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Two-Phase Flow Characteristics Analysis Code : MINCS

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Two-Phase Flow Characteristics Analysis Code : MINCS

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Abstract

Two-phase flow characteristics analysis code: MINCS (Modularized and INtegrated Code System) has been developed to provide a computational tool for analyzing two-phase flow phenomena in one-dimensional ducts. In MINCS, nine types of two-phase flow models — from a basic two-fluid nonequilibrium (2V2T) model to a simple homogeneous equilibrium (1V1T) model — can be used under the same numerical solution method. The numerical technique is based on the implicit finite difference method to enhance the numerical stability. The code structure is highly modularized, so that new constitutive relations and correlations can be easily implemented into the code and hence evaluated. A flow pattern can be fixed regardless of flow conditions, and state equations or steam tables can be selected. It is, therefore, easy to calculate physical or numerical benchmark problems.

Keywords: MINCS, Two-Phase Flow, Correlations, Two-Phase Flow Models, Constitutive Relations, Flow Pattern, State Equations

*Computing and Information Systems Center
**Office of Planning

二相流特性解析コード：MINCS

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（1991年11月22日受理）

要　　旨

一次元流路に於ける二相流現象を解析する為の数値計算の道具として，二相流特性解析コード：MINCSを開発した。

MINCSは，9種類の二相流モデル　――基本的な二流体非平衡モデルから単純な均質平衡流モデルまで――　を同一の数値解法の基で取扱うことができる。数値解法は，数値的安定性の為，陰的有限差分法に基づいている。コードの構造は高度にモジュラー化されており，新しい構成式及び相関式の組み込み，評価を容易に行うことができる。また，流動状態にかかわらず流動様式を固定することが可能であり，状態方程式（蒸気表）も選択することができる。この為，物理的，或いは，数値的なベンチマーク問題への対応も容易である。

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Executive Summary

(i) Program Name

The program name is MINCS.

(ii) Computers

The code is designed for the FACOM M780 computer system. It can also be run on the FACOM VP2600 computer system with no special modifications.

(iii) Programming Languages

The programming language is FORTRAN77-EX. One ASSEMBLER routine is, however, used for data handling.

(iv) Operating Systems

The operating system has been FACOM MSP and MSP-EX.

(v) Problem or Function Description

MINCS performs analyses of two-phase flow phenomena in one-dimensional ducts with using nine types of two-phase flow models. The code is also appropriate for analyzing numerical benchmark problems as well as for evaluating physical correlations.

(vi) Solution Method

The partial differential equations describing the two-phase flow and the wall heat transfer are solved by an implicit finite difference method. The finite difference equations form a system of coupled nonlinear equations that are solved by a Newton iteration procedure.

(vii) Typical Running Time

Running time is highly problem dependent and is a function of the total number of mesh cells and the maximum allowable time step size. Typical times for FACOM M780 and VP2600 computer systems average 4-5(ms) and about 3(ms) per time step per mesh cell, respectively.

(viii) Related and Auxiliary Programs

One output file on FT11F001 contains graphics information that can be used to produce plots. Transient behavior and spatial distribution of variables are plotted after converting the data format. Two auxiliary programs, SPLPLOT and SDPLOT, are also available for this purpose and are documented separately.

(ix) Status

The code is used at the Japan Atomic Energy Research Institute, and has been distributed to the Tokyo University, the Tokyo Institute of Technology, the Japan IBM Co. and the Tsukuba University.

(x) References

Reference are provided in the manual.

(xi) Available Materials

A source listing, a MINCS manual, and sample problems are available.

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NOMENCLATURE

A	area, coefficient matrix
b	body force
B	coefficient matrix
C	coefficient, coefficient matrix
Cvm	added mass coefficient
Cp	specific heat with constant pressure
Cv	specific heat with constant volume
D	diameter
Dh	hydraulic diameter
E	entrainment
f	friction factor, function
F	coefficient matrix
g	gravitational acceleration
G	mass flow rate, coefficient matrix
Gr	Grashof number
h	enthalpy
H	channel height, head
I	moment of inertia
j	superficial velocity
k	thermal conductivity
K	form loss coefficient, compressibility
M	two-phase multiplier
Nu	Nusselt number
p	pressure
p'	added mass force
P	perimeter
Pr	Prandtl number
q	heat flux
Q	heat flux
r	coordinate
R	radius
Re	Reynolds number
S	source term
t	time
T	temperature, torque
u	velocity
U	internal energy
V	volume fraction
w	weighting factor
We	Weber number
x	coordinate
X	quality, vector of dependent variables
Y	vector of non-2V2T variables
z	flow direction

Greek letters

α	volume fraction, void fraction
β	volume fraction, expansion coefficient
θ	upwind degree, implicit degree
δ	film thickness, small value
Δ	added mass force term
ε	relative error, area ratio, small value
φ	angle
ϕ	two-phase multiplier
Γ	mass transfer rate
λ	added mass parameter, heat transfer coefficient
Λ	operation factor for non-2V2T model
μ	viscosity
ρ	density
σ	surface tension
τ	shear stress
ω	angular velocity

Subscripts

b	bubble
c	continuous phase
d	dispersed phase, droplet
e	equilibrium
g	gas phase
i	interface
k	phase
l	liquid phase
m	mixture

1. INTRODUCTION

Recently, considerable progress in predicting behavior of transient two-phase flow and associated heat transfer has been made as a result of efforts at developing physical models, advanced computational techniques and experimental data base of small and large scales. In spite of such recent progress, the currently available two-phase flow models have a number of shortcomings and limitations as pointed out by Wallis [1-1] and Ishii [1-2]. Difficulties in modeling two-phase flow arise from the complicated internal structure of two-phase flow, including a variety of interfacial geometries and flow regime transitions, which must be taken into account. The internal structure as well as the interphase and wall-to-fluid exchange processes are described by the constitutive relation models. These models include numerous empirical correlations which are used beyond the range of experiments on which these correlations are based. The constitutive relation models also often include assumptions regarding quantities which are not directly measurable. It is, therefore, important to assess the models to ensure that these models are mechanistically-based as well as correctly represent the influence of scale, pressure and so on, so that they can be used even beyond the range of experimental basis. Thus, there have been continuous and systematic efforts towards assessing the two-phase flow correlations and models [1-3, 4].

The assessment of newly developed correlations should be performed by comparisons with measured data. Since a correlation or model may describe only a part of constitutive relations, usually it needs to be combined with other field equations to be comparable with experimental data. For this purpose, system computer codes, i.e. codes which were designed to simulate the integral system response of a reactor, such as RELAP5 [1-5] or TRAC-PF1 [1-6] have been used, because there does not exist appropriate two-phase flow characteristics analysis codes which are specifically designed for evaluation of correlations. Difficulties may arise, however, if the assessment is performed in the framework of the system codes because they are rigidly designed to fit a specific type of two-phase flow models, and the criteria and algorism for calculation of flow regime transitions are different for each code. Considerable code modifications are, therefore, often required to implement such new correlations. Further, there exists an essential problem that the performance of a correlation may appear differently depending on the system code used, since numerical treatments employed in the codes may affect the calculated results. In the system codes, a number of numerical techniques are usually used in order to perform stable and fast calculations by smoothing thermal-hydraulic transitions, because these system codes are designed to obtain the overall system behavior with a reasonable CPU time. Such numerical techniques or coding details are not described explicitly in the code manuals, and thus it is not easy for users to use the system codes to evaluate correlations without being bothered by such code-specific numerical problems.

The modeling of two-phase flow basic equations and the numerical techniques for solving the basic equation are also developing day by day, and they should be appropriately evaluated for accuracy as is the case for the constitutive relation models. Since two-phase flow phenomena are usually too much complicated, for the testing of basic equation models or numerical techniques, ideally simplified problems are preferred. For certain problems, the calculated results may be compared with the analytical rigorous solutions [1-3, 4]. In the simplified problems, what is often called the benchmark problems, it is often necessary to set fluid properties equal to some constants, or constitutive relations to some hypothetical ones. Difficulties may arise in this case if this kind of evaluation is performed using the system codes, due to the same reason mentioned above.

In view of the above situations, a general two-phase flow characteristics analysis code would have a substantial advantage over the existing system codes for systematic evaluation and assessment of correlations, or two-phase flow models, or numerical solution techniques. The following features are desirable for such a two-phase flow characteristics analysis code.

(1) Various types of correlations based on various types of two-phase flow models can be evaluated on the same numerical conditions.

(2) The code structure is easy to understand for any users, and thus, it is not difficult to implement any types of correlations into the code.

(3) The flow pattern or flow regime of two-phase flow can be selected by users in order to eliminate the effect of flow regime transition.

(4) No special numerical techniques, which affect the characteristics of correlations, are applied to obtain the stable and smooth results.

(5) Various types of state equations including constants can be adopted in order to calculate simplified flows.

The two-phase flow characteristics analysis code MINCS has been developed for the purpose mentioned above. All the information needed to use MINCS is described in this report. In Section 2, the examples using MINCS are given. The major features of MINCS are also described in Section 2. The physical law and the numerical procedure applied in MINCS are described in Section 3 and 4, respectively. The input requirements are described in Section 5, and sample problems and calculated results are shown in Section 6 for the typical problems. The detailed program structures and functions are explained in APPENDIX 1. The user information for using MINCS is described in APPENDIX 2, and the sample input data are listed in APPENDIX 3.

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2. OVERALL DESCRIPTION

An objective of the MINCS project has been to provide an appropriate computational tool for analyzing two-phase flow characteristics as is stated in Section 1. The basic version, which consisted only of the PIPE component, was completed in 1984 [2-1], and some components were added to the basic version in 1986 [2-2]. Since then, much progress has been made in developing MINCS, and the code was used extensively at the Japan Atomic Energy Research Institute during this developing stage. Several examples using MINCS in published articles are briefly described here, and the major features of MINCS are summarized.

2.1 EXAMPLES OF APPLICATION

2.1.1 PHYSICAL PHENOMENA

Examples related to the physical phenomena are briefly described: evaluation or development of correlations, analyses of experiments, and application to physical benchmark problems. MINCS has its own correlation sets as described in Section 3, and the appropriate correlations are selected corresponding to the two-phase flow model and the flow regime. These correlations are calculated in the subroutine CORSET and its lower subroutines. All the variables needed to calculate correlations are prepared in CORSET, and thus implementation or modification of correlations is easily accomplished by modifying this subroutine.

In Ref. 2-3, various types or relative velocity correlations were compared through the analyses of Toshiba blowdown experiments. The characteristics of the two-fluid model, the drift flux model and the homogeneous model were discussed. The schematic of the test facility and the input model are shown in Fig. 2.1. The comparison between calculated void fraction profiles with using various relative velocity correlations and experimental data is shown in Fig. 2.2. The interfacial shear model used in TRAC-PF1 was also evaluated and the shortcoming of TRAC-PF1 in predicting the interfacial area concentration was pointed out. The new interfacial shear model based on the empirical relative velocity correlation was proposed for the two-fluid model. The GE level swell test was analysed by using MINCS with the new model and TRAC-PF1. The GE level swell test facility and the input model are shown in Fig. 2.3, and the void fraction profiles and the two-phase mixture level during blowdown transients are shown in Fig. 2.4. The proposed interfacial shear model was shown to be more applicable than the mechanistic model to the analyses of blowdown experiments.

A vapor generation model for flashing in the initial blowdown phase was proposed in Ref. 2-4 based on a wall nucleation theory and a bubble transport model. In this analysis, the transport equation for the bubble number density is explicitly integrated in the subroutine CORSET. The applicability of the proposed model was evaluated through the analyses of blowdown experiments with the pressure undershoot during the initial phase. The three blowdown experiments with different scales were analyzed: the HDR-V31.1 blowdown test, the Marviken test No. 24 and the Battelle-Frankfurt SWR-2R test. The schematic of the Marviken pressure vessel and the input model are shown in Fig. 2.5. A pressure undershoot due to a delay in nucleation was well predicted with the proposed vapor generation model as shown in Fig. 2.6. The initial blowdown phases in the three different scale experiments were found to be well predicted by the proposed model. It was shown that the complicated model with differential equations could be evaluated by using MINCS.

In order to assess the applicability and the feasibility of MINCS, calculated results for the physical benchmark problems were submitted to the DOE/EPRI Second International Workshop on Two-Phase Flow Fundamentals in 1987 [2-5]. The benchmark problems proposed were composed of physical and numerical benchmark exercises, and the number of data sets for the physical problems was 10. Among them, three problems were solved with MINCS: "Pressure drop and entrained fractions in fully developed flow", "Annular flow evaporation" and "Level swell during vessel blowdown". In "Annular flow evaporation", the experimental data on the steady state evaporating flow in a uniformly heated tube were given. The entrainment flow rate against the local quality is shown in Fig. 2.7 as an example of the calculated results. The built-in correlations of MINCS were used for the calculations. The comparison with the results by using other computer codes such as TRAC, ATHENA, CATHARE, ATHLET, DRUFAN, RELAP5 and PHOENICS is shown in Ref. 2-5. "Annular flow evaporation" is one of the sample problems for MINCS, and the detailed description of the problem is given in Section 6 and the input data are listed in Appendix 3.

A set of new constitutive relations appropriate to inverted annular film boiling regime was developed in Ref. 2-6. The proposed constitutive relations were applied to the analyses of experiments in which the steady state inverted annular flow was observed in the vertical oriented tube with a hot patch at the inlet section. The steam table for Freon-113 was also implemented for analyzing the cases with Freon-113. A typical void fraction profile calculated by using the proposed constitutive relations is shown in Fig. 2.8.

2.1.2 NUMERICAL PHENOMENA

In MINCS, the implicit finite difference method based on the first order upwind scheme is applied. Thus, the stability of the implicit method and the accuracy of the first order scheme have been frequently discussed in comparison with the other numerical techniques. It is of importance to study the characteristics of the numerical method for understanding the meanings of calculated results. Examples related to the numerical phenomena, such as instability, accuracy and non-physical behavior in calculated results, are described in the following.

Besides the physical benchmark problems, calculated results for numerical benchmark problems were submitted to the DOE/EPRI Second International Workshop on Two-Phase Flow Fundamentals [2-5]. The number of proposed numerical exercises was 14, and 10 of them were solved: "Nozzle flow", "Monopropellant rocket", "Boiling in a pipe", "Faucet flow", "Oscillating manometer", "Expulsion of steam by sub-cooled water", "Sedimentation", "Kelvin-Helmholtz instability", "Shock tube" and "Stratified flow". The initial condition of "Shock tube" is shown in Fig. 2.9. The straight closed duct, of uniform cross-section, was divided into two equal parts by a diaphragm, and the diaphragm was removed at 0 (ms). The purpose of this problem was to test numerical methods for highly transient compressible flow. The pressure distribution at 3 (ms) is shown in Fig. 2.10 along with two results by using other codes. The shape of the shock wave was smeared by the numerical diffusion associated with the first order scheme, though the stable result was obtained.

A numerical treatment of the single phase and the phase transition in the two-fluid model was discussed in Ref. 2-7 through the analysis of "Monopropellant rocket" problem of the above mentioned numerical benchmark exercises. The input model and the boundary conditions are shown in Fig. 2.11. The calculated liquid velocity was compared with the result by the Runge-Kutta method as shown in Fig. 2.12. Although the discontinuity at the vanishing point of the liquid droplet was rounded off, the stable phase transition was calculated.

The numerical stability of stratified two-phase flow was studied in Ref. 2-8. A growth of small amplitude sinusoidal void waves was simulated. The left side of the flow channel shown in Fig. 2.13 was connected to the right side and the cyclic boundary condition was applied. In this analysis, the Kelvin-Helmholtz instability condition derived from the two-fluid model equations was discussed through the numerical analyses. It was shown that the wave growth was dependent on the numerical conditions such as the time step size (see Fig. 2.14), and was defined by the eigenvalue of amplification matrix of discretized equations.

Numerical difficulties in evaluating void wave propagation using a one-dimensional two-fluid model were investigated through sample calculations in Ref. 2-9 and 2-10. It was shown that the numerical instability was strongly dependent on the phasic velocities. The transient behavior of step-shaped small void disturbances with different gas velocities is shown in Fig. 2.15.

Conditions for wave growth and slug initiation in the stratified air-water flow were numerically investigated in Ref. 2-11. The profile of liquid volume fraction in the duct is shown in Fig. 2.16 as an example. The calculated results were compared with the experimental data, and short waves were shown to result in slugging as seen in Fig. 2.16.

In Ref. 2-12, the effect of the virtual mass force in the momentum equations of the two-fluid model on the stability of transient two-phase flow analysis was studied. A one-dimensional sedimentation problem was simulated. The input model is shown in Fig. 2.17. The numerical instability resulting from the ill-posedness of the basic equations was shown to grow when the round off error became smaller (see Fig. 2.18). It was found that the virtual mass force could stabilize the numerical solutions as shown in Fig. 2.19 by changing the eigenvalue of the discretized equation system.

The stability of numerical solutions for stratified two-phase flow was investigated in Ref. 2-13. Numerical examples were shown for the accelerated flow and the wave growth problems. The flow channel and the boundary conditions for the accelerated flow problem are shown in Fig. 2.20. It was indicated that a discretized equation system could be rendered "ill-posed" even if a differential equation system was well-posed. The numerical instability is shown in Fig. 2.21 to grow at the gas velocity below the hyperbolicity limit.

All the references published so far are listed at the end of this section [2-1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14].

2.2 MAJOR FEATURES

The major features of MINCS are described below.

(1) MINCS is not a system code but a two-phase flow characteristics analysis code which is capable of analyzing two-phase flow in one-dimensional ducts. The code structure is highly modularized as shown in Fig. 2.22 [2-2]. Each component cannot directly refer to variables of the other components but data required from the other components are supplied through the component control processor (CCP). Empirical correlations which are new or those contained in the existing constitutive packages can be easily supplied by users via the subroutine CORSET. MINCS has its own constitutive relations and correlations in the subroutine CORSET. It is designed to easily implement specific empirical correlations supplied by users, and thus, the code is appropriate for systematic evaluation and assessment of correlations or two-phase flow models [2-3, 4, 5, 6, 12].

(2) MINCS covers not only the two-fluid nonequilibrium hydrodynamic (2 Velocities and 2 Temperatures in the field equations: 2V2T) model but also simpler models such as the drift-flux (1 Velocity with a Drift-flux correlation: 1VD) model, the homogeneous flow (1V) model, simplified thermal non-equilibrium (1.5T) model which assumes saturation of one phase, and the thermal equilibrium (1T) model. The possible nine combinations are shown in Table 2.1 [2-2]. This variety of models permits MINCS to evaluate the various types of constitutive relations, to extend existing correlations to a new situation [2-3], and to help users in developing new correlations [2-4, 6].

(3) The basic equations including a one-dimensional heat conduction equation of duct walls are discretized by the finite difference method. The finite difference equations for any of the simpler models are systematically derived by an appropriate combination of 2V2T difference equations with variable transformation. Thus, the difference scheme and the solution method are the same among all the nine models in Table 2.1, and numerical errors such as truncation errors or numerical diffusion do not depend on the models provided.

(4) A non-linear implicit numerical scheme is applied to enhance the numerical stability. In addition, calculations of heat conduction can be implicitly coupled with the thermal hydrodynamic calculations. The coefficients of constitutive relations such as interfacial friction factors are, however, explicitly treated in order to make implementation easy.

(5) The flow pattern or flow regime can be fixed regardless of flow conditions. Five types of flow regimes are provided, namely, bubbly flow [2-3, 4, 5], annular flow [2-6], droplet flow [2-5], stratified flow [2-8, 9, 10, 11, 13], and continuous flow in which other four flow patterns are smoothly combined by weighting [2-5].

(6) Various types of state equations for the two phases can be selected. It is possible to solve simplified problems such as incompressible flow problems, and thus, it is easy to solve numerical benchmark problems [2-5, 7, 8, 9, 10, 12, 13].

The envisioned roles of MINCS in development of two-phase flow models are summarized in Fig. 2.23 [2-2].

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Table 2.1 Nine Types of Two-Phase Flow Models (Table 1 in Ref. 2-2)

Model Designation	Dependent Variables*	Restrictions	
		Num.	Imposed on
1V1T	P, h_m, u (= $u_g = u_l$)	3	$u_g = u_l$, h_g, h_l
1V1.5T	P, h_m, x, u (= $u_g = u_l$)	2	$u_g = u_l$, h_g, or h_l
1V2T	P, α, h_g, h_l, u (= $u_g = u_l$)	1	$u_g = u_l$
1VD1T	P, h_m, u_g (or u_l)	3	$u_g - u_l$, h_g, h_l
1VD1.5T	P, h_m, x, u_g (or u_l)	2	$u_g - u_l$, h_g, or h_l
1VD2T	P, α, h_g h_l, u_g (or u_l)	1	$u_g - u_l$
2V1T	P, h_m, u_g u_l	2	h_g, h_l
2V1.5T	P, h_m, x, u_g u_l	1	h_g or h_l
2V2T	P (P_g or P_l), α, h_g, h_l, u_g, u_l	0	

* P: pressure, α: void fraction, h: enthalpy, u: velocity, x: quality
g: gas, l: liquid, m: mixture

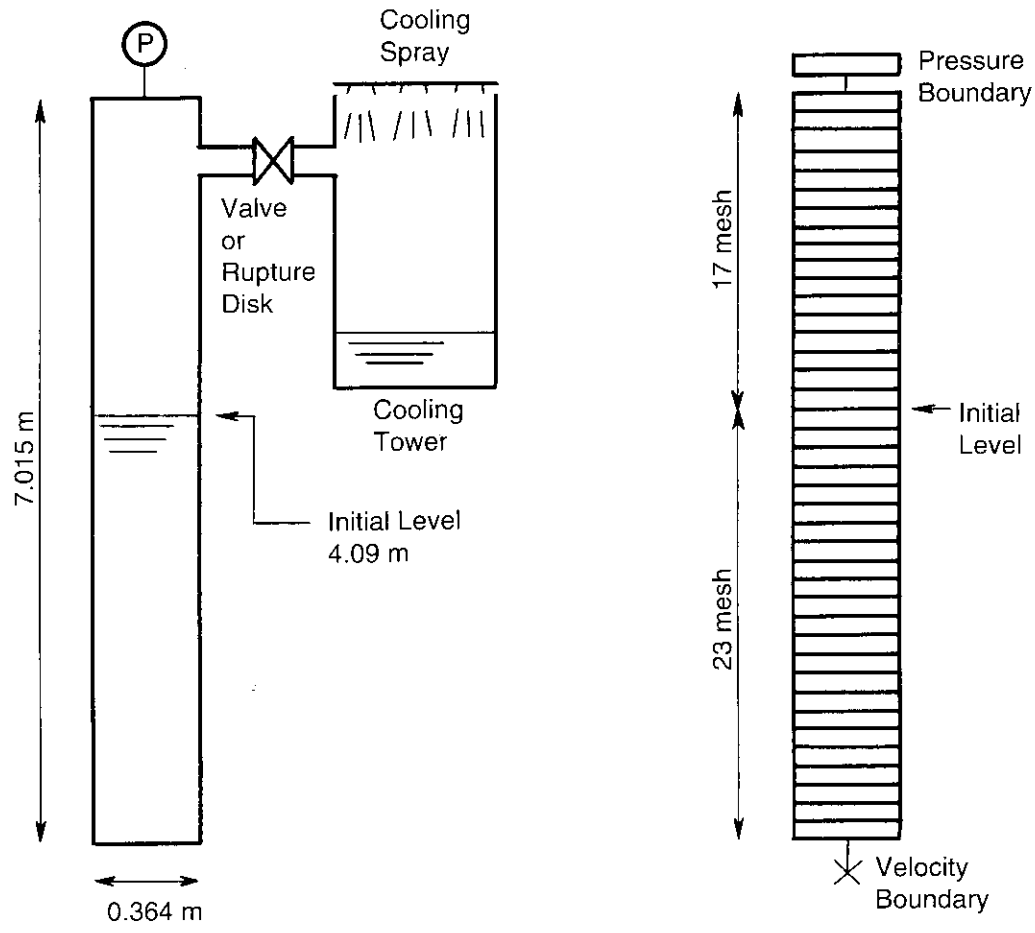

Fig. 2.1 Schematic of the Toshiba blowdown test facility and the input model (Fig. 2 in Ref. 2-3)

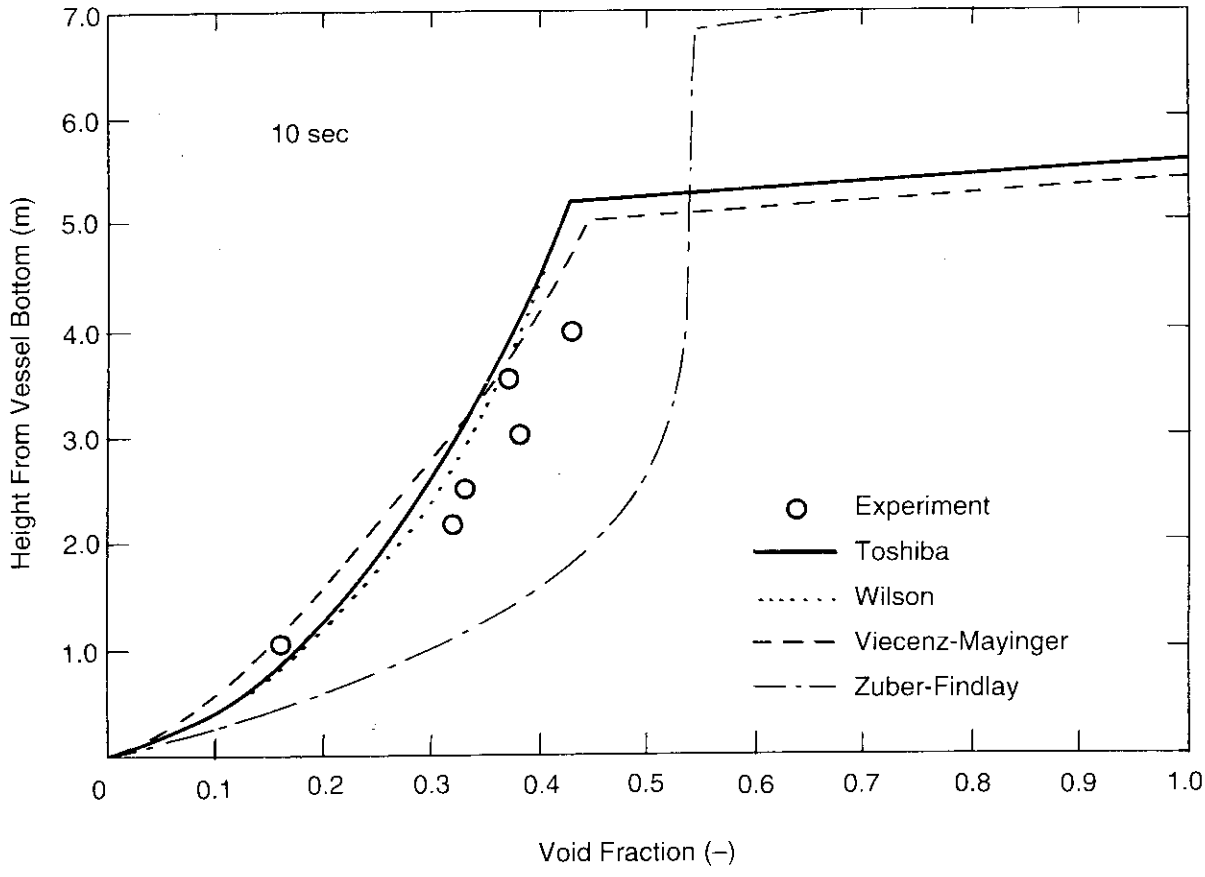

Fig. 2.2 Void fraction profiles with various relative velocity correlations
(Toshiba blowdown test: Fig. 8 in Ref. 2-3)

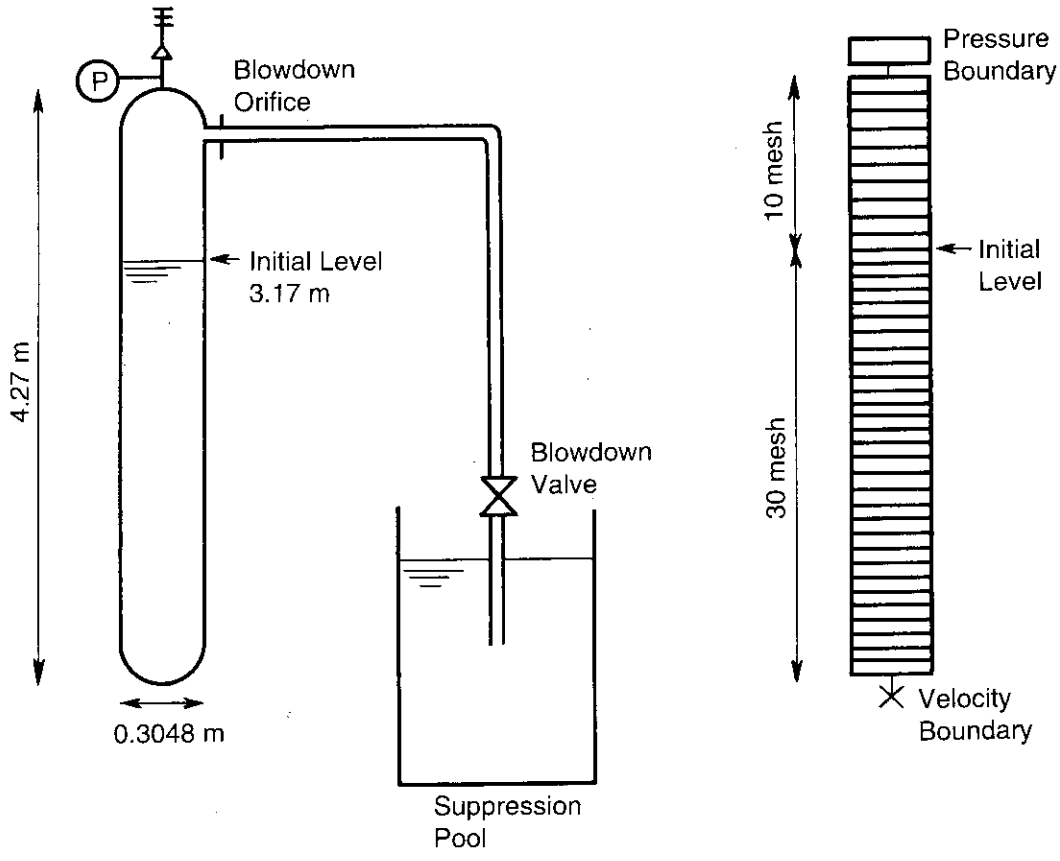

Fig. 2.3 Schematic of the GE level swell test facility and the input model (Fig. 11 in Ref. 2-3)

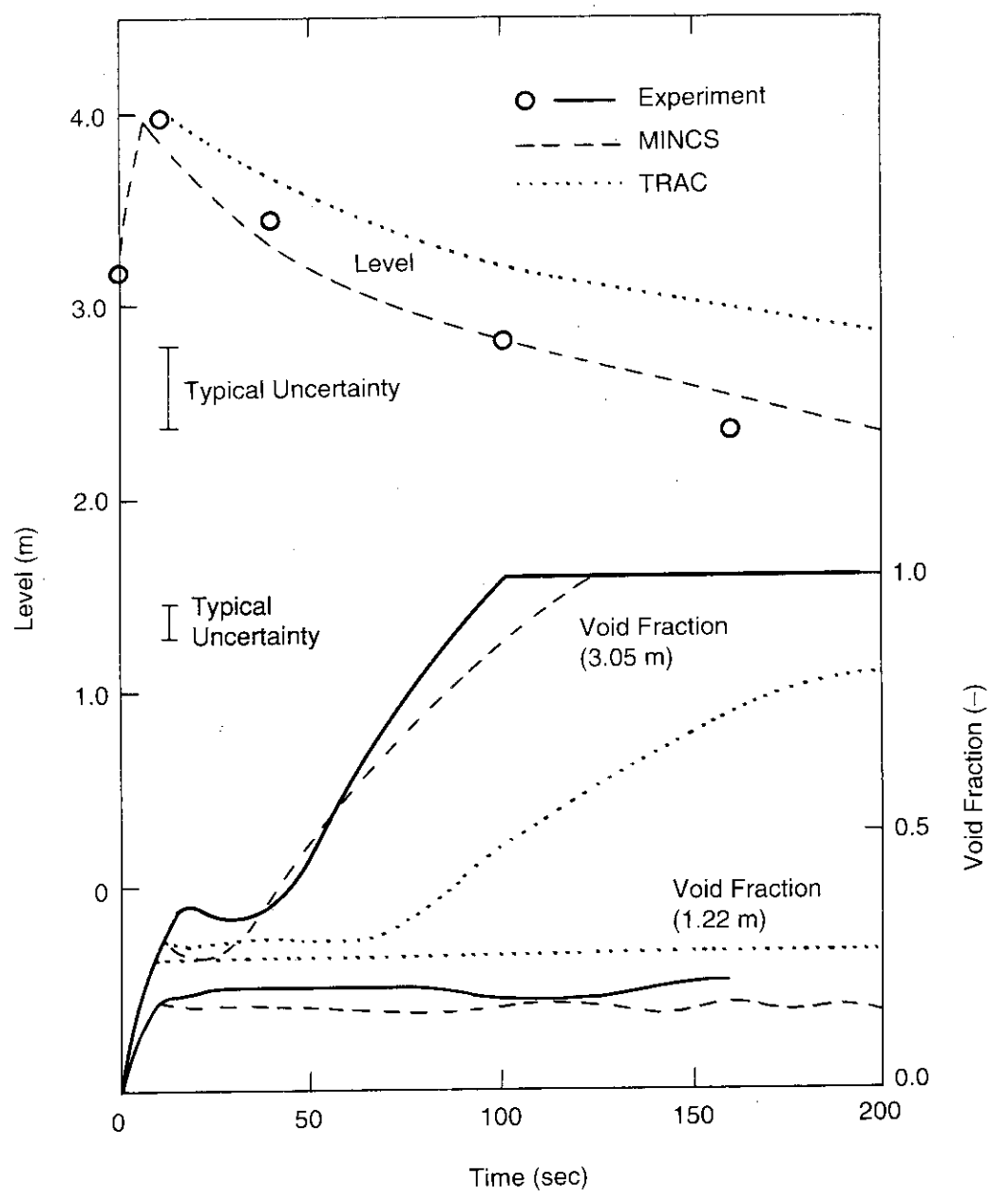

Fig. 2.4 Mixture level and void fraction by using MINCS with the proposed model and TRAC-PF1 (GE level swell test: Fig. 13 in Ref. 2-3)

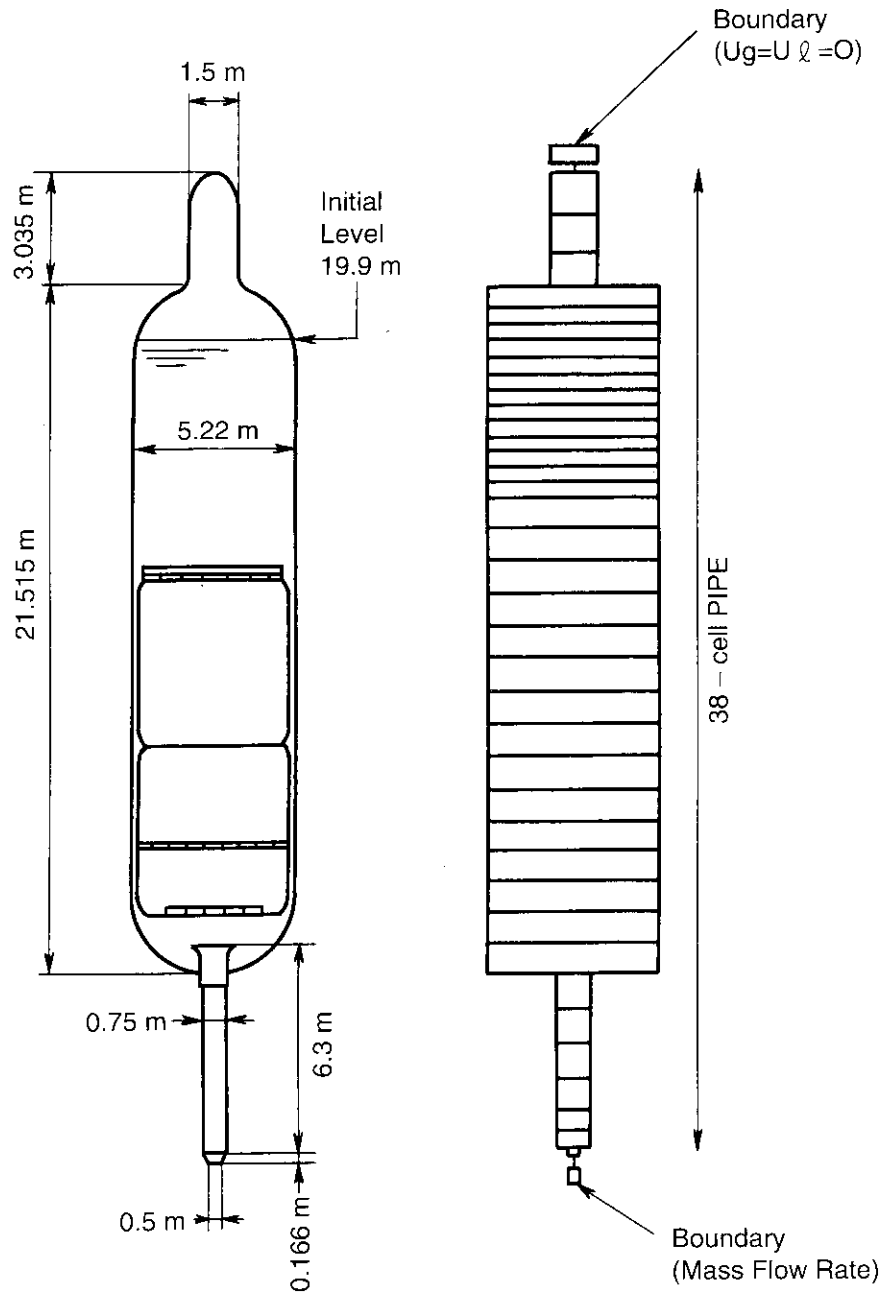

Fig. 2.5 Schematic of the Marviken pressure vessel and the input model (Fig. 8 in Ref. 2-4)

