  -1.0,   0.0,  -1.0,   1.0,
         -1.0,   0.0,   0.0,   0.0,   0.0,
          0.0,  -1.0,   0.0,

znorml= -0.3760020,-0.6283819,   0.0,   0.0,   +1.0,
                     0.0,   0.0,  -1.0,   0.0,   0.0,
                     0.0,   1.0,  -1.0,   0.0,   0.0,
                     0.0,   0.0,   0.0,  -1.0,   -1.0,
```

```
&end
ireg-4.0911752  03 03 03 10 17 18   1  +x -z irregular wall
ireg-4.8732944  05 05 03 10 17 18   2  -x -z irregular wall
reg -1.0        03 03 03 08 03 03   3  shell wall +x
reg -1.0        03 03 03 10 04 04   3  shell wall +x
reg -1.0        04 03 04 10 05 05   3  shell wall +x
reg -1.0        05 05 08 10 03 03   4  shell wall -x
reg -1.0        05 05 05 07 03 06   4
reg -1.0        05 05 05 07 08 12   4
reg -1.0        04 04 07 07 14 16   4
reg -1.0        03 03 03 10 19 19   5  bottom wall +z
reg -1.0        03 05 03 03 16 16   6  shell wall +y
reg  8.7473938  03 03 03 03 17 17   6
reg  2.9157979  05 05 05 03 18 18   6
reg 17.413528   05 05 05 03 17 17   6
reg  5.8045094  05 05 10 10 18 18   7  shell symmetry -y
reg -1.0        03 04 10 03 16 16   7
reg  8.7473938  03 03 10 10 19 19   7
reg  2.9157979  05 05 10 10 17 17   7
reg 17.413528   05 05 10 10 18 18   7
reg  5.8045094  05 05 10 10 19 19   8  top -z
reg -1.0        04 04 07 07 19 19   8  top -z
reg -1.0        04 04 07 07 07 15   9  -x
reg -1.0        07 07 07 08 08 12  10  +x
reg -1.0        07 07 07 14 14 10  10  +x
reg -1.0        06 06 07 07 07 07  11  +y
reg -1.0        06 06 07 07 13 13  11  +y
reg -1.0        06 06 07 07 07 15  12  -y
reg -1.0        06 06 07 07 13 13  12  -y
reg -1.0        07 07 07 07 07 07  12  -y
reg -1.0        06 06 07 07 13 13  12  -y
reg -1.0        06 06 07 07 07 07  13  +z
reg -1.0        06 06 07 07 13 13  13  -z
reg -1.0        06 06 07 07 13 13  14  -z
reg -1.0        02 02 09 09 04 04  15  feed water steam +y
reg -1.0        02 02 10 10 04 04  16  feed water steam -y
reg -1.0        02 02 09 09 04 04  17  feed water steam +z
reg -1.0        02 02 09 09 04 04  18  feed water steam -z
reg -1.0        02 02 09 10 04 04  19  feed water steam +x
reg -1.0        04 04 06 06 20 20  20  inlet +x
reg -1.0        04 04 04 04 20 20  21  inlet -x
reg -1.0        04 04 04 04 20 20  22  inlet +y
reg -1.0        04 04 06 06 20 20  23  inlet -y
reg -1.0        04 04 04 06 15 15  24  inlet -z
reg -1.0        07 07 07 07 15 15  25  outlet -z
&data
 ncolum= 8,
 ifmass=2, ifener=1, ifmom=1,
 istate=0, trest=18000.,
 idtime=0, dt=0.1,
```

149

```
it=1,
eps3=1.e-5, eps1=1.0e-06, vconv=1.0,
omegav= 0.85, omegax = 0.85,
kflow  =   5*0,   0,   -3,   0,   0,   0,
           4*0,  4*0,   2,  4*0,  -4,  2,
veloc  =14*0.0, 4*0,54.518,5*0, 0,
ktemp  = 5*400, 5*400,
         8*400, 1, 4*400, 1, 400,
temp   = 14*46.983, 5*46.22, 6*46.983,
kpres(24)= 1,
pres(24) = 10577.0,

gravz= -9.8,  pres0= 10577.0,  temp0= 46.983,

ntmax=5000, ntprnt=-9999,
istpr=
        081004,  051004,
        061004,  111004,  121004,

nthpr=
        033018,  031004,  021004,  012007,  032007,  3042007,
        052007,  1072007,  2072007,  3072007,
        081004,  082007,  083007,
        2282007, 2281005,
        152007,  1512007,
        800001,  800002,  522007,  532007,

ncorr  = 3,
acorrl = 0.77736,        0.0,         64.0,
bcorrl = -0.16,          1.0,         -1.00,
ccorrl =  0.0,    1.343724581,         0.00,
acorrt = 0.77736,        0.0,         0.3164,
bcorrt = -0.16,          1.0,         -0.25,
ccorrt =  0.0,    1.343724581,         0.00,
reytrn = 2000.,         2000.,       1185.0,

icorr  = 2*1,     2*1,         2,       3,      3,
clenth = 2*0.01786, 2*0.0275,  -1.0,  -1.0,   -1.0,
reylen = 2*0.02933, 2*0.0254,   1.0, 0.254,  0.254,
forcef(1) = 1.00, 2.00,
forcef(3) = 1.00, 2.00,
forcef(5) = 1.00, 1.00, 1.00

ihtcor  = 31,      21,
htclen = 0.0239776, 0.0254,
htcmul =   1.0,     1.0,

heatc1 =  1.0,  3000.0,
heatc2 =  0.023,
heatc3 =  0.8,
heatc4 =  0.4,

c0ro =    0.0,     4.525e3,  1029.903,
c1ro =    0.0,       0.0,   -0.294550,
c2ro = 3.594e-3,     0.0,       0.0,

c0k =  0.0248,     16.44,    0.56788,
c1k = 6.75e-5,      0.0,    0.001082,
c2k =   0.0,        0.0,       0.0,

c0mu = 1.75e-5,     0.0,-2.6196371e-2,
```

```
c1mu =    4.02e-8,        0.0, 6.2049146e-5,
c2mu =      0.0,          0.0, 7.7178238,

turbv=5.0e-3,

c0h  =      0.0,        0.001,   7700.0,
c1h  =    1025.0,      543.54,   4000.0,

wtmol =    28.0,

matype= 22, 1,
mattab= 22, 1,102.3,
tablot= 4*30.0,      tabhit= 4*50.0,
&end
```

top bundle

```
1  yfor  03  05  05  05  11  11
1  yfor  03  05  08  08  11  11
1  yfor  03  05  03  03  12  14
1  yfor  03  05  06  07  12  12
1  yfor  03  05  09  09  12  14
1  yfor  03  05  05  05  13  13
1  yfor  03  05  08  08  13  13
1  yfor  03  05  06  07  14  14
1  yfor  03  05  05  05  15  15
1  yfor  03  05  08  08  15  15

2  yfor  03  05  07  07  11  11
2  yfor  03  05  04  05  12  12
2  yfor  03  05  08  08  12  12
2  yfor  03  05  04  04  13  13
2  yfor  03  05  04  05  14  14
2  yfor  03  05  08  08  14  14
2  yfor  03  05  06  07  15  15

3  zfor  03  05  06  08  10  10
3  zfor  03  05  07  07  11  11
3  zfor  03  05  04  05  11  11
3  zfor  03  05  09  09  11  11
3  zfor  03  05  06  06  12  13
3  zfor  03  05  08  08  13  13
3  zfor  03  05  04  05  14  14
3  zfor  03  05  07  07  14  14
3  zfor  03  05  09  09  14  15

4  zfor  03  05  06  06  11  11
4  zfor  03  05  08  08  11  11
4  zfor  03  05  05  05  12  13
4  zfor  03  05  09  09  12  12
4  zfor  03  05  06  06  14  14
4  zfor  03  05  08  08  14  14
```

bottom bundle

```
1  yfor  03  05  05  05  05  05
1  yfor  03  05  08  08  05  05
1  yfor  03  05  06  07  06  06
1  yfor  03  05  03  03  06  08
1  yfor  03  05  09  09  06  06
1  yfor  03  05  05  05  07  07
1  yfor  03  05  06  07  08  08
```

```
yfor  1   03  05  08  08  07  07
yfor  1   03  05  05  05  09  09
yfor  1   03  05  08  03  09  09

yfor  2   03  05  06  07  05  05
yfor  2   03  05  04  05  06  06
yfor  2   03  05  08  08  06  06
yfor  2   03  05  04  08  08  08
yfor  2   03  05  08  08  08  09
yfor  2   03  05  06  07  09

zfor  3   03  05  06  08  04  04
zfor  3   03  05  07  07  05  05
zfor  3   03  05  04  05  05  05
zfor  3   03  05  09  09  05  05
zfor  3   03  05  06  06  06  07
zfor  3   03  05  08  08  06  07
zfor  3   03  05  04  05  08  08
zfor  3   03  05  07  07  08  08
zfor  3   03  05  09  09  08  08
zfor  3   03  05  06  06  09  09

zfor  4   03  05  06  06  05  05
zfor  4   03  05  08  08  05  05
zfor  4   03  05  04  04  06  07
zfor  4   03  05  09  09  06  07
zfor  4   03  05  06  06  08  08
zfor  4   03  05  08  08  08  08

zfor  5   03  05  07  07  12  13
zfor  5   03  05  07  07  06  07

xfor  6   03  06  07  07  07  07
xfor  6   03  06  07  07  13  13
zfor  7   07  07  07  07  07  14
```

****
                          thermal structures input
****

                    top bundle

&t   n= 1, ixyz= 1, rodfr=-1155.285931,   outr=0.0127,nrow=5,   &end
&f   iht=02,   hyd=0.0254,   &end
&m   mi= 2,   np=2,   dr=3.556e-4,   q=0.0,   &end
&f   iht= 1,   hyd=0.0239776,   &end

                    bottom bundle

&t   n= 2, ixyz= 1, rodfr=-1169.623145,   outr=0.0127,nrow=5,   &end
&f   iht=02,   hyd=0.0254,   &end
&m   mi= 2,   np=2,   dr=3.556e-4,   q=0.0,   &end
&f   iht= 1,   hyd=0.0239776,   &end

                                        top tubes shell side
```
out   1   03  05  04  05  12  14
out   1   03  05  06  06  11  12
out   1   03  05  06  06  14  15
out   1   03  05  07  07  11  11
out   1   03  05  07  07  15  15
out   1   03  05  08  08  11  12
```

```
                                                 top tubes tube side
out  1  03  05  08  08  14  15
out  1  03  05  09  09  12  14
in   1  03  05  04  05  12  14
in   1  03  05  06  06  11  12
in   1  03  05  06  07  14  15
in   1  03  05  07  07  11  11
in   1  03  05  07  08  15  15
in   1  03  05  08  08  11  12
in   1  03  05  08  09  14  15
in   1  03  05  09  09  12  14

                                                 r-ot tubes shell side
out  2  03  05  04  06  06  08
out  2  03  05  06  05  05  06
out  2  03  05  06  06  08  09
out  2  03  05  07  05  05  05
out  2  03  05  07  07  09  09
out  2  03  05  08  08  05  06
out  2  03  05  08  08  08  09
out  2  03  05  09  06  06  08

                                                 bot tubes tube side
in   2  03  05  04  05  05  06
in   2  03  05  06  06  06  08
in   2  03  05  06  07  05  05
in   2  03  05  07  07  08  09
in   2  03  05  07  08  05  06
in   2  03  05  08  08  08  09
in   2  03  05  08  06  06  08
in   2  03  05  09  08  08  08

************* end of thermal structure input ************************
********************************************************************

                                                 irregular #1
alz  0.500   03  03  03  10  17  17
aly  0.750   03  03  03  10  17  17
aly  0.250   03  03  03  10  18  18
al   0.750   03  03  03  10  17  17
al   0.250   03  03  03  10  18  18

alz  0.500   05  05  03  10  17  17
aly  0.750   05  05  03  10  17  17
aly  0.250   05  05  03  10  18  18
al   0.750   05  05  03  10  17  17
al   0.250   05  05  03  10  18  18

alz  0.0000  03  05  07  09  17  17

                                                 irregular #2
alx  0.7500  03  04  07  07  17  17
alx  0.9306  03  04  07  08  18  18
alx  0.6599  03  04  08  08  17  17
alx  0.5208  03  03  08  18  18  18
alx  0.6944  03  04  09  09  17  17
alx  0.7361  03  03  09  09  18  18

aly  0.6377  03  03  06  06  17  17
aly  0.8056  04  04  06  06  17  17
aly  0.6377  05  05  06  06  17  17
aly  0.5729  03  03  07  07  17  17
aly  0.6944  04  04  07  07  17  17
aly  0.5729  05  05  07  07  17  17
aly  0.1823  03  03  07  08  18  18
```

aly	0.8750	04	04	07	07	18	18
aly	0.1823	05	05	07	07	18	18
aly	0.5377	03	03	08	08	17	17
aly	0.6389	04	04	08	08	17	17
aly	0.5377	05	05	08	08	17	17
aly	0.0866	03	03	08	08	18	18
aly	0.4583	04	04	08	08	18	18
aly	0.0866	05	05	08	08	18	18
aly	0.6597	03	03	09	09	17	17
aly	0.6944	04	04	09	09	17	17
aly	0.6597	05	05	09	09	17	17
aly	0.6597	03	03	09	09	18	18
aly	0.6944	04	04	09	09	18	18
aly	0.6597	05	05	09	09	18	18
al	0.6094	03	03	07	07	17	17
al	0.7500	04	04	07	07	17	17
al	0.6094	05	05	07	07	17	17
al	0.2171	03	03	07	07	18	18
al	0.9306	04	04	07	07	18	18
al	0.2171	05	05	07	07	17	17
al	0.5498	03	03	08	08	17	17
al	0.6597	04	04	08	08	17	17
al	0.5498	05	05	08	08	18	18
al	0.1025	03	03	08	08	18	18
al	0.5208	04	04	08	08	18	18
al	0.1025	05	05	09	09	18	18
al	0.6944	03	03	09	09	17	17
al	0.5787	04	04	09	09	17	17
al	0.5787	05	05	09	09	17	17
al	0.1639	03	04	09	09	18	18
al	0.7361	04	04	09	09	18	18
al	0.1639	05	05	09	09	18	18
alx	0.0	03	03	04	09	05	15
alx	1.0	03	03	05	07	07	07
alx	1.0	03	03	07	07	13	13
al	.585392022	03	05	06	08	11	15	tube plates
al	.585392022	03	05	04	09	12	14	
al	1.0	03	05	07	07	13	14	top bundle
al	1.0	03	05	06	08	11	13	
aly	.585392022	03	05	05	08	12	15	top bundle
aly	.585392022	03	05	04	07	13	13	air pipe sides
aly	0.0	03	05	06	08	10	15	
alz	.585392022	03	05	04	09	11	14	
alz	.585392022	03	05	07	07	12	13	air pipe slots
alz	.000408698	03	05	07	07	12	13	
al	.592656796	03	05	06	08	05	09	bottom bundle
al	.592656796	03	05	04	09	06	08	
al	1.0	03	05	07	07	06	08	
al	1.0	03	05	06	08	07	07	bottom bundle
aly	.592656796	03	05	05	08	05	09	
aly	.592656796	03	05	03	09	06	08	air pipe sides
aly	0.0	03	05	06	07	07	07	
alz	.592656796	03	05	06	08	04	09	
alz	.592656796	03	05	05	09	05	08	

```
alz .000408698   03  05  07  07  06  07            air pipe slots

aly 0.0          02  02  09  09  04  04            feedwater inlet

p   10577.00     03  05  03  10  03  20            shell side
p   10577.00     06  06  07  07  07  07            shell side
p   10577.00     06  06  07  07  13  13            shell side
p   10577.00     07  07  07  07  07  15            shell side

flow-.05049999   07  07  07  07  15  15  25        bottom air ejector
?flow-.10100000  07  07  07  07  15  15  25        bottom air ejector
flow 3.4569180   02  02  09  09  04  4   19        steam turbine exhaust
flow 2.1495820   02  02  10  10  4   4   19        steam turbine exhaust
?xmsb0.00008210  04  04  03  04  20  20  24        inlet air
xmsb0.00004105   04  04  04  05  20  20  24   2    inlet air
aly 0.0          04  04  04  04  20  20        2   feedwater inlet
&tubs
     ntubes=38, nmcell=190,
     epstb=1.0e-06, itertb=2,
     iopt(1)=1, 1, 0, 1, 1, 0, 0, 1, 0, 0,
             0, 0, 0, 0, 0, 1,
     tem0tb=37.0,
     vel0tb=2.0025777,   pre0tb=94006.4,
     kpretb(1)=1,0,
     ulbtb1=38*2.0025777,  tlbtb1=38*29.0,
     ulbtb2=38*2.0025777,  tlbtb2=38*29.0,
     atbl=64.0, btbl=-1.00, ctbl=0.0, retrn=1185.0,
     atbt=0.3164, btbt=-0.25, ctbt=0.0, forctb=0.25, facv=1.0,
     imatb=3,
     dmtb = 38*0.0239776,
     tubeno=19*-1155.285931, 19*-1169.623145,
&end
tube  1   2  6  6  6  15  15  -1
tube  2   2  6  7  7  15  15  -1
tube  3   2  6  8  8  15  15  -1
tube  4   2  6  4  5  14  14  -1
tube  5   2  6  5  6  14  14  -1
tube  6   2  6  8  8  14  14  -1
tube  7   2  6  9  9  14  14  -1
tube  8   2  6  4  4  14  14  -1
tube  9   2  6  5  5  13  13  -1
tube 10   2  6  9  9  13  13  -1
tube 11   2  6  4  5  12  12  -1
tube 12   2  6  5  5  12  12  -1
tube 13   2  6  6  6  12  12  -1
tube 14   2  6  8  8  12  12  -1
tube 15   2  6  9  9  12  12  -1
tube 16   2  6  6  6  11  11  -1
tube 17   2  6  7  7  11  11  -1
tube 18   2  6  8  8  11  11  -1
tube 19   2  6  6  6  11  11  -1
tube 20   2  6  7  7  9   9   -1
tube 21   2  6  8  8  9   9   -1
tube 22   2  6  4  4  08  08  -1
tube 23   2  6  5  5  08  08  -1
tube 24   2  6  6  6  08  08  -1
tube 25   2  6  8  8  08  08  -1
tube 26   2  6  9  9  08  08  -1
tube 27   2  6  8  8  08  08  -1
tube 28   2  6  4  4  07  07  -1
```

tube 29	2	6	5	5	7	7	1
tube 30	2	6	9	9	7	7	1
tube 31	2	6	4	4	8	8	1
tube 32	2	6	5	5	6	6	1
tube 33	2	6	6	6	6	6	1
tube 34	2	6	8	8	6	6	1
tube 35	2	6	9	9	6	6	1
tube 36	2	6	6	6	5	5	1
tube 37	2	6	7	7	5	5	1
tube 38	2	6	8	8	5	5	1

```
********* storage allocation variables *********

variable   value  <- - - - - description - - - - ->

igeom        0    geometry flag
ilmax       40    scratch space parameter
imax         7    cells in the x- or r-direction
isolve       1    energy equation solver flag
isolvr       1    pressure equation solver flag
istruc       1    thermal structure flag
iturke       0    turbulence model flag
jmax        10    cells in the y- or theta-direction
kmax        20    cells in the z-direction
matott       2    number of mass equations
mijk       264    scratch space parameter
nforce       7    number of force structures
nlct       920    number of component elements
nlft       460    number of fluid elements
nl1        460    number of surface elements
nmct       816    number of component cells
nmft       408    number of fluid cells
nm1        408    number of computational cells
nnon0     2600    maximum number of matrix non-zeros
nowpd        2    number of words in double precision variable
nowps        2    number of words in single precision variable
nparts       6    thermal structure partitions
nregts       2    thermal structure regions
nspace   17300    number of words in work space
nstruc       2    number of thermal structures
nsurts     228    number of ....
ntts       456    size of thermal structure storage
itube        1    tube-side flag
ntubes      38    total number of condenser tubes
nmcell     190    total number of cells in tube side

********* Sun-4/110 Truncation Error Estimate:        1.E-16 *********
```

```
COMMON /SPACE/ Storage Allocated:      159804 words.   (   639 Kbytes)
Beginning Address:    1189768     122788
Ending Address:       1828984     1be878
Total Storage Estimate: 1689 Kbytes
```

block length of common /space/ (determined from input)   96752   457   0   0   0   4406   58186

cells and surface elements have been counted.   check these values against your expected totals.