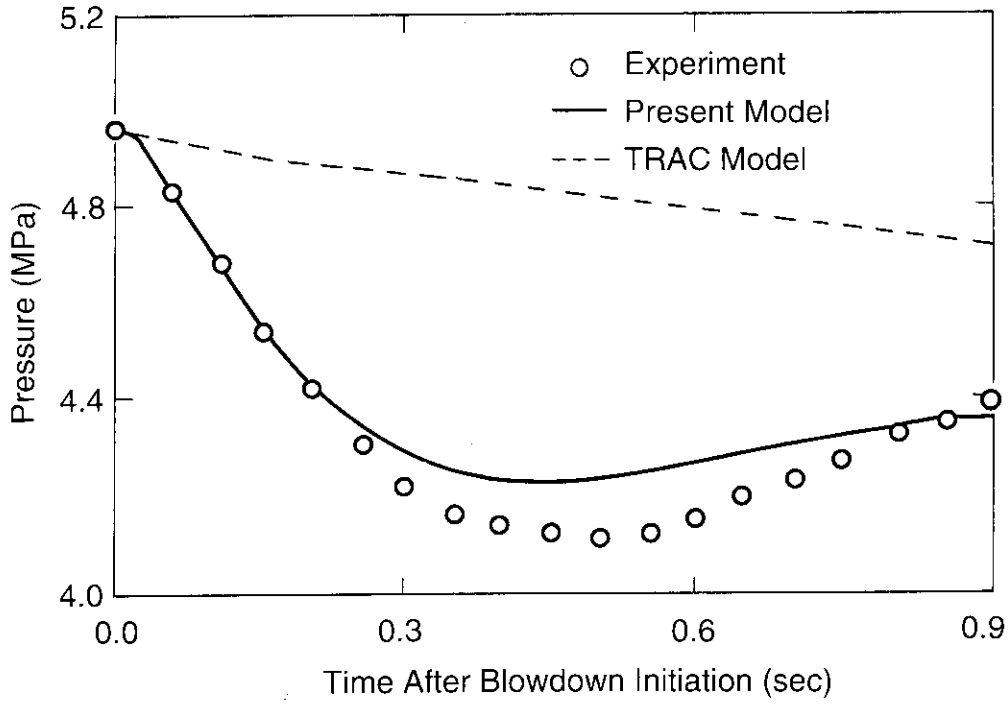

Fig. 2.6 Pressure transient in the top cupora of Marviken blowdown facility with the proposed vapor generation model (Fig. 9 in Ref. 2-4)

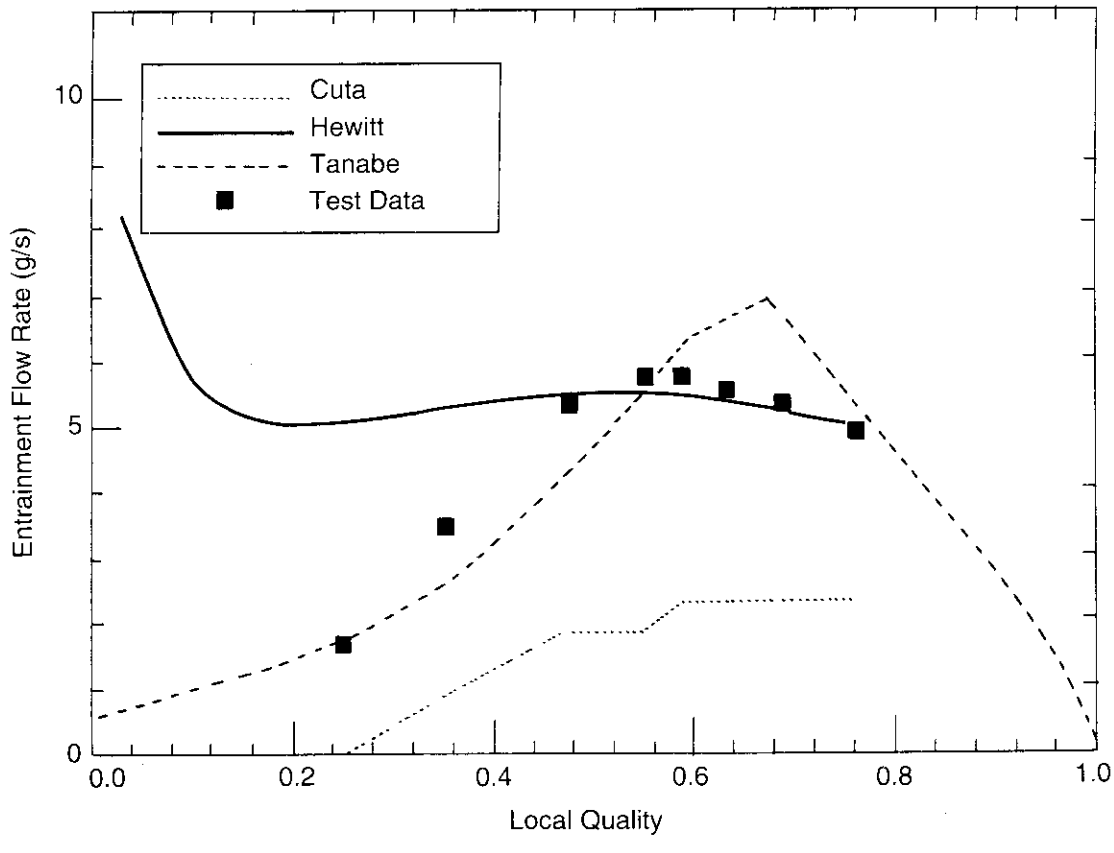

Fig. 2.7 Entrainment flow rate in "Annular flow evaporation" of physical benchmark exercise (Fig. DS12-1 in Ref. 2-5) ("Tanabe" indicates the MINCS results)

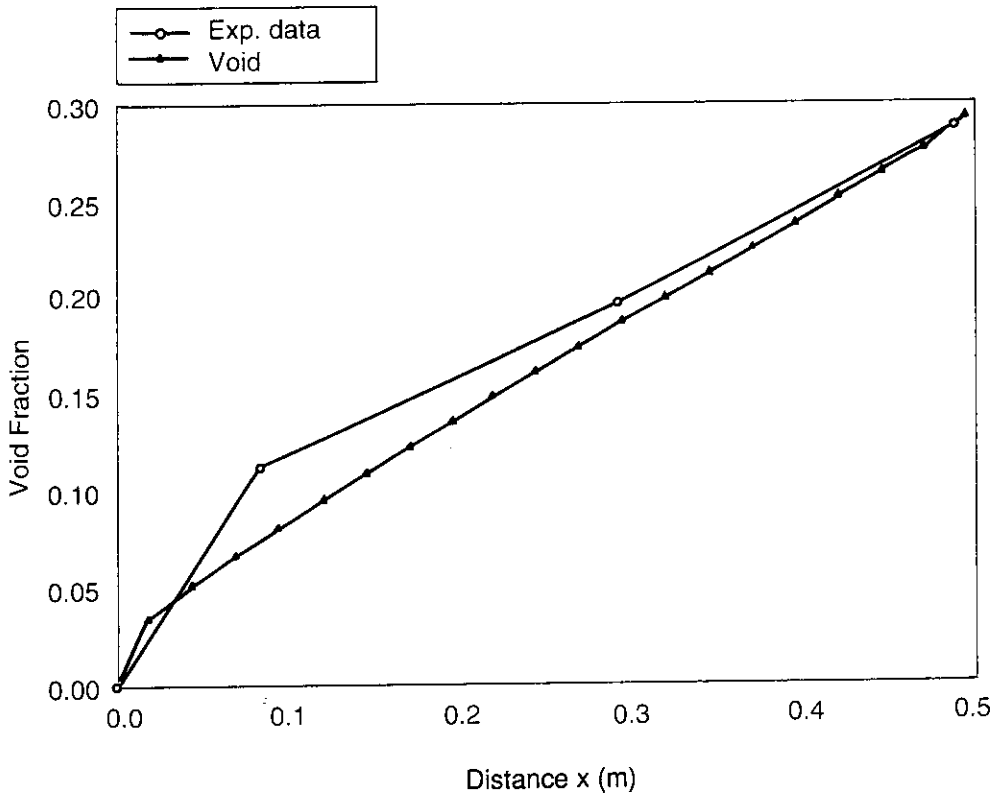

Fig. 2.8 Typical void fraction profile in inverted annular flow (Fig. 3.1 (a) in Ref. 2-6)

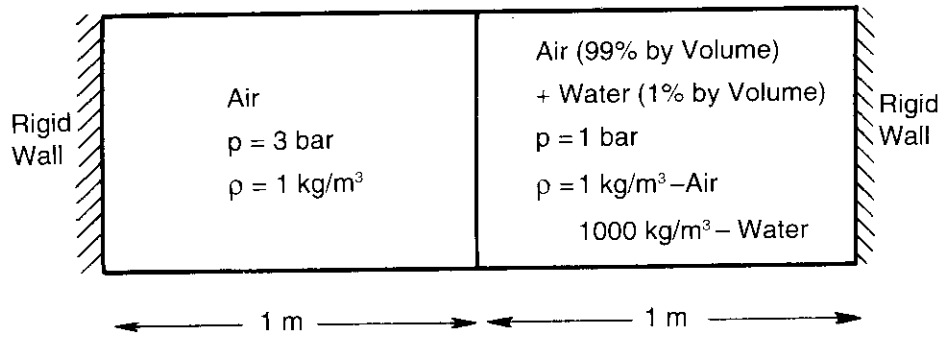

Fig. 2.9 Initial conditions and geometry in "Shock tube" of numerical benchmark exercise (Fig. 2.6-1 in Ref. 2-5)

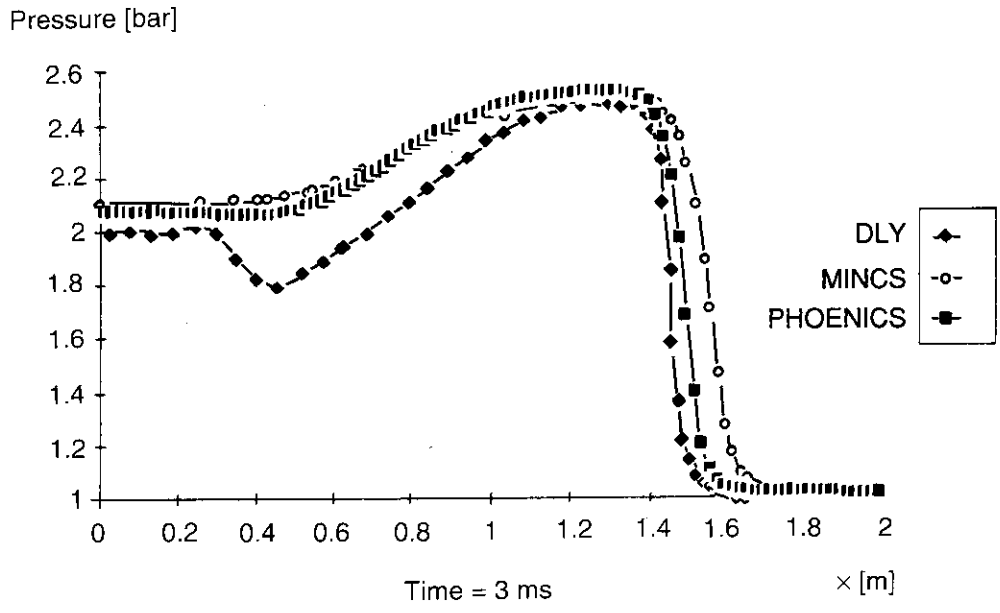

Fig. 2.10 Comparison of pressure distribution in "Shock tube" of numerical benchmark exercise (Fig. 2.6-3a in Ref. 2-5)

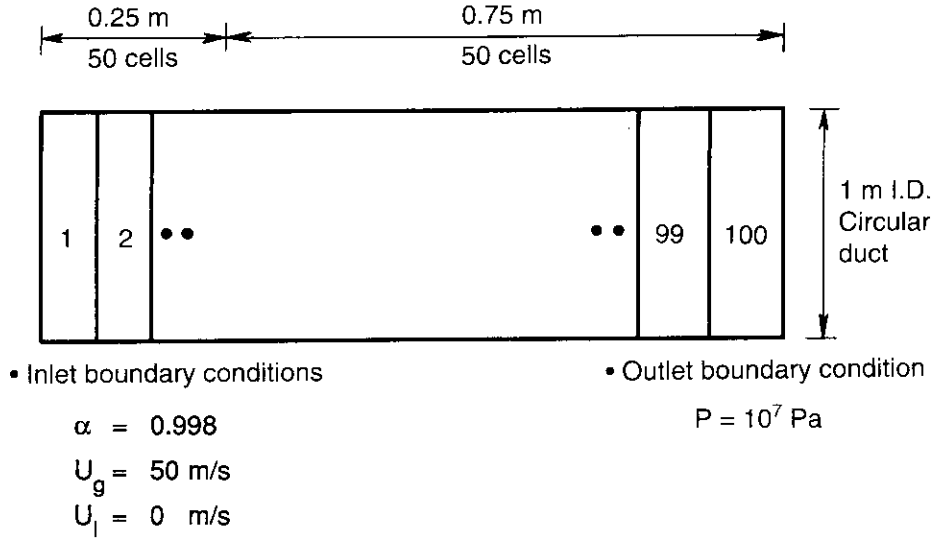

Fig. 2.11 Input model for "Monopropellant rocket" of numerical benchmark exercise (Fig. 3 in Ref. 2-7)

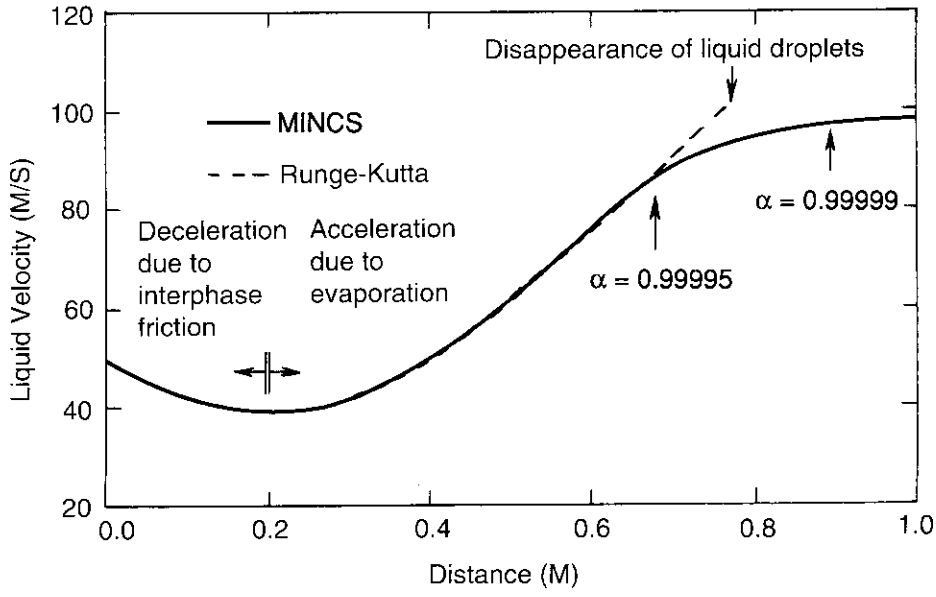

Fig. 2.12 Liquid velocity profiles by MINCS and Runge-Kutta Method in "Monopropellant rocket" of numerical benchmark exercise (Fig. 4 in Ref. 2-7)

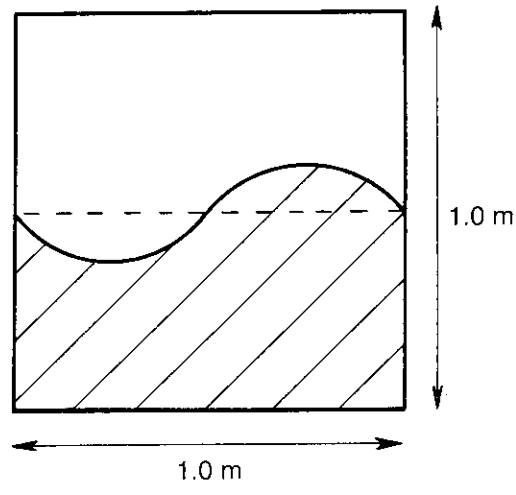

Fig. 2.13 Flow channel of wave growth problem (Fig. 8 in Ref. 2-8)

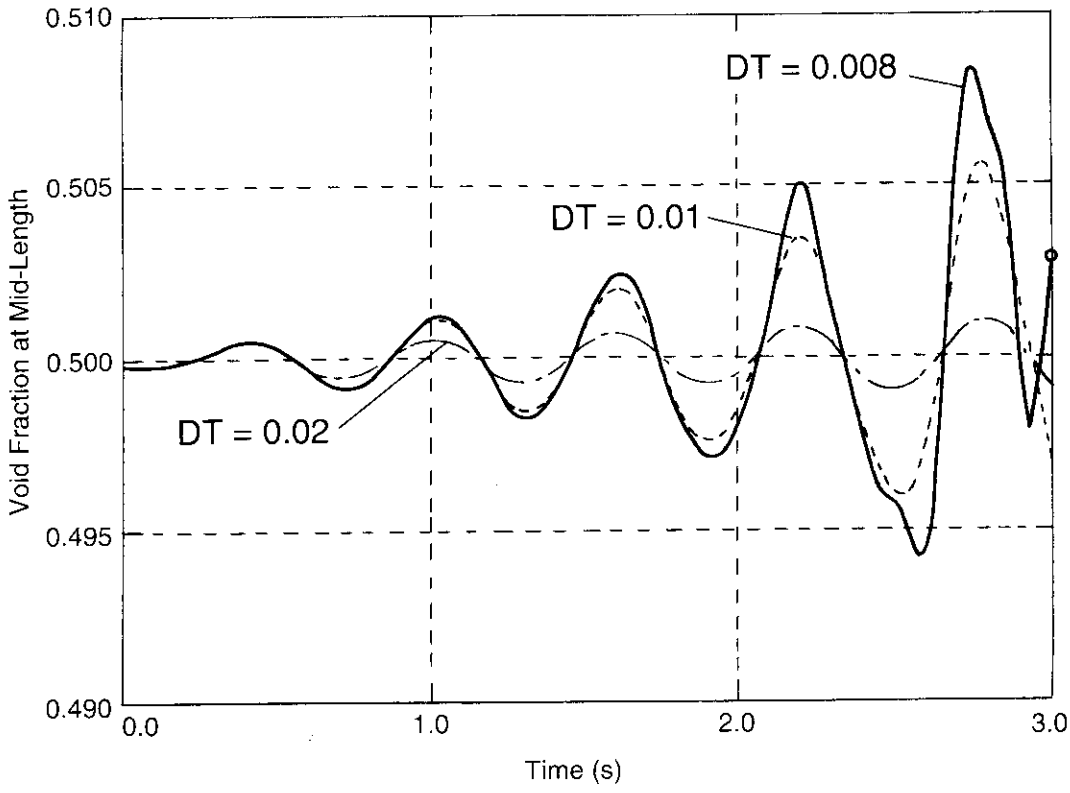

Fig. 2.14 Void fraction transient at the center of flow channel
(initial velocity: Ug = 50.0 m/s, Ul = 0.001 m/s)
(Fig. 14 in Ref. 2-8)

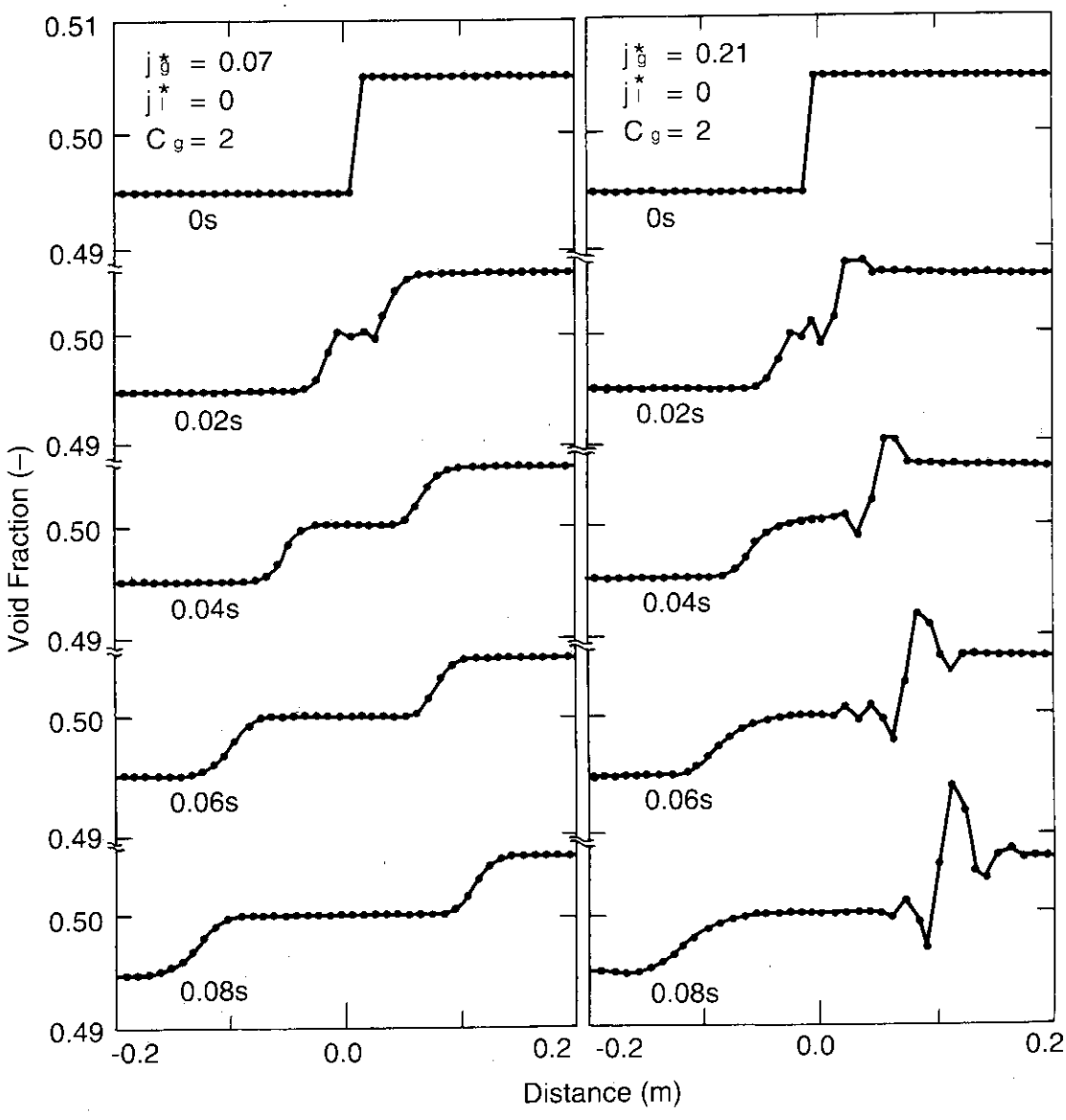

Fig. 2.15 Transient behavior of step-shaped small void disturbances with different gas velocities (Fig. 4 in Ref. 2-10)

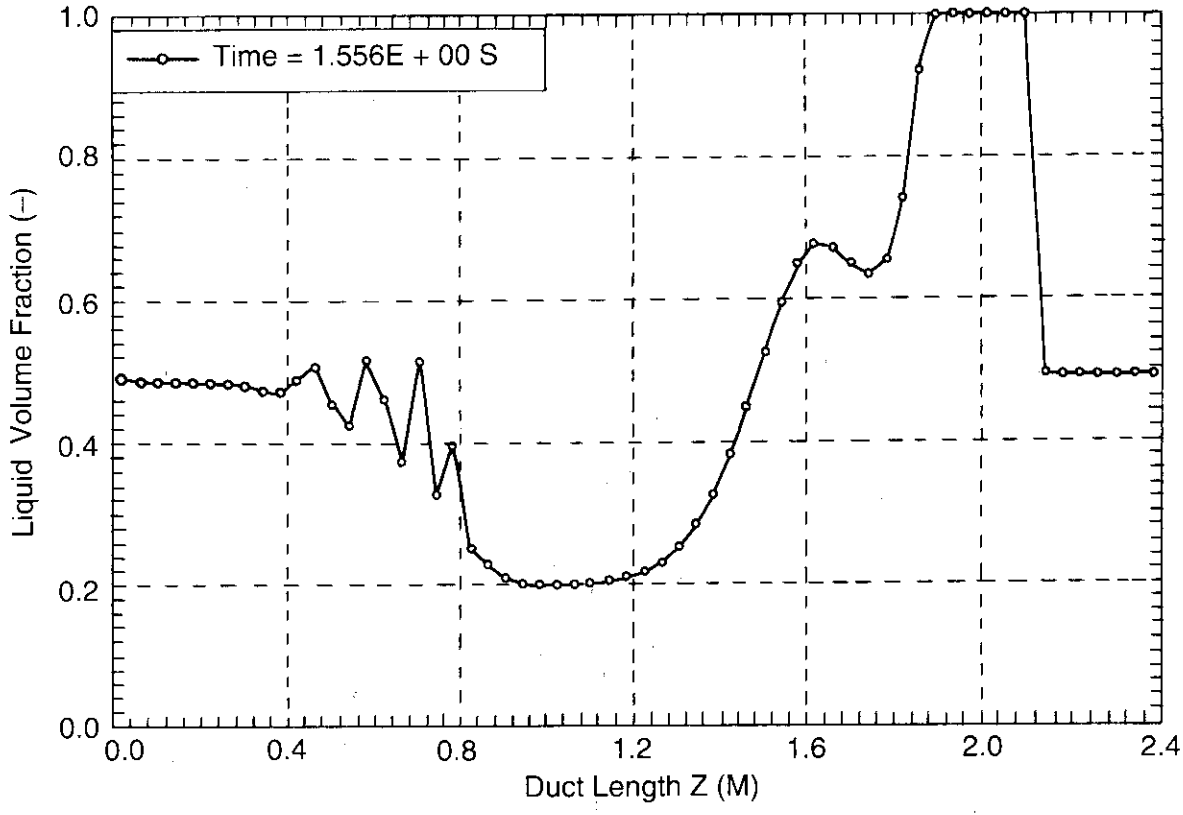

Fig. 2.16 Onset of slugging (initial velocity: Ug = 10.0 m/s, Ul = 0.0 m/s) (Fig. 9c in Ref. 2-11)

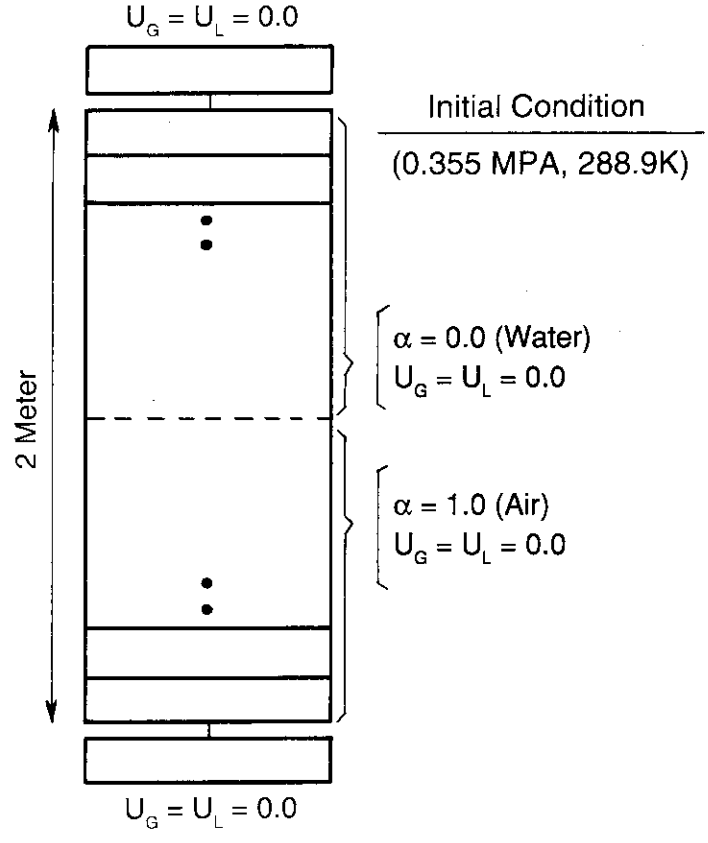

Fig. 2.17 Input model for sedimentation (Fig. 3 in Ref. 2-12)

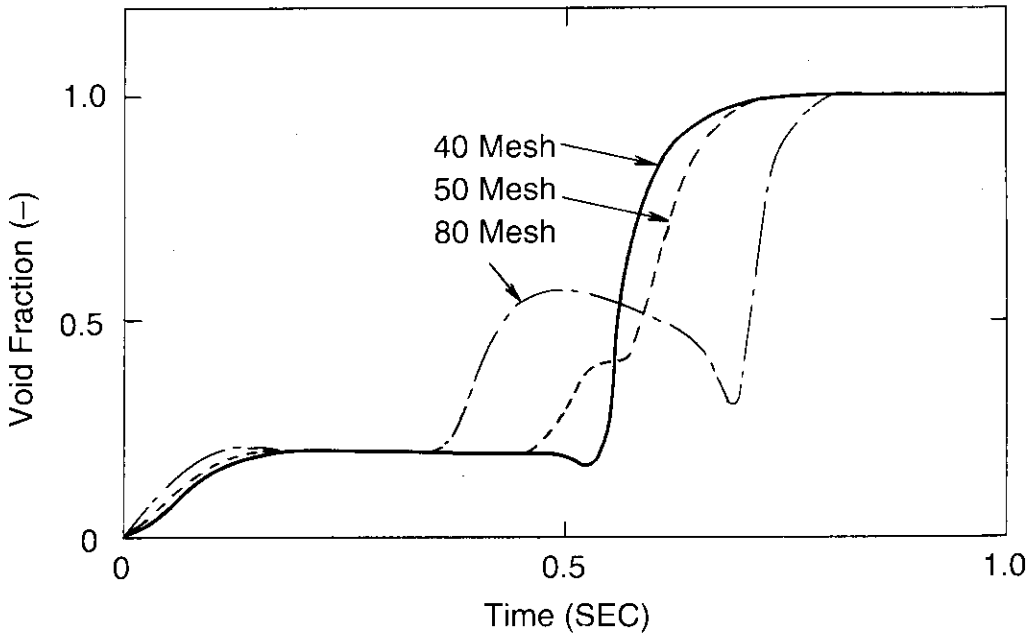

Fig. 2.18 Void fraction transient without virtual mass in sedimentation problem (Fig. 4 in Ref. 2-12)

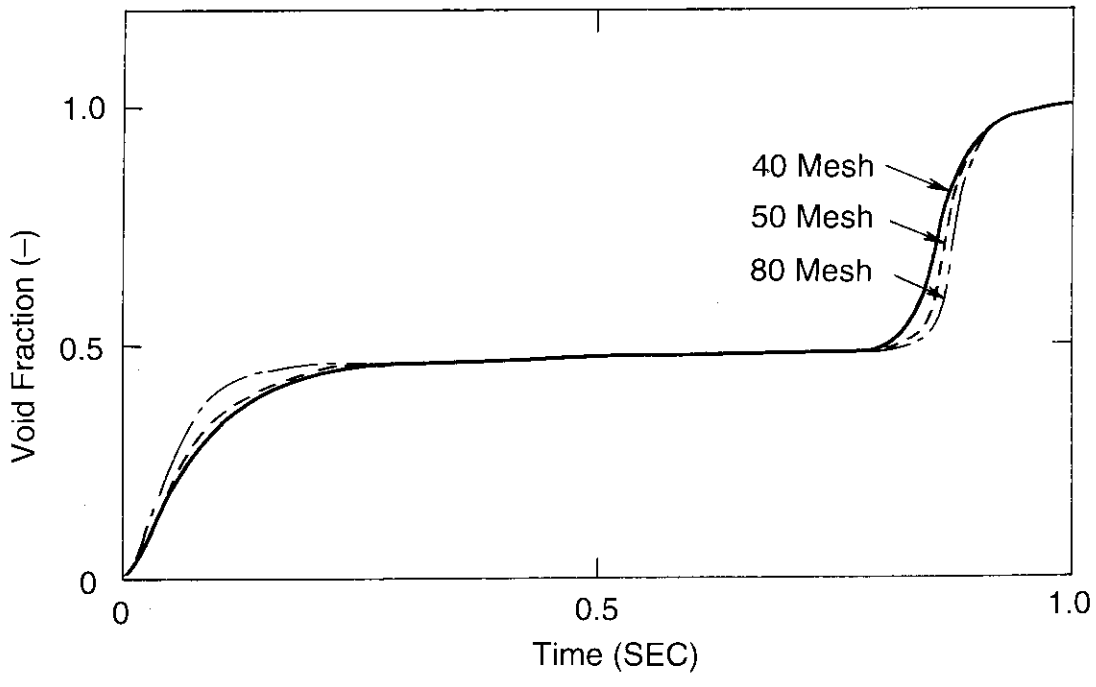

Fig. 2.19 Void fraction transient with virtual mass in sedimentation problem (Fig. 5 in Ref. 2-12)

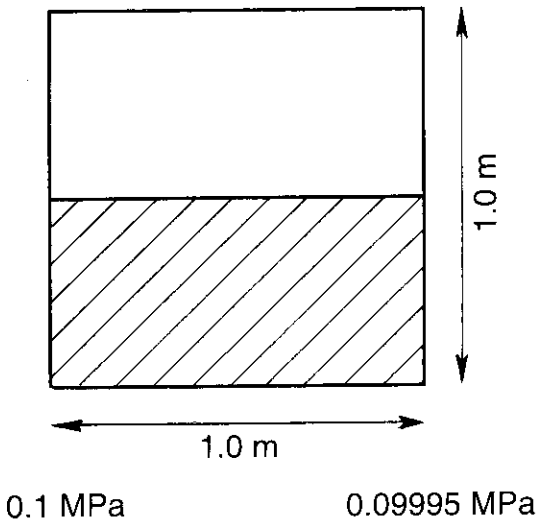

Fig. 2.20 Flow channel and boundary conditions for accelerated flow problem (Fig. 1 in Ref. 2-13)

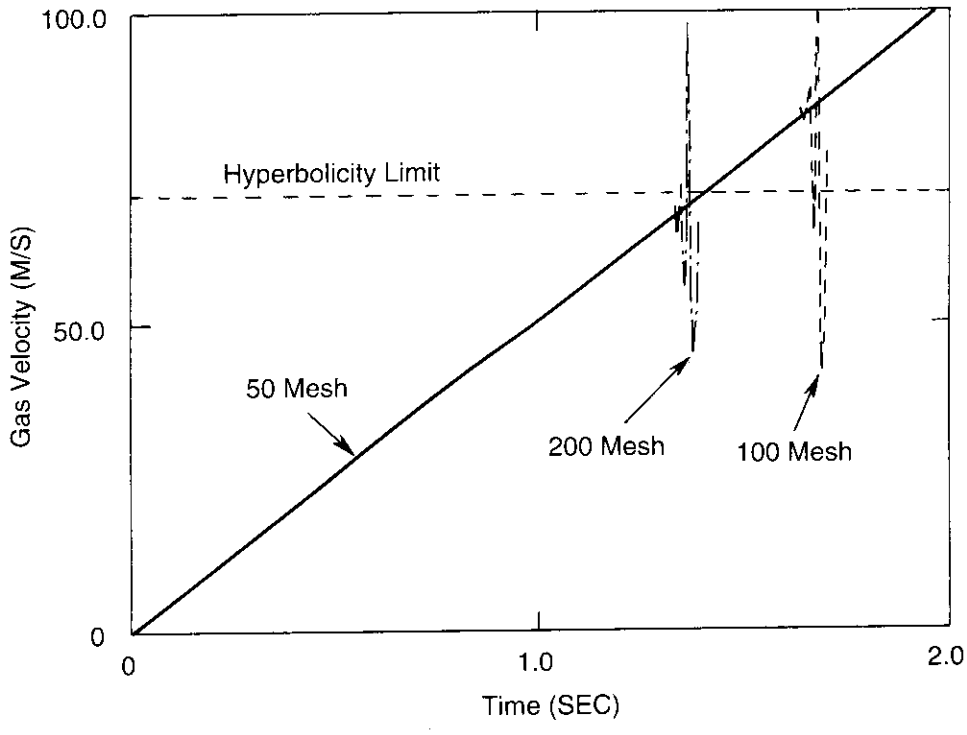

Fig. 2.21 Gas velocity transient at the exit in accelerated flow problem (Fig. 2 in Ref. 2-13)

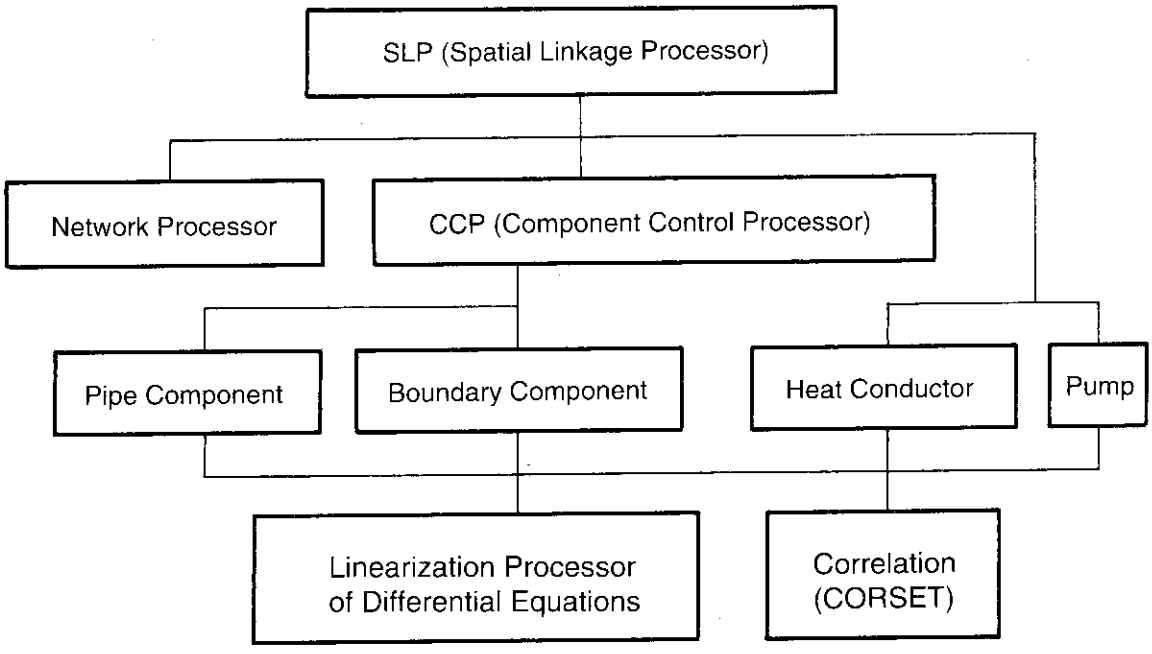

Fig. 2.22 Modularized Code Structure (Fig. 1 in Ref. 2-2)

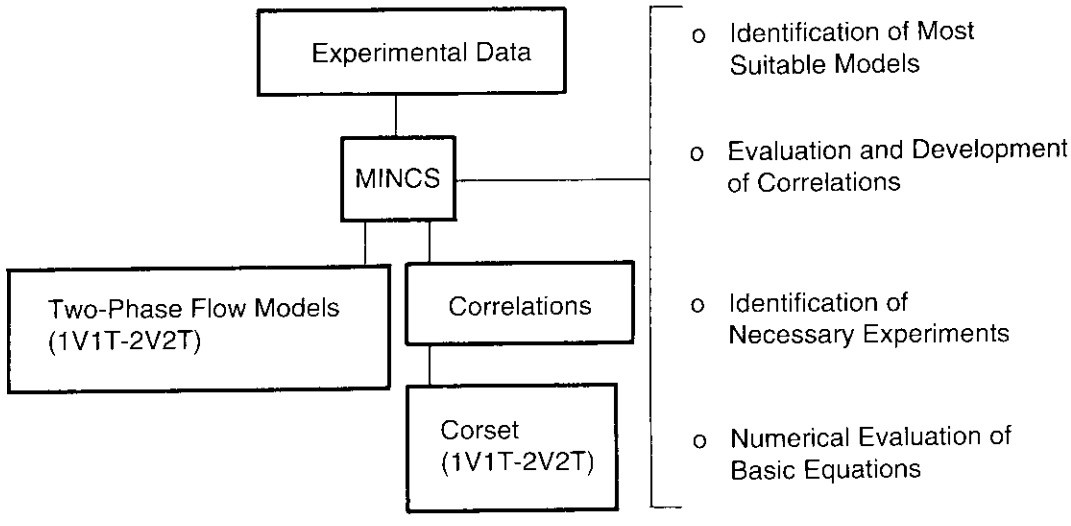

Fig. 2-23 Roles of MINCS (Fig. 2 in Ref. 2-2)

3. PHYSICAL LAW

3.1 FLUID CONSERVATION EQUATIONS

The governing equations for the two-fluid non-equilibrium model are derived from local conservation equations by spatially and temporary averaging [3-1], and consist of mass, momentum and energy conservation equations for gas and liquid phases. The one-dimensional forms of these conservation equations are the basic equations for the 2V2T model applied in MINCS. The basic equations for other models than the 2V2T model are obtained from the 2V2T model equations with some assumptions.

The mass conservation equation is the same for all models and is given as:

$$A\frac{\partial(\alpha_k\rho_k)}{\partial t}+\frac{\partial(\alpha_k\rho_k u_k A)}{\partial z}=A\Gamma_{ik}, \tag{3-1}$$

where conventional notations are used (see nomenclature), and the subscript k is the phase index : k=g for gas and k=l for liquid. Unknowns as dependent variables in this equation are

$$\alpha_g\,(=1-\alpha_l),\ u_g,\ u_l,\ \rho_g \text{ and } \rho_l .$$

The jump condition at the interface is derived from the comparison between the sum of equations for both phases and the equations for the two-phase mixture:

$$\Gamma_{ig}+\Gamma_{il}=0. \tag{3-2}$$

The mass conservation equation given by Eq. (3-1) is always used as the basic mass conservation equation in MINCS. The momentum and energy conservation equations are, however, different according to the two-phase flow models.

3.1.1 2V (UNEQUAL VELOCITY) MODEL

The 2V model is a separated flow model, in which the gas and liquid phases can have different velocities, and the two velocities are calculated by each phasic momentum equation. This model is the most mechanistic model for describing general two-phase flows. However, the interaction between two phases such as an interfacial friction must be considered. The momentum conservation equation in the 2V model is given as:

$$\begin{aligned}\alpha_k\rho_k\frac{\partial u_k}{\partial t}+\alpha_k\rho_k u_k\frac{\partial u_k}{\partial z}+\alpha_k\frac{\partial p_k}{\partial z}+(p_k-p_i)\frac{\partial\alpha_k}{\partial z}\\ =\Gamma_{ik}(u_{ik}-u_k)+\tau_{ik}-p'_{ik}-\tau_{wk}+\alpha_k\rho_k b_z.\end{aligned} \tag{3-3}$$

Unknowns as dependent variables in addition to those in Eq. (3-1) are

$$p_g \text{ and } p_l,$$

and unknowns as source terms are

$$\tau_{ig}\,(=-\tau_{il}),\ p'_{ig}(=-p'_{il}),\ p_k-p_i,\ \tau_{wg} \text{ and } \tau_{wl}.$$

The jump condition obtained from the momentum equation is

$$-p'_{ig}-p'_{il}+\tau_{ig}+\tau_{il}+\Gamma_{ig}u_{ig}+\Gamma_{il}u_{il}=0\ . \tag{3-4}$$

The following relations are assumed in the 2V model:

$$u_{ig} = u_{il} = u_l \quad for\ \Gamma_{ig} > 0\ , \tag{3-5}$$

$$u_{ig} = u_{il} = u_g \quad for\ \Gamma_{ig} < 0\ , \tag{3-6}$$

$$\tau_{ig} = -\tau_{il} \tag{3-7}$$

and

$$p'_{ig} = -p'_{il}\ . \tag{3-8}$$

3.1.2 1VD (DRIFT FLUX) MODEL

The drift flux model is a separated flow model, in which attention is focused on the relative motion between gas and liquid phases. The gas and liquid velocities are calculated by the mixture momentum equation and a correlation describing the relative motion. The following two equations are used in place of the two momentum conservation equations in the 2V model.

(1) mixture momentum equation

The sum of momentum equations in the 2V model with the assumption of $p_g = p_l = p$

(2) correlation for relative velocity

$$u_g - u_l = u_r\ (\alpha_g,\ \rho_g,\ \rho_l,\ \sigma,\ \mathrm{D},\ \text{flow pattern}). \tag{3-9}$$

3.1.3 1V (HOMOGENEOUS) MODEL

In the 1V model, the two-phase flow is assumed to be a homogeneous mixture of gas and liquid, and the relative motion between two phases is not considered. The mixture momentum equation is used in place of the two momentum conservation equations in the 2V model with the assumption of $u_g = u_l = u$. Thus, the separated flow such as a stratified flow cannot be described by the 1V model.

3.1.4 2T (UNEQUAL TEMPERATURE) MODEL

The gas and liquid phases can have different temperatures (or enthalpies or internal energies), and the temperatures of two phases are calculated by each phasic energy equation. In MINCS, the energy equation is written in terms of enthalpy as:

$$\begin{aligned} A\frac{\partial\left(\alpha_k\rho_k\left\{h_k + (1/2)u_k^2\right\}\right)}{\partial t} + \frac{\partial\left(\alpha_k\rho_k u_k\left\{h_k + (1/2)u_k^2\right\}\right)A}{\partial z} \\ -\alpha_k A\frac{\partial p_k}{\partial t} - (p_k - p_i)A\frac{\partial \alpha_k}{\partial t} \\ = A\Gamma_{ik}\left\{h_{ik} + (1/2)u_{ik}^2\right\} + Aq_{ik} + Aq_{wk} + A\alpha_k\rho_k u_k b_z\ . \end{aligned} \tag{3-10}$$

Unknowns as dependent variables in addition to those in Eqs. (3-1) and (3-3) are

h_g and h_l,

and unknowns as source terms are

q_{ig}, q_{il}, q_{wg} and q_{wl}.

The jump condition obtained from the energy equation is

$$\Gamma_{ig}\left\{h_{ig} + (1/2)u_{ig}^2\right\} + q_{ig} + \Gamma_{il}\left\{h_{il} + (1/2)u_{il}^2\right\} + q_{il} = 0. \tag{3-11}$$

The following relations are assumed in the 2T model:

$$h_{ig} = h_{sg}(p_i) \tag{3-12}$$

and

$$h_{il} = h_{sl}(p_i) \tag{3-13}$$

From the jump conditions given by Eqs. (3-2), (3-4) and (3-11), and the assumptions given by Eqs. (3-5), (3-6), (3-7), (3-8), (3-12) and (3-13), we obtain

$$\Gamma_{ig} = -\Gamma_{il} = -\frac{q_{ig} + q_{il}}{h_{sg} - h_{sl}}. \tag{3-14}$$

3.1.5 1.5T (PARTIALLY nonequilibrium) MODEL

In the 1.5T model, the gas and liquid phases can have different temperatures. However, the phase with smaller mass fraction is always assumed to be saturated. Thus, the nonequilibrium phenomena such as flushing cannot be predicted by this model. In the 1.5T model, the mixture energy equation is used in place of two energy conservation equations in the 2T model. The phase change rate is given by empirical correlations, and the temperatures in two phases are determined from an assumption for distributing the energy to each phase. The phase with smaller mass fraction is saturated, and the energy in the other phase is determined from the difference of energy between the mixture and the saturated phase.

(1) mixture energy equation

The sum of energy equations in the 2T model with the assumption of $p_g = p_l = p$.

(2) correlation for phase change

$$\Gamma_{ig} = -\Gamma_{il}(h_m, X, X_e, \text{flow pattern}). \tag{3-15}$$

The equilibrium quality X_e is obtained from the mixture enthalpy and the pressure.

(3) distribution of mixture energy to each phase

$$h_g = h_{sg}(p), h_l = \frac{h_m - X h_{sg}(p)}{(1-X)} \qquad \text{for } X < 0.5 \tag{3-16}$$

and

$$h_g = \frac{h_m - (1-X) h_{sg}(p)}{X}, h_l = h_{sl}(p) \qquad \text{for } X > 0.5. \tag{3-17}$$

3.1.6 1T (EQUILIBRIUM) MODEL

The gas and liquid phases are assumed to be in the equilibrium condition, and the temperatures in two phases are always the same. The mixture energy equation is used in place of the two energy conservation equations in the 2T model. The mixture mass conservation equation (sum of the two mass conservation equations) is always used in the 1T model. The following relations are assumed:

$$h_g = h_{sg}, h_l = h_m \qquad \text{for } h_m < h_{sl}(p), \tag{3-18}$$

$$h_g = h_{sg}(p), h_l = h_{sl}(p), h_m = X h_{sg} + (1-X) h_{sl} \qquad \text{for } h_{sl}(p) < h_m < h_{sg}(p) \tag{3-19}$$

and

$$h_g = h_m,\ h_l = h_{sl} \qquad \text{for } h_m > h_{sg}(p). \tag{3-20}$$

3.2 WALL HEAT CONDUCTION

The heat conduction in the wall can be calculated by using one-dimensional heat conduction equation. The heat conduction equation is applied to the direction perpendicular to the flow direction. The temperature in the wall is coupled with the fluid calculation. Flat and cylindrical plates can be handled in MINCS. The basic equations are:

(1) flat plate

$$\rho C \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}(k \frac{\partial T}{\partial x}) + S(x), \tag{3-21}$$

(2) cylindrical plate

$$\rho C \frac{\partial T}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r}(kr \frac{\partial T}{\partial r}) + S(r), \tag{3-22}$$

where x and r denote the coordinates.

3.3 CONSTITUTIVE RELATIONS

3.3.1 EQUATION OF STATE

The density and temperature for both phases are given as functions of the pressure and enthalpy:

$$\rho_k = \rho_k(p_k, h_k) \quad \text{and} \quad T_k = T_k(p_k, h_k). \tag{3-23}$$

The metastable state such as superheated water or subcooled steam is also included in the above functions.

3.3.2 DYNAMIC PRESSURE FORCE

The pressure differences between each phase and interface are given as the function of velocity, density and void fraction [3-2]:

$$p_k - p_i = f_k(\alpha_g, \rho_g, \rho_l, u_g, u_l). \tag{3-24}$$

The pressure in gas phase is thus obtained in terms of the pressure in liquid phase:

$$p_g = p_l + f_g - f_l. \tag{3-25}$$

3.3.3 ADDED MASS FORCE

The following equation is used as the added mass force term [3-3].

$$\Delta_{cd} = -\alpha_d \rho_c C_{vm} \left\{ \frac{\partial}{\partial t}(u_c - u_d) + u_d \frac{\partial u_c}{\partial z} - u_c \frac{\partial u_d}{\partial z} \right.$$
$$\left. -(1-\lambda_d)(u_c - u_d) \frac{\partial}{\partial z}(u_c - u_d) \right\}, \tag{3-26}$$

where C_{vm} and λ_d are the added mass coefficient and the parameter, respectively, and the subscripts c and d denote the continuous and dispersed phases, respectively.

bubbly flow : $p'_{ig} (= -p'_{il}) = \Delta_{lg}$ (3-27)

and

droplet flow : $p'_{ig} (= -p'_{il}) = -\Delta_{gl}$. (3-28)

3.3.4 HEAT TRANSFER AND FRICTION AT INTERFACE

The interfacial heat transfer and friction terms are defined as:

$$q_{ik} = A_i \lambda_{ik} \{T_s(p_i) - T_k\} \tag{3-29}$$

and

$$\tau_{ik} = \left(\frac{1}{2}\right) A_i (f_{ig}\rho_g + f_{il}\rho_l) |u_g - u_l| (u_g - u_l), \tag{3-30}$$

where A_i, λ_{ik} and f_{ik} are the interfacial area concentration, the heat transfer coefficient and the friction factor, respectively.

3.3.5 HEAT TRANSFER AND FRICTION AT WALL

(1) 2V2T model

In the 2V2T model, the wall heat transfer and friction terms are defined as:

$$q_{wk} = A_{wk} \lambda_{wk} (T_w - T_k) \tag{3-31}$$

and

$$\tau_{wk} = \left(\frac{1}{2}\right) A_{wk} f_{wk} \rho_k |u_k| u_k, \tag{3-32}$$

where A_{wk}, λ_{wk} and f_{wk} are the area concentration between each phase and wall, the heat transfer coefficient and the friction factor, respectively.

(2) 1VD and 1V models

The wall friction term is defined for the mixture as:

$$\tau_{wm} = \tau_{wg} + \tau_{wl} = \left(\frac{1}{2}\right) A_{wm} f_{wm} \Phi \rho_m |u_m| u_m. \tag{3-33}$$

(3) 1.5T and 1T models

(same as 2T case).

3.4 CORRELATIONS

3.4.1 PREPARATIONS

The flow in a pipe is assumed to be composed of continuous and dispersed phases as shown in Fig.3.1. If the continuous phase is gas as seen in the upper part of stratified flow or in the center part of annular flow, the dispersed phase is liquid droplets. On the other hand, if the continuous phase is liquid as seen in the lower part of stratified flow or in the cylindrical part of annular flow, the dispersed phase is gas bubbles as shown in Fig.3.1. Correlations describing exchange of momentum or energy for continuous and dispersed phases, such as friction or heat transfer, are calculated separately, and are combined into one form. In this procedure, each correlation is weighted according to volume fractions. Several variables such as volume fractions, hydraulic diameters and so on are needed to calculate correlations. In the other models than the 2V2T model, however, some of them are not necessary.

3.4.1.1 VOLUME FRACTIONS

Some volume-fraction related variables are defined here.

In MINCS, five types of flow patterns can be considered: continuous, stratified, annular, bubbly and droplet flows. If the continuous flow model is selected, the volume fractions are calculated from the flow condition. While the other flow models are selected, the entrainment fractions are fixed and the flow condition could be very simple.

(1) continuous model

The flow regime maps for the continuous model are shown in Fig.3.2 for the horizontal flow and in Fig.3.3 for the vertical flow. Fig.3.2 is based on the experiment by Govier and Omer [3-4], and Fig. 3.3 is by Govier et al. [3-5].

(a) horizontal flow

$$E_d = \max\left\{E_{\min}, \min\left\{\exp\left(\frac{j_g - 13.7}{0.26}\right), E_{\max}\right\}\right\} \tag{3-34}$$

and

$$E_b = \max\left\{E_{\min}, \min\left\{\exp\left(\frac{j_l - 2.63}{0.26}\right), E_{\max}\right\}\right\}, \tag{3-35}$$

where E_d is the entrainment fraction of droplets in the continuous gas phase and E_b is that of gas bubbles in the liquid phase, and j_g and j_l are the superficial velocities of gas and liquid, respectively. E_{min} and E_{max} are the minimum values for entrainment fractions, and are set equal to 10^{-10} and $1\text{-}10^{-10}$, respectively.

(b) vertical flow

$$E_d = \max\left\{E_{\min}, \min\left\{\exp\left(\frac{j_g - 100}{20}\right), E_{\max}\right\}\right\} \tag{3-36}$$

and

$$E_b = \max\left\{E_{\min}, \min\left\{\exp\left(\frac{0.1 - j_g}{0.03}\right), E_{\max}\right\}\right\}. \quad (3\text{-}37)$$

(2) stratified and annular flow

$$E_d = E_{min} \quad (3\text{-}38)$$

and

$$E_b = E_{min}. \quad (3\text{-}39)$$

(3) bubbly flow

$$E_d = E_{min} \quad (3\text{-}40)$$

and

$$E_b = E_{max}. \quad (3\text{-}41)$$

(4) droplet flow

$$E_d = E_{max} \quad (3\text{-}42)$$

and

$$E_b = E_{min}. \quad (3\text{-}43)$$

The following variables are defined in terms of E_d and E_b for all flow regimes:

$$\beta_c = (1 - E_d)(1 - \alpha), \quad (3\text{-}44)$$

$$\beta_c = E_d (1 - \alpha), \quad (3\text{-}45)$$

$$\alpha_c = (1 - E_b)\alpha \quad (3\text{-}46)$$

and

$$a_b = E_b a. \quad (3\text{-}47)$$

In the above equations, meanings of variables are

α : void fraction,

α_c : volume fraction of continuous gas,

α_b : volume fraction of gas bubble,

β_c : volume fraction of continuous liquid

and

β_d : volume fraction of liquid droplet.

The following volume fractions are also defined:

$$V_g = \alpha_c + \beta_d, \quad (3\text{-}48)$$

$$V_l = \alpha_b + \beta_c, \tag{3-49}$$

$$\alpha_g = \frac{\alpha_c}{V_g} \tag{3-50}$$

and

$$\alpha_l = \frac{\alpha_b}{V_l}. \tag{3-51}$$

3.4.1.2 RADIUS OF BUBBLE AND DROPLET

The radius R of bubble and droplet is defined as

$$R = \frac{0.5We\sigma}{\rho_l (u_g - u_l)^2}, \tag{3-52}$$

where We is the critical Weber number and σ is the surface tension.

(1) bubble

$$R_{pb} = \max\left\{5\times10^{-4}, \min\left(\frac{Dh}{2}\sqrt{1-V_g}, R\right)\right\} \tag{3-53}$$

and

$$We = 1.24. \tag{3-54}$$

(2) droplet

$$R_{pd} = \max\left\{5\times10^{-4}, \min\left(\frac{Dh}{2}\sqrt{V_g}, R\right)\right\} \tag{3-55}$$

and

$$We = 13, \tag{3-56}$$

where Dh is the hydraulic diameter of the flow channel.

3.4.1.3 HYDRAULIC DIAMETER

(1) interface

The hydraulic diameters used to calculate correlations at interface are defined as follows:

(a) stratified flow (Dh_{ic})

$$Dh_{ic} = \frac{V_g \pi Dh}{denom}, \tag{3-57}$$

where

$$denom = \sin\left(\frac{\theta}{2}\right) + \pi - \frac{\theta}{2} \tag{3-58}$$

and θ is an angle between the flow axis and the edges of interface in the perpendicular plane to the flow direction.

(b) annular flow (Dh_{ic})

$$Dh_{ic} = \sqrt{V_g} Dh \,. \tag{3-59}$$

(c) bubbly flow (Dh_{ib})

$$Dh_{ib} = 2R_{pb} \,. \tag{3-60}$$

(d) droplet flow (Dh_{id})

$$D_{id} = 2R_{pd} \,, \tag{3-61}$$

where the subscripts i, b and d denote the interface, bubble and droplet, respectively.

(2) wall

The hydraulic diameters used to calculate correlations at wall are defined as follows.

(a) horizontal flow

$$Dh_{wgc} = \max\left\{\frac{2\pi V_g Dh}{2\pi - \theta}, 2R_{pd}\right\}, \tag{3-62}$$

$$Dh_{wlc} = \max\left\{\frac{2\pi(1-V_g)Dh}{2\pi - \theta}, 2R_{pb}\right\}, \tag{3-63}$$

$$Dh_{wgb} = Dh_{wlc} \tag{3-64}$$

and

$$Dh_{wld} = Dh_{wgc}, \tag{3-65}$$

where the subscripts w, g, l, c, b,.and d denote the wall, gas, liquid, continuous phase, bubble and droplet, respectively.

(b) vertical flow

$$Dh_{wgc} = max\ \{V_g Dh,\ 2R_{pd}\} \,, \tag{3-66}$$

$$Dh_{wlc} = max\ \{V_l Dh,\ 2R_{pb}\} \,, \tag{3-67}$$

$$Dh_{wgb} = Dh_{wlc} \tag{3-68}$$

and

$$Dh_{wld} = Dh_{wgc} \,. \tag{3-69}$$

3.4.1.4 REYNOLDS NUMBER

(1) interface

The Reynolds numbers used to calculate correlations at interface are defined as:

$$\mathrm{Re}_{ic} = \frac{Dh_{ic}\rho_g|u_g - u_l|}{\mu_g}, \tag{3-70}$$

$$\mathrm{Re}_{ib} = \frac{Dh_{ib}\rho_l|u_g - u_l|}{\mu_l} \tag{3-71}$$

and

$$\mathrm{Re}_{id} = \frac{Dh_{id}\rho_g|u_g - u_l|}{\mu_g}, \tag{3-72}$$

where μ is the viscosity.

(2) wall

The Reynolds numbers used to calculate correlations at wall are defined below.

(a) 2V model

$$\mathrm{Re}_{wgc} = \frac{Dh_{wgc}\rho_g|u_g|}{\mu_g}, \tag{3-73}$$

$$\mathrm{Re}_{wgb} = \frac{Dh_{wgb}\rho_g|u_g|}{\mu_g}, \tag{3-74}$$

$$\mathrm{Re}_{wlc} = \frac{Dh_{wlc}\rho_l|u_l|}{\mu_l} \tag{3-75}$$

and

$$\mathrm{Re}_{wld} = \frac{Dh_{wld}\rho_l|u_l|}{\mu_l} \tag{3-76}$$

(b) 1VD and 1V model

$$\mathrm{Re}_{wm} = \frac{DhGm}{\mu_l} \qquad \text{for} \quad \alpha \le \alpha_{\min}, \tag{3-77}$$

$$\mathrm{Re}_{wm} = \frac{DhGm}{\mu_{ls}} \qquad \text{for} \quad \alpha_{\min} < \alpha < \alpha_{\max}, \tag{3-78}$$

and

$$\mathrm{Re}_{wm} = \frac{DhGm}{\mu_g} \qquad \text{for} \quad \alpha_{\max} \le \alpha, \tag{3-79}$$

where the subscript s denotes the saturated condition and the mass flow rate G_m is

$$G_m = \alpha\rho_g u_g + (1-\alpha)\,\rho_l u_l. \tag{3-80}$$

3.4.2 INTERFACE

Correlations at the interface such as the interfacial area, the friction factor and the heat transfer coefficient are defined.

3.4.2.1 INTERFACIAL AREA

The interfacial area is defined as the total area which consists of continuous phase, bubbles and droplets. The interfacial area between the interface and the gas phase is assumed to be the same as that between the interface and the liquid phase.

$$A_{ig} = A_{ic} + A_{ib} + A_{id} \tag{3-81}$$

and

$$A_{il} = A_{ig} = A_i \tag{3-82}$$

(1) stratified flow (A_{ic})

$$A_{ic} = \frac{4\sin(\theta/2)}{\pi Dh}. \tag{3-83}$$

(2) annular flow (A_{ic})

$$A_{ic} = \frac{4\sqrt{V_g}}{Dh}. \tag{3-84}$$

(3) bubbly flow (A_{ib})

$$A_{ib} = \frac{3\alpha_b}{R_{pb}}. \tag{3-85}$$

(4) droplet flow (A_{id})

$$A_{id} = \frac{3\{1-(1-\beta_d)\}}{R_{pd}}. \tag{3-86}$$

3.4.2.2 INTERFACIAL FRICTION FACTOR

The interfacial friction factors for the gas and liquid phases are defined as:

$$f_{ig} = (A_{id}f_{id} + A_{ic}f_{ic}) / (4A_{il}) \tag{3-87}$$

and

$$f_{il} = (A_{ib}f_{ib}) / (4A_{ig}) \tag{3-88}$$

(1) stratified flow (f_{ic})

In this flow regime, the laminar type and the Colebrook type [3-6] correlations are used. If the Reynolds number is smaller than Re_1, the interface is assumed to be smooth and the laminar type correlation is used. If the Reynolds number is larger than Re_2 the interface is assumed to be rough or wavy, and the Colebrook

type correlation is applied. In the following, Re_1 and Re_2 are 1000 and 4000, respectively.

(*a*) $f_{ic} = 0$ for $Re_{ic} \le 10^{-20}$, (3-89)

(*b*) $f_{ic} = 4\dfrac{16}{\mathrm{Re}_{ic}}$ for $10^{-20} < Re_{ic} < Re_1$ (3-90)

and

(*c*) $f_{ic} = 4\left(\dfrac{\mathrm{Re}_2 - \mathrm{Re}_{ic}}{\mathrm{Re}_2 - \mathrm{Re}_1} f_1 + \dfrac{\mathrm{Re}_{ic} - \mathrm{Re}_1}{\mathrm{Re}_2 - \mathrm{Re}_1} f_2\right)$ for $Re_1 \le Re_{ic} \le Re_2$, (3-91)

where

$$f_1 = \frac{16}{\mathrm{Re}_1}, \tag{3-92}$$

$$f_2 = \frac{1}{4x^2} \tag{3-93}$$

and x is the solution of the next equation

$$x = -0.86 \ln\left(\frac{\varepsilon}{3.7 Dh_{ic}} + \frac{2.51x}{\mathrm{Re}_2}\right). \tag{3-94}$$

In the above equation, ε is the interface roughness. (The interface roughness is currently assumed to be the same as the wall roughness specified in input data.)

(*d*) $f_{ic} = \dfrac{1}{x^2}$ for $Re_2 < Re_{ic}$, (3-95)

where x is the solution of the equation

$$x = -0.86 \ln\left(\frac{\varepsilon}{3.7 Dh_{ic}} + \frac{2.51x}{\mathrm{Re}_{ic}}\right). \tag{3-96}$$

(2) annular flow (f_{ic})

In this flow regime, the laminar type correlation and the Wallis type correlation [3-7], which is for a rough annular flow, are applied. The larger friction factor between the two correlations are used.

(*a*) $f_{ic} = 0$ for $Re_{ic} \le 10^{-20}$ (3-97)

and

(*b*) $f_{ic} = 4f$ for $Re_{ic} > 10^{-20}$, (3-98)

where

$f = f_0$ for $(0.8 \le V_g \text{ or } 500 \le f_0)$ (3-99)

and

$$f = \min\left\{f_0 \exp\left(\frac{0.8 - V_g}{0.025}\right), 500\right\} \quad \text{for } (0.8 > V_g \text{ or } 500 > f_0), \tag{3-100}$$

where

$$f_0 = \max\left\{\frac{16}{\mathrm{Re}_{ic}}, 0.005\left[1+75(1-V_g)\right]\right\}. \tag{3-101}$$

(3) bubbly flow (f_{ib})

In this flow regime, the correlation for the flow over sphere [3-8,9] is applied. This correlation is based on the force balance between the gravitational and drag forces on a single particle.

(*a*) $f_{\mathrm{ib}} = 0$ for $Re_{ib} \le 10^{-20}$, (3-102)

and

(*b*) $$f_{ib} = 4\left\{\frac{6\left[1+0.15\left(\mathrm{Re}_{ib}\right)^{0.687}\right]}{\mathrm{Re}_{ib}} + \frac{0.105}{1+4.25\times10^{4}\left(\mathrm{Re}_{ib}\right)^{-1.16}}\right\} \tag{3-103}$$

for $Re_{id} > 10^{-20}$.

(4) droplet flow (f_{id})

In this flow regime, the correlation for the flow over sphere [3-8,9] is also applied.

(*a*) $f_{\mathrm{id}} = 0$ for $Re_{id} \le 10^{-20}$ (3-104)

and

(*b*) $$f_{id} = 4\left\{\frac{6\left[1+0.15\left(\mathrm{Re}_{id}\right)^{0.687}\right]}{\mathrm{Re}_{id}} + \frac{0.105}{1+4.25\times10^{4}\left(\mathrm{Re}_{id}\right)^{-1.16}}\right\} \tag{3-105}$$

for $Re_{id} > 10^{-20}$.

3.4.2.3 INTERFACIAL HEAT TRANSFER COEFFICIENT

The interfacial heat transfer coefficients for the two phases are defined as:

$$\lambda_{ig} = (A_{ich}\lambda_{igc} + A_{ibh}\lambda_{igb} + A_{idh}\lambda_{igd}) / A_{igh} \tag{3-106}$$

and

$$\lambda_{il} = (A_{ich}\lambda_{ilc} + A_{ibh}\lambda_{ilb} + A_{idh}\lambda_{ild}) / A_{ilh}, \tag{3-107}$$

where the subscript h denotes the heat-transfer related values. The variables with subscript h are, however, the same as those without h at present.

(1) stratified flow (λ_{igc}, λ_{ilc})

In this flow regime, the turbulent and the laminar flow heat transfers are, respectively, assumed for the gas and the liquid phases. The Dittus-Boelter type correlation [3-10], which was developed for the turbulent flow heat transfer in a uniformly heated pipe, is applied to the gas phase. The conduction type, which is for the laminar flow heat transfer in a uniformly heated pipe, is used for the liquid phase.

$$\lambda_{igc} = \frac{k_g}{Dh_{ic}}(0.023)\left(\mathrm{Re}_{ic}\right)^{0.8}\left(\mathrm{Pr}_{ig}\right)^{0.4}, \tag{3-108}$$

where Pr_{ig} is the Prandtl number defined as

$$\mathrm{Pr}_{ig} = \frac{Cp_g \mu_g}{k_g}, \tag{3-109}$$

and Cp_g is the specific heat and k_g is the thermal conductivity of gas phase.

$$\lambda_{ilc} = \frac{k_l}{\delta}, \tag{3-110}$$

where k_l is the thermal conductivity of liquid phase and δ is the film thickness defined as

$$\delta = \frac{Dh\{1-\cos(\theta/2)\}}{2}. \tag{3-111}$$

(2) annular flow (λ_{igc}, λ_{ilc})

In this flow regime, the turbulent and the laminar flow heat transfers are, respectively, assumed for the gas and the liquid phases as in the stratified flow region. The Dittus-Boelter type correlation [3-10] is applied for the gas phase, while the conduction type is used for the liquid phase.

$$\lambda_{igc} = \frac{k_g}{Dh_{ic}}(0.023)\left(\mathrm{Re}_{ic}\right)^{0.8}\left(\mathrm{Pr}_{ig}\right)^{0.4} \tag{3-112}$$

and

$$\lambda_{ilc} = \frac{k_l}{\delta}, \tag{3-113}$$

where the film thickness δ for the annular flow is

$$\delta = \frac{Dh}{2}\left(1-\sqrt{a}\right). \tag{3-114}$$

(3) bubbly flow (λ_{igb}, λ_{ilb})

In this flow regime, the laminar flow heat transfer is assumed in the both sides of the interface. The conduction type correlation is applied for the gas phase, while the convection type, which was developed for the interfacial heat transfer from bubbles, is used for the liquid phase [3-11].

$$\lambda_{igb} = \frac{k_g}{\delta}, \tag{3-115}$$

where

$$\delta = \frac{3R_{pb}}{\pi^2}. \tag{3-116}$$

$$\lambda_{ilb} = k_l\left\{\frac{2\rho_l Cp_l\left|u_g-u_l\right|(1/4)(\mathrm{Pr}_{il})^{-0.33}}{\pi k_l R_{pb}}\right\}^{1/2}, \tag{3-117}$$

where Cp_l is the specific heat of liquid and the Prandtl number Pr_{il} is defined as

$$\mathrm{Pr}_{il} = \frac{Cp_l \mu_l}{k_l}. \tag{3-118}$$

(4) droplet flow (λ_{igd}, λ_{ild})

In this flow regime, the laminar flow heat transfer is assumed in the both sides of the interface as in the bubbly flow region. The Lee and Ryley type correlation [3-12], which was developed for the interfacial heat transfer from droplets, is applied for the gas phase, while the conduction type is used for the liquid phase.

$$\lambda_{igd} = \frac{k_g}{R_{pd}} \left\{ 1 + 0.37 \left(\mathrm{Re}_{id} \right)^{1/2} \left(\mathrm{Pr}_{ig} \right)^{0.33} \right\} \tag{3-119}$$

and

$$\lambda_{ilb} = \frac{k_l}{\delta}, \tag{3-120}$$

where

$$\delta = \frac{3R_{pd}}{\pi^2}. \tag{3-121}$$

3.4.3 WALL

Correlations at the wall such as the wall area, the friction factor and the heat transfer coefficient are defined below.

3.4.3.1 WALL AREA

The wall contact area of each phase is defined as the total area which consists of continuous phase, bubbles and droplets.

$$A_{wg} = max \{ 10^{-5}, A_{wgc} + A_{wgb} \}, \tag{3-122}$$

$$A_{wl} = max \{ 10^{-10}, A_{wlc} + A_{wld} \} \tag{3-123}$$

and

$$A_{wm} = A_{wl} + A_{wg} \quad \text{for 1V and 1VD case.} \tag{3-124}$$

(1) stratified flow (A_{wgc}, A_{wgb}, A_{wlc}, A_{wld})

$$A_{wgc} = A_g \alpha_g, \tag{3-125}$$

$$A_{wgb} = A_l \alpha_l, \tag{3-126}$$

$$A_{wlc} = A_l (1 - \alpha_l) \tag{3-127}$$

and

$$A_{wld} = A_g (1 - \alpha_g), \tag{3-128}$$

where A_g and A_l are defined as

$$A_g = \frac{2(2\pi - \theta)}{\pi D h} \tag{3-129}$$

and

$$A_l = \frac{2\theta}{\pi Dh}. \tag{3-130}$$

(2) vertical flow ($A_{wgc}, A_{wgb}, A_{wlc}, A_{wld}$)

$$A_{wgc} = \frac{4\alpha_g(1-E_b)E_d}{Dh}, \tag{3-131}$$

$$A_{wgb} = \frac{4\alpha_l(1-E_d)}{Dh}, \tag{3-132}$$

$$A_{wlc} = \frac{4(1-\alpha_l)(1-E_d)}{Dh} \tag{3-133}$$

and

$$A_{wld} = \frac{4(1-\alpha_g)(1-E_b)}{Dh}. \tag{3-134}$$

3.4.3.2 WALL FRICTION FACTOR

The wall friction factors for the gas and the liquid phases are defined as:

$$f_{wg} = (A_{wgc}f_{wgc} + A_{wgb}f_{wgb}) / (4A_{wg}) \tag{3-135}$$

and

$$f_{wl} = (A_{wlc}f_{wlc} + A_{wld}f_{wld}) / (4A_{wl}). \tag{3-136}$$

(1) stratified and annular flow (f_{wgc})

In this flow regime, the laminar flow is assumed when the Reynolds number is smaller than Re_1, while the turbulent flow is assumed when the Reynolds number is larger than Re_2. Thus, the simple laminar type and the Colebrook type [3-6] correlations are used. In the following, Re_1 and Re_2 are 1000 and 4000, respectively.

(*a*) $f_{wgc} = 0$ for $Re_{wgc} \le 10^{-20}$, (3-137)

(*b*) $f_{wgc} = 4\dfrac{16}{\mathrm{Re}_{wgc}}$ for $10^{-20} < Re_{wgc} < Re_1$ (3-138)

and

(*c*) $f_{wgc} = 4\left(\dfrac{\mathrm{Re}_2 - \mathrm{Re}_{wgc}}{\mathrm{Re}_2 - \mathrm{Re}_1} f_1 + \dfrac{\mathrm{Re}_{wgc} - \mathrm{Re}_1}{\mathrm{Re}_2 - \mathrm{Re}_1} f_2\right)$ for $Re_1 \le Re_{wgc} \le Re_2$, (3-139)

where

$$f_1 = \frac{16}{\mathrm{Re}_1}, \tag{3-140}$$

$$f_2 = \frac{1}{4x^2} \tag{3-141}$$

and x is the solution of the equation

$$x = -0.86 \ln\left(\frac{\varepsilon}{3.7 Dh_{wgc}} + \frac{2.51x}{\mathrm{Re}_2}\right). \tag{3-142}$$

In the above equation, ε is the wall roughness.

(*d*) $f_{wgc} = \dfrac{1}{x^2}$ for $Re_2 < Re_{wgc}$, (3-143)

where x is the solution of the equation

$$x = -0.86 \ln\left(\frac{\varepsilon}{3.7 Dh_{wgc}} + \frac{2.51x}{\mathrm{Re}_{wgc}}\right). \tag{3-144}$$

(2) stratified and annular flow (f_{wfc})

In this flow regime, the laminar type and the Colebrook type [3-6] correlations are also used for the friction factor between the wall and the continuous liquid phase. The equations are, thus, the same as those used for the continuous gas phase. f_{wgc} must, however, be substituted by f_{wfc}, Re_{wgc} by Re_{wfc}, and Dh_{wgc} by Dh_{wfc}.

(3) bubbly flow (f_{wgb})

In this flow regime, the laminar type and the Colebrook type [3-6] correlations are also used. The equations are, thus, the same as those used for the stratified and annular flow regimes. f_{wgc} must, however, be substituted by f_{wgb}, Re_{wgc} by Re_{wgb}, and Dh_{wgc} by Dh_{wgb}.

(4) droplet flow (f_{wld})

In this flow regime, the laminar type and the Colebrook type [3-6] correlations are also used. The equations are, thus, the same as those used for the stratified and annular flow regimes. f_{wgc} must, however, be substituted by f_{wlb}, Re_{wgc} by Re_{wld}, and Dh_{wgc} by Dh_{wld}.

(5) two-phase mixture in 1V adn 1VD models (f_{wm})

In the 1V and 1VD models, the laminar type and the Colebrook type [3-6] correlations and the two-phase multiplier are used. The friction factor is obtained by using the mixture Reynolds number and multiplied by the two-phase multiplier. The equations for correlations are, thus, the same as those used for the stratified and annular flow regimes in the 2V model. f_{wgc} must, however, be substituted by f_{wm}, Re_{wgc} by Re_{wm}, and Dh_{wgc} by Dh. The two-phase multiplier is obtained as a function of pressure and quality.