```
nm      32    irregular computational cells
nm1    408    computational cells (total)
nl      32    irregular surface elements
nl1    458    surface elements (total)
```

Time expended: 1.52 seconds.

********* grid summary **********

imax= 7 jmax= 10 kmax= 20

	x	dx	y	dy	z	dz
1	5.0000000E-01	1.0000000E+00	5.0000000E-01	1.0000000E+00	5.0000000E-01	1.0000000E+00
2	1.5000000E+00	1.0000000E+00	1.5000000E+00	1.0000000E+00	1.5000000E+00	1.0000000E+00
3	3.5382900E+00	3.0765800E+00	2.2873400E+00	5.7468000E-01	2.4656900E+00	9.3138000E-01
4	8.8040300E+00	7.4549000E+00	2.8085500E+00	4.6774000E-01	3.4530950E+00	1.0434300E+00
5	1.5593770E+01	6.1245800E+00	3.2452150E+00	4.0559000E-01	4.2194050E+00	4.8919000E-01
6	1.9156060E+01	1.0000000E+00	3.8456550E+00	7.9529000E-01	4.6365150E+00	3.4503000E-01
7	1.9781520E+01	2.5092000E-01	4.3687600E+00	2.5092000E-01	4.9344900E+00	2.5092000E-01
8			4.8918650E+00	529000E-01	5.2324650E+00	3.4503000E-01
9			5.7260750E+00	6.7313000E-01	5.6495750E+00	4.8919000E-01
10			6.4341050E+00	5.4293000E-01	6.1441700E+00	5.0000000E-01
11					6.6367500E+00	4.8516000E-01
12					7.0641850E+00	3.6971000E-01
13					7.3745000E+00	2.5092000E-01
14					7.6848150E+00	3.6971000E-01
15					8.1122500E+00	4.8516000E-01
16					8.7048300E+00	7.0000000E-01
17					1.0950310E+01	3.7909600E+00
18					1.4741270E+01	3.7909600E+00
19					1.7598775E+01	1.9240500E+00
20					1.9060800E+01	1.0000000E+00

********** surface-surface element summary **********

surface type	surface number	number of surface elements	unit normal vector		
irregular	1	16	0.9266 i	0.0000 j	-0.3760 k
irregular	2	16	-0.7779 i	0.0000 j	-0.6284 k
regular	3	118	-1.0000 i	0.0000 j	0.0000 k
regular	4	118	-1.0000 i	0.0000 j	0.0000 k
regular	5	24	0.0000 i	0.0000 j	1.0000 k
regular	6	49	0.0000 i	-1.0000 j	0.0000 k
regular	7	49	0.0000 i	0.0000 j	-1.0000 k
regular	8	5	-1.0000 i	0.0000 j	0.0000 k
regular	9	9	0.0000 i	0.0000 j	1.0000 k
regular	10	7	0.0000 i	1.0000 j	0.0000 k
regular	11	11	0.0000 i	-1.0000 j	0.0000 k
regular	12	11	0.0000 i	0.0000 j	1.0000 k
regular	13	3	0.0000 i	0.0000 j	-1.0000 k
regular	14	2	0.0000 i	0.0000 j	-1.0000 k
regular	15	1	0.0000 i	0.0000 j	0.0000 k
regular	16	1	0.0000 i	0.0000 j	-1.0000 k
regular	17	2	0.0000 i	0.0000 j	0.0000 k
regular	18	2	0.0000 i	0.0000 j	-1.0000 k
regular	19	2	1.0000 i	0.0000 j	0.0000 k
regular	20	3	-1.0000 i	0.0000 j	0.0000 k
regular	21	3	-1.0000 i	0.0000 j	0.0000 k
regular	22	1	0.0000 i	-1.0000 j	0.0000 k
regular	23	1	0.0000 i	-1.0000 j	0.0000 k
regular	24	3	0.0000 i	0.0000 j	-1.0000 k

regular   25   1   0.0000 i 0.0000 j -1.0000 k

number of mass equations ... matott = 2

rigorous fluid properties for water vapor (22) at pressure = 1.05770E+04 Pa

temperature	enthalpy	conductivity	viscosity	density	specific heat	mass diffusivity	temperature
3.000E+01	2.550E+06	2.020E-02	9.249E-06	7.399E-02	1.929E+03	-4.536E-03	3.000E+01
3.500E+01	2.560E+06	2.016E-02	9.452E-06	7.282E-02	1.931E+03	-4.536E-03	3.500E+01
4.000E+01	2.570E+06	2.033E-02	9.656E-06	7.168E-02	1.933E+03	-4.536E-03	4.000E+01
4.500E+01	2.580E+06	2.058E-02	9.860E-06	7.058E-02	1.935E+03	-4.536E-03	4.500E+01
5.000E+01	2.590E+06	2.087E-02	1.006E-05	6.951E-02	1.937E+03	-4.536E-03	5.000E+01

simplified fluid property coefficients for material 1 at pressure = 1.05770E+04 Pa

c0h =	0.000E+00	c1h =	1.025E+03	c2h =	0.000E+00	c3h =	0.000E+00
c0k =	2.480E-02	c1k =	6.750E-05	c2k =	0.000E+00		
c0mu =	1.753E-05	c1mu =	4.020E-08	c2mu =	0.000E+00		
c0p =	0.000E+00	c1p =	0.000E+00	c2p =	0.000E+00		
c0ro =	0.000E+00	c1ro =	0.000E+00	c2ro =	3.594E-03		
c0d =	0.000E+00	c1d =	0.000E+00	c2d =	0.000E+00		

temperature	enthalpy	conductivity	viscosity	density	specific heat	mass diffusivity	temperature
3.000E+01	3.075E+04	2.682E-02	1.871E-05	1.254E-01	1.025E+03	2.578E-04	3.000E+01
3.500E+01	3.588E+04	2.716E-02	1.891E-05	1.234E-01	1.025E+03	2.678E-04	3.500E+01
4.000E+01	4.100E+04	2.750E-02	1.911E-05	1.214E-01	1.025E+03	2.781E-04	4.000E+01
4.500E+01	4.612E+04	2.784E-02	1.931E-05	1.195E-01	1.025E+03	2.885E-04	4.500E+01
5.000E+01	5.125E+04	2.817E-02	1.951E-05	1.176E-01	1.025E+03	2.992E-04	5.000E+01

simplified solid property coefficients for material 2.

c0k =	1.644E+01	c1k =	0.000E+00	c2k =	0.000E+00
c0ro =	4.525E+03	c1ro =	0.000E+00	c2ro =	0.000E+00
c0h =	1.000E-03	c1h =	5.435E+02		

temperature	conductivity	density	enthalpy	specific heat	temperature
3.000E+01	1.644E+01	4.525E+03	1.631E+04	5.435E+02	3.000E+01
3.500E+01	1.644E+01	4.525E+03	1.902E+04	5.435E+02	3.500E+01
4.000E+01	1.644E+01	4.525E+03	2.174E+04	5.435E+02	4.000E+01
4.500E+01	1.644E+01	4.525E+03	2.446E+04	5.435E+02	4.500E+01
5.000E+01	1.644E+01	4.525E+03	2.718E+04	5.435E+02	5.000E+01

simplified fluid property coefficients for material 3 at pressure = 1.05770E+04 Pa

c0h =	7.700E+03	c1h =	4.000E+03	c2h =	0.000E+00	c3h =	0.000E+00
c0k =	5.679E-01	c1k =	1.082E-03	c2k =	0.000E+00		

c0mu = -2.620E-02   c1mu = 6.205E-05   c2mu = 7.718E+00
c0p = 0.000E+00   c1p = 0.000E+00   c2p = 0.000E+00
c0ro = 1.030E+03   c1ro = -2.945E-01   c2ro = 0.000E+00
c0d = 0.000E+00   c1d = 0.000E+00   c2d = 0.000E+00

temperature	enthalpy	conductivity	viscosity	density	specific heat	mass diffusivity	temperature
3.000E+01	1.277E+05	6.003E-01	1.124E-03	1.021E+03	4.000E+03	2.578E-04	3.000E+01
3.500E+01	1.477E+05	6.058E-01	1.021E-03	1.020E+03	4.000E+03	2.678E-04	3.500E+01
4.000E+01	1.677E+05	6.112E-01	9.314E-04	1.018E+03	4.000E+03	2.781E-04	4.000E+01
4.500E+01	1.877E+05	6.166E-01	8.543E-04	1.017E+03	4.000E+03	2.885E-04	4.500E+01
5.000E+01	2.077E+05	6.220E-01	7.892E-04	1.015E+03	4.000E+03	2.992E-04	5.000E+01

********** heat transfer coefficient structure **********

number of heat transfer coefficients specified (nhtcof) = 2

n = 1 correlation # (ihtcor) = 31   characteristic length (htclen) = 2.397760E-02   multiplier (htcmul) = 1.000000E+00
n = 2 correlation # (ihtcor) = 21   characteristic length (htclen) = 2.540000E-02   multiplier (htcmul) = 1.000000E+00

***** user input correlations *****

number of heat transfer correlations specified (nheatc) = 2
the nusselt number is computed with the following function:

   nusselt = heatc1 + heatc2 * (reynolds number) ** heatc3 * (prandtl number) ** heatc4

correlation heatc1   heatc2   heatc3   heatc4
    1   1.000E+00 2.300E-02 8.000E-01 4.000E-01
    2   3.000E+03 0.000E+00 0.000E+00 0.000E+00

Surface	kflow	veloc	kpres	pres	Ktemp	temp	ihtwal	walldx	matwal
1	0	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
2	0	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
3	0	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
4	0	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
5	0	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
6	-3	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
7	0	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
8	0	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
9	0	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
10	0	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
11	0	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
12	0	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
13	0	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
14	0	0.000E+00	0	0.000E+00	400	4.622E+01	0	1.000E+00	0
15	0	0.000E+00	0	0.000E+00	400	4.622E+01	0	1.000E+00	0
16	0	0.000E+00	0	0.000E+00	40p	4.622E+01	0	1.000E+00	0
17	0	0.000E+00	0	0.000E+00	400	4.622E+01	0	1.000E+00	0
18	2	5.452E+01	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
19	0	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
20	0	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
21	0	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
22	0	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
23	0	0.000E+00	1	1.058E+04	1	4.698E+01	0	1.000E+00	0
24	-4	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0
25	2	0.000E+00	0	0.000E+00	400	4.698E+01	0	1.000E+00	0

********** force structure summary **********

total number of force structures (nforce) = 7

n	icorr(n)	clenth(n)	reylen(n)	forcef(n)
1	1	1.7860E-02	2.9330E-02	1.0000E+00
2	1	1.7860E-02	2.9330E-02	2.0000E+00
3	1	2.7500E-02	2.5400E-02	1.0000E+00
4	1	2.7500E-02	2.5400E-02	2.0000E+00
5	2	-1.0000E+00	-1.0000E+00	1.0000E+00
6	3	-1.0000E+00	2.5400E-01	1.0000E+00
7	3	-1.0000E+00	2.5400E-01	1.0000E+00

total number of correlation types (ncorr) = 3

nt	reytrn(nt)	acorr(nt)	bcorr(nt)	ccorr(nt)	acorrt(nt)	bcorrt(nt)	ccorrt(nt)
1	2.0000E+03	7.7736E-01	-1.6000E-01	0.0000E+00	7.7736E-01	-1.6000E-01	0.0000E+00
2	2.0000E+03	0.0000E+00	1.0000E+00	1.3437E+00	0.0000E+00	1.0000E+00	1.3437E+00
3	1.1850E+03	6.4000E+01	-1.0000E+00	0.0000E+00	3.1640E-01	-2.5000E-01	0.0000E+00

face	force index	i-index range		j-index range		k-index range		number of surfaces
yfor	1	3	5	8	5	11	11	3
yfor	1	3	5	8	5	11	11	3
yfor	1	3	5	9	3	12	14	9
yfor	1	3	5	9	7	12	12	6
yfor	1	3	5	9	9	12	13	9
yfor	1	3	5	8	5	13	13	3
yfor	1	3	5	8	8	14	14	6
yfor	1	3	5	5	7	15	15	3
yfor	2	3	5	8	5	11	11	6
yfor	2	3	5	8	8	12	12	6
yfor	2	3	5	6	7	12	13	3
yfor	2	3	5	4	5	13	14	6
yfor	2	3	5	4	5	14	14	3
yfor	2	3	5	8	8	14	15	6
yfor	2	3	5	6	7	15	10	9
zfor	3	3	5	7	7	10	11	3
zfor	3	3	5	4	5	11	11	6
zfor	3	3	5	9	9	11	11	3
zfor	3	3	5	6	6	12	13	6
zfor	3	3	5	8	8	13	13	6
zfor	3	3	5	4	5	14	14	6
zfor	3	3	5	7	7	14	14	3
zfor	3	3	5	9	8	15	15	9
zfor	4	3	5	6	6	11	11	3
zfor	4	3	5	6	6	11	11	12
zfor	4	3	5	8	8	12	12	6
zfor	4	3	5	9	9	13	13	3
zfor	4	3	5	6	6	14	14	3
zfor	4	3	5	8	8	14	14	6
yfor	1	3	5	5	5	5	5	3
yfor	1	3	5	8	8	5	6	3
yfor	1	3	5	7	7	6	8	6
yfor	1	3	5	3	3	8	7	3
yfor	1	3	5	9	9	7	8	3
yfor	1	3	5	5	5	7	7	6
yfor	1	3	5	6	7	9	9	3
yfor	2	3	5	8	8	9	9	3
yfor	2	3	5	5	5	5	5	6
yfor	2	3	5	6	6	6	6	3
yfor	2	3	5	4	4	8	8	3
yfor	2	3	5	8	8	8	9	6
yfor	3	3	5	6	7	9	9	9
zfor	3	3	5	6	8	4	4	9

label							
zfor	3	3	5	7	7	5	5	3
zfor	3	3	5	4	5	5	5	6
zfor	3	3	5	9	9	6	5	3
zfor	3	3	5	6	6	7	7	6
zfor	3	3	5	8	8	8	8	6
zfor	3	3	5	5	7	8	8	3
zfor	3	3	5	7	9	9	9	3
zfor	4	3	5	9	6	5	5	9
zfor	4	3	5	6	6	6	5	3
zfor	4	3	5	8	8	8	7	12
zfor	4	3	5	5	4	12	8	6
zfor	5	3	5	9	9	13	13	3
zfor	5	3	5	6	6	7	7	3
zfor	6	3	6	8	8	7	8	6
xfor	6	3	6	7	7	13	7	6
xfor	7	7	7	7	7	13	13	4
zfor	7	7	7	7	7	14	14	8

total number of surfaces with forces specified =   355

Condenser Tube Summary:

total channel area = 9.23521E+00   total number of condenser tubes =   1.07344E+04

---

tube side boundary conditions

i	kflotb	ktemtb	kpretb
10	1	1	1
20	-5	400	1

********** thermal structure summaries **********

thermal structure prototype number	number of surface cells outside	inside	heat transfer correlation index outside	inside	hydraulic diameter outside	inside	rod fraction	geometry type	heat source transient function number
1	57	57	2	1	2.540E-02	2.398E-02	-1.155E+03	1	0
2	57	57	2	1	2.540E-02	2.398E-02	-1.170E+03	1	0

	number	material type	volumetric heat source	heat transfer coefficient	partition size	surface area	volume
type 1	1						
fluid							
material		2	0.0000E+00		3.5560E-04	9.2188E+01	3.2323E-02
material		2	0.0000E+00		3.5560E-04	8.9606E+01	3.1405E-02
fluid						8.7025E+01	
type 2	2						
fluid							
material		2	0.0000E+00		3.5560E-04	9.3332E+01	3.2724E-02
material		2	0.0000E+00		3.5560E-04	9.0718E+01	3.1795E-02
fluid						8.8105E+01	

n	ts num	heat transfer area #1 (m**2)	heat transfer area #2 (m**2)	volume (m**3)	heat source (w)
1	1	7.20532E+03	6.80182E+03	4.98094E+00	0.00000E+00
2	2	7.06176E+03	6.66630E+03	4.88170E+00	0.00000E+00
totals		1.42671E+04	1.34681E+04	9.86264E+00	0.00000E+00

********** cell and surface element initialization summary **********

variable name	value	i-index range	j-index range	k-index range	surface number	component number	number of values initialized
alz	5.000E-01	3, 3	3, 10	17, 17			8
aly	7.500E-01	3, 3	3, 10	17, 17			8
aly	2.500E-01	3, 3	3, 10	18, 18			8
al	7.500E-01	3, 3	3, 10	17, 17			8
al	2.500E-01	3, 3	3, 10	18, 18			8
alz	5.000E-01	5, 5	3, 10	17, 17			8
aly	7.500E-01	5, 5	3, 10	17, 17			8
aly	2.500E-01	5, 5	3, 10	18, 18			8
al	7.500E-01	5, 5	3, 10	17, 17			8
al	2.500E-01	5, 5	3, 10	18, 18			8
alz	0.000E+00	3, 5	7, 9	17, 17		1	9
alx	7.500E-01	3, 4	7, 7	18, 18			2
alx	9.306E-01	3, 4	7, 7	17, 17		1	2
alx	6.599E-01	3, 4	8, 8	17, 17			2
alx	5.208E-01	3, 4	8, 8	18, 18			2

alx	6.944E-01	3.	4.	9.	9	17.	17		2
alx	7.361E-01	3.	4.	9.	9	18.	18		2
aly	5.377E-01	3.	3.	6.	6	17.	17		1
aly	8.056E-01	3.	4.	6.	6	17.	17		1
aly	6.377E-01	5.	5.	7.	7	17.	17		1
aly	5.729E-01	3.	4.	7.	7	17.	17		1
aly	6.944E-01	4.	5.	7.	7	17.	17		1
aly	5.729E-01	5.	5.	7.	7	17.	17		1
aly	1.823E-01	5.	3.	7.	7	18.	18		1
aly	8.750E-01	4.	5.	7.	7	18.	18	1	1
aly	1.823E-01	5.	3.	8.	8	18.	18	1	1
aly	5.377E-01	3.	4.	8.	8	17.	17	1	1
aly	6.389E-01	5.	5.	8.	8	17.	17	1	1
aly	5.377E-01	3.	4.	8.	8	18.	18	1	1
aly	8.660E-02	5.	5.	8.	8	18.	18	1	1
aly	4.583E-01	3.	4.	9.	9	18.	18	1	1
aly	8.660E-02	5.	5.	9.	9	17.	17	1	1
aly	6.597E-01	4.	5.	9.	9	17.	17	1	1
aly	6.944E-01	5.	5.	9.	9	17.	18	1	1
aly	6.597E-01	4.	5.	9.	9	18.	18	1	1
aly	6.597E-01	5.	3.	7.	7	18.	18	1	1
aly	6.944E-01	4.	5.	7.	7	18.	18	1	1
al	6.597E-01	5.	3.	7.	7	17.	17	1	1
al	6.094E-01	4.	5.	8.	8	17.	17	1	1
al	6.094E-01	5.	3.	8.	8	18.	18	1	1
al	7.500E-01	4.	5.	8.	8	18.	18	1	1
al	6.094E-01	5.	3.	8.	8	17.	17	1	1
al	2.171E-01	4.	5.	9.	9	17.	17	1	1
al	9.306E-01	5.	3.	9.	9	18.	18	1	1
al	2.171E-01	4.	5.	9.	9	18.	18	1	1
al	5.498E-01	5.	3.	9.	9	17.	17	1	1
al	6.597E-01	4.	5.	9.	9	17.	17	1	1
al	5.498E-01	5.	3.	7.	7	18.	18	1	1
al	1.025E-01	4.	5.	8.	8	18.	18	1	1
alx	5.208E-01	3.	5.	9.	9	18.	18		1
alx	1.025E-01	3.	5.	9.	9	18.	18		132
alx	5.787E-01	3.	4.	4.	7	5.	15		3
al	5.787E-01	3.	7.	7.	8	7.	7		3
al	1.639E-01	3.	7.	6.	9	13.	13		45
al	7.361E-01	3.	6.	4.	7	11.	15		54
al	1.639E-01	3.	7.	7.	8	12.	14		9
al	0.000E+00	3.	5.	6.	9	12.	14		9
al	1.000E+00	3.	4.	5.	7	13.	13		60
aly	1.000E+00	3.	6.	4.	8	11.	15		54
aly	5.854E-01	3.	6.	6.	9	12.	14		6
aly	1.000E+00	3.	4.	7.	7	13.	13		54
alz	1.000E+00	3.	7.	6.	8	10.	15		72
alz	5.854E-01	3.	6.	4.	9	11.	14		6
alz	5.854E-01	3.	4.	7.	7	12.	13		45
al	0.000E+00	3.	6.	6.	6	5.	9		54
al	5.854E-01	3.	4.	4.	8	6.	8		9
al	4.087E-04	3.	7.	7.	7	7.	7		9
aly	5.927E-01	3.	6.	5.	8	5.	8		60
aly	5.927E-01	3.	3.	3.	9	6.	8		63

168

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aly    0.000E+00    3,  5   6,  7   7,  7              6
alz    5.927E-01    3,  5   6,  8   4,  9             54
alz    5.927E-01    3,  5   5,  9   5,  8             60
alz    4.087E-04    3,  5   5,  7   6,  7              6
aly    0.000E+00    2,  2   9,  9   4,  4              1
p      1.058E+04    3,  5   3, 10   3, 20        1   395
p      1.058E+04    6,  6   7,  7   7,  7        1     1
p      1.058E+04    6,  6   7,  7  13, 13        1     9
p     -5.050E-02    7,  7   7,  7  15, 15   25  1     1
flow   3.457E+00    2,  2   9,  9   4,  4        1     1
flow   2.150E+00    2,  2   2, 10   4,  4   19  1     1
flow                4,  4              4,  4   19  1     1
xixsb  4.105E-05    4,  4   3,  4  20, 20        1     1
aly    0.000E+00    4,  4   4,  5  20, 20   24  2     2
```

******** cell volume and surface area summary ********

surface	area (m**2)
1	3.850262E+01
2	4.586326E+01
3	4.077319E+01
4	4.212483E+01
5	7.837626E+01
6	2.232530E+02
7	2.232530E+02
8	2.264016E+01
9	8.897121E-01
10	7.637904E-01
11	1.391552E+00
12	1.391552E+00
13	5.648008E-01
14	5.018400E-01
15	1.043430E+00
16	1.043430E+00
17	1.416060E+00
18	1.416060E+00
19	1.477559E+00
20	1.668620E+00
21	1.668620E+00
22	7.454900E+00
23	7.454900E+00
24	1.243940E+01
25	6.296085E-02
total	7.574354E+02

	total volume	total surface area in i+ direction for all cells	total surface area in j+ direction for all cells	total surface area in k+ direction for all cells	total cell surface area
total (geometric)	1.228935E+03	1.394779E+02	1.822893E+03	1.223666E+03	3.186037E+03
fluid (calculational)	9.478322E+02	9.898111E+01	1.338974E+03	9.348280E+02	2.372783E+03

...giaja... number of non-zeros counted=   2382   space required= 16058
...gdconv... deltah= 5.799E-01 is being reset to dhconv= 1.000E+03 for convergence testing.

*********** control variable summary ***********

variable	value	<------ description ------>
idtime	0	time step determination flag
ienbug	0	energy equation debug flag
ifener	1	energy equation solution flag
ifmass	2	mass species solution flag
ifmom	1	momentum equation solution flag
ifres	1	restart flag
ifx	1	x dimension flag
ify	1	y dimension flag
ifz	1	z dimension flag
igeom	0	0: cartesian -1: cylindrical
imax	7	number of cells in x-direction
iskew	0	skew upwind differencing flag
isolvr	1	matrix solution flag
istate	0	problem state flag
istruc	1	thermal structure flag
it(1)	1	iterations through step lastit
it(2)	10	iterations after step lastit
itermax	0	
itibug	0	
itimaxe	99	
ituaxp	99	
iturke	0	turbulence model flag
jmax	10	number of cells in y-direction
kmax	20	maximum cells in the z-direction
lastdt	99999	time step size changes
lactit	99999	number of iterations change
lnprnt	0	geometry linkage debugging flag
ncorr	3	force structure correlations
nforce	7	number of force structures
nheatc	2	heat transfer correlations
nl	32	irregular surface elements
nl1	458	number of surface elements
matott	2	irregular computational cells
nn	32	number of computational cells
nm1	408	number of surfaces
nsurf	25	maximum number of time steps
ntmax	5000	number of tube-channels in tube side
ntubes	38	number of computational cells in tubes
nucell	190	power condenser flag
itube	1	condensate subcooling model
isubc	0	innudation model
innuda	0	vapor shear effect
ishear	1	fouling thermal resistance model
ifoul	0	iteration no. between shell and tubes
itertb	2	

variable	value	<------ description ------>
alpha	1.0000E+00	time step size through step lastdt
dt(1)	1.0000E-01	time step size after step lastdt
dt(2)	1.0000E-01	
dtime	1.0000E-01	
eps1	1.0000E-06	convergence parameter
eps2	1.0000E-06	convergence parameter
eps3	1.0000E-05	convergence parameter
eps5	1.0000E-05	convergence parameter
vconv	1.0000E+00	convergence parameter
gravx	0.0000E+00	x-component of gravity vector
gravy	0.0000E+00	y-component of gravity vector
gravz	-9.8000E+00	z-component of gravity vector
omega	1.5000E+00	pressure solution
omegad	7.0000E-01	turbulent kinetic energy dissipation
omegae	8.0000E-01	energy equation coefficients
omegak	7.0000E-01	turbulent kinetic energy
omegam	1.0000E+00	
omegar	1.0000E+00	
omegat	7.0000E-01	turbulent viscosity
omegav	8.5000E-01	under-relaxation for momentum equation
omegax	8.5000E-01	under-relaxation for component mass eq
pres0	1.0577E+04	reference pressure
rdtime	8.0000E-01	automatic time step multiplier
relaxe	9.5000E-01	relaxation of energy equation solver
temp0	4.6983E+01	reference temperature
timax	3.6000E+13	maximum simulation time
timeup	3.0800E+00	time ellapsed
trest	1.8000E+04	time allowed for job
tstart	0.0000E+00	initial simulation time
turbc	0.0000E+00	turbulent conductivity
turbv	5.0000E-03	turbulent viscosity
xpres0	0.0000E+00	x-, y-, and z-
ypres0	0.0000E+00	coordinates of the
zpres0	0.0000E+00	pressure reference point
foul	1.0000E-30	fouling model parameter
epstb	1.0000E-06	convergence parameter

********** Date: 10/15/91   Time: 16:48:13   COMMIX-PC-1(.)   Last updated: 10/09/91   Machine Sun4/110 **********

global balances at time= 0.000E+00 seconds for component   1

surface number	mass convected (kg/sec)	thermal energy convected (watt)	heat conducted (watt)	average velocity (m/sec)	average enthalpy (j/kg)	average temperature (celsius)	bulk temperature (celsius)
1	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
2	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
3	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
4	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
5	0.000000E+00	0.000000E+00	0.000000E+03	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
6	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
7	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
8	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
9	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
10	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
11	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
12	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
13	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
14	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
15	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584126E+06	4.698300E+01	0.000000E+00
16	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584126E+06	4.698300E+01	0.000000E+00
17	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584126E+06	4.698300E+01	0.000000E+00
18	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584126E+06	4.698300E+01	0.000000E+00
19	5.606500E+00	1.447934E+07	-4.665506E-02	5.397601E+01	2.582599E+06	4.622000E+01	4.622000E+01
20	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
21	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
22	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
23	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
24	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
25	-5.049999E-02	-1.304983E+05	0.000000E+00	-1.143383E+01	2.584125E+06	4.698300E+01	4.698300E+01

** mass balance **********

mass accumulation rate   :   dmasdt = 0.000000E+00 (kg/s)
net mass convected into configuration   :   flosum = 5.556000E+00 (kg/s)
net mass source   :   xsourc = 0.000000E+00 (kg/s)

global conservation of mass   (dmasdt - flosum - xsourc) =-5.556000E+00 (kg/s)

total mass within configuration   :   tmass   = 6.649063E+01 (kg)

total volume occupied by fluid   :   thlvol = 9.478322E+02 (m**3)

** energy balance **********

enthalpy accumulation rate   :   dhdt   = 0.000000E+00 (watt)
enthalpy stored in liquid condensates   :   qmsl   = 0.000000E+00 (watt)
net enthalpy accumulation rate   :   dhnet   = 0.000000E+00 (watt)
net energy convected into configuration   :   hinsum = 1.434885E+07 (watt)
net heat conducted into configuration   :   qinsum =-4.665506E-02 (watt)
heat generated within configuration   :   qsourc = 0.000000E+00 (watt)
work   :   dpdt   = 0.000000E+00 (watt)

global energy   :(dhnet-hinsum-qinsum-qsource-dpdt) =-1.434885E+07 (watt)

total internal energy within configuration: tenth   = 1.718201E+08 (joules)

at time= 0.00000E+00 seconds. total condensate = 0.00000E+00 kg. total energy to tubes = 0.00000E+00 joules.

****

ts number	volume (m**3)	mass (kg/m**3)	heat capacity (j/c)	total heat (j)	heat transfer to outside (watts)	heat transfer to inside (watts)	instantaneous heat source (watts)
1	4.98094E+00	2.25388E+04	1.22507E+07	5.63498E+08	-3.26117E+08	3.26117E+08	0.00000E+00
2	4.88170E+00	2.20897E+04	1.20066E+07	5.52270E+08	-3.19619E+08	3.19619E+08	0.00000E+00
totals	9.8625E+00	4.46284E+04	2.42573E+07	1.11577E+09	-6.45735E+08	6.45735E+08	0.00000E+00

********* Date: 10/15/91   Time: 16:48:13   COMIX-PC-100   Last updated: 10/09/91   Machine Sun4/110 **********

global balances at time= 0.000E+00 seconds for component   2

surface number	mass convected (kg/sec)	thermal energy convected (watt)	heat conducted (watt)	average velocity (m/sec)	average enthalpy (j/kg)	average temperature (celsius)	bulk temperature (celsius)
1	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
2	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
3	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
4	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
5	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
6	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
7	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
8	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
9	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
10	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
11	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
12	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
13	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
14	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
15	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
16	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
17	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
18	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
19	0.000000E+00	0.000000E+00	0.000000E+00	5.397601E+01	0.000000E+00	4.698300E+01	0.000000E+00
20	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.622000E+01	0.000000E+00
21	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
22	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
23	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.698300E+01	0.000000E+00
24	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.349931E+04	4.698300E+01	0.000000E+00
25	0.000000E+00	0.000000E+00	0.000000E+00	-1.143383E+01	0.000000E+00	4.698300E+01	0.000000E+00

*** mass balance **********

mass accumulation rate	:	dmasdt = 0.000000E+00 (kg/s)
net mass convected into configuration	:	flosum = 0.000000E+00 (kg/s)
net mass source	:	xsourc = 0.000000E+00 (kg/s)

global conservation of mass : (dmasdt - flosum - xsourc) = 0.000000E+00 (kg/s)

total mass within configuration : tmass = 0.000000E+00 (kg)

total volume occupied by fluid : thlvol = 0.000000E+00 (mm**3)

*** energy balance **********

enthalpy accumulation rate	:	dhdt = 0.000000E+00 (watt)
enthalpy stored in liquid condensates	:	qmsl = 0.000000E+00 (watt)
net enthalpy accumulation rate	:	dhnet = 0.000000E+00 (watt)
net energy convected into configuration	:	hinsum = 0.000000E+00 (watt)
net heat conducted into configuration	:	qinsum = 0.000000E+00 (watt)
heat generated within configuration	:	qsourc = 0.000000E+00 (watt)
work	:	dpdt = 0.000000E+00 (watt)

global energy :(dhnet-hinsum-qinsum-qsource-dpdt) = 0.000000E+00 (watt)

total internal energy within configuration: tenth = 0.000000E+00 (joules)

at time= 0.00000E+00 seconds. total condensate = 0.00000E+00 kg. total energy to tubes = 0.00000E+00 joules.

****

ts number	volume (m**3)	mass (kg/m**3)	heat capacity (j/c)	total heat (j)	heat transfer to outside (watts)	heat transfer to inside (watts)	instantaneous heat source (watts)
1	4.98094E+00	2.25388E+04	1.22507E+07	5.63498E+08	-3.26117E+08	3.26117E+08	0.00000E+00
2	4.88170E+00	2.20897E+04	1.20060E+07	5.52270E+08	-3.19619E+08	3.19619E+08	0.00000E+00
totals	9.8626E+00	4.46284E+04	2.42573E+07	1.11577E+09	-6.45735E+08	6.45735E+08	0.00000E+00

********** Date: 10/15/91   Time: 16:48:13   COMMIX-PC-100   Last updated: 10/09/91   Machine Sun4/110 ***********

global balances at time= 0.000E+00 seconds for component 3

surface number	mass convected (kg/sec)	thermal energy convected (watt)	heat conducted (watt)	average velocity (m/sec)	average enthalpy (j/kg)	average temperature (celsius)	bulk temperature (celsius)
1	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
2	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
3	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
4	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
5	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
6	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
7	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
8	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
9	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
10	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
11	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
12	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
13	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
14	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
15	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584126E+06	4.698300E+01	0.000000E+00
16	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584126E+06	4.698300E+01	0.000000E+00
17	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584126E+06	4.698300E+01	0.000000E+00
18	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584126E+06	4.698300E+01	0.000000E+00
19	5.606500E+00	1.447934E+07	-4.665506E-02	5.397601E+01	2.582599E+06	4.622000E+01	4.622000E+01
20	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
21	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
22	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
23	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584125E+06	4.698300E+01	0.000000E+00
24	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584096E+06	4.698300E+01	0.000000E+00
25	-5.049999E-02	-1.304983E+05	0.000000E+00	-1.143383E+01	2.584125E+06	4.698300E+01	4.698300E+01

*** mass balance **********

mass accumulation rate	:	dmasdt = 0.000000E+00 (kg/s)
net mass convected into configuration	:	flosum = 5.556000E+00 (kg/s)
net mass source	:	xsourc = 0.000000E+00 (kg/s)

global conservation of mass   (dmasdt - flosum - xsourc) =-5.556000E+00 (kg/s)

total mass within configuration   : tmass = 6.649063E+01 (kg)

total volume occupied by fluid   : thlvol = 9.478322E+02 (m**3)

*** energy balance **********

enthalpy accumulation rate	:	dhdt = 0.000000E+00 (watt)
enthalpy stored in liquid condensates	:	qmsl = 0.000000E+00 (watt)
net enthalpy accumulation rate	:	dhnet = 0.000000E+00 (watt)
net energy convected into configuration	:	hinsum = 1.434885E+07 (watt)
net heat conducted into configuration	:	qinsum =-4.665506E-02 (watt)
heat generated within configuration	:	qsourc = 0.000000E+00 (watt)
work	:	dpdt = 0.000000E+00 (watt)

global energy   :(dhnet-hinsum-qinsum-qsource) =-1.434885E+07 (watt)

total internal energy within configuration: tenth = 1.718201E+08 (joules)

at time= 0.00000E+00 seconds. total condensate = 0.00000E+00 kg. total energy to tubes = 0.00000E+00 joules.

****

ts number	volume (m**3)	mass (kg/m**3)	heat capacity (j/c)	total heat (j)	heat transfer to outside (watts)	heat transfer to inside (watts)	instantaneous heat source (watts)
1	4.98094E+00	2.25388E+04	1.22507E+07	5.63498E+08	-3.26117E+08	3.26117E+08	0.00000E+00
2	4.88170E+00	2.20897E+04	1.20066E+07	5.52270E+08	-3.19619E+08	3.19619E+08	0.00000E+00
totals	9.8626E+00	4.46284E+04	2.42573E+07	1.11577E+09	-6.45735E+08	6.45735E+08	0.00000E+00

*** pressure (pa)

** p*pold ** component 1 ** i plane 4 ** time step 0 ** time 0.00000E+00 s **

k j-->	3	4	5	6	7	8	9	10
20	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04
19	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04
18	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04
17	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04
16	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04
15	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04
14	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04
13	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04
12	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04
11	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04
10	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04
9	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04
8	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04
7	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04
6	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04
5	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04
4	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04
3	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04	1.057700E+04

*** temperature (c)

** tl ** component 1 ** i plane 4 ** time step 0 ** time 0.00000E+00 s **

k j-->	2	3	4	5	6	7	8	9
21	(4.698300E+01)	(4.698300E+01)	(4.698300E+01)(	4.698300E+01)(	4.698300E+01)(	4.698300E+01)(	4.698300E+01)(	4.698300E+01)
20	(4.698300E+01)	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01
19	(4.698300E+01)	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01
18	(4.698300E+01)	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01
17	(4.698300E+01)	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01
16	(4.698300E+01)	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01
15	(4.698300E+01)	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01
14	(4.698300E+01)	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01
13	(4.698300E+01)	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01
12	(4.698300E+01)	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01
11	(4.698300E+01)	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01
10	(4.698300E+01)	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01
9	(4.698300E+01)	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01
8	(4.698300E+01)	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01
7	(4.698300E+01)	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01	4.698300E+01

	10	11
6	4.698300E+01 4.698300E+01 4.698300E+01 4.698300E+01 4.698300E+01	(4.698300E+01)
5	4.698300E+01 4.698300E+01 4.698300E+01 4.698300E+01 4.698300E+01	(4.698300E+01)
4	4.698300E+01 4.698300E+01 4.698300E+01 4.698300E+01 4.698300E+01	(4.698300E+01)
3	4.698300E+01 4.698300E+01 4.698300E+01 4.698300E+01 4.698300E+01	(4.698300E+01)
2	(4.698300E+01) (4.698300E+01) (4.698300E+01) (4.698300E+01) (4.698300E+01)	(4.698300E+01)

k j-->	10	11
21		(4.698300E+01)
20		(4.698300E+01)
19	4.698300E+01	(4.698300E+01)
18	4.698300E+01	(4.698300E+01)
17	4.698300E+01	(4.698300E+01)
16	4.698300E+01	(4.698300E+01)
15	4.698300E+01	(4.698300E+01)
14	4.698300E+01	(4.698300E+01)
13	4.698300E+01	(4.698300E+01)
12	4.698300E+01	(4.698300E+01)
11	4.698300E+01	(4.698300E+01)
10	4.698300E+01	(4.698300E+01)
9	4.698300E+01	(4.698300E+01)
8	4.698300E+01	(4.698300E+01)
7	4.698300E+01	(4.698300E+01)
6	4.698300E+01	(4.698300E+01)
5	4.698300E+01	(4.698300E+01)
4	4.698300E+01	(4.698300E+01)
3	4.698300E+01	(4.698300E+01)
2	4.698300E+01	(4.698300E+01)

*** volume porosity ( )

** al ** component 1 ** i plane 4 ** time step 0 ** time 0.00000E+00 s **

k j-->	3	4	5	6	7	8	9	10
20	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
19	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
18	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	9.306000E-01	5.208000E-01	7.361000E-01	1.000000E+00
17	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	7.500000E-01	6.597000E-01	6.944000E-01	1.000000E+00
16	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
15	1.000000E+00	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	1.000000E+00
14	1.000000E+00	5.853920E-01	5.853920E-01	5.853920E-01	1.000000E+00	5.853920E-01	5.853920E-01	1.000000E+00
13	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
12	1.000000E+00	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	1.000000E+00
11	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
10	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
9	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
8	1.000000E+00	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01	1.000000E+00
7	1.000000E+00	5.926568E-01	5.926568E-01	5.926568E-01	1.000000E+00	5.926568E-01	5.926568E-01	1.000000E+00
6	1.000000E+00	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01	1.000000E+00
5	1.000000E+00	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01	1.000000E+00
4	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
3	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00

*** y-direction surface permeability ( )

** aly ** component 1 ** i plane 4 ** time step 0 ** time 0.00000E+00 s **

k j-->	2	3	4	5	6	7	8	9

(Note : The values in the parentheses are the boundary surface area in m**2)

*** z-direction surface permeability ( )   ** alz ** component 1 ** i plane 4 ** time step   0 ** time 0.00000E+00 s **
*

(Note : The values in the parentheses are the boundary surface area in m**2)

k j-->	3	4	5	6	7	8	9	10
20	(4.284182E+00)	(3.486955E+00)	(3.023633E+00)	(5.928807E+00)	(1.870584E+00)	(5.928807E+00)	(6.509097E+00)	(4.047489E+00)
19	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	0.000000E+00	1.000000E+00
18	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	0.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
17	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
16	1.000000E+00	1.000000E+00	1.000000E+00	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	1.000000E+00
15	1.000000E+00	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	1.000000E+00
14	1.000000E+00	5.853920E-01	5.853920E-01	5.853920E-01	4.086980E-04	5.853920E-01	5.853920E-01	1.000000E+00
13	1.000000E+00	5.853920E-01	5.853920E-01	5.853920E-01	4.086980E-04	5.853920E-01	5.853920E-01	1.000000E+00
12	1.000000E+00	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	1.000000E+00
11	1.000000E+00	1.000000E+00	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	1.000000E+00	1.000000E+00
10	1.000000E+00	1.000000E+00	1.000000E+00	5.926568E-01	5.926568E-01	5.926568E-01	1.000000E+00	1.000000E+00
> 9	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
8	1.000000E+00	1.000000E+00	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01	

k j-->
10

k	10
20	(1.434360E+01)
19	(2.826123E+01)
18	(2.826123E+01)
17	(5.218430E+01)
16	(3.616819E+00)
15	(2.756151E+00)
14	(1.870584E+00)
13	(2.756151E+00)
12	(3.616819E+00)
11	(3.727450E+00)
10	(3.646863E+00)
9	(2.572164E+00)
8	(1.870584E+00)
7	(2.572164E+00)
6	(3.646863E+00)
5	(7.778666E+00)
4	(6.943345E+00)

k	(7.454900E+00)	0.000000E+00	0.000000E+00	7.454900E+00	0.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
20	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
19	1.000000E+00	1.000000E+00	1.000000E+00	8.056000E-01	8.750000E-01	6.389000E-01	4.583000E-01	6.944000E-01
18	1.000000E+00	1.000000E+00	6.944000E-01	6.944000E-01	6.944000E-01	5.853920E-01	6.944000E-01	6.944000E-01
17	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
16	1.000000E+00	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01
15	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01
14	5.853920E-01	5.853920E-01	5.853920E-01	0.000000E+00	0.000000E+00	0.000000E+00	5.853920E-01	1.000000E+00
13	1.000000E+00	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	5.853920E-01	1.000000E+00	1.000000E+00
12	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
11	1.000000E+00	1.000000E+00	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01
10	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01
9	5.926568E-01	5.926568E-01	5.926568E-01	5.926568E-01	0.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
8	5.926568E-01	1.000000E+00	1.000000E+00	1.000000E+00	0.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
7	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
6	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
5	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
4	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
3	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00

```
7  1.000000E+00  5.926568E-01  4.086980E-04  5.926568E-01  1.000000E+00
6  1.000000E+00  5.926568E-01  4.086980E-04  5.926568E-01  1.000000E+00
5  1.000000E+00  5.926568E-01  5.926568E-01  5.926568E-01  1.000000E+00
4  1.000000E+00  1.000000E+00  5.926568E-01  1.000000E+00  1.000000E+00
3  1.000000E+00  1.000000E+00  1.000000E+00  1.000000E+00  1.000000E+00
2 ( 4.284182E+00 )( 3.486955E+00 )( 3.023633E+00 )( 5.928807E+00 )( 1.870584E+00 )( 5.928807E+00 )( 6.509097E+00 )( 4.047489E+00 )
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****

******** date: 10/15/91   time: 16:48:13   commix-PC-100   last updated: 10/09/91   id# Sun4/110 *********

TUBE SIDE GLOBAL BALANCES AT time= 0.000E+00 Seconds

surface number	mass convected (kg/sec)	enthalpy convected (watt)	heat conducted (watt)	average velocity (m/sec)	average enthalpy (j/kg)	average temperature (celsius)	bulk temperature (celsius)
1	9.914004E+03	1.226362E+09	0.000000E+00	2.002578E+00	1.237000E+05	2.900000E+01	2.900000E+01
2	9.914004E+03	1.226362E+09	0.000000E+00	2.002578E+00	1.237000E+05	2.900000E+01	2.900000E+01

*************************************** mass balance ***********

mass accumulation rate   :   dmasdt = 0.000000E+00 (kg/s)
net mass convected into configuration   :   flosum = 0.000000E+00 (kg/s)
global conservation of mass   : (dmasdt - flosum) = 0.000000E+00 (kg/s)

total mass within configuration   :   tmass   = 9.214601E+04 (kg)

*************************************** energy balance *********

enthalpy accumulation rate   :   dhdt   = 0.000000E+00 (watt)
net enthalpy convected into configuration   :   hinsum = 0.000000E+00 (watt)
heat generated within configuration   :   qsourc = 6.457354E+08 (watt)

global energy   (dhdt-hinsum-qsourc)   =-6.457354E+08 (watt)

total internal energy within configuration: tenth   = 1.434713E+10 (joules)

****

ulbtbm, ultb(i), ulbtbp (velocity)   at time= 0.00000E+00

I =	0	1	2	3	4	5	6	7	8
1	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		
2	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		
3	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		
4	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		
5	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		
6	-2.0026E+00	-2.0026E+00	-2.0126E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		
7	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		
8	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		
9	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		
10	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		
11	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		
12	-2.0036E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		
13	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		
14	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		
15	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		
16	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		
17	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		
18	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		
19	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00	-2.0026E+00		

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20  -2.0026E+00  -2.0026E+00
21  -2.0026E+00  -2.0026E+00
22  -2.0026E+00  -2.0026E+00
23  -2.0026E+00  -2.0026E+00
24  -2.0026E+00  -2.0026E+00
25  -2.0026E+00  -2.0026E+00
26  -2.0026E+00  -2.0026E+00
27  -2.0026E+00  -2.0026E+00
28  -2.0026E+00  -2.0026E+00
29  -2.0026E+00  -2.0026E+00
30  -2.0026E+00  -2.0026E+00
31  -2.0026E+00  -2.0026E+00
32  -2.0026E+00  -2.0026E+00
33  -2.0026E+00  -2.0026E+00
34  -2.0026E+00  -2.0026E+00
35  -2.0026E+00  -2.0026E+00
36  -2.0026E+00  -2.0026E+00
37  -2.0026E+00  -2.0026E+00
38  -2.0026E+00  -2.0026E+00
```

tlbtbm, tltb(i), tlbtbp (temperature) at time= 0.00000E+00

I =	0	1	2	3	4	5	6	7	8
1	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
2	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
3	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
4	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
5	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
6	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
7	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
8	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
9	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
10	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
11	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
12	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
13	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
14	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
15	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
16	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
17	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
18	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
19	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
20	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
21	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
22	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
23	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
24	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
25	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
26	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
27	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
28	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
29	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
30	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
31	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
32	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
33	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		
34	2.9000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	3.7000E+01	2.9000E+01		

```
35  2.9000E+01  3.7000E+01  3.7000E+01  3.7000E+01  3.7000E+01  2.9000E+01
36  2.9000E+01  3.7000E+01  3.7000E+01  3.7000E+01  3.7000E+01  2.9000E+01
37  2.9000E+01  3.7000E+01  3.7000E+01  3.7000E+01  3.7000E+01  2.9000E+01
38  2..00E+01   3.7000E+01  3.7000E+01  3.7000E+01  3.7000E+01  2.9000E+01
```

rlbtbm, roltb(i), rlbtbp (density) at time= 0.00000E+00

I =	0	1	2	3	4	5	6	7	8
1	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
2	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
3	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
4	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
5	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
6	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
7	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
8	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
9	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
10	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
11	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
12	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
13	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
14	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
15	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
16	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
17	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
18	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
19	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
20	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
21	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
22	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
23	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
24	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
25	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
26	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
27	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
28	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
29	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
30	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
31	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
32	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
33	1.0214E+03	1.1190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
34	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
35	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
36	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
37	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		
38	1.0214E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0190E+03	1.0214E+03		

ptb (pressure) at time= 0.00000E+00

I =	0	1	2	3	4	5	6	7	8
1		9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04			
2		9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04			
3		9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04			
4		9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04			

5	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
6	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
7	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
8	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
9	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
10	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
11	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
12	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
13	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
14	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
15	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
16	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
17	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
18	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
19	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
20	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
21	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
22	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
23	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
24	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
25	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
26	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
27	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
28	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
29	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
30	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
31	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
32	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
33	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
34	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
35	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
36	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
37	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04
38	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04	9.4006E+04

qtb (watts) at time= 0.00000E+00

I =	0	1	2	3	4	5	6	7	8
1		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			
2		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			
3		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			
4		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			
5		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			
6		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			
7		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			
8		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			
9		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			
10		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			
11		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			
12		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			
13		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			
14		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			
15		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			
16		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			
17		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			
18		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			
19		0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00			

20	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00
21	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00
22	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00
23	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00
24	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00
25	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00
26	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00
27	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00
28	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00
29	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00
30	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00
31	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00
32	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00
33	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00
34	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00
35	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00
36	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00
37	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00
38	0.0000E+00	7.9984E+06	7.9984E+06	7.9984E+06	0.0000E+00

...gdconv.... deltah= 5.799E-01 is being reset to dhconv= 1.000E+03 for convergence testing.

nt	time	dtime	it	max(dl)/dconv	max(du)/velmax	max(dv)/velmax	max(dw)/velmax	max(dh/h)	runt	courdt	dconv	velmax
1	1.0000E-01	1.00E-01	1	0.00E+00	2.02E+00	1.41E+00	-3.71E+01	-2.53E+00	4.74	1.85E-02	3.79E-06	2.70E+01
2	2.0000E-01	1.00E-01	1	0.00E+00	1.38E-01	-1.78E-01	7.18E+00	-2.01E+00	5.69	6.60E-03	1.05E-05	1.19E+02
3	3.0000E-01	1.00E-01	1	0.00E+00	6.36E-02	9.83E-02	-1.74E+00	4.93E-01	6.63	3.59E-03	1.71E-05	1.67E+02
4	4.0000E-01	1.00E-01	1	0.00E+00	4.67E-02	6.80E-02	2.38E+00	-3.49E-01	7.62	2.92E-03	2.24E-05	1.91E+02
5	5.0000E-01	1.00E-01	1	0.00E+00	5.97E-02	7.26E-02	-1.44E+01	5.25E-01	8.58	2.60E-03	2.45E-05	2.17E+02
6	6.0000E-01	1.00E-01	1	0.00E+00	6.10E-02	6.10E-02	1.16E+01	-3.40E-01	9.54	2.34E-03	2.88E-05	2.30E+02
7	7.0000E-01	1.00E-01	1	0.00E+00	2.28E-02	5.30E-02	1.58E+00	3.93E-01	10.53	2.20E-03	3.03E-05	2.45E+02
8	8.0000E-01	1.00E-01	1	0.00E+00	-1.59E-02	-4.31E-02	-4.25E-01	-1.60E-01	11.51	2.05E-03	3.39E-05	2.51E+02
9	9.0000E-01	1.00E-01	1	0.00E+00	-1.82E-02	4.29E-02	3.23E-01	-1.83E-01	12.49	1.99E-03	3.46E-05	2.58E+02
10	1.0000E+00	1.00E-01	1	0.00E+00	-1.40E-02	2.46E-02	-2.65E-01	-1.47E-01	13.47	1.92E-03	3.68E-05	2.60E+02
11	1.1000E+00	1.00E-01	1	0.00E+00	1.59E-02	2.64E-02	2.15E-01	9.50E-02	14.42	1.89E-03	3.71E-05	2.61E+02
12	1.2000E+00	1.00E-01	1	0.00E+00	1.23E-02	1.64E-02	-1.78E-01	-1.63E-01	15.42	1.84E-03	3.86E-05	2.62E+02
13	1.3000E+00	1.00E-01	1	0.00E+00	1.44E-02	1.60E-02	1.42E-01	-9.24E-02	16.39	1.82E-03	3.88E-05	2.61E+02
14	1.4000E+00	1.00E-01	1	0.00E+00	1.27E-02	-1.39E-02	1.21E-01	-1.81E-01	17.36	1.79E-03	3.99E-05	2.58E+02
15	1.5000E+00	1.00E-01	1	0.00E+00	1.31E-02	-1.71E-02	-9.64E-02	-8.17E-02	18.34	1.78E-03	4.00E-05	2.56E+02
16	1.6000E+00	1.00E-01	1	0.00E+00	1.10E-02	-1.87E-02	8.47E-02	-9.37E-02	19.32	1.76E-03	4.05E-05	2.53E+02
17	1.7000E+00	1.00E-01	1	0.00E+00	1.14E-02	-2.00E-02	-6.65E-02	-6.10E-02	20.32	1.76E-03	4.03E-05	2.50E+02
18	1.8000E+00	1.00E-01	1	0.00E+00	9.27E-03	-1.99E-02	5.70E-02	-8.74E-02	21.32	1.76E-03	4.03E-05	2.48E+02
19	1.9000E+00	1.00E-01	1	0.00E+00	8.97E-03	-1.93E-02	4.07E-02	-8.63E-02	22.31	1.78E-03	3.98E-05	2.46E+02
20	2.0000E+00	1.00E-01	1	0.00E+00	8.15E-03	-1.92E-02	3.43E-02	-6.41E-02	23.26	1.80E-03	3.95E-05	2.43E+02
21	2.1000E+00	1.00E-01	1	0.00E+00	8.74E-03	-1.62E-02	2.57E-02	-6.14E-02	24.32	1.81E-03	3.90E-05	2.41E+02
22	2.2000E+00	1.00E-01	1	0.00E+00	9.95E-03	-1.37E-02	2.18E-02	-8.49E-02	25.34	1.83E-03	3.87E-05	2.39E+02
23	2.3000E+00	1.00E-01	1	0.00E+00	1.09E-02	-1.24E-02	1.53E-02	-8.36E-02	26.29	1.84E-03	3.83E-05	2.37E+02
24	2.4000E+00	1.00E-01	1	0.00E+00	9.26E-03	-1.26E-02	1.39E-02	-7.39E-02	27.30	1.86E-03	3.80E-05	2.35E+02
25	2.5000E+00	1.00E-01	1	0.00E+00	9.45E-03	-1.22E-02	1.59E-02	-1.02E-01	28.29	1.87E-03	3.77E-05	2.34E+02
26	2.6000E+00	1.00E-01	1	0.00E+00	-1.17E-02	9.55E-03	1.52E-02	-8.85E-02	29.33	1.88E-03	3.75E-05	2.33E+02
27	2.7000E+00	1.00E-01	1	0.00E+00	-1.22E-02	9.35E-03	1.34E-02	-7.27E-02	30.34	1.89E-03	3.73E-05	2.32E+02
28	2.8000E+00	1.00E-01	1	0.00E+00	-1.18E-02	8.85E-03	1.07E-02	-5.90E-02	31.30	1.90E-03	3.71E-05	2.31E+02
29	2.9000E+00	1.00E-01	1	0.00E+00	-1.11E-02	7.99E-03	8.53E-03	-4.84E-02	32.26	1.91E-03	3.69E-05	2.30E+02
30	3.0000E+00	1.00E-01	1	0.00E+00	-1.02E-02	7.15E-03	7.61E-03	-4.13E-02	33.23	1.92E-03	3.67E-05	2.29E+02
31	3.1000E+00	1.00E-01	1	0.00E+00	-9.22E-03	6.57E-03	6.69E-03	-3.79E-02	34.25	1.93E-03	3.65E-05	2.29E+02
32	3.2000E+00	1.00E-01	1	0.00E+00	-8.14E-03	5.80E-03	5.60E-03	-3.54E-02	35.30	1.93E-03	3.64E-05	2.28E+02
33	3.3000E+00	1.00E-01	1	0.00E+00	-6.84E-03	5.41E-03	5.37E-03	-3.45E-02	36.35	1.94E-03	3.63E-05	2.27E+02
34	3.4000E+00	1.00E-01	1	0.00E+00	-6.15E-03	5.05E-03	5.40E-03	-3.40E-02	37.32	1.95E-03	3.61E-05	2.27E+02
35	3.5000E+00	1.00E-01	1	0.00E+00	-5.66E-03	4.75E-03	5.41E-03	-3.33E-02	38.31	1.96E-03	3.60E-05	2.26E+02
36	3.6000E+00	1.00E-01	1	0.00E+00	-4.95E-03	4.49E-03	5.30E-03	-3.28E-02	39.27	1.96E-03	3.59E-05	2.26E+02
37	3.7000E+00	1.00E-01	1	0.00E+00	-4.61E-03	4.26E-03	4.79E-03	-3.22E-02	40.24	1.97E-03	3.58E-05	2.25E+02
38	3.8000E+00	1.00E-01	1	0.00E+00	-3.60E-03	4.06E-03	4.41E-03	-3.15E-02	41.22	1.97E-03	3.57E-05	2.25E+02
39	3.9000E+00	1.00E-01	1	0.00E+00	-3.34E-03	3.87E-03	4.02E-03	-3.09E-02	42.25	1.98E-03	3.56E-05	2.24E+02
40	4.0000E+00	1.00E-01	1	0.00E+00	3.17E-03	3.69E-03	3.60E-03	-3.03E-02	43.25	1.98E-03	3.55E-05	2.24E+02
41	4.1000E+00	1.00E-01	1	0.00E+00	2.93E-03	3.60E-03	3.18E-03	-2.94E-02	44.21	1.99E-03	3.54E-05	2.23E+02
42	4.2000E+00	1.00E-01	1	0.00E+00	2.67E-03	3.71E-03	2.84E-03	-2.84E-02	45.18	1.99E-03	3.53E-05	2.23E+02
43	4.3000E+00	1.00E-01	1	0.00E+00	2.49E-03	3.78E-03	2.79E-03	-2.72E-02	46.14	2.00E-03	3.52E-05	2.23E+02
44	4.4000E+00	1.00E-01	1	0.00E+00	2.27E-03	3.52E-03	2.72E-03	-2.65E-02	47.11	2.00E-03	3.51E-05	2.22E+02
45	4.5000E+00	1.00E-01	1	0.00E+00	2.04E-03	3.43E-03	2.70E-03	-2.58E-02	48.05	2.01E-03	3.50E-05	2.22E+02
46	4.6000E+00	1.00E-01	1	0.00E+00	1.81E-03	3.38E-03	2.65E-03	-2.52E-02	49.01	2.01E-03	3.50E-05	2.22E+02
47	4.7000E+00	1.00E-01	1	0.00E+00	1.61E-03	3.51E-03	2.59E-03	-2.46E-02	49.97	2.02E-03	3.49E-05	2.22E+02
48	4.8000E+00	1.00E-01	1	0.00E+00	1.64E-03	3.61E-03	2.92E-03	-2.40E-02	50.94	2.02E-03	3.48E-05	2.21E+02
49	4.9000E+00	1.00E-01	1	0.00E+00	1.54E-03	3.61E-03	3.05E-03	-2.40E-02	51.92	2.02E-03	3.48E-05	2.21E+02
50	5.0000E+00	1.00E-01	1	0.00E+00	1.46E-03	3.19E-03	2.66E-03	-2.34E-02	52.85	2.03E-03	3.47E-05	2.21E+02

nt	time	dtime	it	max(dl)/dconv	max(dul)/velmax	max(dvl)/velmax	max(dul)/velmax	max(dh/h)	runt	courdt	dconv	velmax
51	5.1000E+00	1.00E-01	1	0.00E+00	1.37E-03	-2.94E-03	-2.37E-03	-2.28E-02	53.79	2.03E-03	3.47E-05	2.21E+02
52	5.2000E+00	1.00E-01	1	0.00E+00	1.29E-03	-2.55E-03	-2.12E-03	-2.22E-02	54.75	2.03E-03	3.47E-05	2.20E+02
53	5.3000E+00	1.00E-01	1	0.00E+00	1.20E-03	-2.13E-03	-2.06E-03	-2.17E-02	55.73	2.03E-03	3.46E-05	2.20E+02
54	5.4000E+00	1.00E-01	1	0.00E+00	1.13E-03	-1.86E-03	-2.01E-03	-2.11E-02	56.69	2.04E-03	3.45E-05	2.20E+02
55	5.5000E+00	1.00E-01	1	0.00E+00	1.06E-03	-1.67E-03	-1.94E-03	-2.06E-02	57.65	2.04E-03	3.45E-05	2.20E+02
56	5.6000E+00	1.00E-01	1	0.00E+00	1.01E-03	-1.51E-03	-1.87E-03	-2.00E-02	58.62	2.04E-03	3.45E-05	2.20E+02
57	5.7000E+00	1.00E-01	1	0.00E+00	9.44E-04	-1.38E-03	-1.88E-03	-1.95E-02	59.57	2.04E-03	3.44E-05	2.20E+02
58	5.8000E+00	1.00E-01	1	0.00E+00	8.81E-04	-1.26E-03	-1.78E-03	-1.89E-02	60.58	2.04E-03	3.44E-05	2.19E+02
59	5.9000E+00	1.00E-01	1	0.00E+00	8.24E-04	-1.16E-03	-1.71E-03	-1.84E-02	61.53	2.04E-03	3.44E-05	2.19E+02
60	6.0000E+00	1.00E-01	1	0.00E+00	7.78E-04	-1.07E-03	-1.62E-03	-1.79E-02	62.70	2.05E-03	3.43E-05	2.19E+02
61	6.1000E+00	1.00E-01	1	0.00E+00	7.46E-04	-9.91E-04	-1.55E-03	-1.73E-02	63.66	2.05E-03	3.43E-05	2.19E+02
62	6.2000E+00	1.00E-01	1	0.00E+00	7.10E-04	9.04E-04	-1.46E-03	-1.68E-02	64.61	2.05E-03	3.43E-05	2.19E+02
63	6.3000E+00	1.00E-01	1	0.00E+00	6.72E-04	8.60E-04	-1.38E-03	-1.63E-02	65.63	2.05E-03	3.43E-05	2.19E+02
64	6.4000E+00	1.00E-01	1	0.00E+00	6.32E-04	8.38E-04	-1.31E-03	-1.58E-02	66.79	2.05E-03	3.43E-05	2.19E+02
65	6.5000E+00	1.00E-01	1	0.00E+00	5.92E-04	8.04E-04	-1.24E-03	-1.53E-02	67.85	2.05E-03	3.43E-05	2.19E+02
66	6.6000E+00	1.00E-01	1	0.00E+00	5.52E-04	7.70E-04	-1.17E-03	-1.49E-02	68.85	2.05E-03	3.43E-05	2.19E+02
67	6.7000E+00	1.00E-01	1	0.00E+00	5.12E-04	7.37E-04	-1.11E-03	-1.44E-02	69.84	2.05E-03	3.43E-05	2.19E+02
68	6.8000E+00	1.00E-01	1	0.00E+00	4.74E-04	7.05E-04	-1.05E-03	-1.40E-02	70.81	2.05E-03	3.43E-05	2.19E+02
69	6.9000E+00	1.00E-01	1	0.00E+00	4.37E-04	6.74E-04	-9.91E-04	-1.36E-02	71.76	2.05E-03	3.42E-05	2.19E+02
70	7.0000E+00	1.00E-01	1	0.00E+00	4.02E-04	6.44E-04	-9.37E-04	-1.32E-02	72.78	2.06E-03	3.42E-05	2.18E+02
71	7.1000E+00	1.00E-01	1	0.00E+00	3.68E-04	6.15E-04	-8.87E-04	-1.28E-02	73.76	2.06E-03	3.42E-05	2.18E+02
72	7.2000E+00	1.00E-01	1	0.00E+00	3.36E-04	5.87E-04	-8.39E-04	-1.24E-02	74.73	2.06E-03	3.42E-05	2.18E+02
73	7.3000E+00	1.00E-01	1	0.00E+00	3.06E-04	5.60E-04	-7.94E-04	-1.21E-02	75.68	2.06E-03	3.42E-05	2.18E+02
74	7.4000E+00	1.00E-01	1	0.00E+00	2.78E-04	5.34E-04	-7.52E-04	-1.17E-02	76.63	2.06E-03	3.42E-05	2.18E+02
75	7.5000E+00	1.00E-01	1	0.00E+00	2.58E-04	5.09E-04	-7.12E-04	-1.14E-02	77.60	2.06E-03	3.42E-05	2.18E+02
76	7.6000E+00	1.00E-01	1	0.00E+00	2.42E-04	4.85E-04	-6.75E-04	-1.11E-02	78.58	2.06E-03	3.42E-05	2.18E+02
77	7.7000E+00	1.00E-01	1	0.00E+00	2.28E-04	4.62E-04	-6.40E-04	-1.08E-02	79.55	2.06E-03	3.42E-05	2.18E+02
78	7.8000E+00	1.00E-01	1	0.00E+00	2.17E-04	4.39E-04	-6.05E-04	-1.05E-02	80.53	2.06E-03	3.42E-05	2.18E+02
79	7.9000E+00	1.00E-01	1	0.00E+00	2.06E-04	4.18E-04	-5.74E-04	-1.03E-02	81.50	2.06E-03	3.42E-05	2.18E+02
80	8.0000E+00	1.00E-01	1	0.00E+00	1.97E-04	3.98E-04	-5.44E-04	-1.00E-02	82.46	2.06E-03	3.42E-05	2.18E+02
81	8.1000E+00	1.00E-01	1	0.00E+00	-1.94E-04	3.79E-04	-5.17E-04	-9.65E-03	83.45	2.06E-03	3.42E-05	2.18E+02
82	8.2000E+00	1.00E-01	1	0.00E+00	-1.95E-04	3.60E-04	-4.67E-04	-9.04E-03	84.42	2.06E-03	3.42E-05	2.18E+02
83	8.3000E+00	1.00E-01	1	0.00E+00	-1.95E-04	3.43E-04	-4.44E-04	-8.77E-03	85.37	2.06E-03	3.42E-05	2.18E+02
84	8.4000E+00	1.00E-01	1	0.00E+00	-1.95E-04	3.26E-04	-4.23E-04	-8.45E-03	86.36	2.06E-03	3.42E-05	2.18E+02
85	8.5000E+00	1.00E-01	1	0.00E+00	-1.96E-04	3.10E-04	-4.02E-04	-8.14E-03	87.36	2.06E-03	3.42E-05	2.18E+02
86	8.6000E+00	1.00E-01	1	0.00E+00	-1.96E-04	2.95E-04	-3.83E-04	-8.11E-03	88.32	2.06E-03	3.41E-05	2.18E+02
87	8.7000E+00	1.00E-01	1	0.00E+00	-1.96E-04	2.89E-04	-3.65E-04	-8.10E-03	89.28	2.06E-03	3.41E-05	2.18E+02
88	8.8000E+00	1.00E-01	1	0.00E+00	-1.95E-04	2.89E-04	-3.47E-04	-8.08E-03	90.25	2.06E-03	3.41E-05	2.18E+02
89	8.9000E+00	1.00E-01	1	0.00E+00	-1.96E-04	2.90E-04	-3.31E-04	-8.05E-03	91.34	2.06E-03	3.41E-05	2.18E+02
90	9.0000E+00	1.00E-01	1	0.00E+00	-1.97E-04	2.89E-04	-3.16E-04	-8.02E-03	92.57	2.06E-03	3.41E-05	2.18E+02
91	9.1000E+00	1.00E-01	1	0.00E+00	-1.98E-04	2.89E-04	-3.01E-04	-7.98E-03	93.68	2.06E-03	3.41E-05	2.18E+02
92	9.2000E+00	1.00E-01	1	0.00E+00	-1.99E-04	2.88E-04	-2.87E-04	-7.94E-03	94.75	2.06E-03	3.41E-05	2.18E+02
93	9.3000E+00	1.00E-01	1	0.00E+00	-2.00E-04	2.87E-04	-2.74E-04	-7.89E-03	95.82	2.06E-03	3.41E-05	2.18E+02
94	9.4000E+00	1.00E-01	1	0.00E+00	-2.01E-04	2.86E-04	2.76E-04	-7.85E-03	96.82	2.06E-03	3.41E-05	2.18E+02
95	9.5000E+00	1.00E-01	1	0.00E+00	-2.01E-04	2.84E-04	2.78E-04	-7.81E-03	97.80	2.06E-03	3.41E-05	2.17E+02
96	9.6000E+00	1.00E-01	1	0.00E+00	-2.01E-04	2.83E-04	2.79E-04	-7.77E-03	98.77	2.06E-03	3.41E-05	2.17E+02
97	9.7000E+00	1.00E-01	1	0.00E+00	-2.01E-04	2.81E-04	2.80E-04	-7.72E-03	99.97	2.06E-03	3.41E-05	2.17E+02
98	9.8000E+00	1.00E-01	1	0.00E+00	-2.01E-04	2.80E-04	2.81E-04	-7.68E-03	100.99	2.06E-03	3.41E-05	2.17E+02
99	9.9000E+00	1.00E-01	1	0.00E+00	-2.01E-04	2.78E-04	2.80E-04	-7.64E-03	101.95	2.06E-03	3.41E-05	2.17E+02
100	1.0000E+01	1.00E-01	1	0.00E+00	-2.00E-04	2.76E-04	2.81E-04	-7.60E-03	102.94	2.06E-03	3.41E-05	2.17E+02