3.4.3.3 WALL HEAT TRANSFER COEFFICIENT

The wall heat transfer coefficients for the two phases and for subcool boiling are obtained by the following relations.

$$\lambda_{wg} = \frac{A_{wgh} + A_{wlh}}{A_{wgh}} H_g, \tag{3-145}$$

$$\lambda_{wl} = \frac{A_{wgh} + A_{wlh}}{A_{wlh}} H_f \tag{3-146}$$

and

$$\lambda_{sb} = \frac{A_{wgh} + A_{wlh}}{A_{wlh}} H_{sb}, \tag{3-147}$$

where H_g, H_l and H_{sb} are determined in accordance with each mode of heat transfer [3-13]. The subscript h denotes the heat-transfer related values, however, the variables with subscript h are the same as those without h at present.

The mode of heat transfer is determined from the boiling mode curve shown in Fig.3.4. Four boiling modes are shown in Fig.3.4: single-phase liquid, nucleate boiling, transition boiling and film boiling heat transfers. Other three heat transfer modes than those shown in Fig.3.4 are provided: condensation heat transfer, convection to single-phase vapor and convection to two-phase mixture. The heat transfer coefficients in each mode are described below. In the following, the laminar, turbulent and natural convection heat transfer coefficients are appropriately used by interpolation. The subscripts $_{lam}$ and $_{turb}$ denote the laminar and turbulent flows, respectively.

(1) heat transfer coefficients in each mode

(1-1) condensation heat transfer [3-10, 14] (IDREG = 11)

(*a*) $X < X_{chen}$

$$H_l = H_{forc}\ , \tag{3-148}$$

$$H_g = 0.0\ , \tag{3-149}$$

(*b*) $X \geq X_{chen}$

$$H_l = Hinter(X_{chen},\ 1,\ H_l \text{ of Eq. (3-148)},\ 0,\ X_{con})\ , \tag{3-150}$$

and

$$H_g = Hinter(X_{chen},\ 1,\ H_g \text{ of Eq. (3-165)},\ H_{gs.\ av},\ X_{con})\ , \tag{3-151}$$

where

$$H_{forc} = max\ \{H_{l.\ lam},\ H_{l.\ turb}\}\ , \tag{3-152}$$

$$H_{l,lam} = 4.0\frac{k_l}{Dh}, \tag{3-153}$$

$$H_{l,turb} = 0.023\frac{k_l}{Dh}\left(\mathrm{Re}_{tp}\right)^{0.8}\left(\mathrm{Pr}_l\right)^{0.4}, \tag{3-154}$$

$$Re_{tp} = Re_l F^{1.25}, \tag{3-155}$$

$$\mathrm{Re}_l = \frac{|u_l|\rho_l(1-\alpha)Dh}{\mu_l}, \tag{3-156}$$

$$F = 1 \qquad \text{for } X < 10^{-5} \text{ or } X_{tt}^{-1} < 0.1\ , \tag{3-157}$$

$$F = 2.35\left(X_{tt}^{-1} + 0.213\right)^{0.736} \qquad \text{for } X \geq 10^{-5} \text{ and } X_{tt}^{-1} \geq 0.1\ , \tag{3-158}$$

$$X_{tt} = \left(\frac{1-X}{X}\right)^{0.9}\left(\frac{\rho_g}{\rho_l}\right)^{0.5}\left(\frac{\mu_l}{\mu_g}\right)^{0.1} \qquad \text{for } X \geq 10^{-5}, \tag{3-159}$$

$$\mathrm{Pr}_l = \frac{\mu_l Cp_l}{k_l} \tag{3-160}$$

and

$$H_{gs,\alpha v} = H_g \text{ of Eq. (3-165) after calculation of region (IDREG = 6),} \tag{3-161}$$

$$= 0.0 \text{ before calculation of region (IDREG = 6)} . \tag{3-162}$$

The interpolation is defined as

$$\text{Hinter}\ (x_1, x_2, y_1, y_2, x_0) = \frac{(x_0 - x_1)}{(x_2 - x_1)}(y_2 - y_1) + y_1. \tag{3-163}$$

In the above equations,

$$X_{con} = min\ \{X, 1.0\} \text{ and } X_{chen} = 0.71. \tag{3-164}$$

(1-2) convection to single-phase vapor [3-10,15] (IDREG = 6)

$$H_g = max\ \{H_{g,nc}, H_{g,turb}\} \tag{3-165}$$

and

$$H_l = 0.0, \tag{3-166}$$

where

$$H_{g,nc} = 0.13 k_g \left\{ \frac{\rho_g^2 g |T_w - T_g|}{\mu_g^2 T_g} \right\}^{1/3} \mathrm{Pr}_g^{1/3}, \tag{3-167}$$

$$\mathrm{Pr}_g = \frac{Cp_g \mu_g}{k_g}, \tag{3-168}$$

$$H_{g,turb} = 0.023 \frac{k_g}{Dh} \mathrm{Re}_g^{0.8}\, \mathrm{Pr}_g^{1/3} \tag{3-169}$$

and

$$\mathrm{Re}_g = \frac{\rho_g |u_g| Dh}{\mu_g}. \tag{3-170}$$

(1-3) convection to two-phase mixture [3-10,15] (IDREG = 7)

(*a*) $\alpha > \alpha_{cut}$

$$H_g = 0.0, \tag{3-171}$$

$$H_l = max\ \{H_{l,lam}, H_{l,turb}\}, \tag{3-172}$$

(*b*) $\alpha \le \alpha_{cut}$

$$H_l = Hinter\ (\alpha_{cut}, \alpha_3, H_l \text{ of Eq. (3-172)}, 0, \alpha) \tag{3-173}$$

and

$$H_g = Hinter(\alpha_{cut}, \alpha_2, H_g \text{ of Eq. (3-165)}, H_{gs,\alpha v}, \alpha), \tag{3-174}$$

where

$$H_{l,lam} = 4.0\frac{k_l}{Dh}, \tag{3-175}$$

$$H_{l,turb} = 0.023\frac{k_l}{Dh}(\mathrm{Re}_m)^{0.8}(\mathrm{Pr}_m)^{0.4}, \tag{3-176}$$

$$\mathrm{Re}_m = \frac{G_m Dh}{\mu_m}, \tag{3-177}$$

$$G_m = |\alpha\rho_g u_g + (1-\alpha)\rho_l u_l| \tag{3-178}$$

$$\mu_m = \left(\frac{X_f}{\mu_g} + \frac{1-X_f}{\mu_l}\right)^{-1}, \tag{3-179}$$

$$Xf = 0 \qquad \text{for } u_l = 0, \tag{3-180}$$

$$X_f = \left(1 + \frac{1-\alpha}{\alpha}\frac{\rho_l}{\rho_g S}\right)^{-1} \qquad \text{for } u_l \neq 0,\ u_g \neq 0, \tag{3-181}$$

$$X_f = \left(1 + \frac{1-\alpha}{\alpha}\frac{\rho_l}{\rho_g}\right)^{-1} \qquad \text{for } u_g \neq 0, \tag{3-182}$$

$$S = \left|\frac{u_g}{u_l}\right| \tag{3-183}$$

and

$$\mathrm{Pr}_m = \frac{\mu_l Cp_l}{k_l}. \tag{3-184}$$

In the above equations,

$$\alpha_{cut} = 0.96,\ \alpha_3 = 0.999 \text{ and } \alpha_2 = 1.0. \tag{3-185}$$

(1-4) forced convection to single-phase liquid [3-10] (IDREG = 1)

$$H_g = 0.0 \tag{3-186}$$

and

$$H_l = H_{forc} \text{ of Eq. (3-152).} \tag{3-187}$$

(1-5) liquid natural convection [3-16] (IDREG = 12)

$$H_g = 0.0. \tag{3-188}$$

(*a*) $Gr \le 10^9$

$$H_l = max\ \{H_{l,lam}, H_{l,1}\}, \tag{3-189}$$

(*b*) $10^9 < Gr \le 10^{13}$

$$H_l = 0.021\ (Gr \times Pr_l)^{0.4} k_l / Dh, \tag{3-190}$$

(c) $10^{13} < Gr$

$$H_l = 0.1\left(Gr \times \mathrm{Pr}_l\right)^{0.333} \frac{k_l}{Dh}, \tag{3-191}$$

where

$$H_{l,lam} = 4.0 \frac{k_l}{Dh}, \tag{3-192}$$

$$H_{l,1} = 0.59\left(Gr \times \mathrm{Pr}_l\right)^{0.25} \frac{k_l}{Dh}, \tag{3-193}$$

$$Gr = g \frac{\beta_l \rho_l}{\rho_f} \left|T_w - T_l\right| Dh \left(\frac{Dh}{\mu}\right)^2 \rho_f^2, \tag{3-194}$$

$$\rho_f = \rho_l - \beta_l \rho_l\ (T_{film} - T_l), \tag{3-195}$$

$$T_{film} = \frac{1}{2}\left(T_w + T_1\right) \tag{3-196}$$

and β_l is the expansion coefficient of liquid.

(1-6) nucleate boiling [3-14] (IDREG = 2)

(*a*) $\alpha < \alpha_{cut}$

$$H_g = 0.0, \tag{3-197}$$

$$H_l = H_{forc} + H_{nucb} \min\left\{\frac{T_w - T_s}{T_w - T_l}, 1\right\}, \tag{3-198}$$

(*b*) $\alpha = \alpha_{cut}$

$$H_g = H_g \text{ of Eq. (3-165)}, \tag{3-199}$$

$$H_l = H_l \text{ of Eq. (3-198)}, \tag{3-200}$$

(*c*) $\alpha > \alpha_{cut}$

$$H_l = Hinter\ (\alpha_{cut}, \alpha_3, H_l \text{ of Eq. (3-198)}, 0, \alpha)\ , \tag{3-201}$$

$$H_g = Hinter\ (\alpha_{cut}, \alpha_2, H_g \text{ of Eq. (3-165)}, H_{gs,\ \alpha v}, \alpha)\ , \tag{3-202}$$

where

$$H_{nucb} = Ca\ (T_w - T_s)^{0.24}\ (P_{sup} - P)^{0.75} \quad \text{for } T_w > T_s \text{ and } P_{sup} \ge P, \tag{3-203}$$

$$H_{nucb} = 0 \quad \text{for } T_w \le T_s \text{ or } P_{sup} < P, \tag{3-204}$$

$$Ca = 0.00122 \frac{k_l^{0.79} Cp_l^{0.45} \rho_l^{0.49}}{\sigma^{0.5} \mu_l^{0.29} h_{fg}^{0.24} \rho_g^{0.24}} S, \tag{3-205}$$

$$S = \left\{1 + 0.12 \,\mathrm{Re}_{tpp}^{1.14}\right\}^{-1} \qquad \text{for} \quad \mathrm{Re}_{tpp} < 32.5 \ , \tag{3-206}$$

$$S = \left\{1 + 0.42 \,\mathrm{Re}_{tpp}^{0.78}\right\}^{-1} \qquad \text{for} \quad \mathrm{Re}_{tpp} \geq 32.5 \ , \tag{3-207}$$

$$h_{fg} = h_{gs} - h_{ls}, \tag{3-208}$$

$$Re_{tpp} = min\{Re_{tp} \times 10^4, 70\} \tag{3-209}$$

and

$$P_{\sup} = \left(\frac{T_w - 225.2}{117.8}\right)^{4.484305} \times 10^5. \tag{3-210}$$

(1-7) transition boiling [3-10, 17, 18] (IDREG = 3)

(*a*) $\alpha < \alpha_{cut}$

$$H_g = W_f max\ \{H_{fbb}, H_{fbdr}\}, \tag{3-211}$$

$$H_l = H_{tb} + H_{rl} \frac{T_w - T_s}{T_w - T_l} + D_{fhl}, \tag{3-212}$$

(*b*) $\alpha > \alpha_{cut}$

$$H_l = Hinter\,(\alpha_{cut}, \alpha_3, H_l \text{ of Eq. (3-212)}, 0, \alpha) \tag{3-213}$$

$$H_g = Hinter\,(\alpha_{cut}, \alpha_2, H_g \text{ of Eq. (3-211)}, H_{gs,\,au}, \alpha), \tag{3-214}$$

where

$$W_f = \frac{T_w - T_{chf}}{T_{\min} - T_{chf}}, \tag{3-215}$$

T_{chf} : temperature which gives critical heat flux, (3-216)

T_{min} : minimum stable boiling temperature, (3-217)

$$H_{fbb} = 0.62 \left(\frac{k_g^3 \Delta\rho \rho_g g H_{fgp}}{\mu_g (T_w - T_s) W_l}\right)^{0.25}, P_{\sup} < P, \tag{3-218}$$

$$H_{fgp} = h_{fg} + 0.5 Cp_g max\ \{T_g - T_s, 0\}, \tag{3-219}$$

$$W_l = 2\pi \left\{\frac{\sigma}{g\Delta\rho}\right\}^{0.5}, \tag{3-220}$$

$$H_{fbdr} = \max\left\{H_{g,nc}, 0.023 \frac{k_g}{Dh} \mathrm{Re}_{tp}^{\ 0.8} \mathrm{Pr}_g^{0.4}\right\}, \tag{3-221}$$

$$\mathrm{Re}_{tp}' = \frac{\rho_g \left\{ |u_g|\alpha + |u_l|(1-\alpha) \right\} Dh}{\mu_g}, \tag{3-222}$$

$$H_{tb} = \frac{\gamma Q_{chf} + (1-\gamma) Q_{\min}}{T_w - T_l}, \tag{3-223}$$

$$\gamma = \left(\frac{T_w - T_{\min}}{T_{chf} - T_{\min}} \right)^2, \tag{3-224}$$

where Q_{chf} and Q_{min} are the critical heat flux and the heat flux at the minimum stable film boiling point, respectively.

$$H_{rl} = 5.6697 \times 10^{-8} (1-\alpha) \varepsilon \frac{T_w^4 - T_s^4}{T_w - T_s}, \tag{3-225}$$

where ε is the emissivity.

$$D_{fhl} = D_{fhl}' F_{dfhl}, \tag{3-226}$$

where

$$D_{fhl}' = 0 \qquad \text{for} \quad \alpha_t > 0.05 \text{ or } V_{dif2} \le 0, \tag{3-227}$$

$$D_{fhl}' = max\{0, D_{fhl}''\} \qquad \text{for} \quad \alpha_t \le 0.05 \text{ or } V_{dif2} > 0, \tag{3-228}$$

$$\alpha_t = (1 - a) \min [1, \max \{E_{eq}, 0.07\}], \tag{3-229}$$

$$E_{eq} = 0 \qquad \text{for} \quad |u_g| \le u_{en}, \tag{3-230}$$

$$E_{eq} = 1 - exp\{-0.23 (|u_g| - u_{en})\} \qquad \text{for} \quad |u_g| > u_{en}, \tag{3-231}$$

$$u_{en} = 3.65 \left(\frac{\Delta\rho\sigma}{\rho_g^2} \right)^{0.25}, \tag{3-232}$$

$$V_{dif2} = |u_g - u_l|^2, \tag{3-233}$$

$$D_{fhl}'' = 0.2 D_{fhlp} \frac{T_w - T_s}{T_w - T_l}, \tag{3-234}$$

$$D_{fhlp} = C_1 C_2 \alpha_t^{0.6667} B^{0.25}, \tag{3-235}$$

$$B = \frac{g \rho_l \rho_g H_{fgp} k_l^3}{|T_w - T_s| \mu_g \delta}, \tag{3-236}$$

$$\delta = \frac{We\sigma}{\rho_g V_{dif2}} \tag{3-237}$$

and the constants C_1, C_2, We and F_{dfhl} are respectively 1.0, 1.2760, 4.0 and 1.0.

(1-8) film boiling [3-10, 17] (IDREG = 4)

(*a*) $\alpha \leq \alpha_{cut}$

$$H_g = max\ \{H_{fbb}, H_{fbdr}\}, \tag{3-238}$$

$$H_l = H_{rl}\frac{T_w - T_s}{T_w - T_l} + D_{fhl}, \tag{3-239}$$

(*b*) $\alpha > \alpha_{cut}$

$$H_l = Hinter\,(\alpha_{cut}, \alpha_3, H_l \text{ of Eq. (3-239)}, 0, \alpha), \tag{3-240}$$

$$H_g = Hinter\,(\alpha_{cut}, \alpha_2, H_g \text{ of Eq. (3-238)}, H_{gs,\ \alpha v}, \alpha), \tag{3-241}$$

The selection logic of heat transfer mode is outlined in the flow chart shown in Fig.3.5.

(2) modification for total heat flux

In case of the void fraction smaller than 0.15, the heat transfer coefficients obtained above are slightly modified according to the following relations. This modification is performed after the heat transfer mode is determined as shown in Fig.3.5.

$$H_g = \max\left\{0, \frac{Q_{g1}}{DT_{g1}}\right\} \tag{3-242}$$

and

$$H_l = \max\left\{0, \frac{Q_{l1}}{DT_{l1}}\right\}, \tag{3-243}$$

where

$$DT_{g1} = max\ \{10^{-10}, |T_w - T_g|\}\ sgn\ (T_w - T_g), \tag{3-244}$$

$$DT_{l1} = max\ \{10^{-10}, |T_w - T_l|\}\ sgn\ (T_w - T_l), \tag{3-245}$$

$$Q_{g1} = Hinter\ (0.01, 0.15, 0, H_g(T_w - T_g), \alpha) \quad \text{for} \quad 0.15 > \alpha > 0.01, \tag{3-246}$$

$$Q_{g1} = 0 \quad \text{for} \quad 0.01 \geq \alpha \tag{3-247}$$

and

$$Q_{l1} = H_l(T_w - T_l) + H_g(T_w - T_g) - Qg_1. \tag{3-248}$$

(3) subcool boiling [3-14]

The heat transfer coefficient H_{sb} for subcool boiling is defined in terms of H_{nucb} for nucleate boiling. The subcool boiling model is not shown in Figs.3.4 and 3.5, since this model is included in the single-phase liquid heat transfer mode.

$$H_{sb} = 0.1 H_{nucb} \min\left\{\frac{T_w - T_s}{T_w - T_l}, 1\right\}. \tag{3-249}$$

3.4.4 DRIFT FLUX

The drift flux model [3-19] used in the 1VD model is a separated-flow model in which attention is focused on the relative motion rather than on the motion of the individual phase as described in Section 3.1.2. The relative motion is given as the drift flux j_{gl} by empirical correlations. In MINCS, the drift flux is obtained by the modified Bennet flow regime map shown in Fig.3.6, and is turned into the relative velocity u_{gl} as

$$u_{gl} = \frac{j_{gl}}{\alpha(1-\alpha)}. \tag{3-250}$$

(1) stratified flow

$$j_{gl} = 0. \tag{3-251}$$

(2) annular flow

$$j_{gl} = \frac{\alpha(1-\alpha)}{A}\left\{u_l + \left(A + \frac{\alpha\rho_g}{\rho_m}\right)B\right\}, \tag{3-252}$$

where

$$A = \left\{\frac{\rho_g(76-75\alpha)}{\rho_l\alpha^{1/2}}\right\}^{1/2} \tag{3-253}$$

and

$$B = \left\{\frac{(\rho_l-\rho_g)D(1-\alpha)}{0.0015\rho_l}\right\}^{1/2}. \tag{3-254}$$

(3) bubbly flow

$$j_{gl} = 1.53\alpha\left\{\frac{(\rho_l-\rho_g)g\sigma}{\rho_l^2}\right\}^{1/4}. \tag{3-255}$$

(4) droplet flow

$$j_{gl} = 1.4\alpha(1-\alpha)^2\left\{\frac{(\rho_l-\rho_g)g\sigma}{\rho_g^2}\right\}^{1/4}. \tag{3-256}$$

3.4.5 DYNAMIC PRESSURE FORCE

The pressure differences between each phase and the interface are defined as the differences of static heads in the case of stratified flow. It depends on the shape of flow channel.

3.4.5.1 HORIZONTAL FLOW

(1) stratified flow

(a) rectangular channel

$$p_g - p_i = -\frac{1}{2}\alpha\rho_g Hg \tag{3-257}$$

and

$$p_l - p_i = \frac{1}{2}(1-\alpha)\rho_l Hg, \tag{3-258}$$

where H is the height of channel.

(b) cylindrical channel

$$p_g - p_i = -\frac{gDh}{2\pi}\rho_g\left\{\pi\cos\frac{\theta}{2} + \frac{2}{3\alpha}\sin^3\frac{\theta}{2}\right\} \tag{3-259}$$

and

$$p_l - p_i = \frac{gDh}{2\pi}\rho_l\left\{\frac{2}{3(1-\alpha)}\sin^3\frac{\theta}{2} - \pi\cos\frac{\theta}{2}\right\}. \tag{3-260}$$

(2) bubbly flow

$$p_g - p_i = p_l - p_i = \frac{1}{2}\rho_g\left(u_g - u_l\right)^2. \tag{3-261}$$

(3) droplet flow

$$p_g - p_i = p_l - p_i = \frac{1}{2}\rho_l\left(u_g - u_l\right)^2. \tag{3-262}$$

(4) continuous model

$$p_g - p_i = (1 - E_d - E_b)\,(p_g - p_i)_s + E_b\,(p_g - p_i)_b + E_d\,(p_g - p_i)_d \tag{3-263}$$

and

$$p_l - p_i = (1 - E_d - E_b)\,(p_l - p_i)_s + E_b\,(p_l - p_i)_b + E_d\,(p_l - p_i)_d\ , \tag{3-264}$$

where the subscripts s, b and d denote the stratified, bubbly and droplet flow regime, respectively.

3.4.5.2 VERTICAL FLOW

(1) annular flow

$$p_g - p_i = \frac{1}{2}\alpha\rho_g\frac{\rho_g}{\rho_l}\left(u_g - u_l\right)^2 \tag{3-265}$$

and

$$p_l - p_i = -\frac{1}{2}(1-\alpha)\rho_g\left(u_g - u_l\right)^2. \tag{3-266}$$

(2) bubbly flow

$$p_g - p_i = p_l - p_i = \frac{1}{2}\rho_g\left(u_g - u_l\right)^2. \tag{3-267}$$

(3) droplet flow

$$p_g - p_i = p_l - p_i = \frac{1}{2}\rho_l\left(u_g - u_l\right)^2. \tag{3-268}$$

(4) continuous model

$$p_g - p_i = (1 - E_d - E_b)\,(p_g - p_i)_a + E_b (p_g - p_i)_b + E_d\,(p_g - p_i)_d\,, \tag{3-269}$$

and

$$p_l - p_i = (1 - E_d - E_b)\,(p_l - p_i)_a + E_b\,(p_l - p_i)_b + E_d\,(p_l - p_i)_d\,, \tag{3-270}$$

where the subscript a denotes the annular flow regime.

3.4.6 ADDED MASS FORCE

The coefficients of added mass force term are also determined according to the flow regime.

(1) stratified and annular flow

$$C_{vm} = 0 \tag{3-271}$$

and

$$\lambda_d = 0. \tag{3-272}$$

(2) bubbly flow

$$C_{vm} = \frac{1}{2} \tag{3-273}$$

and

$$\lambda_d = max\,\{2 - 7\alpha,\, 0\}. \tag{3-274}$$

(3) droplet flow

$$C_{vm} = \frac{1}{2} \tag{3-275}$$

and

$$\lambda_d = max\,\{13.3\alpha - 11.3,\, 0\}. \tag{3-276}$$

(4) continuous model

(a) $\alpha_c > \beta_d > max\,\{\beta_c, \alpha_b\}$ or $\beta_c > \alpha_b > max\,\{\alpha_c, \beta_d\}$

$$C_{vm} = \frac{1}{2}\left(E_d + E_b\right) \tag{3-277}$$

and

$$\lambda_d = E_d (\lambda_d)_d + E_b (\lambda_d)_b . \tag{3-278}$$

(b) other than the case of (a)

$$C_{vm} = 0 \tag{3-279}$$

and

$$\lambda_d = 0. \tag{3-280}$$

3.5. SPECIFIC MODELS

3.5.1 CRITICAL FLOW

The critical flow is established at specified velocity points. The homogeneous equilibrium model is applied. That is, the critical mass velocity is determined by the pressure and the enthalpy, then, it is divided by the mixture density to obtain the phasic critical velocity. By multiplying the discharge coefficient, the critical flow velocity is determined.

3.5.2 SUBCOOL BOILING

The subcool boiling model is applied when the wall temperature is higher than the saturation temperature and the liquid phase is in the subcooled condition. In this model, the heat from the wall to the liquid phase is assumed to be used not only to increase the temperature of liquid phase but also to give rise to boiling.

The heat flux related to the subcool boiling is

$$q_{sb} = (A_{wgh} + A_{wlh}) \lambda_{sb} (T_w - T_l) , \tag{3-281}$$

and the vapor generation rate due to subcool boiling is

$$\Gamma_{sb} = \frac{q_{sb}}{h_{fg}}. \tag{3-282}$$

The heat from the wall to the fluid is not altered by using this model, thus, the mixture energy equation remains the same. However, q_{sb} is subtracted from the liquid energy equation, and Γ_{sb} is added to the liquid energy equation.

3.6 PUMP

3.6.1 PUMP CHARACTERISTICS

The characteristics of a pump is described by the "four-quadrant curves". The four-quadrant curves, which are empirical, give the pump head and the hydraulic torque as functions of volumetric flow and pump speed. However, "homologous curves" made from the four-quadrant curves are used in actual calculations [3-20, 21]. The homologous curves determine the pump head ratio and the pump torque ratio as functions of volumetric flow ratio and pump speed ratio.

3.6.2 TWO-PHASE TREATMENT

The pump head and the torque in the two-phase condition are different from those in the single-phase condition. The two-phase condition corresponds to the average void fraction α from 0.2 to 0.9. In this region, the degraded head $H_{2\phi}$ and the degraded torque $T_{2\phi}$ are used. To obtain the pump head or the head ratio H and the pump torque or the torque ratio T over the whole range of void fraction, the two-phase multiplier $M(\alpha)$, $0 \le M(\alpha) \le 1$, is used:

$$H = H_{1\phi} - M_h(\alpha)(H_{1\phi} - H_{2\phi}), \tag{3-283}$$

$$T = T_{1\phi} - M_t(\alpha)(T_{1\phi} - T_{2\phi}), \tag{3-284}$$

or

$$H = H_{1\phi}(1 - M_h(\alpha)), \tag{3-285}$$

$$T = T_{1\phi}(1 - M_t(\alpha)), \tag{3-286}$$

where $H_{1\phi}$ and $T_{1\phi}$ are the head and the torque for the single phase flow, respectively.

The homologous curves are classified into eight types according to the dependent and the independent variables. This classification is shown in Table 3.1. The pump data in two-phase condition are based on the data of Semiscale 1-(1/2) Loop Model and those of the Westinghouse Canada Limited [3-20, 21]. The single-phase and two-phase homologous head curves are shown in Fig.3.7 and 3.8, respectively, for the two-phase condition. The difference between the data for single-phase and those for two-phase are used as the right hand side of Eqs. (3-283) and (3-284).

3.6.3 PRESSURE DIFFERENCE

The pressure difference is given by

$$\Delta p = \rho g H. \tag{3-287}$$

3.6.4 TRIP

The motor of pump is stopped by the 'on' trip signal, while it is activated by the 'off' trip signal. Two types of trip are prepared to determine the pump speed: one is by interpolating the pump speed tables, the other is by solving the equation of motion.

3.6.5 EQUATION OF MOTION

The equation of motion is

$$I\frac{d\omega}{dt} = -T, \tag{3-288}$$

where I, T and ω are the moment of inertia, total torque and angular velocity, respectively. The solution of this equation is

$$\omega_{t+\Delta t} = \omega_t - \frac{T\Delta t}{I}. \tag{3-289}$$

The energy dissipation is given as ωT.

3.6.6 TOTAL PUMP TORQUE

When the motor is not activated, the total torque T is

$$T = T_h + T_f \,, \tag{3-290}$$

where T_h and T_f are the hydraulic torque and frictional torque, respectively. T_h is given as

$$T_h = T_h^o \frac{\rho}{\rho_R}, \tag{3-291}$$

where T^o_h is the hydraulic torque obtained from the homologous curve, ρ is the density and the subscript R indicates the steady state. T_f is

$$T_f = \Sigma T_{f,i} \left(\frac{|\omega|}{\omega_R} \right)^{i-1} . \tag{3-292}$$

3.6.7 MOTOR

The motor torque T_m is added to the total torque:

$$T = T_h + T_f - T_m \,, \tag{3-293}$$

where T_m is determined by the table data.

3.6.8 LOCKING

Three types of locking condition are prepared. The pump speed is set equal to zero (1) after some elapsed time, (2) when the pump speed exceeds a limiting speed, and (3) when the pump speed exceeds a minimum reversed speed.

3.6.9 HOMOLOGOUS CURVE

Two types of homologous curve data are prepared. The Bingham Pump Company data with a specific speed of 4200 rpm and the Westinghouse Electric Corporation data with a specific speed of 5200 rpm are available for the single-phase condition [3-20, 21].

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Table 3.1 Classification of Homologous Curves

Type	α	ν	ν/α	Independent Variable	Dependent Variable	
					Head	Torque
1	>0	≥0	≤1	ν/α	h/α^2 (HAN)	β/α^2 (BAN)
2	>0	≥0	>1	α/ν	h/ν^2 (HVN)	β/ν^2 (BVN)
3	>0	<0	≥-1	ν/α	h/α^2 (HAD)	β/α^2 (BAD)
4	>0	<0	<-1	α/ν	h/ν^2 (HVD)	β/ν^2 (BVD)
5	≤0	≤0	≤1	ν/α	h/α^2 (HAT)	β/α^2 (BAT)
6	≤0	≤0	>1	α/ν	h/ν^2 (HVT)	β/ν^2 (BVT)
7	≤0	>0	≥-1	ν/α	h/α^2 (HAR)	β/α^2 (BAR)
8	≤0	>0	<-1	α/ν	h/ν^2 (HVR)	β/ν^2 (BVR)

h : Head Ratio H/H_R
ν : Flow Ratio Q/Q_R
α : Speed Ratio ω/ω_R
β : Torque Ratio T/T_R

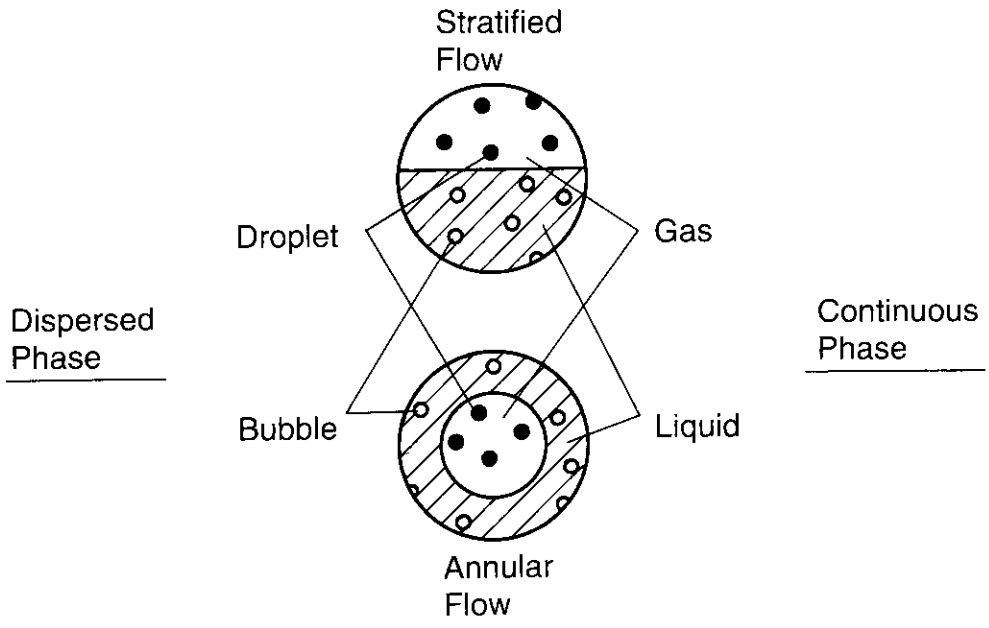


Fig. 3.1 Flow in a Pipe

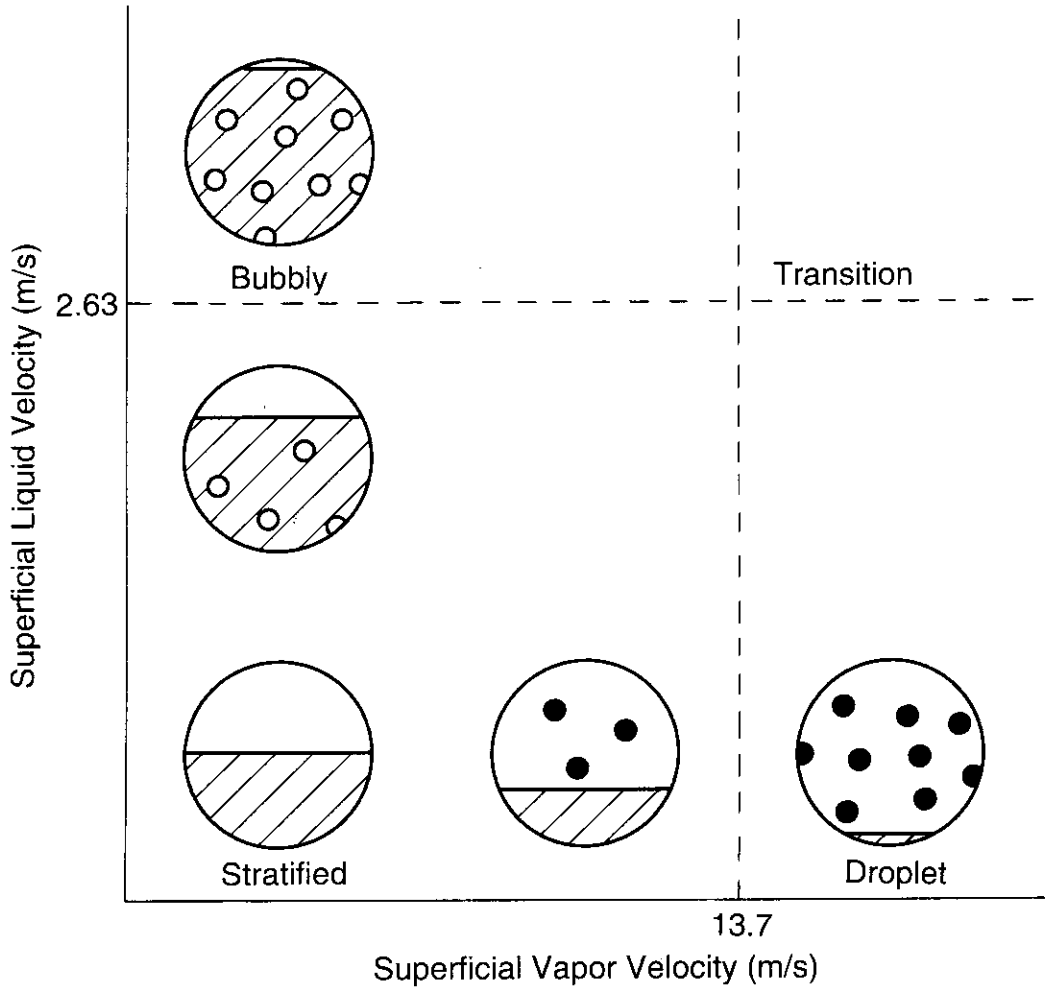


Fig. 3.2 Horizontal Flow Regime Map for Continuous Flow Model

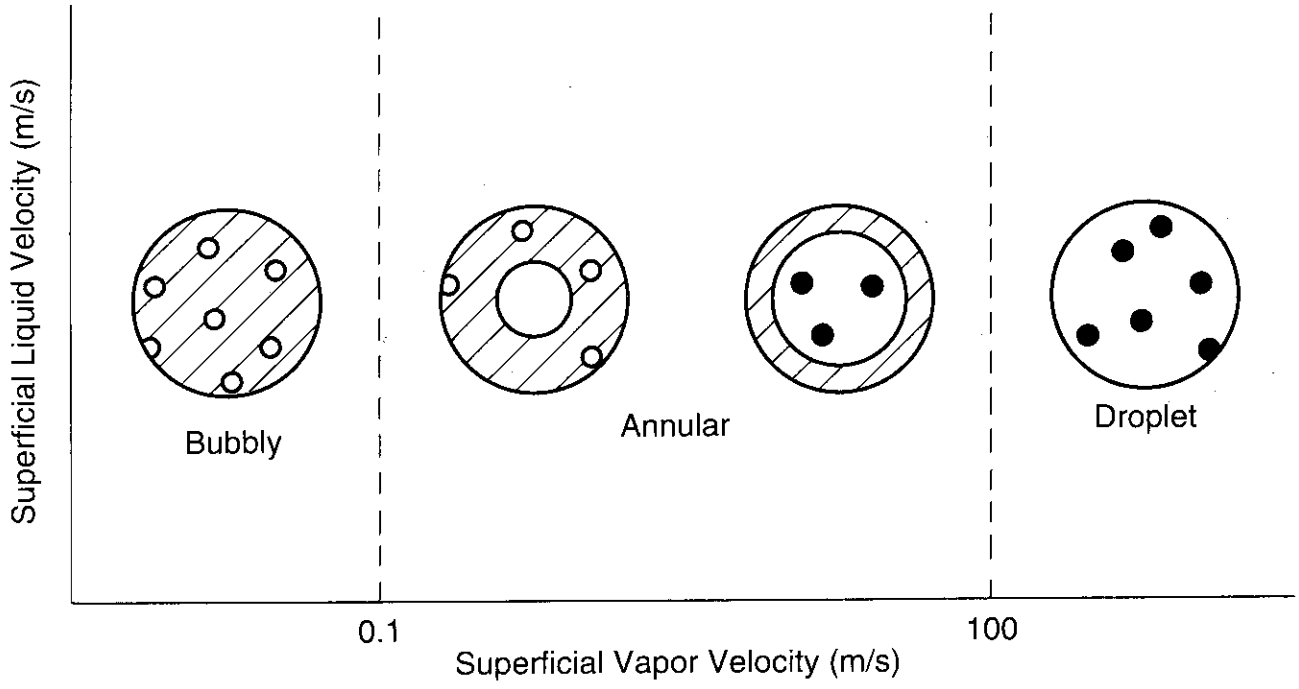


Fig. 3.3 Vertical Flow Regime Map for Continuous Flow Model

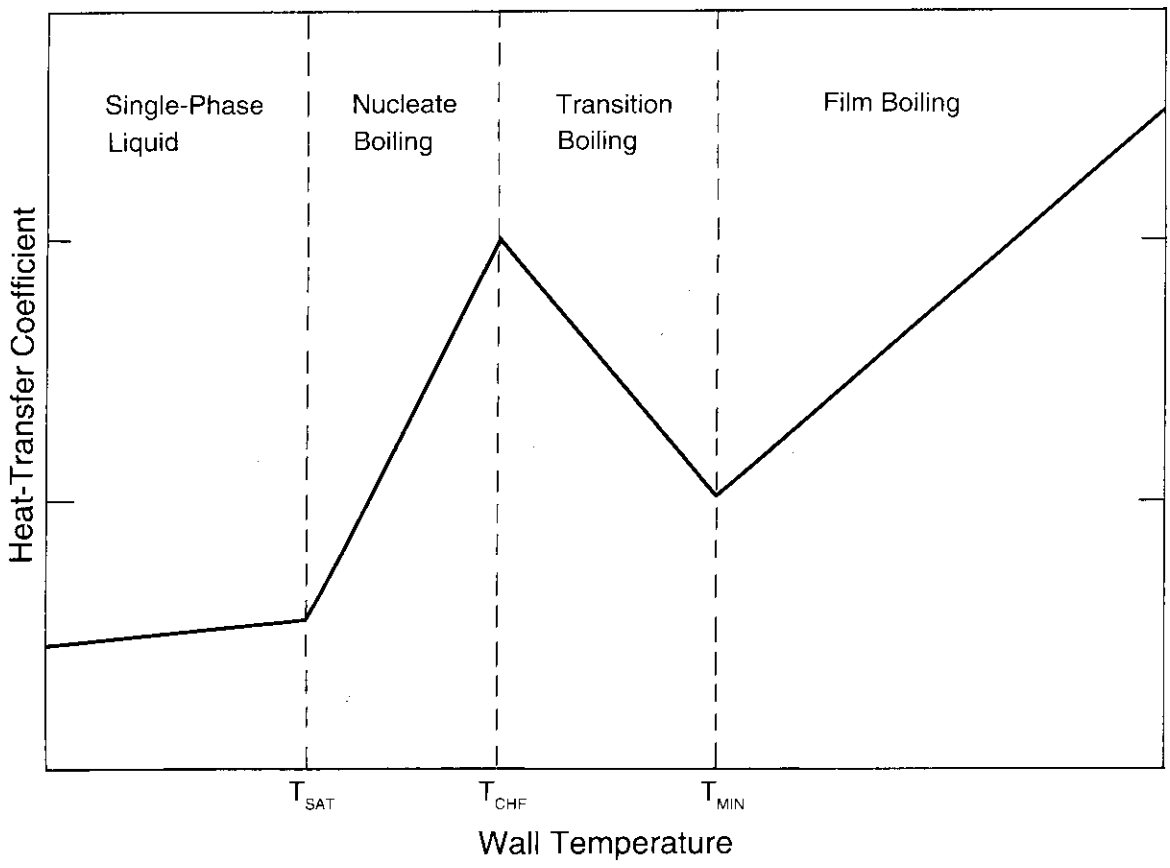


Fig. 3.4 Boiling Mode Curve

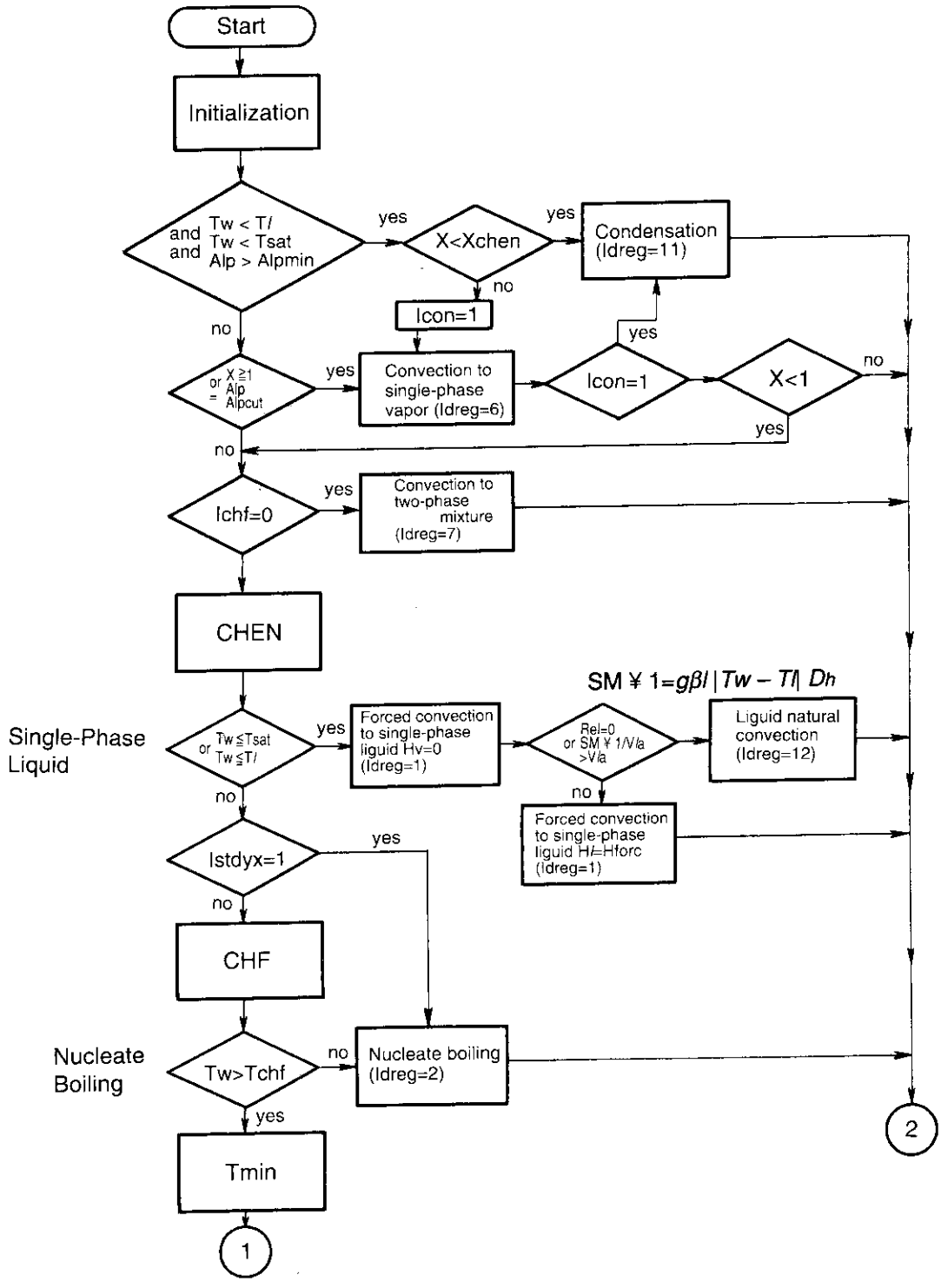


Fig. 3.5 Selection Logic of Heat Transfer mode

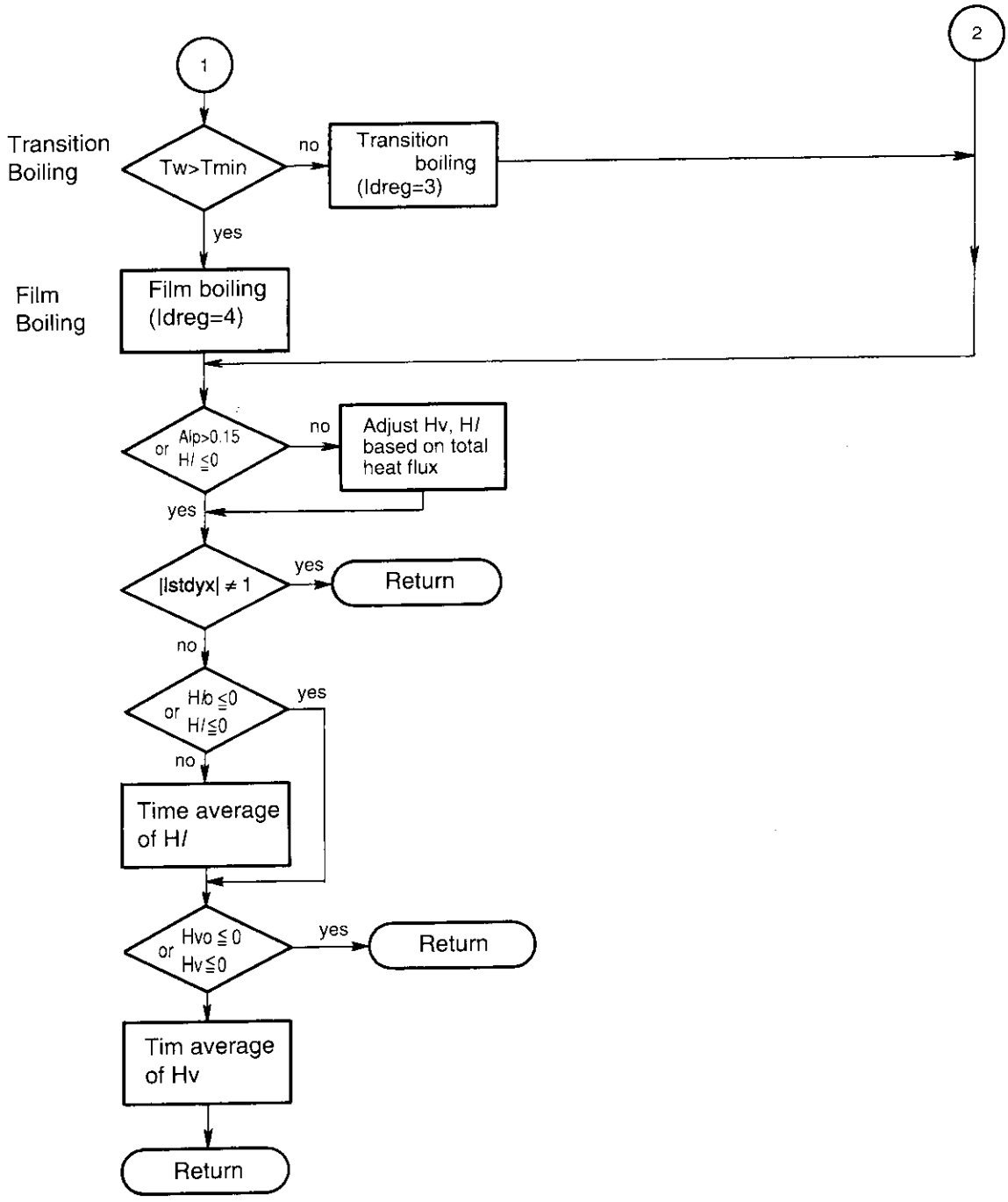


Fig. 3.5 Selection Logic of Heat Transfer mode (continued)

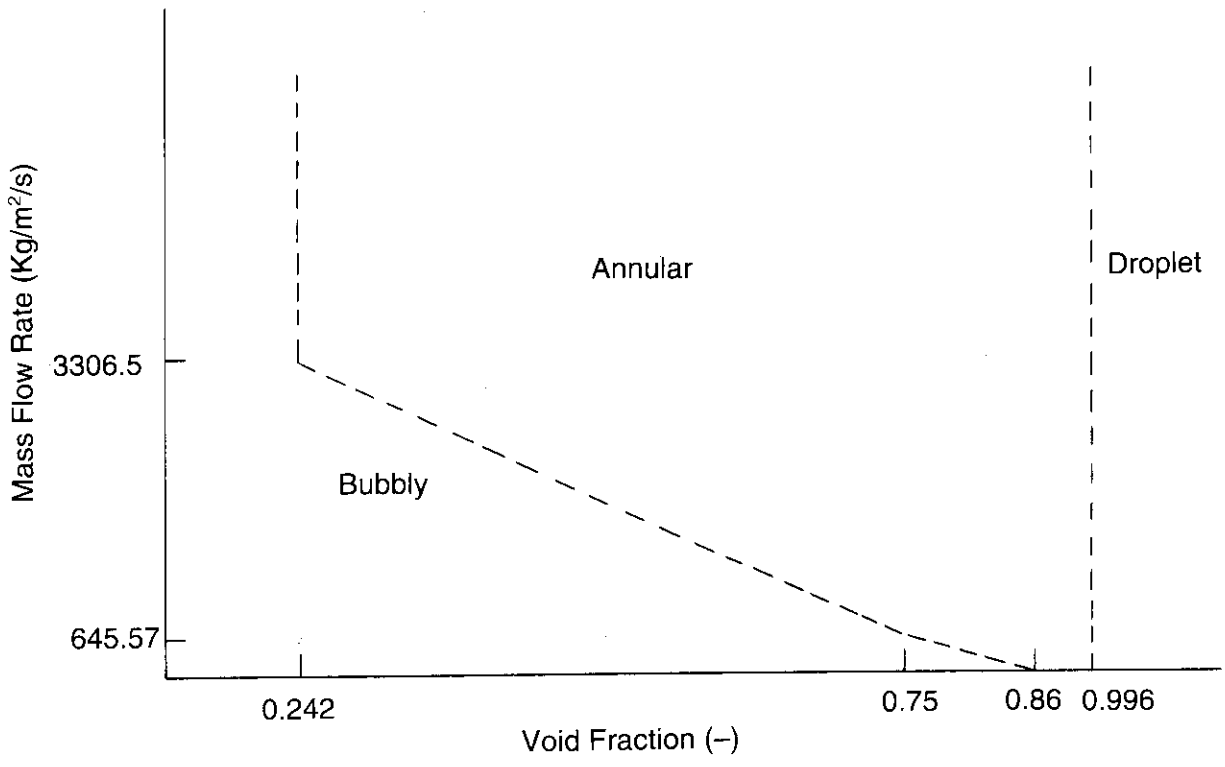


Fig. 3.6 Modified Bennet Flow Regime Map

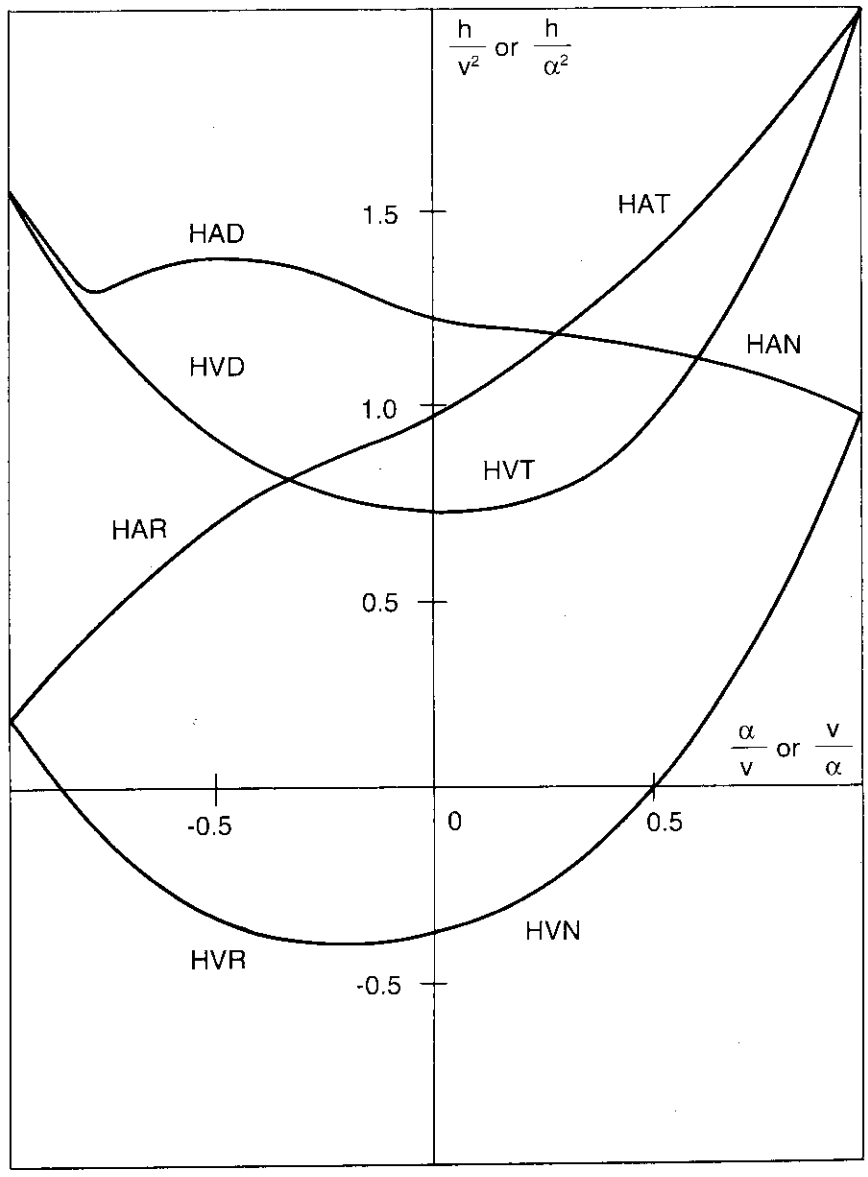


Fig. 3.7 Single-Phase Homologous Head Curves

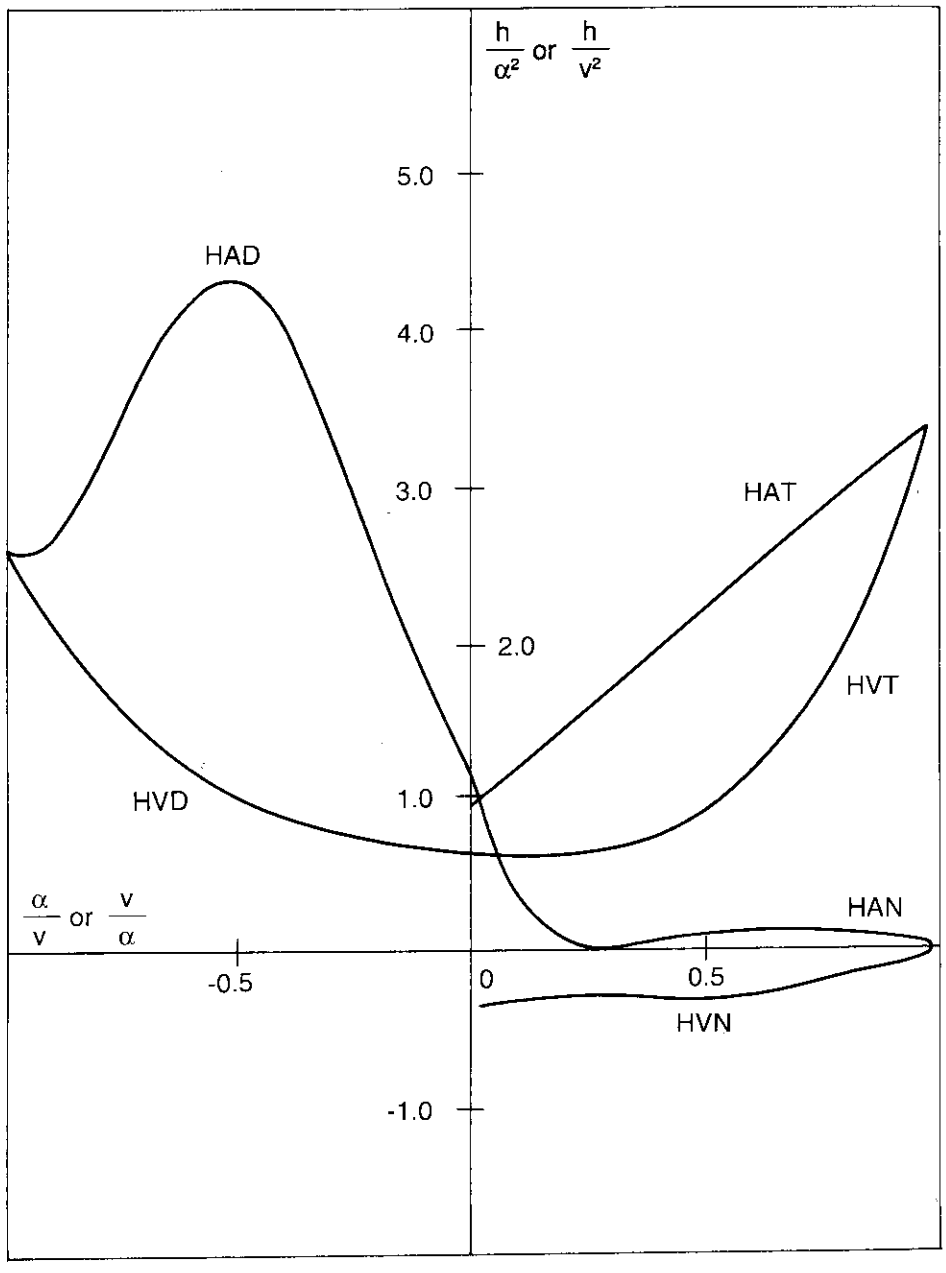


Fig. 3.8 Two-Phase Homologous Head Curves

4. NUMERICAL PROCERDURE

The finite difference method is used to solve the basic differential equations: fluid equations and heat conduction equations. The fully implicit technique is applied to fluid equations except for the terms relating to the constitutive relations describing exchanges between fluids, while the combination of explicit and implicit methods is used to integrate heat conduction equations.

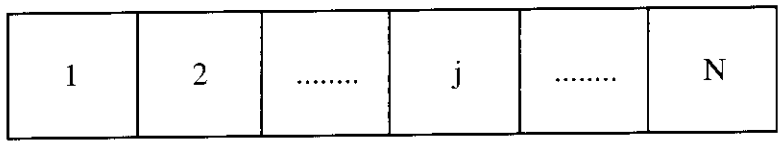
4.1 BASIC METHOD

4.1.1 DISCRETIZED EQUATIONS

4.1.1.1 FLUID EQUATIONS

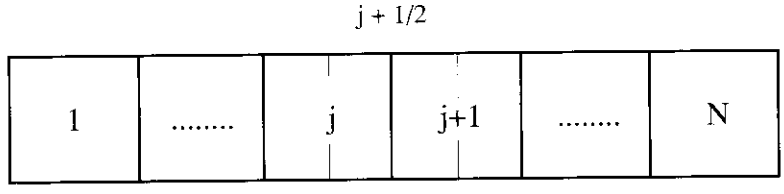
The basic method of spatial discretization for fluid equations is not based on the Taylor series expansion but based on the control volume method. The basic equations are spatially integrated over the control volume and are averaged. The mesh cell configuration for the simple system with a pipe and two boundaries is depicted in Fig. 4.1. The equations for mass and energy conservations are integrated over the cell volume. The momentum conservation equation is however integrated around the cell edge, that is, the control volume is sum of the half cells of left and right cells. At the boundaries, however, only the half cells are used to integrate the momentum equations.

(a) mass and energy



control volume

(b) momentum



control volume

The vector of basic dependent variables is

$$X_j = (\alpha_{gj}, P_j, h_{gj}, h_{lj}, u_{g,\,j+1/2}, u_{l,\,j+1/2})^t = (x_{j\mu}) , \qquad (4\text{-}1)$$

and the discretized equation is

$$A_j\left(X_j^{n+1}, X_{j+1}^{n+1}\right)\left\{G_j\left(X_{j-1}^{n+1}, X_j^{n+1}\right) - G_j\left(X_{j-1}^{n}, X_j^{n}\right)\right\} = \Delta t F_j\left(X_{j-1}^{n+1}, X_j^{n+1}, X_{j-1}^{n+1}\right), \tag{4-2}$$

where

$$A_j = (\alpha_{j\mu\upsilon}),\ G_j = (g_{j\upsilon}),\ F_j = (f_{j\mu}), \tag{4-3}$$

$(\mu = 1, 2, \ldots, 6\ ;\ \upsilon = 1, 2, \ldots, 8\ ;\ j = 1, 2, \ldots, N)$.

(1) convective term

The convective terms in momentum equations are treated as

$$u\left.\frac{\partial u}{\partial z}\right|_{j+1/2} = u_{j+1/2}\frac{u_{j+1} - u_j}{\left(\Delta z_{j+1}/2\right) + \left(\Delta z_j/2\right)}. \tag{4-4}$$

In the above equation, u_j is defined as the combination of central differencing and upwind differencing.

$$u_j = \frac{1}{2A_j}\left\{\left(A_{j-1/2}u_{j-1/2} + A_{j+1/2}u_{j+1/2}\right) + \theta \bullet sgn\left(u_{j+1/2}\right)\left(A_{j-1/2}u_{j-1/2} - A_{j+1/2}u_{j+1/2}\right)\right\}, \tag{4-5}$$

where A_j and θ are the cross sectional area and the upwind degree, respectively. Thus, u_j agrees to central differencing if θ is set equal to zero, and to upwind differencing if θ is set equal to unity.

The convective term at the leftmost edge is defined as

$$u\left.\frac{\partial u}{\partial z}\right|_{j+1/2} = u_{j+1/2}\frac{u_{j+1} - u_{j+1/2}}{\left(\Delta z_{j+1}/2\right)}, \tag{4-6}$$

that is, the control volume at the both sides of the pipe component is defined as half the mesh cell volume as shown in Fig. 4.1.

(2) mass and energy flux term

The mass flux and the energy flux are defined by upwind differencing.

$$\frac{1}{A}\frac{\partial}{\partial z}\left(\alpha_k\rho_k u_k A\right) = \frac{1}{V_j}\left(A_{j+1/2} < \alpha_k\rho_k u_k >_{j+1/2} - A_{j-1/2} < \alpha_k\rho_k u_k >_{j-1/2}\right), \tag{4-7}$$

$$< \alpha_k\rho_k u_k >_{j+1/2} = \frac{1}{2}\left\{\left(\alpha_k\rho_k\right)_{j+1}\left(u_{k,j+1/2} - \left|u_{k,j+1/2}\right|\right) + \left(\alpha_k\rho_k\right)_j\left(u_{k,j+1/2} + \left|u_{k,j+1/2}\right|\right)\right\},$$

where V_j is the volume of j-th cell.

$$\frac{1}{A}\frac{\partial}{\partial z}\left\{\alpha_k\rho_k u_k\left(h_k+\frac{u_k^2}{2}\right)A\right\}=\frac{1}{V_j}\left(A_{j+1/2}<\alpha_k\rho_k\left(h_k+\frac{u_k^2}{2}\right)u_k>_{j+1/2}\right. \tag{4-8}$$

$$\left.-A_{j-1/2}<\alpha_k\rho_k\left(h_k+\frac{u_k^2}{2}\right)u_k>_{j-1/2}\right),$$

$$<\alpha_k\rho_k\left(h_k+\frac{u_k^2}{2}\right)u_k>_{j+1/2}=\frac{1}{2}\left\{\left(\alpha_k\rho_k\left(h_k+\frac{u_k^2}{2}\right)_{j+1}\left(u_{k,j+1/2}-\left|u_{k,j+1/2}\right|\right)\right.\right.$$

$$\left.\left.+\left(\alpha_k\rho_k\left(h_k+\frac{u_k^2}{2}\right)_{j}\left(u_{k,j+1/2}+\left|u_{k,j+1/2}\right|\right)\right)\right\}.$$

(3) added mass force term

The relative velocity appears in the added mass force term. The relative velocity terms are not directly discretized. They are separated at first:

$$\left(u_c-u_d\right)\frac{\partial}{\partial z}\left(u_c-u_d\right)=u_c\frac{\partial u_c}{\partial z}-u_c\frac{\partial u_d}{\partial z}-u_d\frac{\partial u_c}{\partial z}+u_d\frac{\partial u_d}{\partial z}, \tag{4-9}$$

and then, are discretized by using upwind differencing.

4.1.1.2 HEAT CONDUCTION EQUATIONS

The one-dimensional heat conduction equation is solved by the implicit finite difference method. The temperature is defined at the cell edge, while other variables are at the cell center. The mesh cell configuration is shown in Fig. 4.2. The discretized equation is

$$\left(\rho C_p\right)_{j-1/2}^{n}\frac{T_{j-1/2}^{n-1}-T_{j-1/2}^{n}}{\Delta t}=\theta\left\{a_{j-1/2}^{n}T_{j-3/2}^{n+1}-b_{j-1/2}^{n}T_{j-1/2}^{n+1}+c_{j-1/2}^{n}T_{j+1/2}^{n+1}+S_{j-1/2}^{n+1}\right\}$$

$$+(1-\theta)\left\{a_{j-1/2}^{n}T_{j-3/2}^{n}-b_{j-1/2}^{n}T_{j-1/2}^{n}+c_{j-1/2}^{n}T_{j+1/2}^{n}\right.$$

$$\left.+S_{j-1/2}^{n}\right\}, \tag{4-10}$$

where $(\rho C_p)_{j-1/2}$ is the volume weighted average of and $(\rho C_p)_{j-1}$ and $(\rho C_p)_j$, and θ is implicit degree. The tridiagonal matrix equation is

$$a'_{j-1/2}T_{j-3/2}^{n+1}+b'_{j-1/2}T_{j-1/2}^{n+1}+c'_{j-1/2}T_{j-1/2}^{n+1}=d'_{j-1/2}. \tag{4-11}$$

The solution of the matrix equation is

$$T_{j-1/2}^{n+1}=e_{j-1/2}-f_{j-1/2}T_{1/2}^{n+1}-g_{j-1/2}T_{N+1/2}^{n+1}, \tag{4-12}$$

where, $T_{1/2}$ and $T_{N+1/2}$ are the boundary temperatures.

The calculation of heat conduction can be coupled with the fluid calculations. The boundary conditions for heat conduction equations are

(a) implicit coupling with fluid equations,

(b) explicit coupling with fluid equations,

(c) constant boundary temperature,

(d) adiabatic,

(e) heat transfer coefficients and bulk temperatures.

4.1.2 SOLUTION TECHNIQUE

The values of dependent variables at n + 1 time step, X_j^{n+1}, are calculated from the values at n time step, X_j^n, by Newton's method. Let $X_j^{(k)}$ be the (k)-th iteration values of Newton's method and $\delta X_j^{(k)}$ be the difference between (k)-th and (k + 1)-th iteration, the discretized equation is

$$\begin{aligned} &A_j\left(X_j^{(k)}+\delta X_j^{(k)}, X_{j+1}^{(k)}+\delta X_{j+1}^{(k)}\right)\left[G_j\left(X_{j-1}^{(k)}+\delta X_{j-1}^{(k)}, X_j^{(k)}+\delta X_j^{(k)}\right)-G_j\left(X_{j-1}^n, X_j^n\right)\right] \\ &\quad=\Delta t F_j\left(X_{j-1}^{(k)}+\delta X_{j-1}^{(k)}, X_j^{(k)}+\delta X_j^{(k)}, X_{j+1}^{(k)}+\delta X_{j+1}^{(k)}\right). \end{aligned} \tag{4-13}$$

The above equation is expanded by Taylor's method and higher order terms are dropped. The increment, $\delta X_j^{(k)}$, is thus obtained by the linear algebraic equation

$$\begin{aligned} &\left[\left(\frac{\partial a_{j\mu\nu}}{\partial X_{l\beta}}\right)^{(k)}\left(g_{j\nu}^{(k)}-g_{j\nu}^n\right)+a_{j\mu\nu}^{(k)}\left(\frac{\partial g_{j\nu}}{\partial X_{l\beta}}\right)^{(k)}-\Delta t\left(\frac{\partial f_{j\mu}}{\partial X_{l\beta}}\right)^{(k)}\right]\delta X_{l\beta} \\ &\quad=\Delta t f_{j\mu}^{(k)}-a_{j\mu\nu}^{(k)}\left(g_{j\nu}^{(k)}-g_{j\nu}^n\right), \end{aligned} \tag{4-14}$$

where ν and β are vector indices and l denotes the mesh number. Since $g_{j\upsilon}$ is the function of X_{j-1} and X_j, $a_{j\mu\upsilon}$ of X_j and X_{j+1}, and $f_{j\mu}$ of X_{j-1}, X_j and X_{j-1}, the Jacobian in Eq. (4-14) is obtained as the three blocks:

$$\begin{aligned} A_{j\alpha\beta}&=a_{j\alpha\nu}^{(k)}\left(\frac{\partial g_{j\nu}}{\partial X_{j-1\beta}}\right)^{(k)}-\Delta t\left(\frac{\partial f_{j\nu}}{\partial X_{j-1\beta}}\right)^{(k)}, \\ B_{j\alpha\beta}&=a_{j\alpha\nu}^{(k)}\left(\frac{\partial g_{j\nu}}{\partial X_{j\beta}}\right)^{(k)}-\Delta t\left(\frac{\partial f_{j\alpha}}{\partial X_{j\beta}}\right)^{(k)}+\left(\frac{\partial a_{j\alpha\nu}}{X_{j\beta}}\right)^{(k)}\left(g_{j\nu}^{(k)}-g_{j\nu}^n\right), \\ C_{j\alpha\beta}&=-\Delta t\left(\frac{\partial f_{j\alpha}}{\partial X_{j+1\beta}}\right)^{(k)}+\left(\frac{\partial a_{j\alpha\nu}}{\partial X_{j+1\beta}}\right)^{(k)}\left(g_{j\nu}^{(k)}-g_{j\nu}^n\right). \end{aligned} \tag{4-15}$$

The Jacobian is obtained analytically in Ref. 4-1. Equation (4-14) is, thus, written as the block tridiagonal matrix equation shown below. This discretized equation is solved by LU decomposition method.

$$\begin{bmatrix} B_{1\alpha\beta} & C_{1\alpha\beta} & . & . & . & 0 \\ A_{2\alpha\beta} & B_{2\alpha\beta} & C_{2\alpha\beta} & . & . & . \\ . & . & . & . & . & . \\ . & A_{j\alpha\beta} & B_{j\alpha\beta} & C_{j\alpha\beta} & . & . \\ . & . & . & . & . & . \\ . & . & . & . & A_{N\alpha\beta} & B_{N\alpha\beta} \end{bmatrix} \begin{bmatrix} \delta X_1 \\ \delta X_2 \\ . \\ \delta X_j \\ . \\ \delta X_N \end{bmatrix} = \begin{bmatrix} H_1 \\ H_2 \\ . \\ H_j \\ . \\ H_N \end{bmatrix}, \quad (4\text{-}16)$$

where H is the right hand side in Eq. (4-14).

4.1.3 NON-2V2T MODEL

The numbers of basic equations and dependent variables for non-2V2T models are different from those for the 2V2T model. In the non-2V2T models, however, the same discretized equations can be used as in the 2V2T model. In the 1VD model, for instance, the mixture momentum equation is the same as in the 2V2T model except for the assumption of equality of phasic pressures, and the other momentum equation is replaced by the equation for the relative velocity. The momentum equation inherent to the 1VD model based on the mixture velocity is not used. The Jacobian calculation for the 1VD model is, thus, the same as for the 2V2T model.

In the non-2V2T models, however, the number of equations is less than six, and the number of basic dependent variables is reduced. The equations in non-2V2T models can be related to the 2V2T equations by variable transformation.

First, the necessary equations are selected from the 2V2T equations by multiplying an operation factor A:

$$AA\,(X^{n+1})[G\,(X^{n+1}) - G\,(X^n)] = A\Delta t F\,(X^{n+1}), \quad (4\text{-}17)$$

Then, the 2V2T variables, X, are transformed into the non-2V2T variables, Y, and the equation for the Newton's iteration is thus,

$$AJ^{(k)}\left(\frac{\partial X}{\partial Y}\right)^{(k)} \delta Y^{(k)} = H(X(Y))^{(k)}, \quad (4\text{-}18)$$

where J is the 2V2T Jacobian in Eq. (4-15), $(\partial X / \partial Y)$ is the Jacobian for variable transformation, and H represents the right hand side in Eq. (4-14). The detailed formulae of $(\partial X / \partial Y)$ is described in Ref. 4-1.

4.2 NETWORK AND SOLUTION METHOD

4.2.1 PREPARATIONS

The following four procedures are performed to avoid the numerical errors due to the large difference of order among dependent variables, and to avoid difficulties when the two-phase system comes closer to the single phase. These difficulties are related to the singularity of the Jacobian matrix.

4.2.1.1 EQUATIONS TO BE SOLVED

The equations for two-phase mixture are convenient to handle in the non-2V2T models, and the mixture equations are always solved even in the 2V2T model. The equations for the less-massive phase are also to be solved in the 2V2T model.

Let the massive phase equations be

$$A = 0 , \tag{4-19}$$

and the less-massive phase equations be

$$b = 0 , \tag{4-20}$$

then, if the equations for mixture and massive phase are to be solved,

$$A + b = 0 , \tag{4-21}$$

$$A = 0 , \tag{4-22}$$

are the basic equations. In this case, the resulting equations may be

$$A + b \fallingdotseq A , \tag{4-23}$$

then, there may be some possibilities that the equation system is nearly singular. The equations for mixture and less-massive phase are thus to be solved in the 2V2T model.

4.2.1.2 PHASIC MOMENTUM EQUATION

The momentum equation for less-massive phase tends to be very small if $\alpha\rho_g$ or $(1-\alpha)\,\rho_l$ goes to be small. That is, the Jacobiam matrix may be singular when the two-phase system comes closer to the single phase. The less-massive momentum equation is thus divided by $\alpha\rho_g$ or $(1-\alpha)\,\rho_l$.

4.2.1.3 TRANSFORMATION OF ENTHALPY

The enthalpy always appears as the product of the volume fraction and the enthalpy itself in the energy equations. If α or $(1-\alpha)$ is very small, a certain column in the Jacobian matrix related to the enthalpy difference tends to be vanished. The enthalpy is thus transformed into the product of the enthalpy and the volume fraction: $(\alpha_k h_k)$. The energy equation is solved in terms of $(\alpha_k h_k)$, and then h_k is obtained.

4.2.1.4 SCALING

The numerical errors and the singularity of matrix resulted from the extraordinaly large values of solutions are avoided by the scaling technique. Scaling is performed in the Newton's method as

$$\begin{bmatrix} a_{11}w_1 & a_{12}w_2 & \cdots & a_{16}w_6 \\ a_{21}w_1 & a_{22}w_2 & \cdots & a_{26}w_6 \\ a_{31}w_1 & a_{32}w_2 & \cdots & a_{36}w_6 \\ a_{41}w_1 & a_{42}w_2 & \cdots & a_{46}w_6 \\ a_{51}w_1 & a_{52}w_2 & \cdots & a_{56}w_6 \\ a_{61}w_1 & a_{62}w_2 & \cdots & a_{66}w_6 \end{bmatrix} \begin{bmatrix} x_1/w_1 \\ x_2/w_2 \\ x_3/w_3 \\ x_4/w_4 \\ x_5/w_5 \\ x_6/w_6 \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \\ b_6 \end{bmatrix} \tag{4-24}$$

The weighting factor w_k is defined as

(1) 1V, 1VD and 2V model

$w_k = 1$ for velocity .

(2) 1T model

$w_k = 10^6$ for pressure ,

$w_k = 10^6$ for mixture enthalpy .

(3) 1.5T model

$w_k = 10^6$ for pressure ,

$w_k = 10^6$ for mixture enthalpy ,

$w_k = 1$ for quality .