nt	time	dtime	it	max(dl)/dconv	max(du)/velmax	max(dv)/velmax	max(dw)/velmax	max(dh/h)	runt	courdt	dconv	velmax
# 4201	4.2010E+02	1.00E-01	1	0.00E+00	2.16E-06	1.38E-06	2.28E-06	-1.07E-05	4046.13	2.38E-03	2.94E-05	1.82E+02
# 4202	4.2020E+02	1.00E-01	1	0.00E+00	2.16E-06	1.38E-06	2.28E-06	-1.07E-05	4047.09	2.38E-03	2.94E-05	1.82E+02
# 4203	4.2030E+02	1.00E-01	1	0.00E+00	2.16E-06	1.38E-06	2.28E-06	-1.07E-05	4048.05	2.38E-03	2.94E-05	1.82E+02
# 4204	4.2040E+02	1.00E-01	1	0.00E+00	2.16E-06	1.38E-06	2.27E-06	-1.07E-05	4049.01	2.38E-03	2.94E-05	1.82E+02
# 4205	4.2050E+02	1.00E-01	1	0.00E+00	2.15E-06	1.38E-06	2.27E-06	-1.07E-05	4049.97	2.38E-03	2.94E-05	1.82E+02
# 4206	4.2060E+02	1.00E-01	1	0.00E+00	2.15E-06	1.37E-06	2.27E-06	-1.07E-05	4050.93	2.38E-03	2.94E-05	1.82E+02
# 4207	4.2070E+02	1.00E-01	1	0.00E+00	2.15E-06	1.37E-06	2.27E-06	-1.07E-05	4051.89	2.38E-03	2.94E-05	1.82E+02
# 4208	4.2080E+02	1.00E-01	1	0.00E+00	2.15E-06	1.37E-06	2.26E-06	-1.06E-05	4052.85	2.38E-03	2.94E-05	1.82E+02
# 4209	4.2090E+02	1.00E-01	1	0.00E+00	2.14E-06	1.37E-06	2.26E-06	-1.06E-05	4053.81	2.38E-03	2.94E-05	1.82E+02
# 4210	4.2100E+02	1.00E-01	1	0.00E+00	2.14E-06	1.37E-06	2.26E-06	-1.06E-05	4054.77	2.38E-03	2.94E-05	1.82E+02
# 4211	4.2110E+02	1.00E-01	1	0.00E+00	2.14E-06	1.37E-06	2.26E-06	-1.06E-05	4055.72	2.38E-03	2.94E-05	1.82E+02
# 4212	4.2120E+02	1.00E-01	1	0.00E+00	2.14E-06	1.37E-06	2.26E-06	-1.06E-05	4056.69	2.38E-03	2.94E-05	1.82E+02
# 4213	4.2130E+02	1.00E-01	1	0.00E+00	2.14E-06	1.37E-06	2.25E-06	-1.06E-05	4057.66	2.38E-03	2.94E-05	1.82E+02
# 4214	4.2140E+02	1.00E-01	1	0.00E+00	2.14E-06	1.37E-06	2.25E-06	-1.06E-05	4058.61	2.38E-03	2.94E-05	1.82E+02
# 4215	4.2150E+02	1.00E-01	1	0.00E+00	2.13E-06	1.36E-06	2.25E-06	-1.06E-05	4059.57	2.38E-03	2.94E-05	1.82E+02
# 4216	4.2160E+02	1.00E-01	1	0.00E+00	2.13E-06	1.36E-06	2.25E-06	-1.06E-05	4060.53	2.38E-03	2.94E-05	1.82E+02
# 4217	4.2170E+02	1.00E-01	1	0.00E+00	2.13E-06	1.36E-06	2.25E-06	-1.06E-05	4061.48	2.38E-03	2.94E-05	1.82E+02
# 4218	4.2180E+02	1.00E-01	1	0.00E+00	2.13E-06	1.36E-06	2.24E-06	-1.05E-05	4062.42	2.38E-03	2.94E-05	1.82E+02
# 4219	4.2190E+02	1.00E-01	1	0.00E+00	2.12E-06	1.36E-06	2.24E-06	-1.05E-05	4063.39	2.38E-03	2.94E-05	1.82E+02
# 4220	4.2200E+02	1.00E-01	1	0.00E+00	2.12E-06	1.36E-06	2.24E-06	-1.05E-05	4064.34	2.38E-03	2.94E-05	1.82E+02
# 4221	4.2210E+02	1.00E-01	1	0.00E+00	2.12E-06	1.36E-06	2.24E-06	-1.05E-05	4065.29	2.38E-03	2.94E-05	1.82E+02
# 4222	4.2220E+02	1.00E-01	1	0.00E+00	2.12E-06	1.35E-06	2.23E-06	-1.05E-05	4066.24	2.38E-03	2.94E-05	1.82E+02
# 4223	4.2230E+02	1.00E-01	1	0.00E+00	2.12E-06	1.35E-06	2.23E-06	-1.05E-05	4067.20	2.38E-03	2.94E-05	1.82E+02
# 4224	4.2240E+02	1.00E-01	1	0.00E+00	2.11E-06	1.35E-06	2.23E-06	-1.05E-05	4068.16	2.38E-03	2.94E-05	1.82E+02
# 4225	4.2250E+02	1.00E-01	1	0.00E+00	2.11E-06	1.35E-06	2.23E-06	-1.05E-05	4069.12	2.38E-03	2.94E-05	1.82E+02
# 4226	4.2260E+02	1.00E-01	1	0.00E+00	2.11E-06	1.35E-06	2.22E-06	-1.05E-05	4070.09	2.38E-03	2.94E-05	1.82E+02
# 4227	4.2270E+02	1.00E-01	1	0.00E+00	2.11E-06	1.35E-06	2.22E-06	-1.04E-05	4071.05	2.38E-03	2.94E-05	1.82E+02
# 4228	4.2280E+02	1.00E-01	1	0.00E+00	2.11E-06	1.35E-06	2.22E-06	-1.04E-05	4072.00	2.38E-03	2.94E-05	1.82E+02
# 4229	4.2290E+02	1.00E-01	1	0.00E+00	2.10E-06	1.34E-06	2.22E-06	-1.04E-05	4072.95	2.38E-03	2.94E-05	1.82E+02
# 4230	4.2300E+02	1.00E-01	1	0.00E+00	2.10E-06	1.34E-06	2.21E-06	-1.04E-05	4073.93	2.38E-03	2.94E-05	1.82E+02
# 4231	4.2310E+02	1.00E-01	1	0.00E+00	2.10E-06	1.34E-06	2.21E-06	-1.04E-05	4074.89	2.38E-03	2.94E-05	1.82E+02
# 4232	4.2320E+02	1.00E-01	1	0.00E+00	2.10E-06	1.34E-06	2.21E-06	-1.04E-05	4075.84	2.38E-03	2.94E-05	1.82E+02
# 4233	4.2330E+02	1.00E-01	1	0.00E+00	2.10E-06	1.34E-06	2.21E-06	-1.04E-05	4076.79	2.38E-03	2.94E-05	1.82E+02
# 4234	4.2340E+02	1.00E-01	1	0.00E+00	2.09E-06	1.34E-06	2.20E-06	-1.04E-05	4077.75	2.38E-03	2.94E-05	1.82E+02
# 4235	4.2350E+02	1.00E-01	1	0.00E+00	2.09E-06	1.34E-06	2.20E-06	-1.04E-05	4078.70	2.38E-03	2.94E-05	1.82E+02
# 4236	4.2360E+02	1.00E-01	1	0.00E+00	2.09E-06	1.33E-06	2.20E-06	-1.04E-05	4079.66	2.38E-03	2.94E-05	1.82E+02
# 4237	4.2370E+02	1.00E-01	1	0.00E+00	2.09E-06	1.33E-06	2.20E-06	-1.03E-05	4080.62	2.38E-03	2.94E-05	1.82E+02
# 4238	4.2380E+02	1.00E-01	1	0.00E+00	2.08E-06	1.33E-06	2.20E-06	-1.03E-05	4081.59	2.38E-03	2.94E-05	1.82E+02
# 4239	4.2390E+02	1.00E-01	1	0.00E+00	2.08E-06	1.33E-06	2.20E-06	-1.03E-05	4082.54	2.38E-03	2.94E-05	1.82E+02
# 4240	4.2400E+02	1.00E-01	1	0.00E+00	2.08E-06	1.33E-06	2.20E-06	-1.03E-05	4083.50	2.38E-03	2.94E-05	1.82E+02
# 4241	4.2410E+02	1.00E-01	1	0.00E+00	2.08E-06	1.33E-06	2.19E-06	-1.03E-05	4084.46	2.38E-03	2.94E-05	1.82E+02
# 4242	4.2420E+02	1.00E-01	1	0.00E+00	2.08E-06	1.33E-06	2.19E-06	-1.03E-05	4085.42	2.38E-03	2.94E-05	1.82E+02
# 4243	4.2430E+02	1.00E-01	1	0.00E+00	2.08E-06	1.33E-06	2.19E-06	-1.03E-05	4086.39	2.38E-03	2.94E-05	1.82E+02
# 4244	4.2440E+02	1.00E-01	1	0.00E+00	2.07E-06	1.33E-06	2.19E-06	-1.03E-05	4087.36	2.38E-03	2.94E-05	1.82E+02
# 4245	4.2450E+02	1.00E-01	1	0.00E+00	2.07E-06	1.32E-06	2.19E-06	-1.02E-05	4088.32	2.38E-03	2.94E-05	1.82E+02
# 4246	4.2460E+02	1.00E-01	1	0.00E+00	2.07E-06	1.32E-06	2.18E-06	-1.02E-05	4089.27	2.38E-03	2.94E-05	1.82E+02
# 4247	4.2470E+02	1.00E-01	1	0.00E+00	2.07E-06	1.32E-06	2.18E-06	-1.02E-05	4090.23	2.38E-03	2.94E-05	1.82E+02
# 4248	4.2480E+02	1.00E-01	1	0.00E+00	2.07E-06	1.32E-06	2.18E-06	-1.02E-05	4091.19	2.38E-03	2.94E-05	1.82E+02
# 4249	4.2490E+02	1.00E-01	1	0.00E+00	2.06E-06	1.32E-06	2.18E-06	-1.02E-05	4092.14	2.38E-03	2.94E-05	1.82E+02
# 4250	4.2500E+02	1.00E-01	1	0.00E+00	2.06E-06	1.32E-06	2.17E-06	-1.02E-05	4093.09	2.38E-03	2.94E-05	1.82E+02

nt	time	dtime	it	max(dl)/dconv	max(du)/velmax	max(dv)/velmax	max(dw)/velmax	max(dh/h)	runt	courdt	dconv	velmax
# 4251	4.2510E+02	1.00E-01	1	0.00E+00	2.06E-06	1.32E-06	2.17E-06	-1.02E-05	4094.04	2.38E-03	2.94E-05	1.82E+02
# 4252	4.2520E+02	1.00E-01	1	0.00E+00	2.06E-06	1.32E-06	2.17E-06	-1.02E-05	4095.00	2.38E-03	2.94E-05	1.82E+02
# 4253	4.2530E+02	1.00E-01	1	0.00E+00	2.06E-06	1.31E-06	2.17E-06	-1.02E-05	4095.96	2.38E-03	2.94E-05	1.82E+02
# 4254	4.2540E+02	1.00E-01	1	0.00E+00	2.05E-06	1.31E-06	2.17E-06	-1.02E-05	4096.92	2.38E-03	2.94E-05	1.82E+02
# 4255	4.2550E+02	1.00E-01	1	0.00E+00	2.05E-06	1.31E-06	2.16E-06	-1.02E-05	4097.86	2.38E-03	2.94E-05	1.82E+02
# 4256	4.2560E+02	1.00E-01	1	0.00E+00	2.05E-06	1.31E-06	2.16E-06	-1.01E-05	4098.82	2.38E-03	2.94E-05	1.82E+02
# 4257	4.2570E+02	1.00E-01	1	0.00E+00	2.05E-06	1.31E-06	2.16E-06	-1.01E-05	4099.77	2.38E-03	2.94E-05	1.82E+02
# 4258	4.2580E+02	1.00E-01	1	0.00E+00	2.05E-06	1.31E-06	2.16E-06	-1.01E-05	4100.74	2.38E-03	2.94E-05	1.82E+02
# 4259	4.2590E+02	1.00E-01	1	0.00E+00	2.04E-06	1.31E-06	2.16E-06	-1.01E-05	4101.70	2.38E-03	2.94E-05	1.82E+02
# 4260	4.2600E+02	1.00E-01	1	0.00E+00	2.04E-06	1.30E-06	2.15E-06	-1.01E-05	4102.67	2.38E-03	2.94E-05	1.82E+02
# 4261	4.2610E+02	1.00E-01	1	0.00E+00	2.04E-06	1.30E-06	2.15E-06	-1.01E-05	4103.61	2.38E-03	2.94E-05	1.82E+02
# 4262	4.2620E+02	1.00E-01	1	0.00E+00	2.04E-06	1.30E-06	2.15E-06	-1.01E-05	4104.56	2.38E-03	2.94E-05	1.82E+02
# 4263	4.2630E+02	1.00E-01	1	0.00E+00	2.03E-06	1.30E-06	2.15E-06	-1.01E-05	4105.52	2.38E-03	2.94E-05	1.82E+02
# 4264	4.2640E+02	1.00E-01	1	0.00E+00	2.03E-06	1.30E-06	2.14E-06	-1.01E-05	4106.48	2.38E-03	2.94E-05	1.82E+02
# 4265	4.2650E+02	1.00E-01	1	0.00E+00	2.03E-06	1.30E-06	2.14E-06	-1.01E-05	4107.44	2.38E-03	2.94E-05	1.82E+02
# 4266	4.2660E+02	1.00E-01	1	0.00E+00	2.03E-06	1.30E-06	2.14E-06	-1.00E-05	4108.40	2.38E-03	2.94E-05	1.82E+02
# 4267	4.2670E+02	1.00E-01	1	0.00E+00	2.03E-06	1.30E-06	2.14E-06	-1.00E-05	4109.34	2.38E-03	2.94E-05	1.82E+02
# 4268	4.2680E+02	1.00E-01	1	0.00E+00	2.02E-06	1.29E-06	2.13E-06	-1.00E-05	4110.30	2.38E-03	2.94E-05	1.82E+02
# 4269	4.2690E+02	1.00E-01	1	0.00E+00	2.02E-06	1.29E-06	2.13E-06	-1.00E-05	4111.25	2.38E-03	2.94E-05	1.82E+02
# 4270	4.2700E+02	1.00E-01	1	0.00E+00	2.02E-06	1.29E-06	2.13E-06	-1.00E-05	4112.21	2.38E-03	2.94E-05	1.82E+02
# 4271	4.2710E+02	1.00E-01	1	0.00E+00	2.02E-06	1.29E-06	2.13E-05	-1.00E-05	4113.16	2.38E-03	2.94E-05	1.82E+02

```
*************************************************************
*****  steady state has been reached to within eps3= 1.000E-05  *****
*************************************************************

restart file has been written at time  4.271E+02 after iteration     0 of time step  4271
block lengths of other common blocks  (written to restart):
      88    185   1193   3583   8083    377    583    923  15755     41
block lengths of common /space/  (written to restart)
                         96752            457      0      0   4406  58186

plotting information appended to file 10.
```

`********** Date: 10/15/91   Time: 22:48:07   COMMIX-PC-100   Last updated: 10/09/91   Machine Sun4/110 **********`

global balances at time= 4.271E+02 seconds for component   1

surface number	mass convected (kg/sec)	thermal energy convected (watt)	heat conducted (watt)	average velocity (m/sec)	average enthalpy (j/kg)	average temperature (celsius)	bulk temperature (celsius)
1	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584035E+06	4.693834E+01	0.000000E+00
2	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.583891E+06	4.686125E+01	0.000000E+00
3	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.583935E+06	4.688719E+01	0.000000E+00
4	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.583661E+06	4.674701E+01	0.000000E+00
5	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584168E+06	4.700925E+01	0.000000E+00
6	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584067E+06	4.695528E+01	0.000000E+00
7	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584060E+06	4.695181E+01	0.000000E+00
8	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.583891E+06	4.686134E+01	0.000000E+00
9	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.578585E+06	4.414234E+01	0.000000E+00
10	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.578572E+06	4.413617E+01	0.000000E+00
11	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.578666E+06	4.418312E+01	0.000000E+00
12	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.578666E+06	4.418312E+01	0.000000E+00
13	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.578781E+06	4.424053E+01	0.000000E+00
14	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.578811E+06	4.425542E+01	0.000000E+00
15	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584376E+06	4.712053E+01	0.000000E+00
16	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584336E+06	4.709907E+01	0.000000E+00
17	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584360E+06	4.711230E+01	0.000000E+00
18	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584360E+06	4.711230E+01	0.000000E+00
19	5.606500E+00	1.447921E+07	-5.458678E-02	5.347843E+01	2.582575E+06	4.622000E+01	4.622000E+01
20	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584028E+06	4.693458E+01	0.000000E+00
21	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584028E+06	4.693458E+01	0.000000E+00
22	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584027E+06	4.693422E+01	0.000000E+00
23	0.000000E+00	0.000000E+03	0.000000E+00	0.000000E+00	2.584029E+06	4.693672E+01	0.000000E+00
24	1.569338E+02	4.055365E+08	2.492355E-02	1.798419E+02	2.584125E+06	4.698300E+01	4.698300E+01
25	-4.867307E+02	-1.255142E+05	0.000000E+00	-1.255092E+01	2.578720E+06	4.421022E+01	4.421022E+01

`*************************************************************** mass balance **********`

mass accumulation rate :	dmasdt =-5.066113E-06	(kg/s)
net mass convected into configuration :	flosum = 1.624916E+02	(kg/s)
net mass source :	xsource =-1.624916E+02	(kg/s)

global conservation of mass   :   (dmasdt - flosum - xsourc)   =-3.365523E-05 (kg/s)

total mass within configuration   :   tmass   = 6.639990E+01 (kg)

total volume occupied by fluid   :   thlvol   = 9.464799E+02 (m**3)

`*********************************************************** energy balance **********`

enthalpy accumulation rate :	dhdt =-1.334059E+01	(watt)
enthalpy stored in liquid condensates :	qmsl =-3.173406E+07	(watt)
net enthalpy accumulation rate :	dhnet = 3.173405E+07	(watt)
net energy convected into configuration :	hinsum = 4.198902E+08	(watt)
net heat conducted into configuration :	qinsum =-2.966323E-02	(watt)
heat generated within configuration :	qsourc =-3.880631E+08	(watt)
work :	dpdt = 1.076390E+00	(watt)

global energy   :(dhnet-hinsum-qinsum-qsource-dpdt)   =-9.302116E+04 (watt)

total internal energy within configuration: tenth   = 1.715751E+08 (joules)

at time= 4.27100E+02 seconds. total condensate = -1.62492E+02 kg. total energy to tubes = -3.88063E+08 joules.

****

ts number	volume (m**3)	mass (kg/m**3)	heat capacity (j/c)	total heat (j)	heat transfer to outside (watts)	heat transfer to inside (watts)	instantaneous heat source (watts)
1	4.98094E+00	2.25338E+04	1.22507E+07	5.01488E+08	-2.05187E+08	2.05190E+08	0.00000E+00
2	4.88170E+00	2.20897E+04	1.20066E+07	4.78390E+08	-1.82873E+08	1.82876E+08	0.00000E+00
totals	9.8626E+00	4.46284E+04	2.42573E+07	9.79878E+08	-3.88061E+08	3.88066E+08	0.00000E+00

********* Date: 10/15/91   Time: 22:48:08   COMMIX-PC-100   Last updated: 10/09/91   Machine Sun4/110 **********

global balances at time= 4.271E+02 seconds for component   2

surface number	mass convected (kg/sec)	thermal energy convected (watt)	heat conducted (watt)	average velocity (m/sec)	average enthalpy (j/kg)	average temperature (celsius)	bulk temperature (celsius)
1	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.811180E+04	4.693834E+01	0.000000E+00
2	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.803278E+04	4.686125E+01	0.000000E+00
3	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.805937E+04	4.688719E+01	0.000000E+00
4	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.791569E+04	4.674701E+01	0.000000E+00
5	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.818448E+04	4.700925E+01	0.000000E+00
6	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.812916E+04	4.695528E+01	0.000000E+00
7	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.812561E+04	4.695181E+01	0.000000E+00
8	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.803287E+04	4.686136E+01	0.000000E+00
9	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.524590E+04	4.414234E+01	0.000000E+00
10	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.523958E+04	4.413617E+01	0.000000E+00
11	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.528771E+04	4.418312E+01	0.000000E+00
12	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.528771E+04	4.418312E+01	0.000000E+00
13	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.534655E+04	4.424053E+01	0.000000E+00
14	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.536181E+04	4.425542E+01	0.000000E+00
15	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.829855E+04	4.712053E+01	0.000000E+00
16	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.827655E+04	4.709907E+01	0.000000E+00
17	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.829011E+04	4.711230E+01	0.000000E+00
18	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.829011E+04	4.711230E+01	0.000000E+00
19	0.000000E+00	0.000000E+00	0.000000E+00	5.347843E+01	0.000000E+00	4.622000E+01	0.000000E+00
20	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.810794E+04	4.693458E+01	0.000000E+00
21	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.810794E+04	4.693458E+01	0.000000E+00
22	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	4.810757E+04	4.693422E+01	0.000000E+00
23	1.805872E-03	0.000000E+00	0.000000E+00	0.000000E+00	4.810809E+04	4.693472E+01	0.000000E+00
24	1.805872E-03	8.696640E+01	1.707030E-07	1.798419E+02	1.349931E+04	4.698300E+01	4.698300E+01
25	-1.826923E-03	-8.278787E+01	0.000000E+00	-1.255092E+01	4.531548E+04	4.421022E+01	4.421022E+01

** mass balance ***********

mass accumulation rate	:	dmasdt	= 2.158332E-05 (kg/s)
net mass convected into configuration	:	flosum	=-2.105099E-05 (kg/s)
net mass source	:	xsourc	= 0.000000E+00 (kg/s)

global conservation of mass   : (dmasdt - flosum - xsource) = 4.263431E-05 (kg/s)

total mass within configuration   : tmass = 1.593165E-01 (kg)

total volume occupied by fluid   : thlvol = 1.352318E+00 (m**3)

** energy balance **********

enthalpy accumulation rate	:	dhdt	= 1.004877E+00 (watt)
enthalpy stored in liquid condensates	:	qmsl	= 0.000000E+00 (watt)
net enthalpy accumulation rate	:	dhnet	= 1.004877E+00 (watt)
net energy convected into configuration	:	hinsum	= 4.178529E+00 (watt)
net heat conducted into configuration	:	qinsum	= 1.707030E-07 (watt)
heat generated within configuration	:	qsourc	= 0.000000E+00 (watt)
work	:	dpdt	= 1.543273E-02 (watt)

global energy   :(dhnet-hinsum-qinsum-qsource-dpdt) =-3.189085E+00 (watt)

total internal energy within configuration: tenth = 7.490437E+03 (joules)

at time= 4.27100E+02 seconds. total condensate = 0.00000E+00 kg. total energy to tubes = 0.00000E+00 joules.

****

ts number	volume (m**3)	mass (kg/m**3)	heat capacity (j/c)	total heat (j)	heat transfer to outside (watts)	heat transfer to inside (watts)	instantaneous heat source (watts)
1	4.98094E+00	2.25388E+04	1.22507E+07	5.01488E+08	-2.05187E+08	2.05190E+08	0.00000E+00
2	4.88170E+00	2.20897E+04	1.20066E+07	4.78390E+08	-1.82873E+08	1.82876E+08	0.00000E+00
totals	9.8626E+00	4.46284E+04	2.42573E+07	9.79878E+08	-3.88061E+08	3.88066E+08	0.00000E+00

********** Date: 10/15/91   Time: 22:48:08   COMMIX-PC-100   Last updated: 10/09/91   Machine Sun4/110 **********

global balances at time= 4.271E+02 seconds for component 3

surface number	mass convected (kg/sec)	thermal energy convected (watt)	heat conducted (watt)	average velocity (m/sec)	average enthalpy (j/kg)	average temperature (celsius)	bulk temperature (celsius)
1	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.583998E+06	4.693834E+01	0.000000E+00
2	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.583864E+06	4.686125E+01	0.000000E+00
3	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.576759E+06	4.688719E+01	0.000000E+00
4	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.558834E+06	4.674701E+01	0.000000E+00
5	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.583892E+06	4.700925E+01	0.000000E+00
6	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.583931E+06	4.695528E+01	0.000000E+00
7	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.583981E+06	4.695181E+01	0.000000E+00
8	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.583870E+06	4.686134E+01	0.000000E+00
9	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.466969E+06	4.414234E+01	0.000000E+00
10	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.466072E+06	4.413617E+01	0.000000E+00
11	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.473991E+06	4.418312E+01	0.000000E+00
12	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.473991E+06	4.418312E+01	0.000000E+00
13	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.483235E+06	4.424053E+01	0.000000E+00
14	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.486440E+06	4.425542E+01	0.000000E+00
15	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584376E+06	4.712053E+01	0.000000E+00
16	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584336E+06	4.709907E+01	0.000000E+00
17	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584360E+06	4.711230E+01	0.000000E+00
18	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584360E+06	4.711230E+01	0.000000E+00
19	5.606500E+00	1.447921E+07	-5.458678E-02	5.347843E+01	2.582575E+06	4.622000E+01	4.622000E+01
20	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.583999E+06	4.693458E+01	0.000000E+00
21	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.583999E+06	4.693458E+01	0.000000E+00
22	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.583923E+06	4.693422E+01	0.000000E+00
23	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	2.584029E+06	4.693472E+01	0.000000E+00
24	1.569356E+02	4.055366E+08	2.492372E-02	1.798419E+02	2.584096E+06	4.693300E+01	4.693300E+01
25	-5.049999E-02	-1.255970E+05	0.000000E+00	-1.255092E+01	2.487070E+06	4.421022E+01	4.421022E+01

*** mass balance **********

mass accumulation rate   :   dmasdt   = 1.651721E-05 (kg/s)
net mass convected into configuration   :   flosum   = 1.624916E+02 (kg/s)
net mass source   :   xsourc   =-1.624916E+02 (kg/s)

global conservation of mass   (dmasdt - flosum - xsourc) = 8.979080E-06 (kg/s)

total mass within configuration   :   tmass   = 6.655922E+01 (kg)

total volume occupied by fluid   :   thlvol   = 9.478322E+02 (m**3)

*** energy balance *********

enthalpy accumulation rate   :   dhdt   =-1.233571E+01 (watt)
enthalpy stored in liquid condensates   :   qmsl   =-3.173406E+07 (watt)
net enthalpy accumulation rate   :   dhnet   = 3.173405E+07 (watt)
net energy convected into configuration :   hinsum = 4.198902E+08 (watt)
net heat conducted into configuration   :   qinsum =-2.966306E-02 (watt)
heat generated within configuration   :   qsourc =-3.880631E+08 (watt)
work   :   dpdt   = 1.091823E+00 (watt)

global energy   :(dhnet-hinsum-qinsum-qsource-dpdt) =-9.302435E+04 (watt)

total internal energy within configuration: tenth = 1.715826E+08 (joules)

at time= 4.27100E+02 seconds. total condensate = -1.62492E+02 kg. total energy to tubes = -3.88063E+08 joules.

****

ts number	volume (m**3)	mass (kg/m**3)	heat capacity (j/c)	total heat (j)	heat transfer to outside (watts)	heat transfer to inside (watts)	instantaneous heat source (watts)
1	4.98094E+00	2.25388E+04	1.22507E+07	5.01485E+08	-2.05187E+08	2.05190E+08	0.00000E+00
2	4.88170E+00	2.20897E+04	1.20066E+07	4.78390E+08	-1.82873E+08	1.82876E+08	0.00000E+00
totals	9.8626E+00	4.46284E+04	2.42573E+07	9.79878E+08	-3.88061E+08	3.88066E+08	0.00000E+00

** wl ** component 1 ** k plane 18 ** time step4271 ** time 4.27100E+02 s **

*** z-component of velocity (m/s)

```
j  i-->        3                4                5
10     ( 0.000000E+00)   2.917398E+01   ( 0.000000E+00)
 9     ( 0.000000E+00)   4.427724E+00   ( 0.000000E+00)
 8     ( 0.000000E+00)  -5.246696E+00   ( 0.000000E+00)
 7     ( 0.000000E+00)  -1.978146E+01   ( 0.000000E+00)
 6     ( 0.000000E+00)  -1.693341E+02   ( 0.000000E+00)
 5     ( 0.000000E+00)  -1.792703E+02   ( 0.000000E+00)
 4     ( 0.000000E+00)  -1.750489E+02   ( 0.000000E+00)
 3     ( 0.000000E+00)  -4.022562E+01   ( 0.000000E+00)
```

** wl ** component 1 ** i plane 4 ** time step4271 ** time 4.27100E+02 s **

*** z-component of velocity (m/s)

```
k  j-->       3              4              5              6              7              8              9             10
20     ( 0.000000E+00)(-1.798419E+02)(-1.798419E+02)(-1.798419E+02)( 0.000000E+00)( 0.000000E+00)( 0.000000E+00)( 0.000000E+00)
19     -4.022562E+02  -1.846040E+02  -1.831898E+02  -1.752779E+02  -1.978146E+01  -5.246696E+00   4.427724E+00   2.917398E+01
18     -1.750489E+02  -1.750489E+02  -1.792703E+02  -1.693341E+02   0.000000E+00   0.000000E+00   0.000000E+00   3.777392E+01
17     -1.802153E+01  -1.583162E+02  -1.713058E+02  -1.642257E+02  -6.033421E+01  -2.611869E+01  -1.378642E+01   2.359737E+01
16      1.489426E+01  -1.148691E+02  -1.194661E+02  -9.829568E+01  -3.616491E+01  -2.972047E+01  -2.933003E+01  -4.263480E+01
15     -2.798877E+01  -7.746188E+01  -8.667388E+01  -4.663514E+01  -2.658907E+01  -1.776883E+01  -2.880043E+01  -7.006030E+01
14     -8.231197E+01  -6.175362E+01  -6.412986E+01  -3.280329E+01  -1.131094E+02  -1.197664E+01  -1.416395E+01  -7.527052E+01
13     -9.926345E+01  -3.116457E+01  -3.335154E+01  -2.394113E+01   1.011266E+02  -1.083088E+01  -5.461163E+00  -7.554520E+01
12     -1.053403E+02  -1.478684E+01  -1.815001E+01  -2.506959E+01  -1.402067E+01  -1.181461E+00   5.363122E+00  -7.221369E+01
11     -1.075382E+02   2.626096E+00  -1.876263E+00  -8.427072E+00   3.199404E+00   4.252647E+00  -5.608078E-01  -6.012534E+01
10     -1.064941E+02   5.463478E+00  -1.679760E-01   3.199404E+00  -7.340011E+00   9.646878E-02   1.118815E+01  -3.527630E+01
 9     -1.067042E+02  -1.483360E+01  -1.047026E+01  -2.209130E+00   2.230238E+00   2.782333E+00  -6.528306E+00  -2.744966E-01
 8     -1.068810E+02  -1.382263E+01  -1.172633E+01   1.972270E+00  -9.912806E+00   7.374272E+00   1.806015E+00   6.132952E+00
 7     -1.047200E+02  -9.525125E+00  -1.030820E+00   7.519667E+00   1.011792E+02   3.200302E+00   9.368892E+00   1.019832E+01
 6     -1.018899E+02  -7.859276E+00   7.519667E+00   9.077367E+00   9.902114E+00   1.042701E+01   1.829644E+01   1.482339E+01
 5     -9.721117E+01  -5.343703E+00   2.042734E+01   1.746772E+01   1.801949E+01   1.846407E+01   1.229910E+01   2.075831E+01
 4     -8.559659E+01  -2.102197E+01   2.236045E+01   2.236045E+01   1.746772E+01   1.234471E+01   1.846407E+01   2.282266E+01
 3     -5.501767E+01  -2.434894E+01  -1.229856E+01   1.199991E+01   6.687583E+00   1.611066E+01  ( 0.000000E+00)
 2     ( 0.000000E+00)( 0.000000E+00)( 0.000000E+00)( 0.000000E+00)( 0.000000E+00)( 0.000000E+00)( 0.000000E+00)( 0.000000E+00)
```

** vl ** component 1 ** i plane 4 ** time step4271 ** time 4.27100E+02 s **

*** y-component of velocity (m/s)

```
k  j-->    2      3      4      5      6      7      8      9
```

20	(0.000000E+00)	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	(0.000000E+00	-8.062981E+00	-1.022963E+01	-8.219056E+00
19	(0.000000E+00)	-1.199190E+01	-9.258405E+00	-8.171727E+00	-5.482272E+00	1.239021E+00	3.254640E+00	-6.482340E-01	
18	(0.000000E+00)	1.458203E+00	1.737998E+00	1.250862E+00	2.576177E-01	2.088796E+01	1.208322E+01	5.173999E+00	
17	(0.000000E+00)	1.277340E+00	4.481677E+00	8.178997E+00	2.361739E+01	7.405945E+01	7.913099E+01	5.546480E+01	
16	(0.000000E+00)	-4.025895E+01	-2.084838E+01	-7.853689E+01	6.074701E+01	2.006498E+01	1.737278E+01	3.279005E+01	
15	(0.000000E+00)	-6.652206E+01	-2.817307E+01	2.018306E+01	2.165021E+01	2.198788E+01	4.308243E+00	1.386934E+01	
14	(0.000000E+00)	-2.550292E+01	-1.389753E+01	1.202205E+01	3.833059E+00	0.000000E+00	3.700363E+00	3.408687E+00	
13	(0.000000E+00)	-1.357232E+01	-8.038757E+00	3.172511E+00	0.000000E+00	5.078595E+00	-2.303739E+00	-5.485499E+00	
12	(0.000000E+00)	-5.077313E+00	-1.873591E+00	2.089442E+00	6.063554E+00	3.869537E-02	-9.095328E+00	-1.195228E+01	
11	(0.000000E+00)	-8.624100E-01	-2.925784E+00	6.327687E+00	1.163463E+00	-3.976981E+01	-4.614882E+01	-2.542186E+01	
10	(0.000000E+00)	-2.408253E+00	-2.142333E+01	-2.984272E+01	-3.976981E+01	-2.683008E+00	-1.762949E+01	-3.710581E+01	
9	(0.000000E+00)	-1.961819E+00	-9.843207E-01	5.387550E-01	2.717317E+00	1.049822E+00	-9.654989E+00	-1.453684E+01	
8	(0.000000E+00)	-3.320224E+00	-5.209690E-01	1.370375E-01	0.000000E+00	0.000000E+00	-1.309137E+01	-1.366829E+01	
7	(0.000000E+00)	7.588375E+00	-1.609273E+00	3.637956E+00	-4.684205E+00	2.475925E+00	-1.002012E+01	-1.170202E+01	
6	(0.000000E+00)	1.017331E+01	9.620724E-01	9.566266E+00	-1.012417E+00	-4.948660E+00	-1.525459E+01	-6.445715E+00	
5	(0.000000E+00)	1.204126E+01	-2.944268E+00	1.654473E-01	-5.609156E+00	-6.426017E+00	-5.100137E+00	-1.090255E+00	
4	(0.000000E+00)	1.542238E+01	1.355633E+01	4.744029E+01	4.497411E+01	4.268150E+01			
3	(0.000000E+00)	3.178990E+01	4.286022E+01						

k j--> 10

20	(0.000000E+00)
19	(0.000000E+00)
18	(0.000000E+00)
17	(0.000000E+00)
16	(0.000000E+00)
15	(0.000000E+00)
14	(0.000000E+00)
13	(0.000000E+00)
12	(0.000000E+00)
11	(0.000000E+00)
10	(0.000000E+00)
9	(0.000000E+00)
8	(0.000000E+00)
7	(0.000000E+00)
6	(0.000000E+00)
5	(0.000000E+00)
4	(0.000000E+00)
3	(0.000000E+00)

*** x-component of velocity (m/s)

** u1 ** component 1 ** j plane 7 ** time step4271 ** time 4.27100E+02 s **

k i-->

	2	3	4	5	6	7
19	(0.000000E+00)(	-5.954602E+00	9.504924E+00	(0.000000E+00)	0.000000E+00	0.000000E+00
18	(0.000000E+00)(	-8.358989E+00	1.583910E+01	(0.000000E+00)	0.000000E+00	0.000000E+00
17	(0.000000E+00)(	-2.260507E+01	3.023841E+01	(0.000000E+00)	0.000000E+00	0.000000E+00
16	(0.000000E+00)(	0.000000E+00	0.000000E+00	(0.000000E+00)(	0.000000E+00	0.000000E+00
15	(0.000000E+00)(	0.000000E+00	0.000000E+00	(0.000000E+00)(	0.000000E+00	0.000000E+00
14	(0.000000E+00)(	1.197923E+00	4.080010E+00	6.391149E+00	6.392682E+00 (	0.000000E+00
13	(0.000000E+00)(	0.000000E+00	0.000000E+00	(0.000000E+00)(	0.000000E+00	0.000000E+00
12	(0.000000E+00)(	0.000000E+00	0.000000E+00	(0.000000E+00)(	0.000000E+00	0.000000E+00
11	(0.000000E+00)(	0.000000E+00	0.000000E+00	(0.000000E+00)(	0.000000E+00	0.000000E+00
10	(0.000000E+00)(	0.000000E+00	0.000000E+00	(0.000000E+00)(	0.000000E+00	0.000000E+00
9	(0.000000E+00)(	0.000000E+00	0.000000E+00	(0.000000E+00)(	0.000000E+00	0.000000E+00
8	(0.000000E+00)(	1.180505E+00	3.839870E+00	6.125591E+00	6.127367E+00 (	0.000000E+00
7	(0.000000E+00)(	0.000000E+00	0.000000E+00	(0.000000E+00)(	0.000000E+00	0.000000E+00
6	(0.000000E+00)(	0.000000E+00	0.000000E+00	(0.000000E+00)(	0.000000E+00	
5	(0.000000E+00)(	0.000000E+00	0.000000E+00	(0.000000E+00)(		
4	(0.000000E+00)(	1.703271E+01	1.333093E+01			

3   (0.000000E+00) -5.432311E-02   1.358029E+...   (0.000000E+00)

** wl ** component 1 ** j plane 7 ** time step4271 ** time 4.27100E+02 s **

*** z-component of velocity (m/s)

k \ i-->	3	4	5	6	7
		(0.000000E+00)		(0.000000E+00)	
19	0.000000E+00	-1.978146E+01	0.000000E+00		
18	0.000000E+00	0.000000E+00	0.000000E+00		
17	-2.359564E+01	-6.033421E+01	-2.090009E+01		1.255092E+01
16	-2.051631E+01	-3.616491E+01	-2.100323E+01		1.254597E+01
15	-2.658907E+01	-2.313031E+00			1.253416E+01
14	-1.217122E+02	-1.131094E+02	-1.060261E+02	(0.000000E+00)	6.137952E+00
13	-1.085720E+02	1.011266E+02	1.035200E+02	(0.000000E+00)	6.155480E+00
12	-1.069762E+02	-1.402067E+00	8.449145E-02		6.136029E+00
11	5.259983E-01	4.263583E+00	4.201757E+00		6.132608E+00
10	4.661203E+00	-5.189177E+00	-2.439575E+00		6.131404E+00
9	-2.981024E+00	2.230238E+00	9.628424E-01	(0.000000E+00)	6.128978E+00
8	8.859436E-01	-9.912806E+01	-1.026053E+02	(0.000000E+00)(	0.000000E+00)
7	-1.055550E+02	1.011792E+02	1.048364E+02		
6	6.519912E+02	9.902114E+00	1.291710E+00		
5	1.342363E+01	1.801949E+01	1.344153E+01		
4	9.254878E+00	6.687583E+00	5.448820E+00		
3					
2	0.000000E+00	0.000000E+00)(	0.000000E+00)		

** hl ** component 3 ** j plane 7 ** time step4271 ** time 4.27100E+02 s **

*** enthalpy (j/kg)

k \ i-->	2	3	4	5	6	7	8
20	2.583797E+06	(2.583797E+06)	(2.583945E+06)	(2.583699E+06)	2.583699E+06)		
19	2.583797E+06	2.584195E+06	2.583945E+06 (	2.583699E+06	2.583699E+06		
18	2.584195E+06	2.584389E+06	2.583909E+06	2.584033E+06	2.584033E+06	2.487070E+06)	
17	2.584389E+06	2.583948E+06	2.584037E+06	2.584137E+06(	2.584137E+06(	2.487070E+06	2.487071E+06)
16	2.583948E+06	2.583849E+06	2.585332E+06	2.584137E+06)	2.581931E+06	2.487085E+06	2.487087E+06)
15	2.583849E+06	2.557579E+06	2.584114E+06	2.581931E+06	2.515176E+06	2.487123E+06	2.487124E+06)
14	2.557579E+06	2.539001E+06	2.584230E+06	2.551200E+06	2.515175E+06	2.458810E+06	2.458811E+06)
13	2.539001E+06	2.489289E+06	2.572674E+06	2.515737E+06	2.515176E+06	2.457690E+06	2.457691E+06)
12	2.489289E+06	2.582323E+06	2.582447E+06	2.515176E+06	2.400296E+06	2.457665E+06	2.457666E+06)
11	2.582323E+06	2.451651E+06	2.548666E+06	2.295022E+06	2.579877E+06	2.457672E+06	2.457673E+06)
10	2.451651E+06	2.440130E+06	2.582943E+06	2.400294E+06	2.329700E+06	2.457678E+06	2.457679E+06)
9	2.440130E+06	2.507325E+06	2.499813E+06	2.579877E+06	2.457709E+06	2.457693E+06	2.457694E+06)
8	2.507325E+06	2.582912E+06	2.467584E+06	2.329698E+06	2.457712E+06	2.457702E+06	
7	2.582912E+06	2.583401E+06	2.516987E+06	2.252109E+06	2.457704E+06)(		
6	2.583401E+06	2.584050E+06	2.582571E+06	2.457712E+06	2.457145E+06		
5	2.584050E+06	2.584050E+06	2.582789E+06	2.479145E+06	2.552594E+06		
4	2.584050E+06	2.583401E+06	2.583771E+06	2.552593E+06	2.583505E+06		
3	2.584050E+06	2.584050E+06	2.583848E+06	2.583505E+06	2.583630E+06)		
2	2.584050E+06)(	2.584050E+06)(	2.583848E+06)(	2.583630E+06)			

** tl ** component 1 ** j plane 7 ** time step4271 ** time 4.27100E+02 s **

*** temperature (c)

k \ i-->	2	3	4	5	6	7	8
20			(4.689318E+01)	(4.676178E+01)			
19	(4.681794E+01)	(4.681794E+01)	4.689318E+01	4.676178E+01	(4.676178E+01)		
18	4.681794E+01	4.681794E+01	4.687300E+01	4.676178E+01	4.676178E+01		
17	4.703799E+01	4.703799E+01	4.694218E+01	4.694403E+01	4.694403E+01		

```
16  ( 4.714086E+01   4.714086E+01   4.763530E+01   4.700182E+01   4.700182E+01   4.421022E+01)
15  ( 4.691806E+01   4.691806E+01   4.725375E+01   4.674686E+01   4.674686E+01   4.421022E+01)
14  ( 4.687270E+01   4.687270E+01   4.704923E+01   4.662291E+01   4.438360E+01   4.421834E+01)
13  ( 4.459785E+01   4.459785E+01   4.466919E+01   4.439322E+01   4.438360E+01   4.423770E+01)
12  ( 4.661218E+01   4.661218E+01   4.658054E+01   4.528666E+01   4.438660E+01   4.423770E+01)
11  ( 4.636432E+01   4.636432E+01   4.641929E+01   4.585516E+01   4.585516E+01   4.410193E+01)
10  ( 4.683852E+01   4.683852E+01   4.659775E+01   4.677602E+01   4.585516E+01   4.410040E+01)
 9  ( 4.617760E+01   4.617760E+01   4.615006E+01   4.548112E+01   4.677602E+01   4.410496E+01)
 8  ( 4.612135E+01   4.612135E+01   4.612135E+01   4.505079E+01   4.548112E+01   4.410970E+01)
 7  ( 4.43825 E+01   4.43825 E+01   4.599486E+01   4.412725E+01   4.412725E+01   4.411373E+01)
 6  ( 4.684440E+01   4.684440E+01   4.442932E+01   4.413385E+01   4.412725E+01   4.412185E+01)
 5  ( 4.685799E+01   4.685799E+01   4.659867E+01   4.627357E+01   4.627357E+01   4.412185E+01)
 4  ( 4.701366E+01   4.701366E+01   4.662797E+01   4.662824E+01   4.662824E+01)
 3  ( 4.703779E+01   4.703779E+01   4.690565E+01   4.695082E+01   4.695082E+01)
 2  ( 4.703779E+01)( 4.695931E+01)( 4.695931E+01)( 4.695082E+01)
```

*** density (kg/m**3)
*

```
k  i-->
20
19
18  ( 6.976968E-02   6.976968E-02   7.002136E-02   7.002136E-02)
17  ( 7.050850E-02   7.050850E-02   6.995371E-02   6.958213E-02 ( 6.958213E-02)
16  ( 7.085605E-02   7.085605E-02   7.018575E-02   7.019209E-02   7.019209E-02)
15  ( 7.010555E-02   7.010555E-02   7.254657E-02   7.038647E-02   7.038647E-02 ( 7.038647E-02)
14  ( 6.995372E-02   6.995372E-02   7.123888E-02   6.956218E-02   6.956217E-02   6.295986E-02 ( 6.295985E-02)
13  ( 6.303267E-02   6.303267E-02   7.054616E-02   6.967595E-02   6.967595E-02   6.295986E-02   6.298471E-02)
12  ( 6.985361E-02   6.985361E-02   6.301745E-02   6.306317E-02   6.304243E-02   6.298472E-02   6.304405E-02)
11  ( 6.990197E-02   6.990197E-02   6.899559E-02   6.995214E-02   6.304243E-02   6.304405E-02   6.308803E-02)
10  ( 6.986448E-02   6.986448E-02   6.903557E-02   6.982467E-02   6.982466E-02   6.308803E-02   6.310182E-02)
 9  ( 6.995726E-02   6.995726E-02   6.904470E-02   6.969565E-02   6.969564E-02   6.310183E-02   6.311640E-02)
 8  ( 6.998002E-02   6.998002E-02   6.899044E-02   6.992156E-02   6.992155E-02   6.311640E-02   6.313100E-02)
 7  ( 6.316528E-02   6.316528E-02   6.904774E-02   7.002513E-02   6.992155E-02   6.313101E-02   6.314339E-02)
 6  ( 6.987423E-02   6.987423E-02   6.315487E-02   6.320534E-02   6.318499E-02   6.314339E-02   6.316837E-02)
 5  ( 6.991171E-02   6.991171E-02   6.905411E-02   6.977844E-02   6.318498E-02 ( 6.316838E-02   6.316837E-02)
 4  ( 7.042826E-02   7.042826E-02   6.914844E-02   6.966963E-02   6.966962E-02)
 3  ( 7.051035E-02   7.051035E-02   7.006656E-02   7.017023E-02   7.017023E-02)
 2  ( 7.051035E-02)( 7.024711E-02   7.024711E-02 ( 7.022209E-02   7.022208E-02)
```

*** density (kg/m**3)
*
** rl ** component 2 ** j plane 7 ** time step4271 ** time 4.27100E+02 s **

```
k  i-->
20
19
18  ( 1.181035E-01   1.181035E-01   1.185271E-01   1.185271E-01)
17  ( 1.193471E-01   1.193471E-01   1.184132E-01   1.177877E-01 ( 1.177877E-01)
15  ( 1.199321E-01   1.199321E-01   1.188033E-01   1.183145E-01   1.183145E-01)
15  ( 1.186688E-01   1.186688E-01   1.227771E-01   1.191417E-01   1.191417E-01 ( 1.066154E-01)
14  ( 1.184133E-01   1.184133E-01   1.205764E-01   1.177542E-01   1.177542E-01   1.066154E-01 ( 1.066154E-01)
13  ( 1.067359E-01   1.067359E-01   1.194105E-01   1.179472E-01   1.179472E-01   1.066574E-01   1.065574E-01)
12  ( 1.182468E-01   1.182468E-01   1.067097E-01   1.067890E-01   1.067540E-01   1.066578E-01   1.067578E-01)
11  ( 1.183306E-01   1.183306E-01   1.168004E-01   1.184251E-01   1.067540E-01   1.067578E-01   1.068332E-01)
10  ( 1.826531E-01   1.826531E-01   1.168692E-01   1.182050E-01   1.182049E-01   1.068332E-01   1.068566E-01)
 9  ( 1.184256E-01   1.184256E-01   1.168830E-01   1.179790E-01   1.179790E-01   1.068566E-01   1.068812E-01)
 8  ( 1.184645E-01   1.184645E-01   1.167956E-01   1.183718E-01   1.183718E-01   1.068812E-01   1.069059E-01)
 7  ( 1.069620E-01   1.069620E-01   1.168936E-01   1.855004E-01   1.855004E-01   1.069059E-01   1.069269E-01)
     ( 1.069620E-01   1.069441E-01   1.070316E-01   1.069972E-01   1.069972E-01   1.069269E-01   1.069691E-01)
```

```
6   ( 1.182795E-01)  1.182795E-01  1.168989E-01  1.181232E-01 ( 1.069972E-01)( 1.069691E-01)
5   ( 1.183426E-01)  1.183426E-01  1.170577E-01  1.179365E-01 ( 1.179365E-01)
4   ( 1.192120E-01)  1.192120E-01  1.186032E-01  1.187777E-01 ( 1.187777E-01)
3   ( 1.193502E-01)  1.193502E-01  1.189071E-01  1.188650E-01 ( 1.188650E-01)
2   ( 1.193502E-01)( 1.189071E-01) 1.188650E-01
```

*** density (kg/m**3)

** rl ** component 3 ** j plane 7 ** time step4271 ** time 4.27100E+02 s **

```
k  i-->     2          3             4             5             6             7             8
20                ( 6.976983E-02)
19                             ( 7.002142E-02)
18            6.976983E-02  6.995376E-02  6.958220E-02  6.958220E-02
17            7.050881E-02  7.018581E-02  7.019223E-02  7.019223E-02
16            7.085633E-02  7.254663E-02  7.038665E-02  7.038665E-02( 6.390651E-02)  6.390650E-02
15            7.010611E-02  7.123900E-02  6.958178E-02  6.958177E-02  6.393176E-02  6.393174E-02
14            6.995444E-02  7.054630E-02  7.004024E-02  7.004024E-02  6.399199E-02  6.399197E-02
13            6.325670E-02  6.308845E-02  6.371549E-02  6.370018E-02  6.433266E-02  6.433264E-02
12            7.035777E-02  6.905583E-02  6.370018E-02  6.370018E-02  6.435858E-02  6.435856E-02
11            7.097446E-02  6.942080E-02  7.193385E-02  7.193382E-02  6.437381E-02  6.437379E-02
10            6.983167E-02  6.904977E-02  6.973901E-02  6.973900E-02  6.438871E-02  6.438871E-02
 9            7.146722E-02  6.99240?E-02  7.288098E-02  7.288094E-02  6.440138E-02  6.440136E-02
 8            7.162530E-02  7.034959E-02  7.394478E-02  7.394478E-02  6.442687E-02  6.442685E-02
 7            6.390623E-02  6.379587E-02  6.446461E-02  6.444380E-02( 6.444380E-02)( 6.442685E-02)
 6            6.983492E-02  6.906334E-02  7.096506E-02  7.096506E-02  7.001816E-02
 5            6.991717E-02  6.915586E-02  7.001819E-02  7.001819E-02  7.017616E-02
 4            7.042969E-02  7.006885E-02  7.017616E-02  7.017616E-02  7.022694E-02
 3            7.051230E-02  7.024967E-02  7.022694E-02  7.022694E-02
 2           ( 7.051230E-02)( 7.024967E-02) 7.022694E-02
```