(4) 2T model

$w_k = 1$ for void fraction ,

$w_k = 10^6$ for pressure ,

$w_k = 10^6$ for gas enthalpy ,

$w_k = 10^6$ for liquid enthalpy .

4.2.2 TERMINAL MATRIX AND TERMINAL EQUATIONS

The system of MINCS consists of functional units called "module" or "component" and each component is independent of others. The modification of each component can therefore be easily accomplished without referring other components, and it is also easy to add new components to the code system. All components are controlled by the system processor.

The solution procedure of MINCS is based on forward elimination and backward substitution. When we solve the system matrix equation, it is not necessary to use all variables in components, and it is enough to refer only boundary variables of each component relating to boundary equations. The boundary variables are thus solely exchanged between the system processor and each component.

4.2.2.1 FLUID COMPONENT

(1) block tridiagonal matrix equation

At first, the basic equation is discretized

$$A\left(x_{j-1}^{n+1}, x_j^{n+1}, x_{j+1}^{n+1}\right)\left\{g\left(x_{j-1}^{n+1}, x_j^{n+1}, x_{j+1}^{n+1}\right) - g\left(x_{j-1}^{n}, x_j^{n}, x_{j+1}^{n}\right)\right\} = \Delta t f\left(x_{j-1}, x_j, x_{j+1}\right), \tag{4-25}$$

then we obtain the basic equation for Newton method

$$
\begin{aligned}
&\left\{\left(\frac{\partial A}{\partial x_{j-1}}\right)^k\left(g^k-g^n\right)+A^k\left(\frac{\partial g}{\partial x_{j-1}}\right)^k-\Delta t\left(\frac{\partial f}{\partial x_{j-1}}\right)^k\right\}\delta x_{j-1}\\
&+\left\{\left(\frac{\partial A}{\partial x_j}\right)^k\left(g^k-g^n\right)+A^k\left(\frac{\partial g}{\partial x_j}\right)^k-\Delta t\left(\frac{\partial f}{\partial x_j}\right)^k\right\}\delta x_j\\
&+\left\{\left(\frac{\partial A}{\partial x_{j+1}}\right)^k\left(g^k-g^n\right)+A^k\left(\frac{\partial g}{\partial x_{j+1}}\right)^k-\Delta t\left(\frac{\partial f}{\partial x_{j+1}}\right)^k\right\}\delta x_{j+1}\\
&\quad=\Delta t f^k-A^k\left(g^k-g^n\right).
\end{aligned}
\tag{4-26}
$$

The block tridiagonal equation is thus

$$
A_j\delta x_{j-1}+B_j\delta x_j+C_j\delta x_{j+1}=H_j. \tag{4-27}
$$

(2) terminal equation

A pipe component which is in between other two pipes is considered. The pipe component has N cells, and the 1-st cell is assumed to be connected to the left pipe and the N-th cell to the right pipe. Two cells, to which the 1-st cell and N-th cell are connected, are called as the 0-th and (N + 1)-th cells, respectively. The basic equations for the pipe component are

$$
\begin{aligned}
&A_1\delta x_0+B_1\delta x_1+C_1\delta x_2 &&=H_1,\\
&A_2\delta x_1+B_2\delta x_2+C_2\delta x_3 &&=H_2,\\
&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots &&,\\
&A_N\delta x_{N-1}+B_N\delta x_N+C_N\delta x_{N+1} &&=H_N,
\end{aligned}
\tag{4-28}
$$

where δx_0 and δx_{N+1} are the external variables, and thus the equations for the pipe component are

$$
\begin{aligned}
&B_1\delta x_1+C_1\delta x_2 &&=H_1-A_1\delta x_0,\\
&A_2\delta x_1+B_2\delta x_2+C_2\delta x_3 &&=H_2,\\
&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots &&,\\
&A_N\delta x_{N-1}+B_N\delta x_N &&=H_N-C_N\delta x_{N+1}.
\end{aligned}
\tag{4-29}
$$

The above equations are directly solved by multiplying the inverse of the coefficient matrix. We can obtain the solution as

$$
\begin{aligned}
&\delta x_1 &&=R_1+S_1\delta x_0+T_1\delta x_{N+1},\\
&\delta x_2 &&=R_2+S_2\delta x_0+T_2\delta x_{N+1},\\
&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots &&,\\
&\delta x_N &&=R_N+S_N\delta x_0+T_N\delta x_{N+1}.
\end{aligned}
\tag{4-30}
$$

The variables in the pipe component are thus described only by the variables in the external terminals. The coefficient matrix R_i, S_i and T_i are also obtained. This procedure is known as forward elimination.

Forward elimination is performed for other components. We obtain equations for boundary cells such as

$$
-S_1\delta x_0+\delta x_1-T_1\delta x_{N+1}=R_1, \tag{4-31}
$$

$$
-S_N\delta x_0+\delta x_N-T_N\delta x_{N+1}=R_N. \tag{4-32}
$$

These are the terminal equations for the component. The terminal values are obtained by solving all terminal equations with boundary conditions at the same time. These two equations make two rows of the whole matrix equation, and the coefficient matrix of the whole equation system is called as the system matrix.

4.2.2.2 IMPLICIT COUPLING OF HEAT CONDUCTORS

(1) block tridiagonal matrix equation

A heat slab is assumed to be connected to the J-th cell of the pipe component. The heat slab is coupled with the pipe component through the wall heat flux in the energy equation. The increment of the wall temperature δTw appeares in the basic equation of Newton method for fluid when the implicit coupling is used:

$$\begin{aligned}
&B_1\delta x_1 + C_1\delta x_2 && = H_1 - A_1\delta x_0,\\
&A_2\delta x_1 + B_2\delta x_2 + C_2\delta x_3 && = H_2,\\
&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots &&\\
&A_J\delta x_{J-1} + B_J\delta x_J + C_J\delta x_{J+1} && = H_J + \delta H_J\delta Tw_J,\\
&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots &&\\
&A_N\delta x_{N-1} + B_N\delta x_N && = H_N - C_N\delta x_{N+1}.
\end{aligned} \qquad (4\text{-}33)$$

After forward elimination, we obtain

$$\begin{aligned}
\delta x_1 &= R_1 + S_1\delta x_0 + T_1\delta x_{N+1} + U_1\delta Tw_J,\\
\delta x_2 &= R_2 + S_2\delta x_0 + T_2\delta x_{N+1} + U_2\delta Tw_J,\\
&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\\
\delta x_N &= R_N + S_N\delta x_0 + T_N\delta x_{N+1} + U_{N+1}\delta Tw_J.
\end{aligned} \qquad (4\text{-}34)$$

Two rows of the whole equation system are thus

$$-S_1\delta x_0 + \delta x_1 \qquad -T_1\delta x_{N+1} - U_1\delta Tw_J \qquad = R_1, \qquad (4\text{-}35)$$

$$-S_N\delta x_0 \qquad + \delta x_N - T_N\delta x_{N+1} - U_N\delta Tw_J \qquad = R_N. \qquad (4\text{-}36)$$

(2) heat conduction equation

Heat conduction equations for the heat slab are also written as

$$\begin{aligned}
&\beta_2 T_2 + \gamma_2 T_3 && = \delta_2 - \alpha_2 T_1,\\
&\alpha_3 T_2 + \beta_3 T_3 + \gamma_3 T_4 && = \delta_3,\\
&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots &&\\
&\alpha_{M-1} T_{M-2} + \beta_{M-1} T_{M-1} + \gamma_{M-1} T_M && = \delta_{M-1},\\
&\alpha_M T_{M-1} + \beta_M T_M && = \delta_M - \gamma_M T_{M+1}.
\end{aligned} \qquad (4\text{-}37)$$

In the above equation, T_1 and T_{M+1} are the boundary temperatures of the heat slab. The temperatures inside the heat slab can be expressed in terms of the boundary temperatures by forward elimination technique,

$$\begin{aligned}
T_2 &= Q_2 - q_2 T_1 - \gamma_2 T_{M+1},\\
T_3 &= Q_3 - q_3 T_1 - \gamma_3 T_{M+1}.\\
&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\\
T_M &= Q_M - q_M T_1 - T_M T_{M+1}.
\end{aligned} \qquad (4\text{-}38)$$

The equations for two boundary conditions are

$$\beta_1 T_1 + \gamma_1 T_{M+1} = \delta_1 + \varepsilon_L T_L, \tag{4-39}$$

$$\alpha_{M+1} T_1 + \beta_{M+1} T_{M+1} = \delta_{M+1} + \varepsilon_R T_R. \tag{4-40}$$

In the above equations, the first equation is for the case when the left boundary of the heat slab, T_1, is implicitly or explicitly connected to the outside fluid component, and the second equation is for the case when the right boundary, T_{M+1}, is implicitly or explicitly connected to the outside fluid component.

If the left boundary is connected to the J-th cell of the pipe component, T_L is the bulk temperature of the cell and depends on $T_{g,J}$, $T_{l,J}$ and X_j. The basic equation of the Newton method for the boundary temperature is

$$\beta_1 \delta T_1 = \delta_1^{'} + \varepsilon_L \frac{\partial T_L}{\partial X_J} \delta X_J. \tag{4-41}$$

δX_j can be expressed by external terminal values and the wall temperature δT_1, we obtain

$$\beta_1 \delta T_1 = \delta_1^{'} + \varepsilon_L \frac{\partial T_L}{\partial X_J} \left(R_J + S_J \delta X_0 + T_J \delta X_{N+1} + U_J \delta T_1 \right), \tag{4-42}$$

and thus

$$\left(\beta_1 - \varepsilon_L U_J \frac{\partial T_L}{\partial X_J} \right) \delta T_1 - \varepsilon_L \frac{\partial T_L}{\partial X_j} S_J \delta X_0 - \varepsilon_L \frac{\partial T_L}{\partial X_j} T_J \delta X_{N+1} = \delta_1^{'} + \varepsilon_L \frac{\partial T_L}{\partial X_j} R_J, \tag{4-43}$$

where R_J, S_J, T_J and U_J are matrices. This equation is one of the system equations when the fluid component is coupled with the heat slab.

4.2.3 CONVERGENCE CHECK

The iterative calculation is needed to obtain the solution at the new time level since the Newton method is used in MINCS. The convergence of the solution is checked at two stages: in each component and heat conductor, and then in the total system.

4.3.2.1 COMPONENT

The relative error for the component and heat conductor is defined as

$$\varepsilon_c = \left\{ \Sigma \left(\frac{\delta x^k}{\varepsilon_r} \right)^2 \right\}^{1/2}, \tag{4-44}$$

$$\varepsilon_r = max \{ x^k, \varepsilon_{min} \}, \tag{4-45}$$

where δx^k is the increment of k-th iteration, x^k is the value of variable after k-th iteration and ε_{min} is the input value. The convergence in the component is accomplished if the following condition is satisfied

$$\varepsilon_c < \varepsilon_{c0}, \tag{4-46}$$

where ε_{c0} is the input convergence criterion for the component.

4.2.3.2 SYSTEM

The relative error for the fluid system is defined as

$$\varepsilon_S = \{\sum (\varepsilon_C)^2\}^{1/2}. \tag{4-47}$$

The convergence in the total fluid system is accomplished if the following condition is satisfied

$$\varepsilon_s < \varepsilon_{s0}, \tag{4-48}$$

where ε_{S0} is the input convergence criterion for the system.

4.2.4 TIME STEP CONTROL

The time step size is automatically controlled by the time step controller. The time step size is enlarged if the convergence is accomplished, while it is shortened if the convergence is not accomplished within the allowed limit of number of iterations.

4.2.4.1 ENLARGEMENT

The time step size is enlarged by the following relation if the convergence is accomplished:

$$\delta t_{new} = \delta t_{old} \{1 + A \cdot sgn\,(Dn) \mid Dn \mid^{B}\}, \tag{4-49}$$

$$Dn = \frac{n_{mean} - n + D}{n}, \tag{4-50}$$

where n is the number of iteration needed for the last iteration, and n_{mean} is averaged number needed for the former iteration. In the above equations, A, B and D are the constants which are set to 0.8, 1.0 and 3.0, respectively.

4.2.4.2 SHORTENING

The time step size is shortened according to the following relation if the convergence is not accomplished:

(1) first and second shortening

$$\delta t_{new} = \delta t_{old} \frac{1}{\sqrt{2}}, \tag{4-51}$$

(2) after third shortening

$$\delta t_{new} = \delta t_{old} \frac{1}{2}. \tag{4-52}$$

4.3 SINGLE PHASE TREATMENT

Two types of treatments are used for single-phase calculation or phase transition. One is to reset the void fraction or quality to their maximum or minimum values when they are out of their ranges. This kind of treatment is performed at every iteration stages in the Newton method for the 1T and 1.5T models. It is, however, applied only at the input stage for the 2T model. The other way to handle phase transition is to modify the void-fraction related variables in the basic equations.

4.3.1 RESET OF VOID FRACTION OR QUALITY

(1) 1T model

The quality is reset to the minimum value if the mixture enthalpy is smaller than the saturated liquid enthalpy or the mixture density is larger than the saturated liquid density. On the other hand, it is reset to the maximum value if the mixture enthalpy is larger than the saturated gas enthalpy or the mixture density is smaller than the saturated gas density. The minimum and the maximum values of quality are calculated from those of void fraction. The reset of quality is performed at every iteration stages of Newton method.

(2) 1.5T model

The quality is reset to zero if it becomes smaller than zero. It is reset to unity if it becomes larger than unity. This treatment is however not necessary since the quality cannot be out of its range so long as the modified variables are used. The reset of quality is performed at every iteration stages of Newton method.

(3) 2T model

The void fraction is reset to its minimum or maximum values if it is out of range at the input stage. The reset of void fraction is performed only at the input stage.

4.3.2 MODIFICATION OF VARIABLES

The main part of the treatment of phase transition is to modify the void-fraction related variables in the basic equations when the void fraction comes closer to zero or unity. The void fraction is substituted by functions of void fraction $s(\alpha)$. These functions are almost the same as the void fraction itself. The void-fraction related variables are multiplied by other functions of void fraction $r(\alpha)$. These functions are almost unity. The meanings of these functions are as follows.

$s_g(\alpha)$: This function is almost the same as α,
but differs from α around $\alpha = 1$.
It is used for α in the gas equations.

$s_l(\alpha)$: This function is almost the same as α,
but differs from α around $\alpha = 0$.
It is used for α in the liquid equations.

$s_{ig}(\alpha)$: This function is almost the same as α,
but differs from α around $\alpha = 0$ and
$\alpha = 1$. It is used for α in the gas equations.

$s_{il}(\alpha)$: This function is almost the same as α,
but differs from α around $\alpha = 0$ and $\alpha = 1$.
It is used for α in the liquid equations.

$r_g(\alpha)$: This function is almost unity, but differs from
unity around $\alpha = 0$. It is used as the factor for
the void-fraction related terms in the gas equations.

$r_l(\alpha)$: This function is almost unity, but differs from unity
around $\alpha = 1$ It is used as the factor for the
void-fraction related terms in the liquid equations.

$r_i(\alpha)$: This function is almost unity, but differs from
unity around $\alpha = 1$ and $\alpha = 0$. It is used as
the factor for the void-fraction related terms.

However, these functions are defined as follows at present.

$$s_g(\alpha) = s_l(\alpha) = \alpha \qquad : 0 \le \alpha \le 1 \tag{4-53}$$

$$s_{ig}(\alpha) = s_{il}(\alpha) = 0 \qquad : 0 \le \alpha \le \alpha_{min} \tag{4-54}$$

$$= \frac{\alpha - \alpha_{\min}}{\alpha_{\max} - \alpha_{\min}} \qquad : \alpha_{min} \le \alpha \le \alpha_{max} \tag{4-55}$$

$$= 1 \qquad : \alpha_{min} \le \alpha \le 1 \tag{4-56}$$

$$r_g(\alpha) = 0 \qquad : 0 \le \alpha \le \alpha_{min} \tag{4-57}$$

$$= \frac{\alpha - \alpha_{\min}}{\delta\alpha} \qquad : \alpha_{min} \le \alpha \le \alpha_{min} + \delta\alpha \tag{4-58}$$

$$= 1 \qquad : \alpha_{min} + \delta\alpha \le \alpha \le 1 \tag{4-59}$$

$$r_l(\alpha) = 1 \qquad : 0 \le \alpha \le \alpha_{max} - \delta\alpha \tag{4-60}$$

$$= \frac{\alpha_{\max} - \alpha}{\delta\alpha} \qquad : \alpha_{max} - \delta\alpha \le \alpha \le \alpha_{max} \tag{4-61}$$

$$= 0 \qquad : \alpha_{max} \le \alpha \le 1 \tag{4-62}$$

$$r_i(\alpha) = 0 \qquad : 0 \le \alpha \le \alpha_{min} \tag{4-63}$$

$$= \frac{\alpha - \alpha_{\min}}{\delta\alpha} \qquad : \alpha_{min} \le \alpha \le \alpha_{min} + \delta\alpha \tag{4-64}$$

$$= 1 \qquad : \alpha_{min} + \delta\alpha \le \alpha \le \alpha_{max} - \delta\alpha \tag{4-65}$$

$$= \frac{\alpha_{\max} - \alpha}{\delta\alpha} \qquad : \alpha_{max} - \delta\alpha \le \alpha \le \alpha_{max} \tag{4-66}$$

$$= 0 \qquad : \alpha_{max} \le \alpha \le 1 \tag{4-67}$$

$$\alpha_{min} = 10^{-5} \tag{4-68}$$

$$\alpha_{max} = 1\text{-}10^{-5} \tag{4-69}$$

$$\delta\alpha = 9\text{x}10^{-5} \tag{4-70}$$

4.3.2.1 BASIC EQUATIONS

The basic equations are modified by using these function.

Mass conservation:

$$A\frac{\partial}{\partial t}s_g(\alpha)\rho_g + \frac{\partial}{\partial z}s_{ig}(\alpha)\rho_g u_g A = Ar_i(\alpha)\Gamma_{gi}, \tag{4-71}$$

$$A\frac{\partial}{\partial t}\left(1 - s_l(\alpha)\right)\rho_l + \frac{\partial}{\partial z}\left(1 - s_{il}(\alpha)\right)\rho_l u_l A = -Ar_i(\alpha)\Gamma_{gi}, \tag{4-72}$$

Momentum conservation:

$$\begin{aligned} s_g(\alpha)\rho_g\frac{\partial u_g}{\partial t} + s_{ig}(\alpha)\rho_g u_g\frac{\partial u_g}{\partial z} + s_{ig}(\alpha)\frac{\partial p_g}{\partial z} + \left(p_g - p_i\right)r_i(\alpha)\frac{\partial\alpha}{\partial z} \\ = -r_i(\alpha)\Gamma_{gi}(u_{gi} - u_g) + r_i(\alpha)\tau_{gi} - r_i(\alpha)p'_{gi} - r_g(\alpha)\tau_{gw} \\ + s_{ig}(\alpha)\rho_g b_z, \end{aligned} \tag{4-73}$$

$$\begin{aligned} \left(1 - s_l(\alpha)\right)\rho_l\frac{\partial u_l}{\partial t} + \left(1 - s_{il}(\alpha)\right)\rho_l u_l\frac{\partial u_l}{\partial z} + \left(1 - s_{il}(\alpha)\right)\frac{\partial p_l}{\partial z} + \left(p_l - p_i\right)r_i(\alpha)\frac{\partial\alpha}{\partial z} \\ = -r_i(\alpha)\Gamma_{gi}(u_{li} - u_l) + r_i(\alpha)\tau_{li} - r_i(\alpha)p'_{li} - r_l(\alpha)\tau_{lw} \\ + \left(1 - s_{il}(\alpha)\right)\rho_l b_z, \end{aligned} \tag{4-74}$$

Energy conservation:

$$
\begin{aligned}
&A\frac{\partial}{\partial t}\left(s_g(\alpha)\rho_g\left\{h_g+(1/2)u_g^2\right\}\right)+\frac{\partial}{\partial z}\left(s_{ig}(\alpha)\rho_g u_g\left\{h_g+(1/2)u_g^2\right\}\right)A\\
&\qquad -s_{ig}(\alpha)A\frac{\partial p_g}{\partial t}-\left(p_g-p_i\right)Ar_i(\alpha)\frac{\partial\alpha}{\partial t}\\
&=Ar_i(\alpha)\Gamma_{gi}\left\{h_{gi}+(1/2)u_{gi}^2\right\}+Ar_i(\alpha)q_{gi}+Ar_g(\alpha)q_{gw}\\
&\qquad +As_{ig}(\alpha)\rho_g u_g b_z,
\end{aligned}
\tag{4-75}
$$

$$
\begin{aligned}
&A\frac{\partial}{\partial t}\left(\left(1-s_{il}(\alpha)\right)\rho_l\left\{h_l+(1/2)u_l^2\right\}\right)+\frac{\partial}{\partial z}\left(\left(1-s_{il}(\alpha)\right)\rho_l u_l\left\{h_l+(1/2)u_l^2\right\}\right)A\\
&\qquad -\left(1-s_{il}(\alpha)\right)A\frac{\partial p_l}{\partial t}-\left(p_l-p_i\right)Ar_i(\alpha)\frac{\partial\alpha}{\partial t}\\
&=-Ar_i(\alpha)\Gamma_{gi}\left\{h_{li}+(1/2)u_{li}^2\right\}+Ar_i(\alpha)q_{li}+Ar_l(\alpha)q_{lw}\\
&\qquad +A\left(1-s_{il}(\alpha)\right)\rho_l u_l b_z.
\end{aligned}
\tag{4-76}
$$

4.3.2.2 INTERFACIAL AREA

(1) friction

Interfacial area A_i is multiplied by $r_i(\alpha)$, and then added to the small value ε_{ifr}. Interfacial friction terms thus remain when α comes closer to zero or unity.

(2) gas heat transfer

(a) $T_g \le T_s$

Interfacial area A_i is multiplied by $r_i(\alpha)$, and then added to the small value ε_{ihg}. The heat transfer terms thus remain in the case of $\alpha < \alpha_{min}$, and the steam temperature is kept at around the saturation value. Moreover, condensation tends to occur in the case of $\alpha_{max} < \alpha$.

(b) $T_g > T_s$

Interfacial area A_i is multiplied by $r_i(\alpha)$. In the case of $\alpha < \alpha_{min}$, the small value ε_{ihl} is added. The heat transfer terms thus remain and vapourization tends to occur. In the case of $\alpha_{max} < \alpha$, however, ε_{ihg} is not added. Further vapourization thus cannot occur.

(3) liquid heat transfer

(a) $T_l \le T_s$

Interfacial area A_i is multiplied by $r_i(\alpha)$. In the case of $\alpha_{max} < \alpha$, the small value ε_{ihl} is added. The heat transfer terms thus remain and condensation tends to occur. In the case of $\alpha < \alpha_{min}$, however, ε_{ihl} is not added. Further condensation thus cannot occur.

(b) $T_l > T_s$

Interfacial area A_i is multiplied by $r_i(\alpha)$, and then added to the small value ε_{ihl}. The heat transfer terms thus remain in the case of $\alpha_{max} < \alpha$, and the liquid temperature is kept at around the saturation value. Moreover, vapourization tends to occur in the case of $\alpha < \alpha_{min}$.

In the above relations, the small value ε_i for both friction and heat transfer is set equal to 10^{-3} at present.

4.4 SPECIFIC MODELS

4.4.1 SOURCE TERMS

Some source terms are added to the basic equations when the following models are used: the subcool boiling model, the fill-break model and the pump model.

4.4.1.1 SUBCOOL BOILING MODEL

(1) mass transfer rate

The mass transfer due to subcool boiling, which is described in Section 3.5.2, is added to the usual mass transfer rate.

$$\Gamma_{gi} = -\frac{q_{gi} + q_{li}}{h_{fg}} + \Gamma_{sb}, \tag{4-77}$$

where Γ_{sb} is the mass transfer due to subcool boiling which is defined as

$$\Gamma_{sb} = A_{wlh}\lambda_{nc}\frac{T_w - T_l}{h_{fg}}. \tag{4-78}$$

In the above equation, λ_{sb} is the heat transfer coefficient for subcool boiling. It should be noted that Γ_{sb} is explicitly calculated in the subroutine CR2TW and thus differentiation of Γ_{sb} is not calculated in the subroutine INTMSS.

(2) wall heat flux

Some amount of the wall heat flux is used for subcool boiling and it should be subtracted from the liquid energy equation. The mixture energy equation is however not altered. The wall heat flux for subcool boiling is

$$Q_{nc} = A_{wlh}\lambda_{nc}(Tw - Tl). \tag{4-79}$$

Q_{nc} is calculated in the subroutine WLLHT and is implicitly treated.

4.4.1.2 FILL-BREAK MODEL

Some source terms are added to the basic equations when the FILL-BREAK model is attached to the PIPE component. By using this model, the additional mass, momentum and energy can be considered for each mesh point. The following source terms are calculated in the subroutine SOURCE and added to each conservation equation of mass, momentum and energy.

SRC (1, J) : mass source term for gas
SRC (2, J) : mass source term for liquid
SRC (3, J) : energy source term for gas
SRC (4, J) : energy source term for liquid
SRC (5, J) : momentum source term for gas at the left edge of cell
SRC (6, J) : momentum source term for gas at the right edge of cell
SRC (7, J) : momentum source term for liquid at the left edge of cell
SRC (8, J) : momentum source term for liquid at the right edge of cell

4.4.1.3 PUMP COMPONENT

Some source terms are added to the momentum and energy equations when the PUMP component is used. The pressure difference generated by the pump head H is

$$\delta p = \rho g H , \tag{4-80}$$

and is added to the momentum conservation equation. Moreover, the energy source is generated by the pump torque and head. They are calculated in the subroutine PFSETV, and are stored in the following variables:

CC4 (J, N4PHDG) : pressure difference in gas phase
CC4 (J, N4PHDL) : pressure difference in liquid phase
CC4 (J, N4PHEG) : energy source term in gas phase
CC4 (J, N4PHEL) : energy source term in liquid phase

These terms are treated explicitly. The energy source terms are set to zero at present.

4.4.2 FILL-BREAK MODEL

4.4.2.1 SOURCE TERMS

The additional mass, momentum and enegy are directly and simply added to a mesh of pipe component. This model is used to simulate a discharge or an injection. The schema of FILL-BREAK model is shown in Fig. 4.3. The orientation of discharge of injection can be specified. The basic equations of the PIPE component are modified by adding some source terms.

(1) the mass conservation equations

The following source terms are added to J-th mesh cell.

(a) gas phase

(i) $u_{g,s}^{n+1} < 0$

$$\frac{S_{1g,j}}{\Delta x_j} = -\left(\alpha\rho_g\right)_s u_{g,s}^{n+1} \frac{A_s}{\Delta x_j} \tag{4-81}$$

(ii) $u_{g,s}^{n+1} > 0$

$$\frac{S_{1g,j}}{\Delta x_j} = -\left(\alpha\rho_g\right)_j u_{g,s}^{n+1} \frac{A_s}{\Delta x_j} \tag{4-82}$$

(b) liquid phase

(i) $u_{l,s}^{n+1} < 0$

$$\frac{S_{1l,j}}{\Delta x_j} = -\left((1-\alpha)\rho_l\right)_s u_{l,s}^{n+1} \frac{A_s}{\Delta x_j} \tag{4-83}$$

(ii) $u_{l,s}^{n+1} > 0$

$$\frac{S_{1l,j}}{\Delta x_j} = -\left((1-\alpha)\rho_l\right)_j u_{l,s}^{n+1} \frac{A_s}{\Delta x_j} \tag{4-84}$$

(2) the energy conservation equations

(a) gas phase

(i) $u_{g,s}^{n+1} < 0$

$$\frac{S_{2g,j}}{\Delta x_j} = -\left(\alpha\rho_g\left\{h_g + \frac{1}{2}u_g^2\right\}\right)_s^{n+1} u_{g,s}^{n+1} \frac{A_s}{\Delta x_j} \tag{4-85}$$

(ii) $u_{g,s}^{n+1} > 0$

$$\frac{S_{2g,j}}{\Delta x_j} = -\left(\alpha\rho_g\left\{h_g + \frac{1}{2}u_g^2\right\}\right)_j^{n+1} u_{g,s}^{n+1} \frac{A_s}{\Delta x_j} \tag{4-86}$$

(b) liquid phase

(i) $u_{l,s}^{n+1} < 0$

$$\frac{S_{2l,j}}{\Delta x_j} = -\left((1-\alpha)\rho_l\left\{h_l + \frac{1}{2}u_l^2\right\}\right)_s^{n+1} u_{l,s}^{n+1} \frac{A_s}{\Delta x_j} \tag{4-87}$$

(ii) $u_{l,s}^{n+1} > 0$

$$\frac{S_{2l,j}}{\Delta x_j} = -\left((1-\alpha)\rho_l\left\{h_l + \frac{1}{2}u_l^2\right\}\right)_j^{n+1} u_{l,s}^{n+1} \frac{A_s}{\Delta x_j} \tag{4-88}$$

(3) the momentum conservation equations

The distribution ratio is defined as η to (j – 1/2)-th cell edge and $1-\eta$ to (j + 1/2)-th cell edge. The mesh cell configuration is shown in Fig. 4.4.

(a) gas phase

(i) $u_{g,s}^{n+1} < 0, (j-1/2) - junction$

$$\frac{A_{j-1/2}}{\left(\Delta x_j/2\right)} S_{3g,j-1/2} = -\eta\left(\alpha\rho_g u_g \cos\theta\right)_s^{n+1} u_{g,s}^{n+1} \frac{A_s}{\left(\Delta x_j/2\right)} \tag{4-89}$$

(ii) $u_{g,s}^{n+1} < 0, (j+1/2) - junction$

$$\frac{A_{j+1/2}}{\left(\Delta x_j/2\right)} S_{3g,j+1/2} = -(1-\eta)\left(\alpha\rho_g u_g \cos\theta\right)_s^{n+1} u_{g,s}^{n+1} \frac{A_s}{\left(\Delta x_j/2\right)} \tag{4-90}$$

(iii) $u_{g,s}^{n+1} > 0, (j-1/2) - junction$

$$\frac{A_{j-1/2}}{(\Delta x_j / 2)} S_{3g,j-1/2} = -\eta(\alpha\rho_g)_j^{n+1} u_{g,j-1/2}^{n+1} u_{g,s}^{n+1} \frac{A_s}{(\Delta x_j / 2)} \tag{4-91}$$

(iv) $u_{g,s}^{n+1} > 0, (j+1/2) - junction$

$$\frac{A_{j+1/2}}{(\Delta x_j / 2)} S_{3g,j+1/2} = -(1-\eta)(\alpha\rho_g)_j^{n+1} u_{g,j+1/2}^{n+1} u_{g,s}^{n+1} \frac{A_s}{(\Delta x_j / 2)} \tag{4-92}$$

(b) liquid phase

(i) $u_{l,s}^{n+1} < 0, (j-1/2) - junction$

$$\frac{A_{j-1/2}}{(\Delta x_j / 2)} S_{3l,j-1/2} = -\eta((1-\alpha)\rho_l u_l \cos\theta)_s^{n+1} u_{l,s}^{n+1} \frac{A_s}{(\Delta x_j / 2)} \tag{4-93}$$

(ii) $u_{l,s}^{n+1} < 0, (j+1/2) - junction$

$$\frac{A_{j+1/2}}{(\Delta x_j / 2)} S_{3l,j+1/2} = -(1-\eta)((1-\alpha)\rho_l u_l \cos\theta)_s^{n+1} u_{l,s}^{n+1} \frac{A_s}{(\Delta x_j / 2)} \tag{4-94}$$

(iii) $u_{l,s}^{n+1} > 0, (j-1/2) - junction$

$$\frac{A_{j-1/2}}{(\Delta x_j / 2)} S_{3l,j-1/2} = -\eta((1-\alpha)\rho_l)_j^{n+1} u_{l,j-1/2}^{n+1} u_{l,s}^{n+1} \frac{A_s}{(\Delta x_j / 2)} \tag{4-95}$$

(iv) $u_{l,s}^{n+1} > 0, (j+1/2) - junction$

$$\frac{A_{j+1/2}}{(\Delta x_j / 2)} S_{3l,j+1/2} = -(1-\eta)((1-\alpha)\rho_l)_j^{n+1} u_{l,j+1/2}^{n+1} u_{l,s}^{n+1} \frac{A_s}{(\Delta x_j / 2)} \tag{4-96}$$

4.4.2.2 FILL

For the FILL case, the variables with the subscript (s) are constant values.

4.4.2.3 BREAK

For the BREAK case, the velocities with the subscript (s) are calculated by solving the following equation

$$\begin{aligned}\alpha_k\rho_k \frac{\partial u_k}{\partial t} + \alpha_k\rho_k u_k \frac{\partial u_k}{\partial z} = &-\alpha_k \frac{\partial p}{\partial z} + \frac{1}{2} A_i \left(f_{gi}\rho_g + f_{li}\rho_l\right)|u_{k'} - u_k|(u_{k'} - u_k) \\ &+\Gamma_{ki}(u_{ki} - u_k) - \frac{1}{2}\alpha_k A_{loss}\varepsilon_k\rho_k |u_k| u_k - \alpha_k\rho_k g \frac{dZ}{dz},\end{aligned} \tag{4-97}$$

where z and Z denote the direction of BREAK and gravity, respectively. The mesh cell configuration is shown in Fig. 4.5.

(1) discretization

The velocities in radial direction at the center of j-th cell are assumed to be zero. The index ξ denotes the location of FB: 1 for the top, 0 for the side and –1 for the bottom. The discretized equation is

$$
\begin{aligned}
&(\alpha_k\rho_k)_j^n \frac{u_{k,s}^{n+1}-u_{k,s}^n}{\Delta t} + (\alpha_k\rho_k)_j^n \frac{u_{k,s}^{n+1}}{2}\frac{u_{k,s}^n}{(\delta Dh_j/2)} \\
&\quad = -\alpha_{k,j}^n \frac{p_s - p_j^{n+1}}{(\delta Dh_j/2)} + \frac{1}{2}A_{i,j}\left(f_{gi}\rho_g + f_{fi}\rho_f\right)_j^n |u_k - u_k|_s^n \left(u_{k',s}^{n+1} - u_{k,s}^{n+1}\right) \\
&\quad + \Gamma_{ki,j}^n \left(u_{ki,s}^{n+1} - u_{k,s}^{n+1}\right) - \frac{1}{2}\frac{\alpha_{k,j}^n}{(\delta Dh_j/2)}\varepsilon_{k,s}\rho_{k,j}^n |u_k|_s^n u_{k,s}^{n+1} \\
&\quad - (\alpha_k\rho_k)_j^n g\xi\cos\varphi,
\end{aligned}
\tag{4-98}
$$

where δDh is the hydraulic diameter of j-th cell, and φ is the angle between the PIPE and the horizontal plane:

$$
\cos\varphi = \left\{1 - \left(\frac{\Delta Z_j}{\Delta x_j}\right)^2\right\}^{1/2}, \tag{4-99}
$$

and the following equation is assumed:

$$
\Gamma_{ki,j}^n \left(u_{ki,s}^{n+1} - u_{k,s}^{n+1}\right) = \frac{1}{2}\left(\Gamma_{gi,j}^n + \left|\Gamma_{gi,j}^n\right|\right)\left(u_{l,s}^{n+1} - u_{g,s}^{n+1}\right) \qquad \text{for k = g,} \tag{4-100}
$$

$$
= -\frac{1}{2}\left(\Gamma_{gi,j}^n - \left|\Gamma_{gi,j}^n\right|\right)\left(u_{g,s}^{n+1} - u_{l,s}^{n+1}\right) \qquad \text{for k = 1.} \tag{4-101}
$$

(2) solution

The discretized equations are expressed as

$$
X_1 u_{g,s}^{n+1} + Y_1 u_{l,s}^{n+1} = C_1, \tag{4-102}
$$

$$
X_2 u_{g,s}^{n+1} + Y_2 u_{l,s}^{n+1} = C_2. \tag{4-103}
$$

The solution of these equations are

$$
u_{g,s}^{n+1} = \frac{C_1 Y_2 - C_2 Y_1}{X_1 Y_2 - X_2 Y_1}, \tag{4-104}
$$

$$
u_{l,s}^{n+1} = \frac{C_2 X_1 - C_1 X_2}{X_1 Y_2 - X_2 Y_1}. \tag{4-105}
$$

4.4.3 FORM LOSS MODEL

The pressure drop due to form loss can be considered by using the form loss model. This model is usefull for representing a sudden expansion or contraction of flow area by a one-dimensional pipe component. Two types of form loss are prepared: one is to give form loss coefficients in the input deck, and the other is to calculate them from the variation of flow area. The calculated form loss model is described here.

4.4.3.1 FORM LOSS COEFFICIENTS

The form loss coefficients are defined as

$$K_g = \left\{ \left(\frac{\alpha_{gm}}{\alpha_{gd}} \frac{\varepsilon_{gt}\varepsilon_{gc}}{\varepsilon_g} - 1 \right) / \varepsilon_{gc} \right\}^2, \tag{4-106}$$

$$K_l = \left\{ \left(\frac{\alpha_{lm}}{\alpha_{ld}} \frac{\varepsilon_{lt}\varepsilon_{lc}}{\varepsilon_l} - 1 \right) / \varepsilon_{lc} \right\}^2, \tag{4-107}$$

where K_g and K_l are the form loss coefficients for gas and liquid, respectively, α_{gd} and α_{ld} are the void fraction and holdup in the downstream side, respectively. K_g is set to zero when Lotte's model is selected. The form loss coefficient for the mixture is

$$K_m = \left(1 - \frac{A_{j+1}}{A_{j+1/2}} \right)^2 \qquad \text{for } u_m > 0, \tag{4-108}$$

$$K_m = \left(1 - \frac{A_j}{A_{j+1/2}} \right)^2 \qquad \text{for } u_m < 0. \tag{4-109}$$

K_m is set to 10^{10} if $A_{j+1/2}$ is zero.

4.4.3.2 PARAMETERS

Some parameters are calculated. One parameter C is defined as

$$C = \frac{A_{j+1/2}}{\min\left(A_j, A_{j+1}\right)}. \tag{4-110}$$

(1) for gas phase

In the gas flow direction, let the upstream side cell area be A_u and the downstream aide cell area A_d, ε_g is defined as A_u / A_d.

(i) $C \geq 1, \varepsilon_g > 1$

$$\varepsilon_{gt} = \frac{A_{j+1/2}}{A_u}, \tag{4-111}$$

$$\varepsilon_{gc} = 1.0. \tag{4-112}$$

(ii) $C \geq 1, \varepsilon_g \leq 1$

$$\varepsilon_{gt} = \varepsilon_g, \tag{4-113}$$

$$\varepsilon_{gc} = \left(1 + \sqrt{0.45\left(1 - \varepsilon_{gt}\right)} \right)^{-1}. \tag{4-114}$$

(iii) $C < 1$

$$\varepsilon_{gt} = \frac{A_{j+1/2}}{A_u}, \tag{4-115}$$

$$\varepsilon_{gc} = \varepsilon_g\left(\varepsilon_{gt} + \sqrt{2.7\left(1-\varepsilon_{gt}\right)\left(1-\varepsilon_{gt}^2\right)}\right)^{-1}. \tag{4-116}$$

(2) for liquid phase

In the liquid flow direction, let the upstream side cell area be A_u and the downstream side cell area A_d, ε_l is defined as A_u / A_d.