*** pressure (pa)

** p+pold ** component 1 ** i plane 4 ** time step4271 ** time 4.27100E+02 s **

```
k  j-->      3            4            5            6            7            8            9            10
20        1.046002E+04  1.057700E+04  1.057700E+04  1.057700E+04  1.055476E+04  1.055342E+04  1.055564E+04  1.056079E+04
19        1.059825E+04  1.048109E+04  1.050890E+04  1.054209E+04  1.054395E+04  1.054255E+04  1.054170E+04  1.054274E+04
18        1.065185E+04  1.058520E+04  1.056953E+04  1.055155E+04  1.055155E+04  1.058754E+04  1.059983E+04  1.061074E+04
17        1.088875E+04  1.064852E+04  1.064423E+04  1.062979E+04  1.058102E+04  1.079834E+04  1.065768E+04  1.074690E+04
16        1.105978E+04  1.104635E+04  1.119168E+04  1.129465E+04  1.074934E+04  1.054079E+04  1.060712E+04  1.065348E+04
15        1.071525E+04  1.130790E+04  1.137233E+04  1.101548E+04  1.063860E+04  1.041843E+04  1.043553E+04  1.047690E+04
14        1.055590E+04  1.066000E+04  1.072796E+04  1.059564E+04  9.436387E+03  1.039807E+04  1.038845E+04  1.044112E+04
13        1.048716E+04  1.047495E+04  1.050586E+04  1.053495E+04  1.039083E+04  1.037368E+04  1.038847E+04  1.043363E+04
12        1.045627E+04  1.042852E+04  1.043228E+04  1.041866E+04  1.039171E+04  1.037537E+04  1.046285E+04  1.045621E+04
11        1.045290E+04  1.043740E+04  1.042439E+04  1.040065E+04  1.039874E+04  1.037541E+04  1.046668E+04  1.051224E+04
10        1.043638E+04  1.043363E+04  1.041808E+04  1.040628E+04  1.037641F+04  1.036697E+04  1.052277E+04  1.059422E+04
 9        1.042866E+04  1.043441E+04  1.038569E+04  1.038667E+04  1.038008E+04  1.037623E+04  1.051187E+04  1.063669E+04
 8        1.044512E+04  1.038491E+04  1.038742E+04  1.038720E+04  9.449978E+03  1.038974E+04  1.051048E+04  1.063497E+04
 7        1.044651E+04  1.038293E+04  1.039649E+04  1.038518E+04  1.038720E+04  1.038731E+04  1.053319E+04  1.063183E+04
 6        1.046642E+04  1.039884E+04  1.048299E+04  1.041769E+04  1.041527E+04  1.043137E+04  1.061572E+04  1.062571E+04
 5        1.049593E+04  1.046642E+04  1.055019E+04  1.055756E+04  1.056194E+04  1.058175E+04  1.061126E+04  1.062490E+04
 4        1.056902E+04  1.055387E+04  1.060655E+04  1.058280E+04  1.059078E+04  1.059718E+04  1.062675E+04  1.065249E+04
 3        1.071756E+04  1.065431E+04
```

*** pressure (pa)

** p+pold ** component 1 ** j plane 7 ** time step4271 ** time 4.27100E+02 s **

```
k  i-->     3            4            5            6            7
```

*** pressure (pa)
*

                                   ** p*pold ** component 1 ** k plane 7 ** time step4271 ** time 4.27100E+02 s **

j i-->	3	4	5	6
19	1.055476E+04			
18	1.063258E+04	1.054395E+04	1.048461E+04	
17	1.068813E+04	1.058102E+04	1.058203E+04	
16	1.095857E+04	1.061308E+04		
15	1.056820E+04	1.074934E+04	1.048114E+04	
14	1.054394E+04	1.063860E+04	1.049424E+04	
13	9.436592E+03	9.436387E+03	9.435207E+03	9.431825E+03
12	1.052055E+04	1.039083E+04	1.049274E+04	
11	1.051985E+04	1.039171E+04	1.049193E+04	
10	1.052945E+04	1.037674E+04	1.050210E+04	
9	1.052214E+04	1.037641E+04	1.049442E+04	
8	1.052374E+04	1.038008E+04	1.049606E+04	
7	9.450173E+03	9.449978E+03	9.448917E+03	9.445682E+03
6	1.053110E+04	1.040018E+04	1.049842E+04	
5	1.053716E+04	1.041527E+04	1.049347E+04	
4	1.061974E+04	1.056194E+04	1.057845E+04	
3	1.063286E+04	1.059078E+04	1.058675E+04	

j i-->	3	4	5	6	7
10	1.063707E+04	1.063497E+04	1.058411E+04		
9	1.057692E+04	1.051048E+04	1.050176E+04		
8	1.052562E+04	1.038974E+04	1.049624E+04		
7	9.450173E+03	9.449978E+03	9.448917E+03	9.445682E+03	9.443042E+03
6	1.052732E+04	1.038720E+04	1.049912E+04		
5	1.053266E+04	1.038742E+04	1.050246E+04		
4	1.053285E+04	1.038293E+04	1.050265E+04		
3	1.057095E+04	1.044512E+04	1.053774E+04		

*** mass fraction ( )
*

                             ** XmS ** component 2 ** j plane 7 ** time step4271 ** time 4.27100E+02 s **

k i-->	2	3	4	5	6	7	8
20							
19		5.134991E-06)	2.168928E-06)				
18	5.134991E-06)	5.134991E-06	2.168928E-06 (	2.509361E-06)			
17	1.062556E-05)	1.051048E-05	1.747128E-06	2.509361E-06 (	2.509361E-06)		
16	9.645667E-06)	9.645667E-06	2.036466E-06	5.120666E-06	2.509361E-06)		
15	1.956716E-05)	1.956716E-05	2.043570E-06	6.478171E-06	5.120666E-06)		
14	2.495751E-05)	2.495751E-05	4.097959E-06	6.478171E-06	6.478171E-06)(	3.617669E-02)	
13	8.649978E-03)	8.649978E-03	4.863665E-06	6.882278E-04	6.882278E-04)	3.617669E-02	3.617669E-02)
12	1.750917E-02)	1.750917E-02	2.748580E-03	1.270890E-02	2.521830E-02)	3.617669E-02	3.617697E-02)
11	3.692248E-02)	3.692248E-02	3.623597E-04	2.500371E-02	2.521830E-02)	3.617720E-02	3.617720E-02)
10	6.011703E-04)	6.011703E-04	1.355829E-02	1.127437E-01	2.521830E-02)	4.724824E-02	4.724824E-02)
9	5.162375E-02)	5.162375E-02	1.794352E-04	7.163855E-02	7.163855E-02)	4.768923E-02	4.768923E-02)
8	5.612529E-02)	5.612529E-02	3.261860E-02	1.519174E-03	1.519174E-03)	4.770261E-02	4.770261E-02)
7	2.831584E-02)	2.831584E-02	4.521123E-02	9.920729E-02	9.920729E-02)	4.770356E-02	4.770356E-02)
6	3.736254E-04)	3.736254E-04	2.453855E-02	1.295017E-01	4.770501E-02)	4.770417E-02	4.770417E-02)
5	1.908930E-04)	1.908930E-04	3.267472E-04	4.770516E-02	4.770501E-02)	4.770464E-02	4.770464E-02)
4	4.971194E-05)	4.971194E-05	2.623568E-04	4.085546E-02	1.216374E-02)		
3	6.739354E-05)	6.739354E-05	7.991640E-05	1.216374E-02	2.065120E-04)		
2		6.739354E-05)(	8.915371E-05	2.065120E-04	1.689962E-04)		
			8.915371E-05)(	1.689962E-04			

*** mass fraction ( )
*

                             ** XmS ** component 2 ** i plane 5 ** time step4271 ** time 4.27100E+02 s **

k j-->	2	3	4	5	6	7	8	9
20	(3.289993E-05)	3.289993E-05)(	4.104808E-05)(	3.975789E-11)(	4.240408E-11)	2.509361E-06)(	2.582165E-06)(	2.678653E-06)
19	(3.289993E-05)	3.289993E-05)(	3.289031E-05)(	1.099101E-05)(	2.018615E-06)(	2.509361E-06	2.582165E-06	2.678653E-06
18	(3.115610E-05)	3.115610E-05	3.202239E-05	1.656674E-05	5.776207E-06	5.120666E-06	3.724181E-06	2.778026E-06
17	(2.734806E-05)	2.734806E-05	2.718904E-05	1.493586E-05	6.364099E-06	6.478171E-06	9.875682E-06	6.977587E-06
16	(2.618071E-05)	2.618071E-05	2.499400E-05	1.686660E-05	4.475013E-04	6.882278E-04	2.363020E-03	2.594490E-05
15	(5.069202E-05)	5.069202E-05	3.423103E-04	4.257076E-04	2.407265E-02	1.270890E-02	4.463574E-02	3.304919E-03
14	(1.033056E-04)	1.033056E-04	1.103405E-04	1.116542E-02	4.026831E-02	2.500371E-02	7.155505E-02	1.754239E-02
13	(1.195000E-04)	1.195000E-04	9.765879E-03	1.843816E-02	1.160067E-01	1.127437E-01	1.220810E-01	1.985472E-02
12	(1.199213E-04)	1.199213E-04	1.315582E-03	2.231617E-03	4.822882E-02	7.163855E-02	6.221492E-02	5.465166E-04
11	(1.657763E-04)	1.657763E-04	1.954865E-03	1.975051E-03	1.969351E-03	1.519174E-03	1.310683E-03	1.862923E-04
10	(1.671007E-04)	1.671007E-04	1.969871E-03	2.943090E-03	6.455793E-02	9.920729E-02	7.211747E-02	2.825462E-04
9	(1.701085E-04)	1.701085E-04	5.124375E-03	2.227316E-02	1.342261E-01	1.295017E-01	8.882176E-02	4.085920E-03
8	(1.755015E-04)	1.755015E-04	9.154415E-03	3.049463E-02	5.868426E-02	4.770616E-02	3.072439E-02	5.609452E-03
7	(1.868318E-04)	1.868318E-04	1.266043E-02	9.405103E-03	7.126772E-02	4.085546E-02	4.265974E-02	7.775386E-04
6	(1.844148E-04)	1.844148E-04	4.168667E-04	3.459645E-04	7.091283E-03	1.216374E-04	4.303917E-03	1.511554E-04
5	(1.777999E-04)	1.777999E-04	2.373675E-04	2.349930E-04	2.189481E-04	2.065120E-04	1.649459E-04	1.392588E-04
4								
3	(1.648429E-04)	1.648429E-04	1.763374E-04	1.768643E-04	1.709247E-04	1.689962E-04	1.630706E-04	1.544393E-04
2	(1.648429E-04)	1.648429E-04)(	1.763374E-04)(	1.768643E-04)(	1.709247E-04)(	1.689962E-04)(	1.630706E-04)(	1.544393E-04)

k j-->	10	11
20	(2.881882E-06)	2.881882E-06)
19	2.881882E-06	3.247506E-06)
18	3.247506E-06	6.361988E-06)
17	6.361988E-06	1.281569E-05)
16	1.281569E-05	5.846678E-05)
15	5.846678E-05	6.936973E-05)
14	6.936973E-05	8.762936E-05)
13	8.762936E-05	8.614642E-05)
12	8.614642E-05	8.336706E-05)
11	8.336706E-05	1.158526E-04)
10	1.158526E-04	1.325855E-04)
9	1.325855E-04	1.303693E-04)
8	1.303693E-04	1.263980E-04)
7	1.263980E-04	1.284191E-04)
6	1.284191E-04	1.321474E-04)
5	1.321474E-04	1.431076E-04)
4	1.431076E-04	
3	1.431076E-04	
2	(1.431076E-04)	

*** volumetric heat source (w/m**3)   ** qsour ** component 1 ** j plane 7 ** time step4271 ** time 4.27100E+02 s **
*

k i-->	2	3	4	5	6	7	8
20	(0.000000E+00)	(0.000000E+00)	(0.000000E+00)	0.000000E+00			
19	(0.000000E+00)	0.000000E+00	0.000000E+00	0.000000E+00	(0.000000E+00)		
18	(0.000000E+00)	0.000000E+00	0.000000E+00	0.000000E+00	(0.000000E+00)	0.000000E+00	0.000000E+00
17	(0.000000E+00)	0.000000E+00	0.000000E+00	0.000000E+00	(0.000000E+00)(	0.000000E+00	0.000000E+00
16	(0.000000E+00)	-2.114464E+06	-2.930194E+06	-4.316151E+06	0.000000E+00	0.000000E+00	0.000000E+00
15	(0.000000E+00)	0.000000E+00	0.000000E+00	0.000000E+00	(0.000000E+00)	0.000000E+00	0.000000E+00
14	(0.000000E+00)	0.000000E+00	0.000000E+00	0.000000E+00	(0.000000E+00)	0.000000E+00	0.000000E+00
13	(0.000000E+00)	0.000000E+00	0.000000E+00	0.000000E+00	(0.000000E+00)	0.000000E+00	0.000000E+00
12	(0.000000E+00)	-1.148589E+06	-1.560771E+06	-9.868209E+05	0.000000E+00	0.000000E+00	0.000000E+00
11	(0.000000E+00)	0.000000E+00	0.000000E+00	0.000000E+00	(0.000000E+00)	0.000000E+00	0.000000E+00
10	(0.000000E+00)	0.000000E+00	0.000000E+00	0.000000E+00	(0.000000E+00)	0.000000E+00	0.000000E+00
9	(0.000000E+00)	-7.878762E+05	-1.375247E+06	-6.362819E+05	0.000000E+00	0.000000E+00	0.000000E+00

```
8  ( 0.000000E+00)  0.000000E+00   0.000000E+00   0.000000E+00  ( 0.000000E+00  ( 0.000000E+00)
7  ( 0.000000E+00)  0.000000E+00   0.000000E+00   0.000000E+00  ( 0.000000E+00  ( 0.000000E+00)
6  ( 0.000000E+00)  0.000000E+00   0.000000E+00   0.000000E+00 (  0.000000E+00  ( 0.000000E+00)
5  ( 0.000000E+00) -2.581967E+06  -3.210167E+06  -2.859745E+06 ( 0.000000E+00  ( 0.000000E+00)
4  ( 0.000000E+00)  0.000000E+00   0.000000E+00   0.000000E+00  ( 0.000000E+00)
3  ( 0.000000E+00)  0.000000E+00   0.000000E+00   0.000000E+00  ( 0.000000E+00)
2  ( 0.000000E+00)( 0.000000E+00)
```

** mass source (kg/s/m**3)

** emdot ** component 1 ** j plane 7 ** time step 4271 ** time 4.27100E+02 s **

k i-->	3	4	5	6	7
19	0.000000E+00	0.000000E+00	0.000000E+00		
18	0.000000E+00	0.000000E+00	0.000000E+00		
17	0.000000E+00	0.000000E+00	0.000000E+00		
16	0.000000E+00	-1.227638E+00	-1.807427E+00		
15	-8.855923E-01	0.000000E+00	0.000000E+00		
14	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	
13	0.000000E+00	0.000000E+00	0.000000E+00		
12	0.000000E+00	-6.533996E-01	-4.129111E-01		
11	-4.808196E-01	0.000000E+00	0.000000E+00		
10	0.000000E+00	0.000000E+00	0.000000E+00		
9	-3.297640E-01	-5.755812E-01	-2.661484E-01	0.000000E+00	
8	0.000000E+00	0.000000E+00	0.000000E+00		
7	0.000000E+00	0.000000E+00	0.000000E+00		
6	0.000000E+00	0.000000E+00	-1.197438E+00		
5	-1.081333E+00	-1.344127E+00	0.000000E+00		
4	0.000000E+00	0.000000E+00			
3	0.000000E+00	0.000000E+00			

thermal structure number 1 at time= 4.271E+02 seconds

element cell	1st cell	fluid temperature (tf1)	(tcs)	<--material temperatures---> / (tf1-tf2)	shell-side heat coefficients (htgs)	(htss)	(hstrel)	2nd cell	fluid temperature	tube-side heat transfer coefficients (fouling)	(convective)	(tubeside all)
1	30412	4.6811E+01 / 7.5927E+00	4.2047E+01 / 4.1514E+01		2.5342E+03 / 4.1383E+01	2.2648E+04 / 4.1115E+01	2.2791E+03 / 4.0976E+01	30412	3.9219E+01	1.0000E+30	7.2758E+03	7.2758E+03
2	40412	4.6654E+01 / 8.2363E+00	4.6504E+01 / 4.4923E+01		2.2971E+05 / 4.4552E+01	1.9858E+04 / 4.3787E+01	2.1737E+04 / 4.3393E+01	40412	3.8418E+01	1.0000E+30	7.3171E+03	7.3171E+03
3	50412	4.6668E+01 / 1.3771E+01	4.0115E+01 / 3.8696E+01		4.5057E+03 / 3.8377E+01	2.0817E+04 / 3.7720E+01	3.7040E+03 / 3.7382E+01	50412	3.2897E+01	1.0000E+30	6.9748E+03	6.9748E+03
4	30512	4.6803E+01 / 7.5282E+00	4.3495E+01 / 4.2656E+01		5.3895E+03 / 4.2463E+01	2.1269E+04 / 4.2066E+01	4.2999E+03 / 4.1862E+01	30512	3.9275E+01	1.0000E+30	7.3032E+03	7.3032E+03
5	40512	4.6648E+01 / 8.5546E+00	4.6598E+01 / 4.4976E+01		7.3319E+05 / 4.584E+01	2.2400E+04 / 4.3775E+01	2.1736E+04 / 4.3359E+01	40512	3.8093E+01	1.0000E+30	7.3064E+03	7.3064E+03
6	50512	4.6555E+01 / 1.4296E+01	3.8271E+01 / 3.7140E+01		2.9806E+03 / 3.6872E+01	2.1815E+04 / 3.6323E+01	2.6223E+03 / 3.6040E+01	50512	3.2259E+01	1.0000E+30	6.9171E+03	6.9171E+03
7	30413	4.6843E+01 / 6.5769E+00	4.6700E+01 / 4.5463E+01		1.9414E+05 / 4.5163E+01	2.2400E+04 / 4.4546E+01	2.0082E+04 / 4.4229E+01	30413	4.0266E+01	1.0000E+30	7.4076E+03	7.4076E+03
8	40413	4.6743E+01 / 8.3126E+00	4.6729E+01 / 4.5404E+01		2.6423E+06 / 4.5005E+01	2.7842E+04 / 4.4183E+01	2.7552E+04 / 4.3761E+01	40413	3.8431E+01	1.0000E+30	7.3348E+03	7.3348E+03
9	50413	4.6639E+01 / 1.4130E+01	3.9041E+01 / 3.7754E+01		3.5036E+03 / 3.7467E+01	2.0682E+04 / 3.6874E+01	2.9960E+03 / 3.6569E+01	50413	3.2510E+01	1.0000E+30	6.9462E+03	6.9462E+03
10	30513	4.6846E+01 / 6.6769E+00	4.6702E+01 / 4.5437E+01		1.9514E+05 / 4.5134E+01	2.2213E+04 / 4.4509E+01	1.9943E+04 / 4.4187E+01	30513	4.0169E+01	1.0000E+30	7.4028E+03	7.4028E+03
11	40513	4.6802E+01	4.6794E+01		5.0625E+06	2.7414E+04	2.7266E+04	40513	3.8309E+01	1.0000E+30	7.3299E+03	7.3299E+03

12	50513	8.4925E+00	4.5422E+01	4.5015E+01	4.4177E+01	4.3746E+01	50513	3.2272E+01	1.0000E+30	6.9239E+03	6.9239E+03
13	30414	4.6646E+01	3.8331E+01	3.0024E+03	2.0553E+04	2.6197E+03	30414	4.1822E+01	1.0000E+30	7.4885E+03	7.4885E+03
14	40414	1.4374E+01	3.7174E+01	3.6905E+01	2.6752E+04	2.6447E+04	40414	4.0326E+01	1.0000E+30	7.4326E+03	7.4326E+03
15	50414	5.0658E+00	4.6032E+01	2.3234E+06	4.5283E+01	4.5024E+01	50414	3.5341E+01	1.0000E+30	7.2114E+03	7.2114E+03
16	30514	4.7089E+01	4.7084E+01	4.5787E+01	3.3275E+04	3.3098E+04	30514	4.1855E+01	1.0000E+30	7.4902E+03	7.4902E+03
17	40514	6.7627E+00	4.6148E+01	6.2296E+06	4.5119E+01	4.4762E+01	40514	4.0366E+01	1.0000E+30	7.4363E+03	7.4363E+03
18	50514	4.6754E+01	4.6502E+01	4.5812E+01	2.4924E+04	2.2051E+04	50514	3.5334E+01	1.0000E+30	7.2109E+03	7.2109E+03
19	30611	1.1412E+01	4.4568E+01	1.9126E+05	4.2974E+01	4.2422E+01	30611	3.6867E+01	1.0000E+30	7.1229E+03	7.1229E+03
20	40611	4.6897E+01	4.6889E+01	4.4046E+01	2.6678E+04	2.6424E+04	40611	3.6037E+01	1.0000E+30	7.1532E+03	7.1532E+03
21	50611	5.0421E+01	4.6045E+01	2.7758E+06	4.5300E+01	4.5042E+01	50611	3.0889E+01	1.0000E+30	6.7765E+03	6.7765E+03
22	30612	6.8481E+00	4.7214E+01	5.8801E+01	3.2410E+04	3.2325E+04	30612	3.7832E+01	1.0000E+30	7.2050E+03	7.2050E+03
23	40612	4.6760E+01	4.6242E+01	1.2429E+07	4.5203E+01	4.4843E+01	40612	3.6706E+01	1.0000E+30	7.2419E+03	7.2419E+03
24	50612	1.1426E+01	4.6462E+01	4.5902E+01	2.5177E+04	2.1790E+04	50612	2.9832E+01	1.0000E+30	6.8851E+03	6.8851E+03
25	30614	4.6535E+01	4.4550E+01	1.6198E+05	4.2958E+01	4.2407E+01	30614	3.9909E+01	1.0000E+30	7.3926E+03	7.3926E+03
26	40614	9.6675E+00	3.9792E+01	1.8509E+05	1.8509E+03	1.7198E+03	40614	3.7939E+01	1.0000E+30	7.3171E+03	7.3171E+03
27	50614	4.6565E+01	3.9279E+01	3.9144E+01	3.8866E+01	3.8723E+01	50614	3.1482E+01	1.0000E+30	6.8500E+03	6.8500E+03
28	30615	1.0528E+01	4.3765E+01	1.1415E+04	2.0319E+04	7.3088E+03	30615	4.2037E+01	1.0000E+30	7.5004E+03	7.5004E+03
29	40615	4.6176E+01	4.2193E+01	4.1847E+01	4.1136E+01	1.1492E+03	40615	4.0575E+01	1.0000E+30	7.4551E+03	7.4551E+03
30	50615	1.5287E+01	3.3756E+01	3.3601E+01	2.3892E+04	3.3120E+01	50615	3.5317E+01	1.0000E+30	7.2107E+03	7.2107E+03
31	30711	4.6674E+01	4.1823E+01	3.4961E+03	3.3284E+01	3.0326E+03	30711	3.3990E+01	1.0000E+30	6.9341E+03	6.9341E+03
32	40711	8.8418E+00	4.1081E+01	8.0898E+01	2.2878E+04	4.0326E+01	40711	3.3158E+01	1.0000E+30	6.9033E+03	6.9033E+03
33	50711	4.6637E+01	4.6584E+01	8.0966E+05	4.0520E+01	2.4029E+04	50711	3.0421E+01	1.0000E+30	6.7157E+03	6.7157E+03
34	30715	9.3308E+00	4.4559E+01	4.4396E+01	2.4764E+04	4.2956E+01	30715	4.1767E+01	1.0000E+30	7.4861E+03	7.4861E+03
35	40715	4.5244E+01	3.1328E+01	4.5220E+02	3.4446E+01	4.4521E+02	40715	4.0251E+01	1.0000E+30	7.4304E+03	7.4304E+03
36	50715	1.5412E+01	3.1109E+01	3.1041E+01	2.8804E+04	3.0829E+01	50715	3.5160E+01	1.0000E+30	7.1949E+03	7.1949E+03
37	30811	4.6853E+01	4.6800E+01	5.6117E+05	3.0901E+01	2.1899E+04	30811	3.5700E+01	1.0000E+30	7.0568E+03	7.0568E+03
38	40811	6.9436E+01	4.5495E+01	4.5173E+01	2.2788E+04	4.4171E+01	40811	3.4703E+01	1.0000E+30	7.0338E+03	7.0338E+03
39	50811	9.0300E+00	4.6965E+01	9.0203E+06	4.4511E+01	2.8445E+04	50811	3.0868E+01	1.0000E+30	6.7673E+03	6.7673E+03
40	30812	4.6479E+01	4.5555E+01	1.8092E+05	2.8535E+04	1.6723E+03	30812	3.6055E+01	1.0000E+30	7.0583E+03	7.0583E+03
41	40812	1.4997E+01	3.6080E+01	3.5026E+01	2.2108E+04	3.4391E+01	40812	3.5400E+01	1.0000E+30	7.1316E+03	7.1316E+03

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42 50812  1.1123E+01  4.2553E+01  4.1328E+01  4.0903E+01        50812  2.9427E+01  1.0000E+30  6.6367E+03  6.6367E+03
          4.5149E+01  3.0178E+01  2.1505E+02  2.1371E+02
43 30814  1.5723E+01  3.0049E+01  2.9977E+01  2.9940E+01        30814  3.9317E+01  1.0000E+30  7.3592E+03  7.3592E+03
          4.6816E+01  4.6590E+01  1.3717E+05  1.8711E+04
44 40814  7.4990E+00  4.5159E+01  4.4824E+01  4.4134E+01  4.3779E+01   40814  3.7262E+01  1.0000E+30  7.2765E+03  7.2765E+03
          4.6637E+01  4.6630E+01  5.7442E+06  2.5645E+04  2.5531E+04
45 50814  9.3749E+01  4.5035E+01  4.4593E+01  4.3683E+01  4.3215E+01   50814  3.0695E+01  1.0000E+30  6.7739E+03  6.7739E+03
          4.6209E+01  3.3808E+01  1.0352E+03  2.4012E+04  9.9241E+02
46 30815  1.5514E+01  3.3135E+01  3.2849E+01  3.2702E+01        30815  4.1404E+01  1.0000E+30  7.4678E+03  7.4678E+03
          4.6890E+01  4.6881E+01  2.6886E+06  2.5322E+04  2.5086E+04
47 40815  5.4859E+00  4.5924E+01  4.5662E+01  4.5122E+01  4.4844E+01   40815  3.9801E+01  1.0000E+30  7.4016E+03  7.4016E+03
          4.6867E+01  4.6865E+01  1.9483E+07  2.8440E+04  2.8399E+04
48 50815  7.0661E+00  4.5751E+01  4.5408E+01  4.4702E+01  4.4339E+01   50815  3.4721E+01  1.0000E+30  7.1533E+03  7.1533E+03
          4.6734E+01  4.5017E+01  2.5307E+04  2.2568E+04  1.1930E+04
49 30912  1.2013E+01  4.3091E+01  4.2621E+01  4.1156E+01        30912  3.8929E+01  1.0000E+30  7.2844E+03  7.2844E+03
          4.6747E+01  4.3359E+01  5.5441E+01  5.4206E+03  1.1813E+04
50 40912  7.8184E+00  4.2497E+01  4.2294E+01  4.1876E+01  4.1661E+01   40912  3.7683E+01  1.0000E+30  7.2731E+03  7.2731E+03
          4.6575E+01  4.6007E+01  6.0747E+04  1.9632E+04  1.4837E+04
51 50912  8.8928E+01  4.4248E+01  4.3875E+01  4.3107E+01  4.2711E+01   50912  3.2135E+01  1.0000E+30  6.9035E+03  6.9035E+03
          4.6537E+01  3.7919E+01  2.7549E+01  2.7549E+04  2.4470E+03
52 30913  1.4402E+01  3.6835E+01  3.6578E+01  3.6050E+01  3.5778E+01   30913  3.9755E+01  1.0000E+30  7.3747E+03  7.3747E+03
          4.6805E+01  4.6266E+01  5.1549E+04  2.1589E+04  1.5216E+04
53 40913  7.0497E+00  4.4980E+01  4.4679E+01  4.4062E+01  4.3743E+01   40913  3.7915E+01  1.0000E+30  7.3014E+03  7.3014E+03
          4.6580E+01  4.6550E+01  1.2284E+04  2.2090E+04  2.2090E+04
54 50913  8.6650E+00  4.4910E+01  4.4511E+01  4.3690E+01  4.3267E+01   50913  3.1993E+01  1.0000E+30  6.8958E+03  6.8958E+03
          4.6555E+01  3.7544E+01  2.5176E+03  2.1467E+04  2.2534E+04
55 30914  1.4562E+01  3.6488E+01  3.6242E+01  3.5738E+01  3.5478E+01   30914  4.1240E+01  1.0000E+30  7.4590E+03  7.4590E+03
          4.6846E+01  3.6834E+01  2.0941E+06  2.5202E+04  2.4902E+04
56 40914  5.6063E+00  4.5853E+01  4.5586E+01  4.5035E+01  4.4752E+01   40914  3.9604E+01  1.0000E+30  7.3876E+03  7.3876E+03
          4.6669E+01  4.6667E+01  1.3884E+07  2.6745E+04  2.6694E+04
57 50914  7.0651E+00  4.5495E+01  4.5156E+01  4.4458E+01  4.4099E+01   50914  3.4580E+01  1.0000E+30  7.1397E+03  7.1397E+03
          4.6720E+01  4.4602E+01  2.0008E+04  2.2952E+04  1.0689E+04
          1.2140E+01  4.2756E+01  4.2297E+01  4.1354E+01  4.0869E+01
```

thermal structure number   2 at time= 4.271E+02 seconds

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1st                                / (tf1-tf2)                   shell-side heat coefficients    2nd       fluid        tube-side heat transfer coefficients
element   fluid temperature                                                                      cell      temperature  (fouling) (convective) (tubeside all)
cell      (tf1)       (tcs)        <---material temperatures--->  (htgs)      (htss)    (hstrel)

115 30406  4.6856E+01  4.6167E+01  3.9053E+04  2.2446E+04  1.4254E+04   30406  3.9904E+01  1.0000E+30  7.3810E+03  7.3810E+03
           6.9517E+01  4.4967E+01  4.4676E+01  4.4077E+01  4.3768E+01
116 40406  6.4584E+01  4.5921E+01  5.0665E+04  2.3444E+04  1.6028E+04   40406  3.8121E+01  1.0000E+30  7.3012E+03  7.3012E+03
           8.4630E+00  4.4488E+01  4.4125E+01  4.3378E+01  4.2993E+01
117 50406  4.6665E+01  3.9615E+01  4.0099E+03  2.1322E+04  3.3752E+03   50406  3.2729E+01  1.0000E+30  6.9639E+03  6.9639E+03
           1.3935E+01  3.8289E+01  3.7983E+01  3.7354E+01  3.7030E+01
118 30506  4.6850E+01  4.6469E+01  6.7968E+04  2.3266E+04  1.7333E+04   30506  4.0499E+01  1.0000E+30  7.4156E+03  7.4156E+03
           6.3516E+00  4.5355E+01  4.5075E+01  4.4498E+01  4.4201E+01
119 40506  4.6589E+01  4.6326E+01  1.2440E+05  2.4089E+04  2.0181E+04   40506  3.8783E+01  1.0000E+30  7.3404E+03  7.3404E+03
           7.8059E+00  4.4612E+01  4.3883E+01  3.3508E+01  4.4752E+01
120 50506  4.6681E+01  4.0232E+01  7.0092E+03  2.2237E+04  5.3293E+03   50506  3.3530E+01  1.0000E+30  7.0403E+03  7.0403E+03
           1.3151E+01  3.9860E+01  3.9096E+01  3.8702E+01  3.8702E+01
121 30407  4.6841E+01  4.6497E+01  7.6816E+04  2.3911E+04  1.8235E+04   30407  4.0433E+01  1.0000E+30  7.4135E+03  7.4135E+03
           6.4080E+00  4.5390E+01  4.5104E+01  4.4516E+01  4.4213E+01
122 40407  7.8759E+00  4.6558E+01  7.6347E+04  2.4332E+04  1.8451E+04   40407  3.8682E+01  1.0000E+30  7.3326E+03  7.3326E+03
           4.6133E+01  4.4552E+01  4.4731E+01  4.3731E+01  4.3360E+01
123 50407  4.6683E+01  4.0126E+01  6.7957E+03  2.1976E+04  5.1906E+03   50407  3.3486E+01  1.0000E+30  7.0359E+03  7.0359E+03
           1.3197E+01  3.9755E+01  3.9000E+01  3.8611E+01  3.8611E+01
```

#	code						code				
124	30507	4.6786E+01	4.3394E+01	7.4264E+03	5.4958E+03	2.1140E+04	30507	3.7665E+01	1.0000E+30	7.2096E+03	7.2096E+03
125	40507	9.4065E+00	4.2203E+01	4.1930E+01	4.1081E+01	4.1370E+01	40507	3.5706E+01	1.0000E+30	7.1209E+03	7.1209E+03
126	50507	4.6524E+01	4.2507E+01	6.9666E+03	5.1750E+03	2.0123E+04	50507	3.1199E+01	1.0000E+30	6.8081E+03	6.8081E+03
127	30408	1.0819E+01	4.1116E+01	4.0815E+01	3.9870E+01	4.0190E+01	30408	4.1000E+01	1.0000E+30	7.4440E+03	7.4440E+03
128	40408	4.6414E+01	3.5256E+01	1.4892E+03	1.3976E+03	2.2717E+04	40408	3.9354E+01	1.0000E+30	7.3698E+03	7.3698E+03
129	50408	1.5215E+01	3.4524E+01	3.4345E+01	3.3784E+01	3.3975E+01	50408	3.4398E+01	1.0000E+30	7.1217E+03	7.1217E+03
130	30508	4.6843E+01	4.6638E+01	1.2171E+05	2.0851E+04	2.5162E+04	30508	3.8152E+01	1.0000E+30	7.2526E+03	7.2526E+03
131	40508	5.8427E+00	4.5649E+01	5.3380E+01	4.4541E+01	4.4827E+01	40508	3.6599E+01	1.0000E+30	7.1856E+03	7.1856E+03
132	50508	4.6567E+01	4.6373E+01	1.5969E+05	2.2201E+04	2.5786E+04	50508	3.1807E+01	1.0000E+30	6.8687E+03	6.8687E+03
133	30605	7.2128E+00	4.5174E+01	4.4840E+01	4.3798E+01	4.4152E+01	30605	4.0704E+01	1.0000E+30	7.4291E+03	7.4291E+03
134	40605	4.6721E+01	4.4046E+01	1.5320E+04	9.3104E+03	4.0963E+01	40605	3.8985E+01	1.0000E+30	7.3525E+03	7.3525E+03
135	50605	1.2323E+01	4.2319E+01	1.1875E+01	4.0494E+01	4.0963E+01	50605	3.3775E+01	1.0000E+30	7.0638E+03	7.0638E+03
136	30606	4.6771E+01	4.3686E+01	7.5828E+03	5.6244E+03	2.1777E+04	30606	3.7122E+01	1.0000E+30	7.1854E+03	7.1854E+03
137	40606	8.6193E+00	4.2611E+01	2.4358E+01	4.1570E+01	4.1838E+01	40606	3.5567E+01	1.0000E+30	7.1352E+03	7.1352E+03
138	50606	4.6516E+01	4.3705E+01	1.0598E+04	7.0954E+03	2.1470E+04	50606	3.0112E+01	1.0000E+30	6.7065E+03	6.7065E+03
139	30608	9.9173E+01	4.2317E+01	4.1995E+01	4.0991E+01	4.1332E+01	30608	3.1901E+01	1.0000E+30	6.7818E+03	6.7818E+03
140	40608	4.6513E+01	3.6996E+01	2.2316E+04	2.0258E+04	1.9963E+04	40608	3.1313E+01	1.0000E+30	6.7511E+03	6.7511E+03
141	50608	1.4706E+01	3.6029E+01	3.5799E+01	3.5083E+01	3.5326E+01	50608	2.9719E+01	1.0000E+30	6.6382E+03	6.6382E+03
142	30609	4.6859E+01	4.6671E+01	1.3786E+05	2.0042E+04	2.3451E+04	30609	3.4472E+01	1.0000E+30	6.9723E+03	6.9723E+03
143	40609	6.1553E+00	4.5563E+01	4.5283E+01	4.4407E+01	4.4705E+01	40609	3.3538E+01	1.0000E+30	6.9368E+03	6.9368E+03
144	50609	7.6464E+00	4.6643E+01	1.9320E+05	2.1395E+04	2.4060E+04	50609	3.0493E+01	1.0000E+30	6.7252E+03	6.7252E+03
145	30705	4.6690E+01	4.5113E+01	8.5913E+04	6.1758E+03	2.1965E+04	30705	4.0388E+01	1.0000E+30	7.4154E+03	7.4154E+03
146	40705	1.2916E+01	4.2472E+01	4.0431E+01	3.9209E+01	3.9624E+01	40705	3.8557E+01	1.0000E+30	7.3330E+03	7.3330E+03
147	50705	4.6766E+01	4.0823E+01	5.7914E+03	4.5412E+03	2.1036E+04	50705	3.3039E+01	1.0000E+30	6.9952E+03	6.9952E+03
148	30709	9.6436E+00	4.2726E+01	4.1360E+01	4.0572E+01	4.0840E+01	30709	3.2855E+01	1.0000E+30	6.8424E+03	6.8424E+03
149	40709	4.6535E+01	4.3757E+01	1.2196E+04	7.6460E+03	2.0493E+04	40709	3.2291E+01	1.0000E+30	6.8357E+03	6.8357E+03
150	50709	1.0965E+01	4.2104E+01	6.1115E+02	5.9739E+02	2.6526E+04	50709	2.9907E+01	1.0000E+30	6.6613E+03	6.6613E+03
151	30805	4.5873E+01	3.2129E+01	3.1722E+01	3.1438E+01	3.1535E+01	30805	4.1037E+01	1.0000E+30	7.4486E+03	7.4486E+03
152	40805	1.5761E+01	1.812E+01	7.2779E+02	7.0814E+02	2.6231E+04	40805	3.9356E+01	1.0000E+30	7.3734E+03	7.3734E+03
153	50805	1.2449E+01	4.2009E+01	4.1577E+01	4.0687E+01	4.0228E+01	50805	3.4268E+01	1.0000E+30	7.1104E+03	7.1104E+03