(i) $C \geq 1, \varepsilon_l > 1$

$$\varepsilon_{lt} = \frac{A_{j+1/2}}{A_u}, \tag{4-117}$$

$$\varepsilon_{lc} = 1.0. \tag{4-118}$$

(ii) $C \geq 1, \varepsilon_l \leq 1$

$$\varepsilon_{lt} = \varepsilon_l, \tag{4-119}$$

$$\varepsilon_{lc} = \left(1+\sqrt{0.45\left(1-\varepsilon_{lt}\right)}\right)^{-1}. \tag{4-120}$$

(iii) $C < 1$

$$\varepsilon_{lt} = \frac{A_{j+1/2}}{A_u}, \tag{4-121}$$

$$\varepsilon_{lc} = \varepsilon_l\left(\varepsilon_{lt} + \sqrt{2.7\left(1-\varepsilon_{lt}\right)\left(1-\varepsilon_{lt}^2\right)}\right)^{-1}. \tag{4-122}$$

4.4.3.3 VOID FRACTION AND HOLDUP

The void fraction α_{gm} and the holdup α_{lm} are obtained.

(1) Lotte's model

$$\alpha_{gm} = 0, \tag{4-123}$$

$$\alpha_{lm} = \frac{1}{2}\left\{\left(\alpha_{l,j} + \alpha_{l,j+1}\right) + sgn\left(u_l\right)\left(\alpha_{l,j} - \alpha_{l,j+1}\right)\right\}. \tag{4-124}$$

(2) modified Lotte's model

$$\alpha_{gm} = \frac{1}{2}\left\{\left(\alpha_{g,j} + \alpha_{g,j+1}\right) + sgn\left(u_g\right)\left(\alpha_{g,j} - \alpha_{g,j+1}\right)\right\}, \tag{4-125}$$

$$\alpha_{lm} = \frac{1}{2}\left\{\left(\alpha_{l,j} + \alpha_{l,j+1}\right) + sgn\left(u_l\right)\left(\alpha_{l,j} - \alpha_{l,j+1}\right)\right\}. \tag{4-126}$$

(3) homogeneous model

(i) $U_g \neq 0, U_l \neq 0$

$$\alpha_{gm} = \frac{\alpha_{g,j}\left|u_g\right|}{\alpha_{g,j}\left|u_g\right| + \alpha_{l,j}\left|u_l\right|}, \tag{4-127}$$

$$\alpha_{lm} = \frac{\alpha_{l,j}|u_l|}{\alpha_{g,j}|u_g| + \alpha_{l,j}|u_l|}. \tag{4-128}$$

(ii) $u_g = 0, u_l = 0$

$$a_{gm} = a_{g,j}, \tag{4-129}$$

$$a_{lm} = a_{l,j}. \tag{4-130}$$

4.4.4 STEAM TABLE

The steam table is used to obtain some fluid properties as a function of the pressure and the enthalpy. Spline functions are used to interpolate the property data, and the steam table consists of the coefficients of spline functions.

4.4.4.1 SATURATION LINE

The saturation line is interpolated by the spline function of degree three. When the data (x_i, y_i)(i=1, . . , N) are given, the interpolated value S(x), which corresponds to the value of x between x_i and x_{i+1}, is

$$S(x) = y_i + C_1\left(\frac{x - x_i}{x_{i+1} - x_i}\right) + C_2\left(\frac{x - x_i}{x_{i+1} - x_i}\right)^2 + C_3\left(\frac{x - x_i}{x_{i+1} - x_i}\right)^3. \tag{4-131}$$

The coefficients C_1, C_2 and C_3 are prepared by the steam table.

The saturation line is divided into 8 regions, and each region is divided into smaller regions.

Region No.	Pressure Range (Pa)	Number of Detailed Division
1	$1.0 \times 10^3 - 5.0 \times 10^3$	50
2	$5.0 \times 10^3 - 1.0 \times 10^4$	50
3	$1.0 \times 10^4 - 1.0 \times 10^5$	100
4	$1.0 \times 10^5 - 1.0 \times 10^6$	100
5	$1.0 \times 10^6 - 1.6 \times 10^6$	50
6	$1.6 \times 10^6 - 1.8 \times 10^6$	50
7	$1.8 \times 10^6 - 2.1 \times 10^7$	100
8	$2.1 \times 10^7 - 2.2 \times 10^7$	100

4.4.4.2 TEMPERATURE AND SPECIFIC VOLUME

The surfaces made from the temperatures T_g and T_l and the specific volumes υ_g and υ_l are interpolated by the spline function of degree three. When the data (x_i, y_j, f_{ij}) (i=1, . . , I, j=1, . . , J) are given, the interpolated value s(x, y), which corresponds to the value of (x, y) on the region $[x_i, x_{i+1}] \times [y_j, y_{j+1}]$, is

$$S(x,y) = \Sigma\Sigma C_{l,k}\left(\frac{x - x_i}{x_{i+1} - x_i}\right)^l\left(\frac{x - x_i}{x_{i+1} - x_i}\right)^k. \tag{4-132}$$

The coefficients $C_{l,k}$ are prepared by the steam table.

The T - υ surfaces are divided into 4 regions, and each region is divided into more smaller regions.

(1) for steam

Region No.	Pressure Range (Pa)	Number of Detailed Division
1	$1.0 \times 10^3 - 1.0 \times 10^4$	4
2	$1.0 \times 10^4 - 1.0 \times 10^5$	4
3	$1.0 \times 10^5 - 1.5 \times 10^6$	8
4	$1.5 \times 10^6 - 2.2 \times 10^7$	16

Region No.	Enthalpy Range (J/kg)	Number of Detailed Division
1	$2.1 \times 10^6 - 2.6 \times 10^6$	10
2	$2.6 \times 10^6 - 3.1 \times 10^6$	10
3	$3.1 \times 10^6 - 3.5 \times 10^6$	6
4	$3.5 \times 10^6 - 3.95 \times 10^6$	6

(1) for water

Region No.	Pressure Range (Pa)	Number of Detailed Division
1	$1.0 \times 10^3 - 6.0 \times 10^6$	6
2	$6.0 \times 10^6 - 8.0 \times 10^6$	12
3	$8.0 \times 10^6 - 1.9 \times 10^7$	8
4	$1.9 \times 10^7 - 2.2 \times 10^7$	6

Region No.	Enthalpy Range (J/kg)	Number of Detailed Division
1	$2.5 \times 10^4 - 1.0 \times 10^5$	6
2	$1.0 \times 10^5 - 1.1 \times 10^6$	4
3	$1.1 \times 10^6 - 1.65 \times 10^6$	8
4	$1.65 \times 10^6 - 2.1 \times 10^6$	16

4.4.4.3 OTHER PROPERTIES

The specific internal energy U, expansion coefficient β, specific heat with constant pressure C_p and specific heat with constant volume C_υ are

$$U = h - p\upsilon, \tag{4-133}$$

$$\beta = \frac{1}{\upsilon}\left(\frac{\partial \upsilon}{\partial T}\right)_p = \frac{1}{\upsilon}\left(\frac{\partial \upsilon}{\partial h}\right)_p \left(\frac{\partial h}{\partial T}\right)_p, \tag{4-134}$$

$$C_p = \left(\frac{\partial h}{\partial T}\right)_p, \tag{4-135}$$

$$C_\upsilon = C_p - T\frac{\beta^2}{K_\upsilon}. \tag{4-136}$$

The compressibility K is obtained by linear function of T_g and T_l.

REFERENCES

[4-1] M.Akimoto et al. , MINCS: A Computer Code for Transient Thermo-Hydraulic Analysis in a Light Water Reactor System – MINCS-PIPE: A Computer Code for Transient Two-Phase Flow Analysis in One-Dimensional Ducts –, JAERI-M, 84-202 (1984).

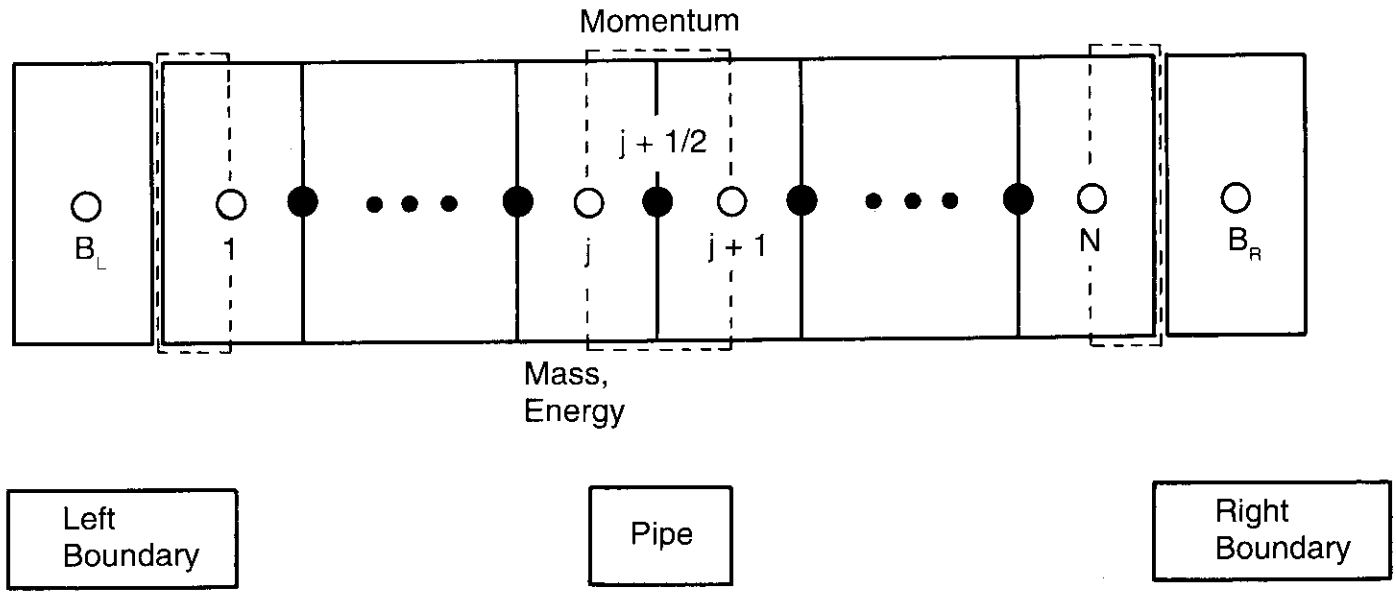


Fig. 4.1 Mesh Cell Configuration for Fluid

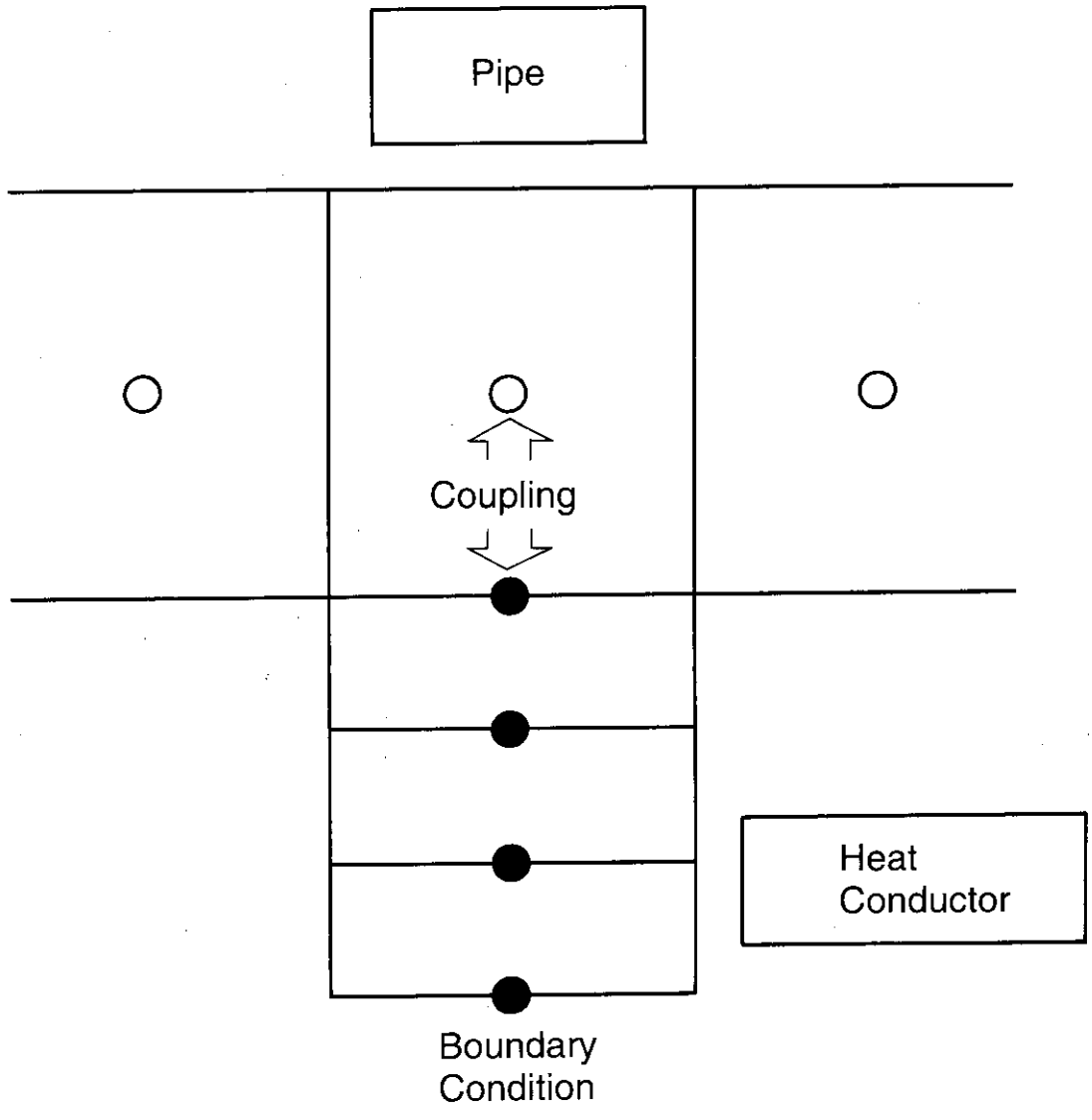


Fig. 4.2 Mesh Cell Configuration for Heat Conductor

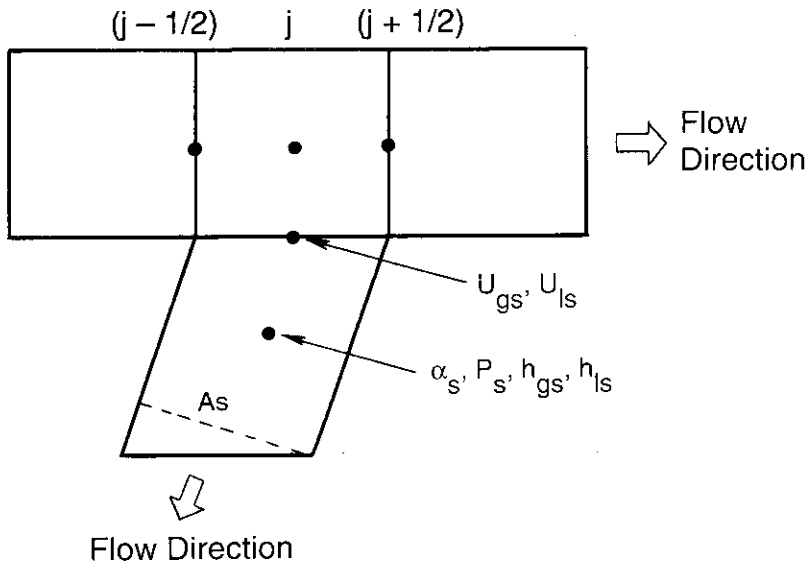


Fig. 4.3 Schema of FILL-BREAK Model

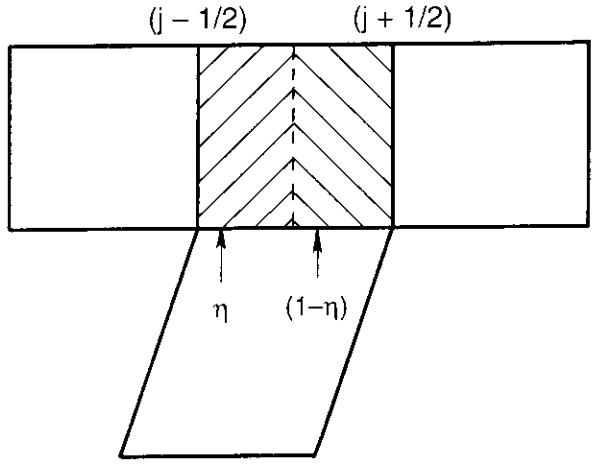


Fig. 4.4 Distribution of Momentum Source Term

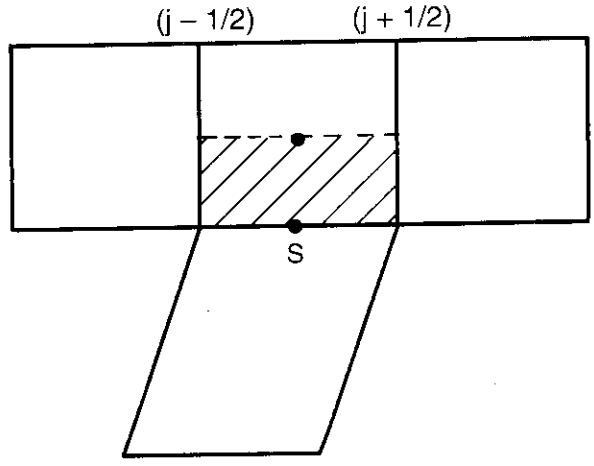


Fig. 4.5 Momentum Cell for Break Velocity

5. INPUT REQUIREMENT

5.1 GENERAL DESCRIPTION

Input data consist of eight data blocks as

1. System control data,
2. Valve definition data,
3. Form loss definition data,
4. Pump definition data,
5. Material property data,
6. Component definition data,
7. Network definition data,
8. Heat conductor definition data.

Each data block is composed of several data cards: Card-1, Card-2, ... , and each data card has several input data. It should be noted that one 'Card' does not mean one record or one line in input data file, so the 'Card' can consist of two or more lines. Except for character strings, input data are written in free format and two consecutive data are separated by a comma or blanks. The input method is essentially the same as the list-direct input of FORTRAN77:

READ (IN,*) .....

The preprocessor of input data has however several extended capabilities as described below.

(1) Elimination of sequence numbers

Only the data between 1st and 72nd columns of one line have a meaning. If there are too many data to be input in one 'Card', data can be continued to the successive lines. It should be noted however two or more 'Card' data must not be in one line.

(2) Comment lines

The line, which has a symbol '*' at the 1st column, is a comment line and is eliminated by the preprocessor for input data. Comment lines can be inserted arbitrarily in input data.

(3) Comment description without using comment line

A comment can be inserted in the data by using the form of '/* ..... */'. The part ' ..... ' between '/*' and '*/' consists of arbitrary characters. This type of comment can be continued to two or more lines. The part of '/* ..... */' is not simply eliminated but replaced by blanks. So, one can put data before and after the comment, and those data are used normally.

(4) Print of input data

The input data are printed on the output list. The total number and the effective number of the input lines are counted and printed.

(5) Print control of input data

The print of input data is controlled by inserting some control commands in input data. Control commands listed below can be used when the print of input data is not necessary or only partially necessary. The control commands should be written from the 1st column, and are eliminated from the input data by the preprocessor.

'@LISTOFF'

After this command, the print of input data is suppressed until '@LISTON' command appears.

'@LISTON'

After this command, input data are printed again.

'@EJECT'

The print of input data is advanced to the 1st line of next page. This command is neglected if it is inserted in '@LISTOFF' and '@LISTON' commands.

5.2 INPUT DESCRIPTION

5.2.1 SYSTEM CONTROL DATA

The system control data consist of following 'Card's:

Card-1	Title card,
Card-2	Calculation option card,
Card-3	Enthalpy calculation option card,
Card-4	Correlation and steam table option card,
Card-5	Problem dimension card,
Card-6	Convergence criterion card,
Card-7	Debug option card,
Card-8	Windward fraction card,
Card-9	Gravitational acceleration card,
Card-10	Time step control card,
Card-11	Edit control card.

The system control data are needed in the case of restart calculations.

- Card-1 Title card

'TITLE'

'TITLE'

This is the title of the calculation and the first card of input data. It is printed as a header of each page of output list. Arbitrary 72 characters can be used.

- Card-2 Calculation option card

'IRST', 'ISTDY'

'IRST'

Restart calculation flag:

0 : Non-restart calculation.
1 : Restart calculation.
(In this case, only 'IDF' and 'IDV' have meaning. The other system option data are read from the restart file)

'ISTDY'

Steady state calculation option:

0 : Transient calculation.
1 : Steady state calculation.
(not available at present)

• Card-3 Enthalpy calculation option

'NONCMP'

'NONCMP'

Enthalpy calculation option:

0 : Enthalpy is calculated.
1 : Enthalpy is fixed.

• Card-4 Correlation and steam table option card

'NUC', 'MOMEN', 'IEOS'

'NUC'

Subcool-boiling model option flag:

0 : Subcool-boiling model is used.
1 : Subcool-boiling model is not used.

'MOMEN'

Constitutive-relation package option flag:

1 : MINCS continuous model.
2 : TRAC-PF1 correlation.
(not available at present)

'IEOS'

Steam table option flag:

0 : Gas phase is steam and liquid phase is water.

1 : Gas phase is air and liquid phase is water.

2 : Densities of two phases are given by

$\rho_g = \rho_{g0} + C_{g0} (P - P_0)$,

$\rho_l = \rho_{l0} + C_{l0} (P - P_0)$.

3 : Gas phase is air and liquid density is given by

$\rho_l = \rho_{l0} + C_{l0} (P - P_0)$.

4 : Liquid phase is water and gas density is given by

$\rho_g = \rho_{g0} + C_{g0} (P - P_0)$.

>5 : Arbitrary.

• Card-4-1 Parameters for steam table

(This card must be inserted if IEOS is not zero)

'RHOG00', 'CG00', 'RHOL00', 'CL00', 'P00', 'HGS00', 'HLS00', 'CPG00', 'CPL00'

'RHOG00'

ρ_{g0}.

'CG00'

C_{g0}.

'RHOL00'

ρ_{l0}.

'CL00'

C_{l0}.

'P00'

P_0.

'HGS00'

Saturation enthalpy of gas phase.

'HLS00'

Saturation enthalpy of liquid phase.

'CPG00'

Specific heat of gas.

'CPL00'

Specific heat of liquid.

• Card-5 Problem dimension card

'NCOMP', 'MXCNCO', 'IDV', 'NHEAT', 'MXHEAT', 'NUMPMP', 'NUMSG', 'IDF', 'MAXTB', 'MATNUM'

'NCOMP'

Number of components.

'MXCNCO'

Number of entries of network table. Note that MXCNCO must be greater than or equal to the maximum number of terminals of components.

'IDV'

Number of valve definition data sets.

'NHEAT'

Total number of heat conductors.

'MXHEAT'

Maximum number of heat conductors which are connected to each fluid component.

'NUMPMP'

Number of pumps.

'NUMSG'

Number of steam generators (must be zero at present).

'IDF'

Number of form loss definition data sets.

'MAXTB'

Maximum length of tablels for material properties' data of heat conductors.

'MATMUM'

Number of materials.
If the built-in material-properties data (6 materials are shown below) are used, MATNUM should be zero.

MAT = 6 : SUS 304.
MAT = 7 : SUS 316.
MAT = 8 : SUS 347.
MAT = 9 : Carbon Steel A508.
MAT = 10 : Inconel 718.
MAT = 12 : Inconel 600.
MAT is defined by Card-3-5 of heat conductor definition data.

• Card-6 Convergence criterion card

In case of non-restart calculation
'MAXITR', 'MAXIMP', 'EPS', 'EPSC', 'EPSCR'

In case of restart calculation
'MAXITR', 'MAXIMP', 'EPS', 'EPSC', 'EPSCR', 'RTIME', 'NRSTP'

'MAXITR'

Maximum number of iterations.

'MAXIMP'

Maximum number of Jacobian calculation.
(if 0 is input, MAXIMP is set to be 10000)

'EPS'

Convergence criterion for total system.

'EPSC'

Convergence criterion for each component.

'EPSCR'

Minimum value of dependent variables which is used to evaluate the relative error in each iteration

$$error = \left\{ \sum \left(\frac{\Delta x_{i,j}^k}{x_{i,j}^k} \right)^2 \right\}^{1/2} , x_{i,j}^k \geq EPSCR,$$

where $\Delta x_{i,j}^k$ is k-th increment for i-th variable of j-th mesh cell.

'RTIME'

Problem restart time. Restart calculation starts from the last dump time which is smaller than RTIME.

'NRSTP'

(Not used)

• Card-7 Debug option card

'IDBS'

'IDBS'

System debug option.

0 : No debug print.
1 : Relative errors are printed every time step.
2 : System Jacobian matrix is printed and calculation is terminated at one iteration.

• Card-8 Windward fraction card

'THET'

'THET'

Degree of upwind for momentum convective term.

momentum convective term = THET* (upwind difference term) + (1-THET) * (central difference term).

• Card-9 Gravitational acceleration card

'GRAV'

'GRAV'

Gravitational acceleration.
(input 0.0 for standard value of 9.80665)

• Card-10 Time step control card

'DELTI', 'DELT', 'ENDTIM', 'NTIM'

'DELTI'

Initial value of time step width (s).

'DELT'

Maximum allowable time step width (s).

'ENDTIM'

Problem end time.

'NTIM'

Number of time domains defined by maximum time step width.

• Card-10-1 Table for time step width

('TIM (I)', 'DLT (I)'), I = 1, NTIM

'TIM (I)'

End time for I-th domain (s).

'DLT (I)'

Maximum allowable time step width in I-th domain (s).

• Card-11 Edit control card

'MPRT', 'NTPRT', 'MPLT', 'NTPLT', 'MRST', 'NTRST'

'MPRT'

Print-edit interval (time steps).

'NTPRT'

Number of time domains defined by print-edit interval.

'MPLT'

Plot-edit interval (time steps).

'NTPLT'

Number of time domains defined by plot-edit interval.

'MRST'

Restart-dump interval (time steps).

'NTRST'

Number of time domains defined by restart-dump interval.

• Card-11-1 Table for print-edit interval

(This card must be inserted if NTPRT is greater than zero)

('TIMPR (I)', 'NPRT (I)'), I = 1, NTPRT

'TIMPR (I)'

End time of I-th domain (s).

'NPRT (I)'

Print-edit interval in I-th domain (time steps).

• Card-11-2 Table for plot-edit interval

(This card must be inserted if NTPLT is greater than zero)

('TIMPL (I)', 'NPLT (I)'), I = 1, NTPLT

'TIMPL (I)'

End time of I-th domain (s).

'NPLT (I)'

Plot-edit interval in I-th domain (time steps).

• Card-11-3 Table for restart-dump interval

(This card must be inserted if NTRST is greater than zero)

('TIMRS (I)', 'NRST (I)'), I = 1, NTRST

'TIMRS (I)'

End time of I-th domain (s).

'NRST (I)'

Restart-dump interval in I-th domain (time steps).

5.2.2 VALVE DEFINITION DATA

These input data define valve characteristics. If 'IDV' in system control data is greater than zero, these data must be inserted. The valve definition data consist of following 'Card's:

Card-1 Valve definition card,
Card-2 Valve characteristics table card.

For a normal valve, the table of time versus normalized valve flow area is to be input. For a check valve, the table of pressure difference versus normalized valve flow area is to be input. These data, Card-1 and Card-2, must be repeated IDV times. These data are also necessary in case of the restart calculation.

• Card-1 Valve definition card

'VNAME', 'IVTYPE', 'IVKONT'

'VNAME'

Valve name. The number of characters is less than or equal to 12 and it must be put in between two apostrophes.

'IVTYPE'

Type of valve.

1 : Normal valve.
2 : Check valve.

'IVKONT'

Table length of time versus normalized valve flow area or that of pressure difference versus normalized valve flow area.

• Card-2 Valve characteristics table card

'VALTAB (K)', K = 1, IVKONT*2

'VALTAB (2* K-1)', K = 1, IVKONT

Time (s) for IVTYPE = 1
Pressure difference (Pa) for IVTYPE = 2.

'VALTAB (2* K)', K = 1, IVKONT

Normalized valve flow area.

5.2.3 FROM LOSS DEFINITION DATA

These input data define form loss coefficient tables. Form loss of gas, liquid and mixture are to be input. These data (Card-1) must be repeated IDF times. By means of these input data, pressure loss is calculated as

pressure loss = $(1/2) * \rho * FMLOSS * u^2$.

These data must be omitted if IDV of system control data is less than or equal to zero. They are necessary in case of the restart calculation.

• Card-1 Form loss coefficient card

'FMLOSS (K)', K = 1, 6

'FMLOSS (K)'

Form loss data.

K = 1 : Gas (normal flow).
K = 2 : Gas (inverse flow).
K = 3 : Liquid (normal flow).
K = 4 : Liquid (inverse flow).
K = 5 : Mixture (normal flow).
K = 6 : Mixture (inverse flow).

5.2.4 PUMP DEFINITION DATA

These input data define pump characteristics. If NUMPMP is greater than zero, these data must be inserted. In the case of restart calculations, only the trip data are needed. The pump definition data consist of following 'Card's:

Card-1 Dimension card,
Card-2 Pump identification card,
Card-3 Pump definition card,
Card-4 Motor torque card,
Card-5 Homologous curve card,
Card-6 Pump locking data,
Card-7 Pump speed table after coastdown,
Card-8 Variable moment of inertial data,
Card-9 Trip data card.

• Card-1 Dimension card

'NPMPD', 'NPCHRC', 'NMOTRC', 'NPSTP', 'NPSPED', 'NINERT'

'NPMPD'

Number of pumps defined in this data block. This number may be different from the number of pumps which can be actually used.

'NPCHRC'

Number of homologous curves.

'NMOTRC'

Number of motor torque curves.

'NMOTRC'

Number of locking data.

'NPSPED'

Number of pump speed curves after coastdown.
It corresponds to the type-1 trip.

'NINERT'

Number of variable moment of inertia table.

• Card-2 Pump identification card

'IPUMP (I)', I = 1, NUMPMP

'IPUMP (I)'

The number of pumps defined. The pumps which can be actually used, are related to the pump definition data by this card. The order of IPUMP (I) is corresponding to that of pumps which can be actually used. NUMPMP is defined by the system-option card.

• Card-3 Pump definition card

This card must be inserted NPMPD times.

'IPC', 'ITPMP', 'IRP', 'IPM', 'IMT', 'IPSPD', 'INERT', 'ISTOP', 'POMGAR', 'PSRAT', 'PFLOWR', 'PHEADR', 'PTORKR', 'PINRTA', 'VRHOI', 'TORKMR', ('TORKF (I)', I = 1, 4)

'IPC'

Number of homologous curves to be used in this pump.
(1 ≦ IPC ≦ NPCHRC)

'ITPMP'

Trip number for type-2 trip. This trip is used only when type-1 trip is not used.

'IRP'

Reverse rotation option flag:

1 : Allow reverse rotation,
0 : Inhibit reverse rotation.

'IPM'

Option flag for two-phase degraded performance:

0 : Not used,
1 : Torque T and head H are obtained as
$T = T_1 - Mt\,(a)\,(T_1 - T_2)$, $H = H_1 - Mh\,(a)\,(H_1 - H_2)$,
2 : Torque T and head H are obtained as
$T = T_1\,(1 - Mt\,(a))$, $H = H_1\,(1 - M_h\,(a))$,
where the subscript 1 denotes the performance in single phase and the subscript 2 in two phase.

'IMT'

Motor torque curve number.
If IMT is zero, no curves are used.
In initialization, motor torque is automatically set to the value so that the total pump torque equals to zero.

'IPSPD'

Pump speed curve number after coastdown.
If IPSPD is zero, type-2 trip is used.

'INERT'

Variable moment of inertia data number for type-1 trip.
If INERT is zero, constant moment of inertia PINRTA is used.

'ISTOP'

Pump locking data number.

'POMGAR'

Rated speed (rad/s).

'PSRAT'

Pump speed ratio of initial speed to rated speed.
Pump speed in initialization stage is calculated by this ratio for type-2 trip.

'PFLOWR'

Rated flow (m^3/sec).

'PHEADR'

Rated head (m).

'PTORKR'

Rated torque (N* m).

'PINRTA'

Moment of inertia (kg* m^2).

'VRHOI'

Rated density (kg/m^3).

'TORMKR'

Rated pump motor torque (N* m).

'TORKF (I)', I = 1,4

Coefficients of frictional torque (N* m)
The frictional torque is calculated by

$$T = TORKF(1) + TORKF(2) * (POMGA/POMGAR) + TORKF(3) * (POMGA/POMGAR)^2 + TORKF(4) * (POMGA/POMGAR)^3,$$

where POMGA is pump speed.

• Card-4 Motor torque card

These cards must be inserted NMOTRC times.
If NMOTRC is zero, these cards are omitted.

• Card-4 (a)

'NTMO'

'NTMO'

Number of points on curve.

• Card-4 (b)

'PTMO (I)', I = 1, NTMO*2

'PTMO (2* J-1)', J = 1, NTMO
Motor torque normalized by the rated motor torque.

'PTMO (2* J)', J = 1, NTMO
Pump speed normalized by the rated pump speed.

• Card-5 Homologous curve card

'NOIN'

'NOIN'

Option flag to select homologous curves:

0 : Use of input curves,
1 : Use of curves set-1, Bingham Pump Ns = 4200,
2 : Use of curves set-2, Westinghouse Electric Corporation pump Ns = 5200.

The following 'Card's from Card 5-1 to 5-34 are required only when NOIN = 0. A set of 'Card-5' — Card-5 and Card-5-1 to Card-5-34 — must be repeated NPCHRC times.

• Card-5-1 Single-phase HAN curve card

• Card-5-1 (a)

'NPHD'

'NPHD'

Number of data points of the single-phase HAN curve.

• Card-5-1 (b)

'PHEAD (I)', I = 1, NPHD*2

'PHEAD (I)', I = 1, NPHD*2

HAN head curve data: v / α *vs.* h / α^2.

- Card-5-2 Single-phase HVN curve card
- Card-5-2 (a)

'NPHD'

'NPHD'

Number of data points of the single-phase HVN curve.

- Card-5-2 (b)

'PHEAD (I)', I = 1, NPHD*2

'PHEAD (I)', I = 1, NPHD*2

HVN head curve data: α / v *vs.* h / v^2.

- Card-5-3 Single-phase HAD curve card
- Card-5-3 (a)

'NPHD'

'NPHD'

Number of data points of the single-phase HAD curve.

- Card-5-3 (b)

'PHEAD (I)', I = 1, NPHD*2

'PHEAD (I)', I = 1, NPHD*2

HAD head curve data: v / α *vs.* h / α^2.

- Card-5-4 Single-phase HVD curve card
- Card-5-4(a)

'NPHD', ('PHEAD (I)', I=1, NPHD*2)

'NPHD'

Number of data points of the single-phase HVD curve.

- Card-5-4 (b)

'PHEAD (I)', I = 1, NPHD*2

'PHEAD (I)', I = 1, NPHD*2

HVD head curve data: α / v *vs.* h / v^2.

- Card-5-5 Single-phase HAT curve card
- Card-5-5 (a)

'NPHD', ('PHEAD (I)', I = 1, NPHD*2)

'NPHD'

Number of data points of the single-phase HAT curve.

• Card-5-5 (b)

'PHEAD (I)', I = 1, NPHD*2

'PHEAD (I)', I = 1, NPHD*2

HAT head curve data: v / α *vs.* h / α^2.

• Card-5-6 Single-phase HVT curve card

• Card-5-6 (a)

'NPHD'

'NPHD'

Number of data points of the single-phase HVT curve.

• Card-5-6 (b)

'PHEAD (I)', I = 1, NPHD*2

'PHEAD (I)', I = 1, NPHD*2

HVT head curve data: α / v *vs.* h / v^2.

• Card-5-7 Single-phase HAR curve card

• Card-5-7 (a)

'NPHD'

'NPHD'

Number of data points of the single-phase HAR curve.

• Card-5-7 (b)

'PHEAD (I)', I = 1, NPHD*2

'PHEAD (I)', I = 1, NPHD*2

HAR head curve data: v / α *vs.* h / α^2.

• Card-5-8 Single-phase HVR curve card

• Card-5-8 (a)

'NPHD'

'NPHD'

Number of data points of the single-phase HVR curve.

• Card-5-8 (b)

'PHEAD (I)', I = 1, NPHD*2

'PHEAD (I)', I = 1, NPHD*2

HVR head curve data: α / v *vs.* h / v^2.

- Card-5-9 Single-phase BAN curve card
- Card-5-9 (a)

'NPTK'

'NPTK'

Number of data points of the single-phase BAN curve.

- Card-5-9 (b)

'PTORK (I)', I = 1, NPTK*2

'PTORK (I)', I = 1, NPTK*2

BAN torque curve data: v / α *vs.* β / α^2.

- Card-5-10 Single-phase BVN curve card
- Card-5-10 (a)

'NPTK'

'NTPK'

Number of data points of the single-phase BVN curve.

- Card-5-10 (b)

'PTORK (I)', I = 1, NPTK*2

'PTORK (I)', I = 1, NPTK*2

BVN torque curve data: α / v *vs.* β / v^2.

- Card-5-11 Single-phase BAD curve card
- Card-5-11 (a)

'NPTK'

'NPTK'

Number of data points of the single-phase BAD curve.

- Card-5-11 (b)

'PTORK (I)', I = 1, NPTK*2

'PTORK (I)', I = 1, NPTK*2

BAD torque curve data: v / α *vs.* β / α^2.

- Card-5-12 Single-phase BVD curve card
- Card-5-12 (a)

'NPTK'

'NPTK'

Number of data points of the single-phase BVD curve.

• Card-5-12 (b)

'PTORK (I)', I = 1, NPTK∗2

'PTORK (I)', I = 1, NPTK∗2

BVD torque curve data: α / v *vs.* β / v^2.

• Card-5-13 Single-phase BAT curve card

• Card-5-13 (a)

'NPTK'

'NPTK'

Number of data points of the single-phase BAT curve.