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154  30806  4.6821E+01  4.5759E+01  2.8212E+04  1.1886E+04  2.0538E+04   30806  3.8624E+01  1.0000E+30  7.3101E+03  7.3101E+03
            8.1964E+00  4.4300E+01  4.3976E+01  4.2966E+01  4.3309E+01
155  40806  4.6568E+01  4.5841E+01  5.3123E+04  1.5188E+04  2.1268E+04   40806  3.6637E+01  1.0000E+30  7.2267E+03  7.2267E+03
            9.9317E+00  4.4023E+01  4.3605E+01  4.2303E+01  4.2745E+01
156  50806  4.6245E+01  3.3033E+01  8.1559E+02  7.8945E+02  2.4630E+04   50806  3.0424E+01  1.0000E+30  6.7446E+03  6.7446E+03
            1.5822E+01  3.2596E+01  3.2479E+01  3.2116E+01  3.2240E+01
157  30808  3.9290E+01  3.8616E+01  2.1620E+04  1.9782E+03  2.3266E+04   30808  3.5561E+01  1.0000E+30  7.0508E+03  7.0508E+03
            1.0984E+01  3.8447E+01  3.8098E+01  3.7918E+01  3.8098E+01
158  40808  4.6546E+01  4.1300E+01  5.4898E+03  4.3851E+03  2.1793E+04   40808  3.4516E+01  1.0000E+30  7.0402E+03  7.0402E+03
            1.1913E+01  4.0008E+01  3.9703E+01  3.8754E+01  3.9076E+01
159  50808  4.6430E+01  3.1730E+01  5.2827E+02  5.1833E+02  2.7552E+04   50808  2.9973E+01  1.0000E+30  6.6841E+03  6.6841E+03
            1.5653E+01  3.1463E+01  3.1384E+01  3.1137E+01  3.1221E+01
160  30809  4.6395E+01  3.9628E+01  2.2356E+03  2.0480E+03  2.4406E+04   30809  3.6072E+01  1.0000E+30  7.0819E+03  7.0819E+03
            1.0323E+01  3.9009E+01  3.8508E+01  3.8335E+01  3.8508E+01
161  40809  4.1249E+01  4.0134E+01  5.1225E+03  2.3018E+03  2.3372E+04   40809  3.5065E+01  1.0000E+30  7.0670E+03  7.0670E+03
            1.1274E+01  4.0134E+01  3.9852E+01  3.8973E+01  3.9272E+01
162  50809  4.5848E+01  3.4254E+01  1.2126E+03  1.1562E+03  2.4850E+04   50809  3.0862E+01  1.0000E+30  6.7691E+03  6.7691E+03
            1.4986E+01  3.3688E+01  3.3536E+01  3.3062E+01  3.3224E+01
163  30906  4.6956E+01  4.6941E+01  1.6295E+06  2.4085E+04  2.4447E+04   30906  4.1556E+01  1.0000E+30  7.4755E+03  7.4755E+03
            5.3997E+00  4.5971E+01  4.5715E+01  4.4916E+01  4.5187E+01
164  40906  4.6851E+01  4.6798E+01  5.6668E+05  2.4266E+04  2.5351E+04   40906  3.9989E+01  1.0000E+30  7.4068E+03  7.4068E+03
            6.8626E+00  4.5615E+01  4.5291E+01  4.4279E+01  4.4623E+01
165  50906  4.6785E+01  4.6183E+01  7.8032E+04  1.8111E+04  2.3585E+04   50906  3.5183E+01  1.0000E+30  7.1955E+03  7.1955E+03
            1.1602E+01  4.4191E+01  4.3683E+01  4.2099E+01  4.2637E+01
166  30907  4.6933E+01  4.6861E+01  3.6240E+05  2.1829E+04  2.3228E+04   30907  4.0860E+01  1.0000E+30  7.4397E+03  7.4397E+03
            6.0733E+00  4.5737E+01  4.5455E+01  4.4575E+01  4.4874E+01
167  40907  4.6807E+01  4.6673E+01  2.4579E+05  2.2071E+04  2.4248E+04   40907  3.9133E+01  1.0000E+30  7.3635E+03  7.3635E+03
            7.6743E+00  4.5319E+01  4.4964E+01  4.3857E+01  4.4233E+01
168  50907  4.6725E+01  4.2776E+01  9.3549E+03  6.5051E+03  2.1355E+04   50907  3.3867E+01  1.0000E+30  7.0731E+03  7.0731E+03
            1.2858E+01  4.1046E+01  4.0646E+01  3.9401E+01  3.9824E+01
169  30908  4.6924E+01  4.6689E+01  1.0556E+05  1.9033E+04  2.3219E+04   30908  4.0972E+01  1.0000E+30  7.4421E+03  7.4421E+03
            5.5921E+00  4.5618E+01  4.5349E+01  4.4511E+01  4.4796E+01
170  40908  4.6809E+01  4.6633E+01  1.8063E+05  2.0896E+04  2.3629E+04   40908  3.9327E+01  1.0000E+30  7.3711E+03  7.3711E+03
            7.4815E+00  4.5292E+01  4.4950E+01  4.3881E+01  4.4244E+01
171  50908  4.6750E+01  4.1959E+01  1.3474E+04  8.3159E+03  2.1723E+04   50908  3.4247E+01  1.0000E+30  7.1081E+03  7.1081E+03
            1.2503E+01  4.1528E+01  4.0642E+01  4.0185E+01
```

*** molecular diffusivity   (m**2/s)   ** diffu ** component   1 ** j plane   7 ** time step4271 ** time 4.27100E+02 s **

k i-->	3	4	5	6	7
19	2.941331E-04	2.931737E-04	2.948525E-04		3.222891E-04
18	2.913352E-04	2.934310E-04	2.925266E-04		3.221730E-04
17	2.900385E-04	2.925506E-04	2.917935E-04		3.218964E-04
16	2.928540E-04	2.839012E-04	2.949180E-04		3.214856E-04
15	2.934306E-04	2.886242E-04	2.942834E-04		3.214132E-04
14	3.224498E-04	2.919442E-04	3.220126E-04	3.221053E-04	3.213452E-04
13	2.935245E-04	3.226258E-04	2.914630E-04		3.212774E-04
12	2.930133E-04	2.971203E-04	2.927015E-04		3.212199E-04
11	2.937613E-04	2.974555E-04	2.943919E-04		3.211040E-04
10	2.925502E-04	2.969315E-04	2.918319E-04		
9	2.923855E-04	2.965989E-04	2.908674E-04		
8	3.214773E-04	2.961531E-04	3.209327E-04	3.210270E-04	
7	2.937278E-04	3.215946E-04	2.934167E-04		
6	2.935879E-04	2.968924E-04	2.934166E-04		
5	2.916357E-04	2.965259E-04	2.943166E-04		
4	2.930009E-04	2.930009E-04	2.926060E-04		
3	2.913274E-04	2.923173E-04	2.924106E-04		

*** turbulent diffusivity   (m**2/s)   ** diffut ** component 1 ** j plane 7 ** time step4271 ** time 4.27100E+02 s **

k / i-->	3	4	5	6	7
19	7.166422E-02	7.140672E-02	7.185747E-02		
18	7.091312E-02	7.147579E-02	7.123295E-02		
17	7.056532E-02	7.123948E-02	7.103620E-02		
16	7.132046E-02	6.892118E-02	7.185790E-02		7.823931E-02
15	7.147509E-02	7.018627E-02	7.138756E-02		7.820841E-02
14	7.904301E-02	7.087543E-02	7.847387E-02		7.813480E-02
13	7.106536E-02	7.925381E-02	6.817898E-02	7.849271E-02	7.772104E-02
12	7.044787E-02	7.245765E-02	6.950834E-02		7.768974E-02
11	7.154952E-02	7.202454E-02	7.169590E-02		7.767136E-02
10	6.996214E-02	7.241154E-02	6.860505E-02		7.765337E-02
9	6.980775E-02	7.150622E-02	6.761807E-02		7.763812E-02
8	7.823965E-02	7.107363E-02	7.756197E-02	7.758699E-02	7.760739E-02
7	7.154620E-02	7.837500E-02	7.045725E-02		
6	7.151319E-02	7.239731E-02	7.141003E-02		
5	7.099279E-02	7.230045E-02	7.124927E-02		
4	7.090962E-02	7.135838E-02	7.119775E-02		
3		7.117471E-02			

206

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********* date: 10/15/91    time: 22:48:15    commix-PC-100    last updated: 10/09/91    id# Surf/110 **********

TUBE SIDE GLOBAL BALANCES AT time= 4.271E+02 Seconds

surface    mass        enthalpy    heat        average     average      average      bulk
number     convected   convected   conducted   velocity    enthalpy     temperature  temperature
           (kg/sec)    (watt)      (watt)      (m/sec)     (j/kg)       (celsius)    (celsius)

  1        9.934078E+03  1.228845E+09  0.000000E+00  2.006632E+00  1.237000E+05  2.900000E+01  2.900000E+01
  2        9.934073E+03  1.616982E+09  0.000000E+00  2.012301E+00  1.627386E+05  3.875964E+01  3.876783E+01

************************************ mass balance ***********

            mass accumulation rate                          :           dmasdt    = 5.297312E-03  (kg/s)
            net mass convected into configuration           :           flosum    =-5.287810E-03  (kg/s)
            global conservation of mass                     :    (dmasdt - flosum ) = 9.501565E-06  (kg/s)

            total mass within configuration                 :           tmass     = 9.218419E+04  (kg)

************************************ energy balance *********

            enthalpy accumulation rate                      :           dhdt      =-7.253789E+04  (watt)
            net enthalpy convected into configuration       :           hinsum    =-3.881366E+08  (watt)
            heat generated within configuration             :           qsourc    = 3.880641E+08  (watt)

            global energy                                   :   (dhdt-hinsum-qsourc)  = 1.416488E+00  (watt)

            total internal energy within configuration:               tenth     = 1.382290E+10  (joules)

******************************************************************************************************

ulbtbm, ultbti), ulbtbp (velocity)    at time=  4.27100E+02

I =       0           1           2           3           4           5           6           7           8
  1  -2.0218E+00  0.0000E+00  -2.0218E+00  -2.0209E+00  -2.0179E+00  -2.0142E+00  -2.0142E+00
  2  -2.0210E+00  0.0000E+00  -2.0210E+00  -2.0201E+00  -2.0171E+00  -2.0136E+00  -2.0136E+00
  3  -2.0200E+00  0.0000E+00  -2.0200E+00  -2.0190E+00  -2.0161E+00  -2.0127E+00  -2.0127E+00
  4  -2.0212E+00  0.0000E+00  -2.0212E+00  -2.0203E+00  -2.0174E+00  -2.0137E+00  -2.0137E+00
  5  -2.0213E+00  0.0000E+00  -2.0213E+00  -2.0204E+00  -2.0174E+00  -2.0138E+00  -2.0138E+00
  6  -2.0156E+00  0.0000E+00  -2.0156E+00  -2.0145E+00  -2.0107E+00  -2.0093E+00  -2.0093E+00
  7  -2.0139E+00  0.0000E+00  -2.0139E+00  -2.0127E+00  -2.0089E+00  -2.0079E+00  -2.0079E+00
  8  -2.0195E+00  0.0000E+00  -2.0195E+00  -2.0185E+00  -2.0156E+00  -2.0123E+00  -2.0123E+00
  9  -2.0167E+00  0.0000E+00  -2.0167E+00  -2.0156E+00  -2.0121E+00  -2.0101E+00  -2.0101E+00
 10  -2.0164E+00  0.0000E+00  -2.0164E+00  -2.0153E+00  -2.0118E+00  -2.0099E+00  -2.0099E+00
 11  -2.0152E+00  0.0000E+00  -2.0152E+00  -2.0141E+00  -2.0107E+00  -2.0089E+00  -2.0089E+00
 12  -2.0136E+00  0.0000E+00  -2.0136E+00  -2.0132E+00  -2.0100E+00  -2.0077E+00  -2.0077E+00
 13  -2.0138E+00  0.0000E+00  -2.0138E+00  -2.0131E+00  -2.0097E+00  -2.0078E+00  -2.0078E+00
 14  -2.0096E+00  0.0000E+00  -2.0090E+00  -2.0050E+00  -2.0045E+00  -2.0045E+00  -2.0045E+00
 15  -2.0045E+00  0.0000E+00  -2.0045E+00  -2.0041E+00  -2.0006E+00  -2.0004E+00  -2.0004E+00
 16  -2.0128E+00  0.0000E+00  -2.0128E+00  -2.0121E+00  -2.0083E+00  -2.0070E+00  -2.0070E+00
 17  -2.0068E+00  0.0000E+00  -2.0068E+00  -2.0063E+00  -2.0034E+00  -2.0023E+00  -2.0023E+00
 18  -1.9985E+00  0.0000E+00  -1.9985E+00  -1.9980E+00  -1.9965E+00  -1.9956E+00  -1.9956E+00
 19  -2.0035E+00  0.0000E+00  -2.0035E+00  -2.0029E+00  -2.0007E+00  -1.9996E+00  -1.9996E+00
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					0
20	-1.9999E+00	-1.9999E+00	-1.9994E+00	-1.9976E+00	-1.9968E+00	0.0000E+00
21	-1.9952E+00	-1.9952E+00	-1.9949E+00	-1.9935E+00	-1.9930E+00	0.0000E+00
22	-2.0045E+00	-2.0045E+00	-2.0039E+00	-2.0015E+00	-2.0004E+00	0.0000E+00
23	-2.0188E+00	-2.0188E+00	-2.0178E+00	-2.0149E+00	-2.0118E+00	0.0000E+00
24	-2.0105E+00	-2.0105E+00	-2.0096E+00	-2.0069E+00	-2.0052E+00	0.0000E+00
25	-1.9925E+00	-1.9925E+00	-1.9921E+00	-1.9912E+00	-1.9908E+00	0.0000E+00
26	-2.0031E+00	-2.0031E+00	-2.0024E+00	-1.9998E+00	-1.9993E+00	0.0000E+00
27	-2.0187E+00	-2.0187E+00	-2.0177E+00	-2.0148E+00	-2.0117E+00	0.0000E+00
28	-2.0171E+00	-2.0171E+00	-2.0161E+00	-2.0131E+00	-2.0105E+00	0.0000E+00
29	-2.0083E+00	-2.0083E+00	-2.0073E+00	-2.0047E+00	-2.0035E+00	0.0000E+00
30	-2.0184E+00	-2.0184E+00	-2.0174E+00	-2.0143E+00	-2.0115E+00	0.0000E+00
31	-2.0156E+90	-2.0156E+00	-2.0146E+00	-2.0114E+00	-2.0093E+00	0.0000E+00
32	-2.0173E+00	-2.0173E+00	-2.0163E+00	-2.0133E+00	-2.0106E+00	0.0000E+00
33	-2.0076E+00	-2.0076E+00	-2.0067E+00	-2.0035E+00	-2.0029E+00	0.0000E+00
34	-2.0119E+00	-2.0119E+00	-2.0108E+00	-2.0071E+00	-2.0063E+00	0.0000E+00
35	-2.0204E+00	-2.0204E+00	-2.0195E+00	-2.0167E+00	-2.0131E+00	0.0000E+00
36	-2.0179E+00	-2.0179E+00	-2.0169E+00	-2.0139E+00	-2.0111E+00	0.0000E+00
37	-2.0170E+00	-2.0170E+00	-2.0159E+00	-2.0127E+00	-2.0104E+00	0.0000E+00
38	-2.0189E+00	-2.0189E+00	-2.0179E+00	-2.0149E+00	-2.0119E+00	0.0000E+00

tlbtbn, tlbtb(i), tlbtbp (temperature) at time= 4.27100E+02

I =	0	1	2	3	4	5	6	7	8
1	4.2037E+01	4.2037E+01	4.2037E+01	4.0575E+01	3.5317E+01	2.9000E+01	2.9000E+01		
2	4.1767E+01	4.1767E+01	4.1767E+01	4.0251E+01	3.5160E+01	2.9000E+01	2.9000E+01		
3	4.1404E+01	4.1404E+01	4.1404E+01	3.9801E+01	3.4721E+01	2.9000E+01	2.9000E+01		
4	4.1822E+01	4.1822E+01	4.1822E+01	4.0326E+01	3.5341E+01	2.9000E+01	2.9000E+01		
5	4.1855E+01	4.1855E+01	4.1855E+01	4.0366E+01	3.5334E+01	2.9000E+01	2.9000E+01		
6	3.9909E+01	3.9909E+01	3.9909E+01	3.7939E+01	3.1482E+01	2.9000E+01	2.9000E+01		
7	3.9317E+01	3.9317E+01	3.9317E+01	3.7262E+01	3.0695E+01	2.9000E+01	2.9000E+01		
8	4.1240E+01	4.1240E+01	4.1240E+01	3.9604E+01	3.4580E+01	2.9000E+01	2.9000E+01		
9	4.0266E+01	4.0266E+01	4.0266E+01	3.8431E+01	3.2510E+01	2.9000E+01	2.9000E+01		
10	4.0169E+01	4.0169E+01	4.0169E+01	3.8309E+01	3.2272E+01	2.9000E+01	2.9000E+01		
11	3.9755E+01	3.9755E+01	3.9755E+01	3.7915E+01	3.1993E+01	2.9000E+01	2.9000E+01		
12	3.9219E+01	3.9219E+01	3.9219E+01	3.8418E+01	3.2897E+01	2.9000E+01	2.9000E+01		
13	3.9275E+01	3.9275E+01	3.9275E+01	3.8093E+01	3.2259E+01	2.9000E+01	2.9000E+01		
14	3.7832E+01	3.7832E+01	3.7832E+01	3.6706E+01	2.9832E+01	2.9000E+01	2.9000E+01		
15	3.6056E+01	3.6056E+01	3.6055E+01	3.5400E+01	2.9427E+01	2.9000E+01	2.9000E+01		
16	3.8929E+01	3.8929E+01	3.8929E+01	3.7683E+01	3.2135E+01	2.9000E+01	2.9000E+01		
17	3.6867E+01	3.6867E+01	3.6867E+01	3.6037E+01	3.0889E+01	2.9000E+01	2.9000E+01		
18	3.3990E+01	3.3990E+01	3.3990E+01	3.3158E+01	3.0421E+01	2.9000E+01	2.9000E+01		
19	3.5700E+01	3.5700E+01	3.5700E+01	3.4703E+01	3.0868E+01	2.9000E+01	2.9000E+01		
20	3.4472E+01	3.4472E+01	3.4472E+01	3.3538E+01	3.0493E+01	2.9000E+01	2.9000E+01		
21	3.2855E+01	3.2855E+01	3.2855E+01	3.2291E+01	2.9907E+01	2.9000E+01	2.9000E+01		
22	3.6072E+01	3.6072E+01	3.6072E+01	3.5065E+01	3.0862E+01	2.9000E+01	2.9000E+01		
23	4.1000E+01	4.1000E+01	4.1000E+01	3.9554E+01	3.4398E+01	2.9000E+01	2.9000E+01		
24	3.8152E+01	3.8152E+01	3.8152E+01	3.6599E+01	3.1807E+01	2.9000E+01	2.9000E+01		
25	3.1901E+01	3.1901E+01	3.1901E+01	3.1313E+01	2.9719E+01	2.9000E+01	2.9000E+01		
26	3.5561E+01	3.5561E+01	3.5561E+01	3.4516E+01	2.9973E+01	2.9000E+01	2.9000E+01		
27	4.0972E+01	4.0972E+01	4.0972E+01	3.9327E+01	3.4247E+01	2.9000E+01	2.9000E+01		
28	4.0433E+01	4.0433E+01	4.0433E+01	3.8682E+01	3.3486E+01	2.9000E+01	2.9000E+01		
29	3.7380E+01	3.7380E+01	3.7380E+01	3.5706E+01	3.1199E+01	2.9000E+01	2.9000E+01		
30	4.0860E+01	4.0860E+01	4.0860E+01	3.9133E+01	3.3867E+01	2.9000E+01	2.9000E+01		
31	3.9905E+01	3.9905E+01	3.9904E+01	3.8121E+01	3.2729E+01	2.9000E+01	2.9000E+01		
32	4.0499E+01	4.0499E+01	4.0499E+01	3.8783E+01	3.3530E+01	2.9000E+01	2.9000E+01		
33	3.7122E+01	3.7122E+01	3.7122E+01	3.5567E+01	3.0112E+01	2.9000E+01	2.9000E+01		
34	3.8624E+01	3.8624E+01	3.8624E+01	3.6637E+01	3.0424E+01	2.9000E+01	2.9000E+01		

35	4.1556E+01	4.1556E+01	3.9989E+01	3.5183E+01	2.9000E+01	2.9000E+01
36	4.0704E+01	4.0704E+01	3.8985E+01	3.3775E+01	2.9000E+01	2.9000E+01
37	4.0389E+01	4.0388E+01	3.8557E+01	3.3039E+01	2.9000E+01	2.9000E+01
38	4.1038E+01	4.1037E+01	3.9356E+01	3.4268E+01	2.9000E+01	2.9000E+01

rlbtbm, roltb(i), rlbtbp (density) at time= 4.27100E+02

I =	0	1	2	3	4	5	6	7	8
1	1.0175E+03	1.0175E+03	1.0175E+03	1.0180E+03	1.0195E+03	1.0214E+03	1.0214E+03		
2	1.0176E+03	1.0176E+03	1.0176E+03	1.0180E+03	1.0195E+03	1.0214E+03	1.0214E+03		
3	1.0177E+03	1.0177E+03	1.0177E+03	1.0182E+03	1.0197E+03	1.0214E+03	1.0214E+03		
4	1.0176E+03	1.0176E+03	1.0176E+03	1.0180E+03	1.0195E+03	1.0214E+03	1.0214E+03		
5	1.0176E+03	1.0176E+03	1.0181E+03	1.0187E+03	1.0206E+03	1.0214E+03	1.0214E+03		
6	1.0181E+03	1.0181E+03	1.0183E+03	1.0189E+03	1.0209E+03	1.0214E+03	1.0214E+03		
7	1.0183E+03	1.0183E+03	1.0178E+03	1.0182E+03	1.0197E+03	1.0214E+03	1.0214E+03		
8	1.0178E+03	1.0178E+03	1.0180E+03	1.0186E+03	1.0203E+03	1.0214E+03	1.0214E+03		
9	1.0180E+03	1.0180E+03	1.0181E+03	1.0186E+03	1.0204E+03	1.0214E+03	1.0214E+03		
10	1.0181E+03	1.0181E+03	1.0182E+03	1.0187E+03	1.0205E+03	1.0214E+03	1.0214E+03		
11	1.0182E+03	1.0182E+03	1.0184E+03	1.0186E+03	1.0202E+03	1.0214E+03	1.0214E+03		
12	1.0184E+03	1.0184E+03	1.0183E+03	1.0187E+03	1.0204E+03	1.0214E+03	1.0214E+03		
13	1.0183E+03	1.0183E+03	1.0188E+03	1.0191E+03	1.0211E+03	1.0214E+03	1.0214E+03		
14	1.0188E+03	1.0188E+03	1.0193E+03	1.0195E+03	1.0212E+03	1.0214E+03	1.0214E+03		
15	1.0193E+03	1.0193E+03	1.0184E+03	1.0188E+03	1.0204E+03	1.0214E+03	1.0214E+03		
16	1.0184E+03	1.0184E+03	1.0190E+03	1.0193E+03	1.0208E+03	1.0214E+03	1.0214E+03		
17	1.0190E+03	1.0190E+03	1.0199E+03	1.0201E+03	1.0209E+03	1.0214E+03	1.0214E+03		
18	1.0199E+03	1.0199E+03	1.0194E+03	1.0197E+03	1.0208E+03	1.0214E+03	1.0214E+03		
19	1.0194E+03	1.0194E+03	1.0197E+03	1.0200E+03	1.0209E+03	1.0214E+03	1.0214E+03		
20	1.0197E+03	1.0197E+03	1.0202E+03	1.0204E+03	1.0211E+03	1.0214E+03	1.0214E+03		
21	1.0202E+03	1.0202E+03	1.0193E+03	1.0196E+03	1.0208E+03	1.0214E+03	1.0214E+03		
22	1.0193E+03	1.0193E+03	1.0178E+03	1.0183E+03	1.0198E+03	1.0214E+03	1.0214E+03		
23	1.0178E+03	1.0178E+03	1.0187E+03	1.0191E+03	1.0205E+03	1.0214E+03	1.0214E+03		
24	1.0187E+03	1.0187E+03	1.0205E+03	1.0207E+03	1.0211E+03	1.0214E+03	1.0214E+03		
25	1.0205E+03	1.0205E+03	1.0194E+03	1.0197E+03	1.0211E+03	1.0214E+03	1.0214E+03		
26	1.0194E+03	1.0194E+03	1.0178E+03	1.0183E+03	1.0198E+03	1.0214E+03	1.0214E+03		
27	1.0178E+03	1.0178E+03	1.0180E+03	1.0185E+03	1.0200E+03	1.0214E+03	1.0214E+03		
28	1.0180E+03	1.0180E+03	1.0189E+03	1.0194E+03	1.0207E+03	1.0214E+03	1.0214E+03		
29	1.0189E+03	1.0189E+03	1.0179E+03	1.0184E+03	1.0199E+03	1.0214E+03	1.0214E+03		
30	1.0179E+03	1.0179E+03	1.0181E+03	1.0187E+03	1.0203E+03	1.0214E+03	1.0214E+03		
31	1.0181E+03	1.0181E+03	1.0180E+03	1.0185E+03	1.0210E+03	1.0214E+03	1.0214E+03		
32	1.0180E+03	1.0180E+03	1.0190E+03	1.0194E+03	1.0200E+03	1.0214E+03	1.0214E+03		
33	1.0190E+03	1.0190E+03	1.0185E+03	1.0191E+03	1.0209E+03	1.0214E+03	1.0214E+03		
34	1.0185E+03	1.0185E+03	1.0177E+03	1.0181E+03	1.0195E+03	1.0214E+03	1.0214E+03		
35	1.0177E+03	1.0177E+03	1.0179E+03	1.0184E+03	1.0200E+03	1.0214E+03	1.0214E+03		
36	1.0179E+03	1.0179E+03	1.0180E+03	1.0185E+03	1.0202E+03	1.0214E+03	1.0214E+03		
37	1.0180E+03	1.0180E+03	1.0178E+03	1.0183E+03	1.0198E+03	1.0214E+03	1.0214E+03		
38	1.0178E+03	1.0178E+03							

ptb (pressure) at time= 4.27100E+02

I =	0	1	2	3	4	5	6	7	8
1	5.8284E+04	5.8284E+04	5.9664E+04	7.0019E+04	9.1100E+04	9.4006E+04			
2	5.8274E+04	5.8274E+04	5.9655E+04	7.0018E+04	9.1102E+04	9.4006E+04			
3	5.8239E+04	5.8239E+04	5.9622E+04	6.9996E+04	9.1104E+04	9.4006E+04			
4	5.8290E+04	5.8290E+04	5.9671E+04	7.0032E+04	9.1101E+04	9.4006E+04			

5	5.8289E+04	5.9670E+04	7.0029E+04	9.1101E+04	9.4006E+04
6	5.7957E+04	5.9344E+04	6.9773E+04	9.1113E+04	9.4006E+04
7	5.7892E+04	5.9281E+04	6.9729E+04	9.1116E+04	9.4006E+04
8	5.8229E+04	5.9612E+04	6.9992E+04	9.1105E+04	9.4006E+04
9	5.8052E+04	5.9437E+04	6.9851E+04	9.1110E+04	9.4006E+04
10	5.8031E+04	5.9417E+04	6.9834E+04	9.1111E+04	9.4006E+04
11	5.8015E+04	5.9402E+04	6.9828E+04	9.1113E+04	9.4006E+04
12	5.8158E+04	5.9546E+04	6.9937E+04	9.1117E+04	9.4006E+04
13	5.8080E+04	5.9468E+04	6.9876E+04	9.1116E+04	9.4006E+04
14	5.7885E+04	5.9278E+04	6.9720E+04	9.1125E+04	9.4005E+04
15	5.7908E+04	5.9306E+04	6.9769E+04	9.1135E+04	9.4006E+04
16	5.8074E+04	5.9463E+04	6.9881E+04	9.1144E+04	9.4006E+04
17	5.8023E+04	5.9418E+04	6.9866E+04	9.1130E+04	9.4006E+04
18	5.8043E+04	5.9448E+04	6.9962E+04	9.1147E+04	9.4005E+04
19	5.8040E+04	5.9439E+04	6.9921E+04	9.1137E+04	9.4006E+04
20	5.8035E+04	5.9438E+04	6.9946E+04	9.1144E+04	9.4006E+04
21	5.8031E+04	5.9439E+04	6.9970E+04	9.1153E+04	9.4006E+04
22	5.8031E+04	5.9429E+04	6.9902E+04	9.1135E+04	9.4006E+04
23	5.8218E+04	5.9601E+04	6.9987E+04	9.1106E+04	9.4006E+04
24	5.8048E+04	5.9440E+04	6.9889E+04	9.1123E+04	9.4006E+04
25	5.8032E+04	5.9444E+04	6.9999E+04	9.1159E+04	9.4006E+04
26	5.7955E+04	5.9355E+04	6.9844E+04	9.1138E+04	9.4006E+04
27	5.8205E+04	5.9588E+04	6.9975E+04	9.1106E+04	9.4006E+04
28	5.8143E+04	5.9528E+04	6.9932E+04	9.1110E+04	9.4006E+04
29	5.8003E+04	5.9398E+04	6.9870E+04	9.1227E+04	9.4006E+04
30	5.8169E+04	5.9553E+04	6.9946E+04	9.1107E+04	9.4005E+04
31	5.8083E+04	5.9470E+04	6.9889E+04	9.1113E+04	9.4006E+04
32	5.8147E+04	5.9532E+04	6.9933E+04	9.1109E+04	9.4006E+04
33	5.7910E+04	5.9305E+04	6.9781E+04	9.1129E+04	9.4906E+04
34	5.7886E+04	5.9277E+04	6.9737E+04	9.1120E+04	9.4006E+04
35	5.8279E+04	5.9661E+04	7.0030E+04	9.1103E+04	9.4006E+04
36	5.8164E+04	5.9549E+04	6.9945E+04	9.1108E+04	9.4006E+04
37	5.8099E+04	5.9484E+04	6.9893E+04	9.1110E+04	9.4006E+04
38	5.8204E+04	5.9587E+04	6.9974E+04	9.1106E+04	9.4006E+04

qtb (watts) at time= 4.27100E+02

I =	0	1	2	3	4	5	6	7	8
1	0.0000E+00	0.0000E+00	3.9094E+06	5.8039E+06	8.4872E+06	0.0000E+00			
2	0.0000E+00	0.0000E+00	4.0533E+06	5.6170E+06	8.2739E+06	0.0000E+00			
3	0.0000E+00	0.0000E+00	4.2851E+06	5.6031E+06	7.6796E+06	0.0000E+00			
4	0.0000E+00	0.0000E+00	4.0001E+06	5.5007E+06	8.5178E+06	0.0000E+00			
5	0.0000E+00	0.0000E+00	3.9815E+06	5.5535E+06	8.5081E+06	0.0000E+00			
6	0.0000E+00	0.0000E+00	5.2554E+06	7.1095E+06	8.3248E+06	0.0000E+00			
7	0.0000E+00	0.0000E+00	5.4780E+06	7.2259E+06	3.2286E+06	0.0000E+00			
8	0.0000E+00	0.0000E+00	4.3703E+06	5.5397E+06	7.4896E+06	0.0000E+00			
9	0.0000E+00	0.0000E+00	4.8973E+06	5.5217E+06	4.7042E+06	0.0000E+00			
10	0.0000E+00	0.0000E+00	4.9626E+06	6.6488E+06	4.3854E+06	0.0000E+00			
11	0.0000E+00	0.0000E+00	4.9070E+06	6.5194E+06	4.0090E+06	0.0000E+00			
12	0.0000E+00	0.0000E+00	2.1336E+06	6.0733E+06	5.2180E+06	0.0000E+00			
13	0.0000E+00	0.0000E+00	3.1515E+06	6.4188E+06	4.3635E+06	0.0000E+00			
14	0.0000E+00	0.0000E+00	2.9974E+06	7.5508E+06	1.1121E+06	0.0000E+00			
15	0.0000E+00	0.0000E+00	1.7393E+06	5.5474E+06	5.6899E+05	0.0000E+00			
16	0.0000E+00	0.0000E+00	3.3200E+06	6.1012E+06	4.1956E+06	0.0000E+00			
17	0.0000E+00	0.0000E+00	2.2053E+06	5.6474E+06	2.5224E+06	0.0000E+00			
18	0.0000E+00	0.0000E+00	2.2018E+06	2.9920E+06	1.8917E+06	0.0000E+00			
19	0.0000E+00	0.0000E+00	2.6448E+06	4.2021E+06	2.4908E+06	0.0000E+00			

20	0.0000E+00	2.4747E+06	3.3317E+06	1.9879E+06	0.0000E+00
21	0.0000E+00	1.4918E+06	2.6040E+06	1.2048E+06	0.0000E+00
22	0.0000E+00	2.6734E+06	4.6072E+06	2.4845E+06	0.0000E+00
23	0.0000E+00	4.3976E+06	5.4633E+06	7.2425E+06	0.0000E+00
24	0.0000E+00	4.1348E+06	5.2648E+06	3.7536E+06	0.0000E+00
25	0.0000E+00	1.5547E+06	1.7387E+06	9.5390E+05	0.0000E+00
26	0.0000E+00	2.7721E+06	4.9767E+06	1.2973E+06	0.0000E+00
27	0.0000E+00	4.3935E+06	5.5979E+06	7.0409E+06	0.0000E+00
28	0.0000E+00	4.744E+06	5.7232E+06	6.0147E+06	0.0000E+00
29	0.0000E+00	4516E+06	4.9465E+06	2.9366E+06	0.0000E+00
30	0.0000E+00	5117E+06	5.8033E+06	6.5291E+06	0.0000E+00
31	0.0000E	4.7579E+06	5.9346E+06	4.9961E+06	0.0000E+00
32	0.000	4.5801E+06	5.7865E+06	6.0739E+06	0.0000E+00
33	0.0000E+00	4.1349E+06	5.9864E+06	1.4844E+06	0.0000E+00
34	0.0000E+00	5.2946E+06	6.8305E+06	1.9043E+06	0.0000E+00
35	0.0000E+00	4.1898E+06	5.3015E+06	8.3022E+06	0.0000E+00
36	0.0000E+00	4.5895E+06	5.7417E+06	6.4039E+06	0.0000E+00
37	0.0000E+00	4.8888E+06	6.0783E+06	5.4149E+06	0.0000E+00
38	0.0000E+00	4.4914E+06	5.6085E+06	7.0692E+06	0.0000E+00

Appendix E. Sensitivity Study: Effect of Condenser Inlet Air Mass Fraction and Exit Mass Flow Rate of Air Extraction System on Steam Condensation Rate

As a steam/air mixture passes a bank of condensing tubes in a power plant condenser, noncondensible air tends to accumulate at the interface between metal surfaces and condensate films. Because air is a poor conductor, its presence on a condenser tube surface could significantly retard the overall steam condensing rate. To improve condenser performance, an air extraction system or ejector is used to remove noncondensible air. The amount of air to be removed depends on the air mass concentration and its distribution in the shell side and the extraction flow rate through the ejectors. Thus, a sensitivity study was performed to study the effects of inlet air mass fraction and mass flow at the exit (ejector) on the steam condensing rate. The following cases were investigated in this sensitivity study.

1. Varying inlet air mass fraction: All the conditions are identical to the sample problem in Appendix D except that the inlet mass fraction is changed from 4.11×10^{-5} in the Sample Problem to 0, 2.05×10^{-5}, 8.21×10^{-5}, and 16.42×10^{-5}.

2. Varying the exit mass flow rate: All the conditions are identical to Case 1 except that the exit mass flow rate is increased by 100 percent.

Table E-1 lists the conditions imposed in each case and the corresponding calculated steam condensation rates. These results are also shown in Fig. E.1, where it is evident that decreasing the inlet air mass fraction or increasing the exit mass flow rate increases the steam condensation rate in the condenser. Figs. E.2-E.4 show the constant air mass fraction line for cases 1.3, 1.4, and 2.4 (defined in table E-1), respectively.

Note that whereas Figs. E.2 and E.3 show that the more air mass enters the condenser, the more air will accumulate near the tube bank, resulting in decreasing the steam condensation rate, Figs. E.3 and E.4 show that increasing the exit mass flow rate results in reducing the air accumulating near the tube bank and increasing the steam condensation rate.

Table E-1. Effect of condenser inlet air mass fraction and exit mass flow rate of an air extraction system on steam condensation rate

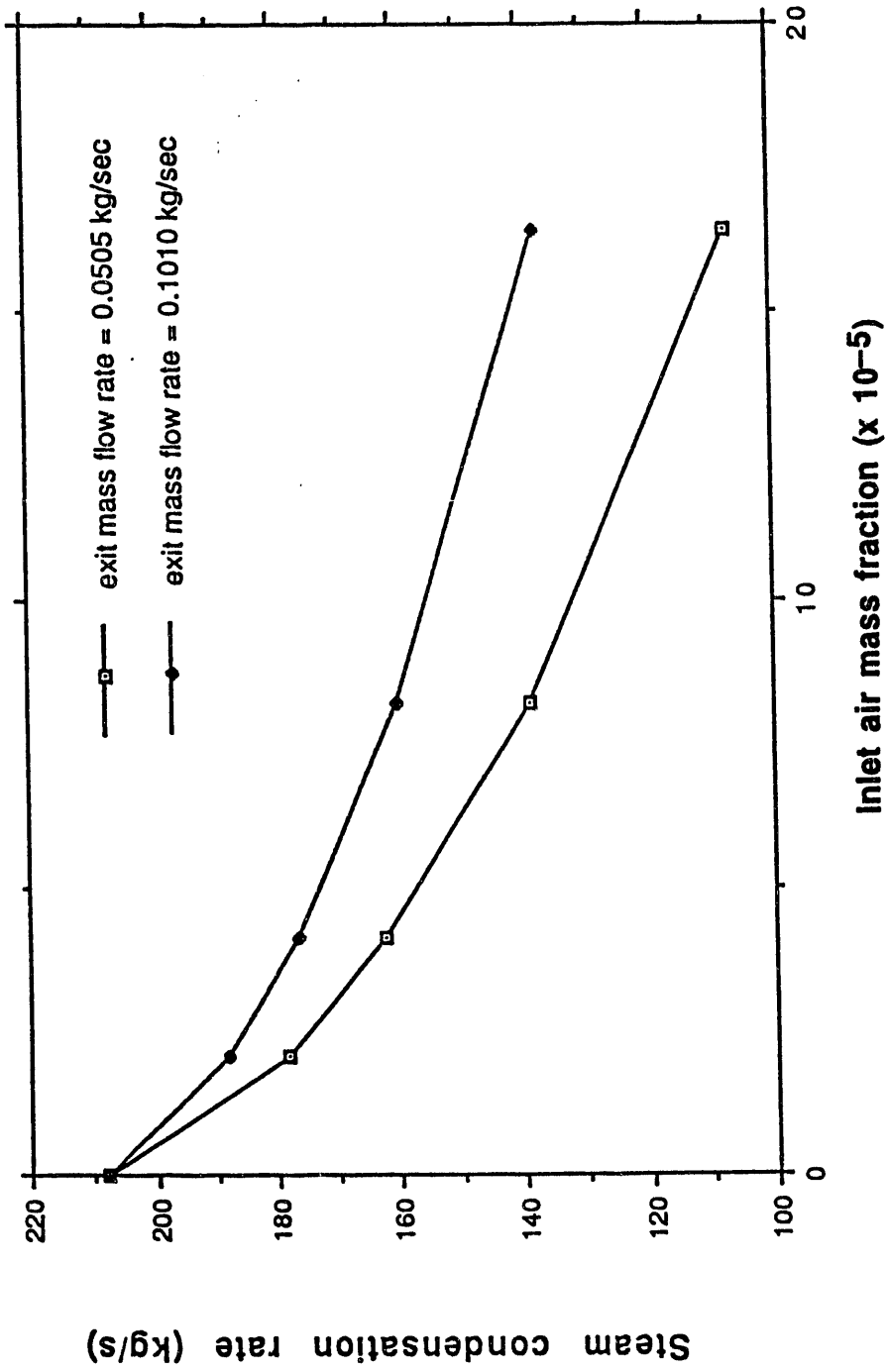| Case No.	Inlet Air Mass Fraction (10^{-5})	Mass Flow Rate at Extraction Pipe (kg/s)	Calculated Steam Condensation (kg/s)
1.1	0	0.0505	208.9
1.2	2.05	0.0505	178.1
1.3[a]	4.11	0.0505	162.5
1.4	8.21	0.0505	138.6
1.5	16.42	0.0505	106.7
2.1	0	0.1010	208.9
2.2	2.05	0.1010	188.1
2.3	4.	0.1010	176.6
2.4	8.21	0.1010	160.0
2.5	16.42	0.1010	137.6

[a]Sample Problem in Appendix D

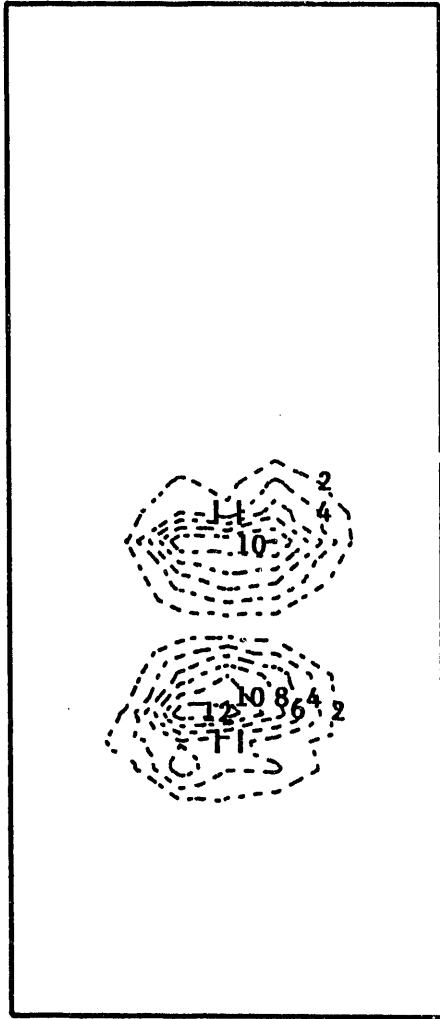Fig. E.1. Effect of inlet air mass fraction and exit mass flow rate on steam condensation rate

Fig. E.2. Constant air mass fraction
lines (%) at I = 5 plane for
Case 1.3

Inlet air mass fraction = 4.11 x 10^{-5}
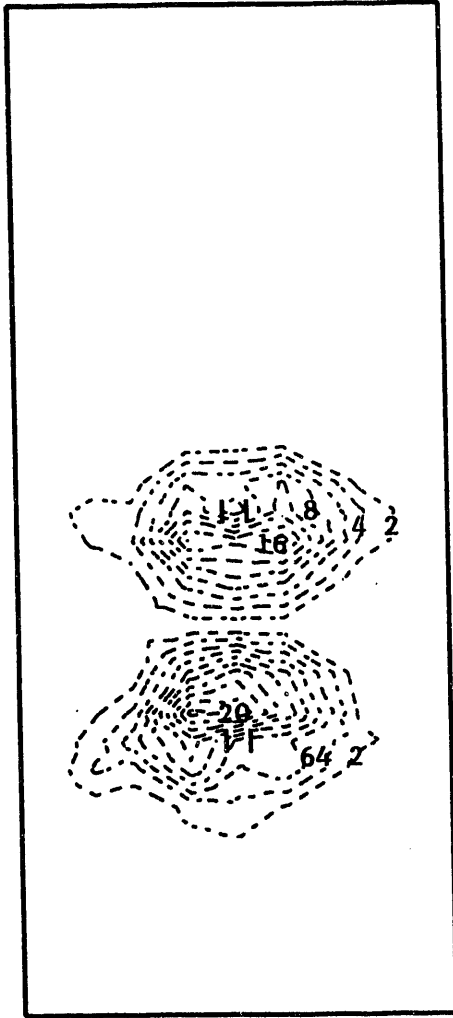Exit mass flow rate = 0.0505 kg/sec
Contour line increment = 2%

Fig. E.3. Constant air mass fraction lines (%) at I = 5 plane for Case 1.4

Inlet air mass fraction = 8.21×10^{-5}
Exit mass flow rate = 0.0505 kg/sec
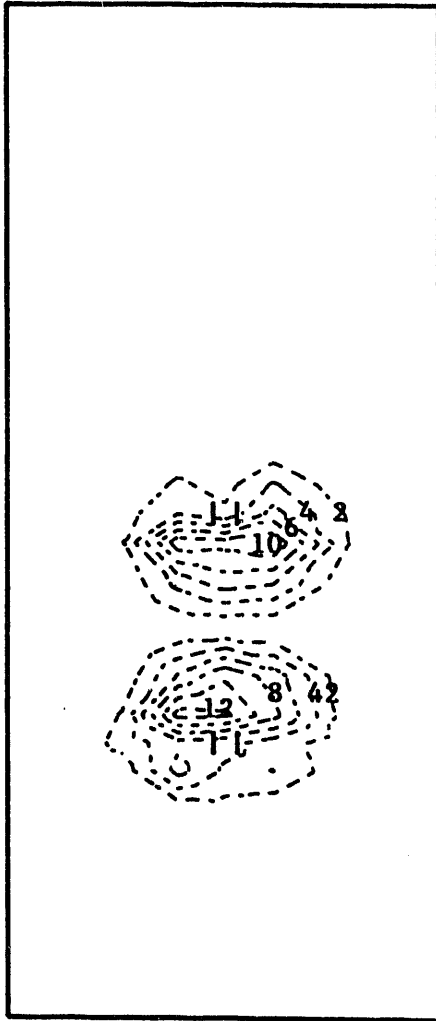Contour line increment = 2%

Fig. E.4. *Constant air mass fraction lines (%) at I = 5 plane for Case 2.4*

Inlet air mass fraction = 8.21×10^{-5}
Exit mass flow rate = 0.0101 kg/sec
Contour line increment = 2%

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