• Card-5-13 (b)

'PTORK (I)', I = 1, NPTK∗2

'PTORK (I)', I = 1, NPTK∗2

BAT torque curve data: v / α *vs.* β / α^2.

• Card-5-14 Single-phase BVT curve card

• Card-5-14 (a)

'NPTK'

'NPTK'

Number of data points of the single-phase BVT curve.

• Card-5-14 (b)

'PTORK (I)', I = 1, NPTK∗2

'PTORK (I)', I = 1, NPTK∗2

BVT torque curve data: α / v *vs.* β / v^2.

• Card-5-15 Single-phase BAR curve card

• Card-5-15 (a)

'NPTK'

'NPTK'

Number of data points of the single-phase BAR curve.

• Card-5-15 (b)

'PTORK (I)', I = 1, NPTK∗2

'PTORK (I)', I = 1, NPTK∗2

BAR torque curve data: v / α *vs.* β / α^2.

- Card-5-16 Single-phase BVR curve card
- Card-5-16 (a)

'NPTK'

'NPTK'

Number of data points of the single-phase BVR curve.

- Card-5-16 (b)

'PTORK (I)', I = 1, NPTK*2

'PTORK (I)', I = 1, NPTK*2

BVR torque curve data: α / v *vs.* β / v^2.

- Card-5-17 Two-phase HAN curve card
- Card-5-17 (a)

'NPHD2'

'NPHD2'

Number of data points of the HAN curve, which is defined as (single-phase)-(two-phase) HAN curve.

- Card-5-17 (b)

'PHEAD2 (I)', I = 1, NPHD2*2

'PHEAD2 (I)', I = 1, NPHD2*2

Two-phase HAN curve data: v / α *vs.* h / α^2, which are defined as (single-phase) - (two-phase) HAN curve data.

- Card-5-18 Two-phase HVN curve card
- Card-5-18 (a)

'NPHD2'

'NPHD2'

Number of data points of the two-phase HVN curve.

- Card-5-18 (b)

'PHEAD2 (I)', I = 1, NPHD2*2

'PHEAD2 (I)', I = 1, NPHD2*2

Two-phase HVN curve data: α / v *vs.* h / v^2.

- Card-5-19 Two-phase HAD curve card

• Card-5-19 (a)

'NPHD2'

'NPHD2'

Number of data points of the two-phase HAD curve.

• Card-5-19 (b)

'PHEAD2 (I)', I = 1, NPHD2∗2

'PHEAD2 (I)', I = 1, NPHD2∗2

Two-phase HAD curve data: v / α *vs.* h / α^2.

• Card-5-20 Two-phase HVD curve card

• Card-5-20 (a)

'NPHD2'

'NPHD2'

Number of data points of the two-phase HVD curve.

• Curd-5-20 (b)

'PHEAD2 (I)', I = 1, NPHD2∗2

'PHEAD2 (I)', I = 1, NPHD2∗2

Two-phase HVD curve data: α / v *vs.* h / v^2.

• Card-5-21 Two-phase HAT curve card

• Card-5-21 (a)

'NPHD2'

'NPHD2'

Number of data points of the two-phase HAT curve.

• Card-5-21 (b)

'PHEAD2 (I)', I = 1, NPHD2∗2

'PHEAD2 (I)', I = 1, NPHD2∗2

Two-phase HAT curve data: v / α *vs.* h / α^2.

• Card-5-22 Two-phase HVT curve card

• Card-5-22 (a)

'NPHD2'

'NPHD2'

Number of data points of the two-phase HVT curve.

• Card-5-22 (b)

'PHEAD2 (I)', I = 1, NPHD2*2

'PHEAD2 (I)', I = 1, NPHD2*2

Two-phase HVT curve data: α / v *vs.* h / v^2.

• Card-5-23 Two-phase HAR curve card

• Card-5-23 (a)

'NPHD2'

'NPHD2'

Number of data points of the two-phase HAR curve.

• Card-5-23 (b)

'PHEAD2 (I)', I = 1, NPHD2*2

'PHEAD2 (I)', I = 1, NPHD2*2

Two-phase HAR curve data: v / α *vs.* h / α^2.

• Card-5-24 Two-phase HVR curve card

• Card-5-24 (a)

'NPHD2'

'NPHD2'

Number of data points of the two-phase HVR curve.

• Card-5-24 (b)

'PHEAD2 (I)', I = 1, NPHD2*2

'PHEAD2 (I)', I = 1, NPHD2*2

Two-phase HVR curve data: α / v *vs.* h / v^2.

• Card-5-25 Two-phase BAN curve card

• Card-5-25 (a)

'NPTK2'

'NPTK2'

Number of data points of the two-phase BAN curve.

• Card-5-25 (b)

'PTORK2 (I)', I = 1, NPTK2*2

'PTORK2 (I)', I = 1, NPTK2*2

BAN torque curve data: v / α *vs.* β / α^2.

- Card-5-26 Two-phase BVN curve card
- Card-5-26 (a)

'NPTK2'

'NPTK2'

Number of data points of the two-phase BVN curve.

- Card-5-26 (b)

'PTORK2 (I)', I = 1, NPTK2*2

'PTORK2 (I)', I = 1, NPTK2*2

BVN torque curve data: α / v *vs.* β / v^2.

- Card-5-27 Two-phase BAD curve card
- Card-5-27 (a)

'NPTK2'

'NPTK2'

Number of data points of the two-phase BAD curve.

- Card-5-27 (b)

'PTORK2 (I)', I = 1, NPTK2*2

'PTORK2 (I)', I = 1, NPTK2*2

BAD torque curve data: v / α *vs.* β / α^2.

- Card-5-28 Two-phase BVD curve card
- Card-5-28 (a)

'NPTK2'

'NPTK2'

Number of data points of the two-phase BVD curve.

- Card-5-28 (b)

'PTORK2 (I)', I = 1, NPTK2*2

'PTORK2 (I)', I = 1, NPTK2*2

BVD torque curve data: α / v *vs.* β / v^2.

- Card-5-29 Two-phase BAT curve card
- Card-5-29 (a)

'NPTK2'

'NPTK2'

Number of data points of the two-phase BAT curve.

• Card-5-29 (b)

'PTORK2 (I)', I = 1, NPTK2*2

'PTORK2 (I)', I = 1, NPTK2*2

BAT torque curve data: v / α *vs.* β / α^2.

• Card-5-30 Two-phase BVT curve card

• Card-5-30 (a)

'NPTK2'

'NPTK2'

Number of data points of the two-phase BVT curve.

• Card-5-30 (b)

'PTORK2 (I)', I = 1, NPTK2*2

'PTORK2 (I)', I = 1, NPTK2*2

BVT torque curve data: α / v *vs.* β / v^2.

• Card-5-31 Two-phase BAR curve card

• Card-5-31 (a)

'NPTK2'

'NPTK2'

Number of data points of the two-phase BAR curve.

• Card-5-31 (b)

'PTORK2 (I)', I = 1, NPTK2*2

'PTORK2 (I)', I = 1, NPTK2*2

BAR torque curve data: v / α *vs.* β / α^2.

• Card-5-32 Two-phase BVR curve card

• Card-5-32 (a)

'NPTK2'

'NPTK2'

Number of data points of the two-phase BVR curve.

• Card-5-32 (b)

'PTORK2 (I)', I = 1, NPTK2*2

'PTORK2 (I)', I = 1, NPTK2*2

BVR torque curve data: α / v *vs.* β / v^2.

- Card-5-33 Two-phase multiplier for pump head
- Card-5-33 (a)

'NPHM'

'NPHM'

Number of data points of the curve.

- Card-5-33 (b)

'PHDM (I)', I = 1, NPHM*2

'PHDM (2* J-1)', J = 1, NPHM

Void fraction.

'PHDM (2* J)', J = 1, NPHM

Head multiplier.

- Card-5-34 Two-phase multiplier for pump torque
- Card-5-34 (a)

'NPTM'

'NPTM'

Number of data points of the curve.

- Card-5-34 (b)

'PTKM (I)', I = 1, NPTM*2

'PTKM (2* J-1)', J = 1, NPHM

Void fraction.

'PTKM (2* J)', J = 1, NPHM

Torque multiplier.

- Card-6 Pump locking data

This card must be inserted NPSTP times.

'CAVCON', 'FPUMP', 'SPUMP'

'CAVCON'

Time to lock (s). If CAVCON is less than or equal to zero, no locking occurs through time.

'FPUMP'

Forward speed to lock (rad/s). If FPUMP is zero, no locking occurs through forward speed.

'SPUMP'

Reverse speed to lock (rad/s). Normally SPUMP should be negative. If SPUMP is zero, no locking occurs through reverse speed.

• Card-7 Pump speed table after coastdown

These cards must be inserted NPSPED times.

• Card-7 (a)

'ITPSP', 'NPSP'

'ITPSP'

Trip number for type-1 trip.

'NPSP'

Number of data points of the curve.

• Card-7 (b)

'PSPEED (I)', I = 1, NPSP*2

'PSPEED (2* I-1)', 'I = 1, NPSP

Time (s).

'PSPEED (2* I)', I = 1, NPSP

Pump speed (rad/s).

• Card-8 Variable moment of inertia data

This card must be inserted NINERT times.

'RTRIP', ('VARIN (I)', I = 1, 4)

'RTRIP'

Pump speed above which variable moment of inertia is to be used.

'VARIN (I)', I = 1, 4

Coefficients for variable moment of inertia.
Moment of inertia (Kg* m^2) is calculated as

$$I = VARIN\,(1) + VARIN\,(2) * S + VARIN\,(3) * S^2 + VARIN\,(4) * S^3,$$

where S denotes the normalized pump speed: POMGA/POMGAR.

• Card-9 Trip data card

Trip data for the pump motor are defined by this card.

When the pump motor is on-state, signal value of this trip is positive and when it is off-state, this value is negative.

'KTRIP'

'KTRIP'

Number of trip tables to be read.

• Card-9-1 Trip table card

These cards must be inserted KTRIP times.

• Card-9-1 (a)

'NTABTR'

'NTABTR'

Number of data points of this pump trip.

• Card-9-1 (b)

'TTRIP (I)', I = 1, NTABTR*2

'TTRIP (2* I-1)', I = 1, NTABTR

Time (s).

'TTRIP(2* I)' , I = 1, NTABTR

Signal value.

5.2.5 MATERIAL-PROPERTIES DATA FOR HEAT CONDUCTORS

These input data define material-properties of heat conductors. For each material, material identification number, density, specific heat, thermal conductivity and emissivity are to be input as functions of temperature. The built-in materials are as follows.

Material Identification number	Material
6	SUS 304
7	SUS 316
8	SUS 347
9	Carbon Steel A508
10	Inconel 718
12	Inconel 600

The material identification number must be different from that of built-in materials. The material-properties data must not be input in case of restart calculations. The material-properties data consist of following 'Card's.

Card-1 Material definition card
Card-2 Material properties card

These data are repeated MATNUM times.

• Card-1 Material definition card

'MATID'

'MATID'

Material identification number.

• Card-2-1 Material properties card: Density

• Card-2-1 (a)

'LENTB'

'LENTB'

Length of data table of density.

• Card-2-1 (b)

'TBMAT (I)', I = 1, LENTB*2

'TBMAT (2* I-1)', I = 1, LENTB

Temperature (K).

'TBMAT (2* I)', I = 1,LENTB

Density (kg/m^3).

• Card-2-2 Material properties card: Specific heat

• Card-2-2 (a)

'LENTB'

'LENTB'

Length of data table of specific heat.

• Card-2-2 (b)

'TBMAT (I)', I = 1, LENTB*2

'TBMAT (2* I-1)', I = 1, LENTB

Temperature (K).

'TBMAT (2* I)', I = 1, LENTB

Specific heat (J/kg/K).

• Card-2-3 Material properties card: Thermal conductivity

• Card-2-3 (a)

'LENTB'

'LENTB'

Length of data table of thermal conductivity.

• Card-2-3 (b)

'TBMAT (I)', I = 1, LENTB*2

'TBMAT (2* I-1)', I = 1, LENTB

Temperature (K).

'TBMAT (2* I)', I = 1, LENTB

Thermal conductivity (J/m/K/s).

• Card-2-4 Material properties card: Emissivity

• Card-2-4 (a)

'LENTB'

'LENTB'

Length of data table of emissivity.

• Card-2-4 (b)

'TBMAT (I)', I = 1, LENTB*2

'TBMAT (2* I-1)', I = 1, LENTB

Temperature (K).

'TBMAT (2* I)', I = 1, LENTB

Emissivity.

5.2.6 COMPONENT DEFINITION DATA

These input data define fluid components which make up the thermal-hydraulic system. Component definition data must be repeated NCOMP times. Component definition data consist of following 'Card's:

Card-1 Component type definition data,
Card-2 Component dependent data.

Component type definition data are common to all types of components and component dependent data are different according to the types of components. These data must be omitted in restart calculation.

• Card-1 Component type definition card

'MDLNAM', 'IMTYP', 'METV', 'METT'

'MDLNAM'

Name of component (less than or equal to 12 characters starting from the first column).

'IMTYP'

Type number of component:

–2 : Left boundary component,
–1 : Right boundary component,
1 : Pipe component.

'METV'

Option flag for two-phase flow model related to flow homogeneity:

0 : 1V (homogeneous model),
1 : 1VD (drift flux model),
2 : 2V (unequal velocity model).

'METT'

Option flag for two-phase flow model related to thermal non-equilibrium:

0 : 1T (thermal equilibrium model),
1 : 1.5T (simplified thermal non-equilibrium model),
2 : 2T (thermal non-equilibrium model).

(1) PIPE component dependent data

• Card-2-1 Number of mesh cells and fill-breaks

'N', 'NVAL', 'NFB'

'N'

Number of mesh cells in a pipe component.

'NVAL'

Not used at present.

'NFB'

Number of fills and breaks.

• Card-2-2 Debug option card

'IDB', 'ICUTS', 'IDUTE'

'IDB'

Option flag for debug printing:

0 : No print of Jacobian,
1 : Print of Jacobian.

'ICUTS'

First mesh cell number from which Jacobians are printed.

'ICUTE'

Last mesh cell number to which Jacobians are printed.

• Card-2-3 Correlation option card

'ICJO', 'IHCON', 'IADMP', 'IREC', 'IECFG', 'IFLOW'

'ICJO'

Option flag for implicit treatment of correlation:

0 : Implicit treatment (not usable at present),
1 : Explicit treatment.

'IHCON'

Not used at present.

'IADMP'

Option flag for added mass force and dynamic pressure force:

0 : Use neither,
1 : Use dynamic pressure force,
2 : Use added mass force,
3 : Use both.

'IREC'

Option flag for pipe geometry:

0 : Cylindrical,
1 : Rectangular (longer side is used as height),
2 : Rectangular (shorter side is used as height).

'IECFG'

Option flag for pressure loss models of flow expansion and contraction:

1 : Lotte's model,
2 : Modified Lotte's model,
3 : Homogeneous model.

'IFLOW'

Option flag for flow regimes:

0 : MINCS continuous model,
1 : Stratified flow,
2 : Annular flow,
3 : Bubbly flow,
4 : Droplet flow.

• Card-2-4 Geometric data card

'I', 'IEC', 'IFM', 'IVL', 'IPM', 'IHTM', 'AREA0', 'DELX', 'AREA1', 'DELEV', 'DHF', 'DHH', 'ROGH'

'I'

Mesh cell number.

'IEC'

Option flag for pressure loss calculation of flow expansion and contraction:

0 : calculated,
1 : not calculated.

'IFM'

Form loss definition data table number.
(zero means no form loss)

'IVL'

Valve number.
(zero means no valve)

'IPM'

Pump number to be used.
(zero means no pump)

'IHTM'

Arbitrary positive number assigned to I-th mesh cell.

It must be unique in the component. A set of this number and the component number defines the mesh cell uniquely.

This number corresponds to NODEL or NODER in the boundary condition card (Card-4) of heat conductor definition data.

'AREA0'

Cross-sectional area at the center of mesh cell (m^2).

'DLEX'

Length of mesh cell (m).

'AREA1'

Cross-sectional area at the right edge of mesh cell(m^2).

'DELEV'

Height of the right edge of I-th mesh cell from the left edge of the same mesh cell (m).

'DHF'

Flow equivalent diameter at the center of mesh cell.

'DHH'

Heat equivalent diameter at the center of mesh cell.

'ROGH'

Roughness of the wall of mesh cell.

These data must be repeated N times. However, if the (I + 1)-th, (I + 2)-th, ... mesh cell data are all the same as the I-th mesh cell data, the (I + 1)-th, (I + 2)-th, ... mesh cell data can be omitted. In that case, the first and the last mesh cell data cannot be omitted.

• Card-2-5 Initial value data card

'I', ('X (I)', I = 1,8)

'I'

Mesh cell number.

'X (I)', I = 1,8

Initial value of physical quantity:

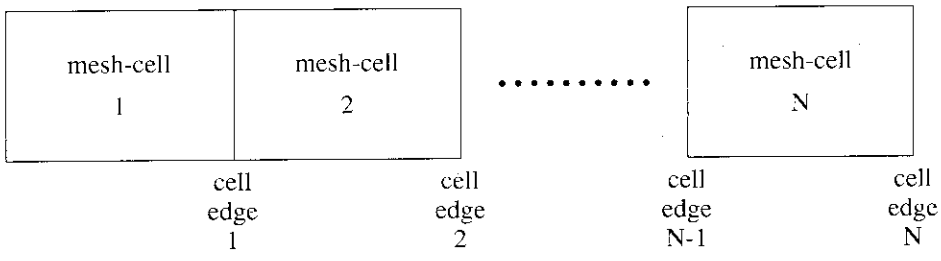
1 : Void fraction,
2 : Pressure (Pa),
3 : Enthalpy of gas (J/kg),
4 : Enthalpy of liquid (J/kg),
5 : Velocity of gas (m/s),
6 : Velocity of liquid (m/s),
7 : Enthalpy of the mixture of gas and liquid (J/kg),
8 : Quality.

These data must be repeated N times. However, if the (I + 1)-th, (I + 2)-th, ... mesh cell data are all the same as the I-th mesh cell data, the (I + 1)-th, (I + 2)-th, ... mesh cell data can be omitted. In that case, the first and the last mesh cell data cannot be omitted.

<Note>

- Data X (7) and X (8) have no meaning in the case of 2T calculation.
- When X (3) or X (4) are set to 0.0 in 2T calculation, generated values for X (3) or X (4) become saturated values.
- When X (7) is set to 0.0 in 1T or 1.5T calculation, a generated value for X (7) becomes a saturated value in accordance with X (8).
- In the case of 1T or 1.5T calculation, X (1), X (3) and X (4) have no meaning.
- If negative values are given to X (3) or X (4), they are recognized as the temperature with negative sign.
- If negative value is given to X (7), it is recognized as the mixture temperature with negative sign.

The mesh-cell configuration of a PIPE component is shown below. Quantities from mesh-cell 1 to mesh-cell N and those from cell-edge 1 to cell-edge N belong to the PIPE component.



- Card-2-6 Fill-break data card

(This card must be inserted NFB times)

'IFBPOS', 'IFB', 'IUPDWN', ('IFBTB (J)', J = 1, 8), 'DIAFAC', 'ETA', 'FBANGL', 'FBGLOS', 'FBLLOS', 'AREAS'

'IFBPOS'

Node number of which has fill or break.

'IFB'

Fill-break type:

−2 : Fill with critical flow model,
1 : Break,
2 : Fill.

'IUPDWN'

Location of fill or break:

−1 : Bottom of mesh cell,
0 : Side of mesh cell,
1 : Top of mesh cell.

'IFBTB (I)', I = 1, 8

Table length of (time vs. boundary value) tables:

I = 1 : Void fraction,
I = 2 : Pressure,
I = 3 : Enthalpy of gas,
I = 4 : Enthalpy of liquid,
I = 5 : Velocity of gas,
I = 6 : Velocity of liquid,
I = 7 : Enthalpy of mixture,
I = 8 : Quality.

'DIAFAC'

Multiplication factor to the half of mesh-cell diameter.

This value is used to calculate the break velocity, usually it is set equal to unity.

If IFB is −2, DIAFAC is a discharge coefficient.

'ETA'

Momentum distribution ratio to the (I-1/2)-th junction.
(0.0 < ETA < 1.0)

'FBANGL'

Cosine of an angle between pipe and fill or break.

'FBGLOS'

Form loss coefficient for gas.

'FBLLOS'

Form loss coefficient for liquid.

'AREAS'

Flow area of fill or break.

• Card-2-7 Initial value data for fill and break

(This card has the same format as Card-2-5, and must be inserted NFB times corresponding to IFBPOS)

• Card-2-8 Table data for time dependent boundary condition

'TABL (K, J)', K = 1, IFBTB (J)*2

(This card must be inserted when IFBTB (J) > 0, the order is as follows:

(K, J) = (1, 1), (2, 1), ..., (8, 1),
(1, 2), (2, 2), ..., (8, 2),
.....,
(1, NFB), (2, NFB), ... (8, NFB).)

(2) BOUNDARY component dependent data

• Card-2-1 Boundary condition data card

'IBNDY', ('ITB (K)', K = 1, 8)

'IBNDY'

Boundary condition:

-2 : Boundary velocities are calculated as the critical flow by homogeneous equilibrium model.
1 : Boundary velocities are calculated (pressure boundary).
2 : Boundary velocities are fixed (velocity boundary).

'ITB (K)', k = 1, 8

Length of the table of time dependent boundary values.

• Card-2-2 Debug option card

'IDB', 'ICUTS', 'ICUTE'

'IDB'

Debug print option:

0 : No Print of Jacobian,
1 : Print Jacobian.

'ICUTS'

Not used at present.

'ICUTE'

Not used at present.

• Card-2-3 Correlation option card

'ICJO', 'IHCON', 'IADMP', 'IREC', 'IECFG', 'IFLOW'

'ICJO'

Option flag for implicit treatment of correlation:

0 : Implicit treatment (not usable at present),
1 : Explicit treatment.

'IHCON'

Not used at present.

'IADMP'

Option flag for added mass force and dynamic pressure force:

0 : Use neither,
1 : Use dynamic pressure force,
2 : Use added mass force,
3 : Use both.

'IREC'

Option flag for pipe geometry:

0 : Cylindrical,
1 : Rectangular (longer side is used as height).
2 : Rectangular (shorter side is used as height).

'IECFG'

Option flag for pressure loss models of flow expansion and contraction:

1 : Lotte's model
2 : Modified Lotte's model,
3 : Homogeneous model.

'IFLOW'

Option flag for flow regimes:

0 : MINCS continuous model,
1 : Stratified flow,
2 : Annular flow,
3 : Bubbly flow,
4 : Droplet flow.

• Card-2-4 Discharge coefficient data card

'VELFAC'

'VELFAC'

Discharge coefficient for critical flow.
(This card is omitted when IBNDY is 1 or 2)

• Card-2-5 Geometric data card

'I', 'IEC', 'IFM', 'IVL', 'IPM', 'IHTM', 'AREA0', 'DELX', 'AREA1', 'DELEV', 'DHF', 'DHH', 'ROGH'

'I'

Mesh cell number.

'IEC'

Option flag for pressure loss calculation of flow expansion and contraction:

0 : calculated,
1 : not calculated.

'IFM'

Form loss definition data table number.
(zero means no form loss)

'IVL'

Valve number.
(zero means no valve)

'IPM'

PUMP number to be used.
(zero means no pump)

'IHTM'

Arbitrary positive number assigned to I-th mesh cell.

It must be unique in the component. A set of this number and the component number defines the mesh cell uniquely. This number corresponds to NODEL or NODER in the boundary condition card (Card-4) of heat conduction definition data.

'AREA0'

Cross-sectional area at the center of mesh cell (m^2).

'DELX'

Length of mesh cell (m).

'AREA1'

Cross-sectional area at the right edge of mesh cell (m^2).

'DELEV'

Height of the right edge of I-th mesh cell from the left edge of the same mesh cell (m).

'DHF'

Flow equivalent diameter at the center of mesh cell.

'DHH'

Heat equivalent diameter at the center of mesh cell.

'ROGH'

Roughness of the wall of mesh cell.

• Card-2-6 Initial value data card

'I', ('X (I)', I = 1, 8)

'I'

Mesh cell number.

'X (I)', I = 1, 8

Initial value of physical quantity:

1 : Void fraction,
2 : Pressure (Pa),
3 : Enthalpy of gas (J/kg),
4 : Enthalpy of liquid (J/kg),
5 : Velocity of gas (m/s),
6 : Velocity of liquid (m/s),
7 : Enthalpy of the mixture of gas and liquid (J/kg),
8 : Quality.

<Note>

- Data X (7) and X (8) have no meaning in the case of 2T calculation.
- When X (3) or X (4) are set to 0.0 in 2T calculation, generated values for X (3) or X (4) become saturated values.
- When X (7) is set to 0.0 in 1T or 1.5T calculation, a generated value for X (7) becomes a saturated value in accordance with X (8).
- In the case of 1T or 1.5T calculation, X (1), X (3) and X (4) have no meaning.
- If negative values are given to X (3) or X (4), they are recognized as the temperature with negative sign.
- If negative value is given to X (7), it is recognized as the mixture temperature with negative sign.

• Card-2-7 Time dependent boundary value data card

(This card must be inserted only when ITB is positive)

('TABL (I, K)', I = 1, ITB (K)*2)

'TABL (2* J-1, K)', J = 1, ITB (K)

Time (s).

'TABL (2* J, K)', J = 1, ITB (K)

K = 1 : Void fraction,
K = 2 : Pressure (Pa),
K = 3 : Enthalpy of gas (J/kg),
K = 4 : Enthalpy of liquid (J/kg),
K = 5 : Velocity of gas (m/s),
K = 6 : Velocity of liquid (m/s),
K = 7 : Enthalpy of mixture of gas and liquid (J/kg),
K = 8 : Quality.

This table is used with interpolation.

5.2.7 NETWORK DEFINITION DATA

The network is defined as follows:

(1) Assign an arbitrary but unique number to each junction adjacent to components,

(2) Specify the number of junction to which the terminal of each component is connected.

These data must be omitted in the case of restart calculations.

Note that two junctions with different polarity can be connected and those with the same polarity cannot be connected. The polarity is defined as

Left boundary component : −1,
Right boundary component : 1,
Left-side end of pipe component : 1,
Right-side end of pipe component : −1.

That is, the left boundary component can be connected to the left-side end of pipe component, the right-side end of pipe component can be connected to the right boundary component or the left-side end of another pipe component, and so on.

- Card-1 Network specification card

(This card must be repeated NCOMP times)

'MDLNAM', 'JUNC1' (, 'JUNC2')

'MDLNAM'

Component name starting from the first column. This name must be defined in the component type definition card of component definition data.

'JUNC1' (, 'JUNC2')

Junction number to which the terminals of component are connected. In the PIPE component, JUNC1 is for the left end, and JUNC2 is for the right end.

5.2.8 HEAT CONDUCTOR DEFINITION DATA

This data block defines a heat conductor module. This block is omitted in the case of restart calculation. Heat conductor definition data consist of following 'Card's:

Card-1 Print-edit option card
Card-2 Table control card
Card-3 Geometry, material and initial condition card
Card-4 Boundary condition card

• Card-1 Print-edit option card

'IDBG'

'IDBG'

Print-edit option flag for heat conductor module:

0 : No print,
1 : Print.

• Card-2 Table control card

'NPOW', 'NPWMAX', 'NTBLK', 'MAXBLK', 'NHTC', 'MAXHTC'

'NPOW'

Number of power curve tables.

'NPWMAX'

Maximum length of power curve tables.

'NTBLK'

Number of bulk temperature tables.

'NTBLK'

Maximum length of bulk temperature tables.

'NHTC'

Number of heat transfer coefficient tables.

'MAXHTC'

Maximum length of heat transfer coefficient tables.

• Card-2-1 Power curve card

'NPWLEN', 'POWER'

'NPWLEN'

Length of power curve tables.

'POWER'

Power (w).

• Card-2-2 Power curve table card

('FRAC (1, J)', 'FRAC (2, J)'), J = 1, NPWLEN

'FRAC (1, J)', J = 1, NPWLEN

Time (s).

'FRAC (2, J)', J = 1, NPWLEN

Power fraction.

Card-2-1 and Card-2-2 must be repeated NPOW times.

• Card-2-3 Bulk temperature card

'NTBLEN'

'NTBLEN'

Length of bulk temperature table.

• Card-2-4 Bulk temperature table card

('TBLKT (1, J)', 'TBLKT (2, J)'), J = 1, NTBLEN

'TBLKT (1, J)', J = 1, NTBLEN

Time (s).

'TBLKT (2, J)', J = 1, NTBLEN

Bulk temperature (K).

Card-2-3 and Card-2-4 must be repeated NTBLK times.

In the case of fixed boundary temperature condition, the table data are used as the boundary temperature of heat slab.

• Card-2-5 Heat transfer coefficient card

'NHTLEN'

'NHTLEN'

Length of heat transfer coefficient table.

• Card-2-6 Heat transfer coefficient table card

('HTCT (1, J)', 'HTCT (2, J)'), J = 1, NHTLEN

'HTCT (1, J)', J = 1, NHTLEN

Time (s)

'HTCT (2, J)', J = 1, NHTLEN

Heat transfer coefficient ($W/m^2/K$).

Card-2-5 and Card-2-6 must be repeated NHTC times.

• Card-3-1 Name card

'HNAME'

'HNAME'

Name of heat conductor (less than or equal to 12 characters starting from the first column).

• Card-3-2 Geometry card

'ICYL', 'NODE'

'ICYL'

Geometry indicator:

0 : Rectangular,
1 : Cylindrical.

'NODE'

Number of mesh cells of heat conductor.

• Card-3-3 Volume card

'TOTVOL'

'TOTVOL'

Volume of heat conductor.

• Card-3-4 Coordinate card

'XR (I)', I = 1, NODE + 1

'XR (I)'

Distance from the center of pipe mesh cell to I-th cell edge of heat conductor.

• Card-3-5 Material identification card

'MAT (I)', I = 1, NODE

'MAT (I)'

Material identification number of I-th mesh cell of heat conductor.

• Card-3-6 Initial temperature card

'TEMPO (I)', I = 1, NODE + 1

'TEMPO (I)'

Initial temperature of I-th cell edge of heat conductor (K).

• Card-3-7 Power fraction card

'FPWR (I)', I = 1, NODE + 1

'FPWR (I)'

Power fraction of I-th mesh cell of heat conductor.

Card-3-1 to Card-3-7 must be repeated NHEAT times.

- Card-4 Boundary condition card

'HNAME', 'IPOWX', 'ITYPL', 'COMP (1)' (or 'LBULKL'), 'NODEL' (or 'LHTCL'), 'ITYPR', 'COMP (2)' (or 'LBULKR'), 'NODER' (or 'LHTCR')

'HNAME'

Name of heat conductor starting from the first column.
This name must be the same as that defined by Card 3-1.

'IPOWX'

Table number of power table used for this heat conductor.

'ITYPL'

Boundary condition for left boundary:

−100 : Implicit coupling with fluid,
−10 : Explicit coupling with fluid,
−1 : Constant temperature,
0 : Adiabatic,
>0 : Boundary condition is given by the designated bulk temperature table and heat transfer coefficient table.

'COMP (1)'

Name of component to be connected to the left side of the heat conductor.

'LBULKL'

Table number of bulk temperature table for the left side boundary condition.

'NODEL'

Same as IHTM in the geometric data card (Card-2-4) of component definition data. It is the unique number of the mesh cell connected to the left side of the heat conductor.

'LHTCL'

Table number of heat transfer coefficient table for the left side boundary condition.

'ITYPR'

Boundary condition for right boundary:
−100 : Implicit coupling with fluid,
−10 : Explicit coupling with fluid,
−1 : Constant temperature,
0 : Adiabatic,
>0 : Boundary condition is given by the designated bulk temperature table and heat transfer coefficient table.

'COMP (2)'

Name of component to be connected to the right side of the heat conductor.

'LBULKR'

Table number of bulk temperature table for the right side boundary condition.

'NODER'

Same as IHTM in the geometric data card (Card-2-4) of component definition data. It is the unique number of the mesh cell connected to the right side of the heat conductor.

'LHTCR'

Table number of heat transfer coefficient table for the right side boundary condition.

Card-4 must be repeated NHEAT times.

6. SAMPLE PROBLEMS

Four sample problems are shown in this section. Selected problems are the annular flow evaporation, the valve controlled flow, the pump controlled flow and the Kelvin-Helmholtz instability problems. The input decks for the sample problems are listed in APPENDIX 3.

6.1 ANNULAR FLOW EVAPORATION

6.1.1 PROBLEM DESCRIPTION

This problem is based on the data set No.12 in the physical benchmark problem presented at the International Workshop on Two-Phase Flow Fundamentals [6-1]. Subcooled water flows into the vertical oriented pipe from the bottom inlet. The pipe wall is uniformly heated and thus evaporation occurs. The input model is shown in Fig. 6.1.1.

The heated pipe is made from stainless steel. It is 2.438 (m) in length and 9.296 (mm) in inner diameter with 1.651 (mm) thick wall. Inlet flow boundary conditions are fixed at the bottom of the pipe. The flow rate is 297.0 ($kg/s/m^2$), the temperature is 111.1 (deg-c) and the pressure is 377.1 (kPa). The wall heat flux is 207.3 (KW/m^2).

The pipe is simulated by 20-mesh pipe component which has two boundary components. Each mesh of the pipe has 6-mesh heat conductor. The outmost mesh in the heat conductor has the heat source. The heat flux is linearly increased and then set to the constant.

6.1.2 CALCULATED RESULTS

The profiles of void fraction at several time steps are shown in Fig. 6.1.2. The void fraction is shown to be increasing from upstream to downstream due to evaporation. However, it is found that no steady state solution can be obtained within this time scale. The continuous correlation model of MINCS is used in this calculation. The continuous model tends to underestimate the interfacial heat transfer, and the flow regimes corresponding to annular and droplet flows are quite simple. The more detailed heat transfer models are, thus, desirable for this problem.

6.2 VALVE CONTROLLED FLOW

6.2.1 PROBLEM DESCRIPTION

The flow in the horizontal pipe is controlled by a valve. The pipe is 1 (m) in length and 0.026 (m) in diameter. It is simulated by 20-mesh pipe component. The valve is located at the 8-th mesh cell edge. The pressures at both ends of the pipe are fixed. The schema of input model and the valve condition are shown in Figs. 6.2.1 and 6.2.2, respectively.

6.2.2 CALCULATED RESULTS

The gas velocity transients in the 4-th and 8-th mesh cells are shown in Fig. 6.2.3. The transients are complicated, however, it is clearly shown that the velocity in the 8-th mesh is zero when the valve is entirely closed.

6.3 PUMP CONTROLLED FLOW

6.3.1 PROBLEM DESCRIPTION

The flow in the loop is controlled by a pump. The flow loop is 15 (m) in total length. It consists of 4 pipes: 2 vertical pipes and 2 horizontal pipes. The pump is located in the bottom horizontal pipe. One vertical pipe has the contracting section and the pressure loss of this section is mainly balanced with the pump head. The input model and the pump condition are schematically shown in Figs. 6.3.1 and 6.3.2.

6.3.2 CALCULATED RESULTS

The liquid velocity transient in the top horizontal pipe is shown in Fig. 6.3.3. The pump speed and the pump total torque are shown in Figs. 6.3.4 and 6.3.5, respectively. It is found that the flow in the loop in controlled by the pump.

6.4 KELVIN-HELMHOLTZ INSTABILITY

6.4.1 PROBLEM DESCRIPTION

This problem is based on the numerical benchmark test No.2.5 presented at the International Workshop on Two-Phase Flow Fundamentals [7-1]. The inviscid stratified flow is flowing in the 1 (m) long rectangular pipe. The pipe cross section is 1 (m) by 1(m) and the inlet and the outlet are connected, that is, the cyclic boundary condition is used. The initial velocities are 50.0 (m/s) for gas and 0.001 (m/s) for liquid and the void fraction is 0.5. The small sinusoidal perturbation with wavelength of 1.0 (m) is superposed on the initial void distribution. The flow channel is simulated by 2 pipe components, each has 100 mesh cells. The schema of flow channel is shown in Fig. 6.4.1.

In this problem, the subroutine CORSET is modified to perform an inviscid calculation. The friction coefficients are set to zero in CORSET. Moreover, the four subroutines are modified to perform 200 mesh calculation. MINCS is originally designed to handle 50 mesh cells and the memory size is set to relatively small value. It is, thus, necessary to enlarge some parameters for large calculations. At first, the memory size which is defined in MAIN program should be enlarged to some necessary value. The maximum mesh-cell number is then modified. The subroutines which must be modified are MAKEJB, SETFJ and SETFJ3.

6.4.2 CALCULATED RESULTS

The profiles of void fraction at several time steps are shown in Fig. 6.4.2. The initial disturbance is found to be growing and the unstable results are obtained.

REFERENCES

[6-1] G.F.Hewitt et al., Multiphase Science and Technology
Vol.3, Hemisphere(1987)

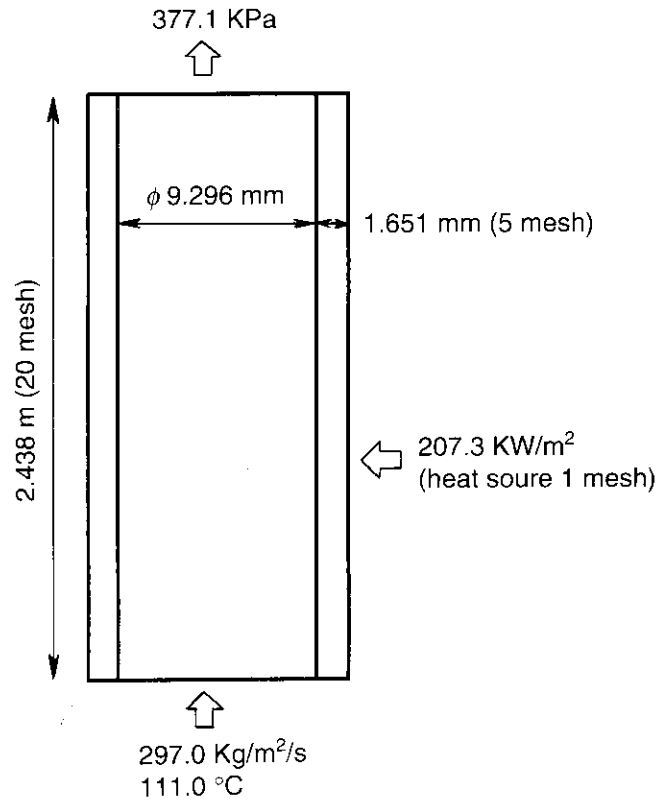


Fig. 6.1.1 Input Model of Sample Problem 6.1

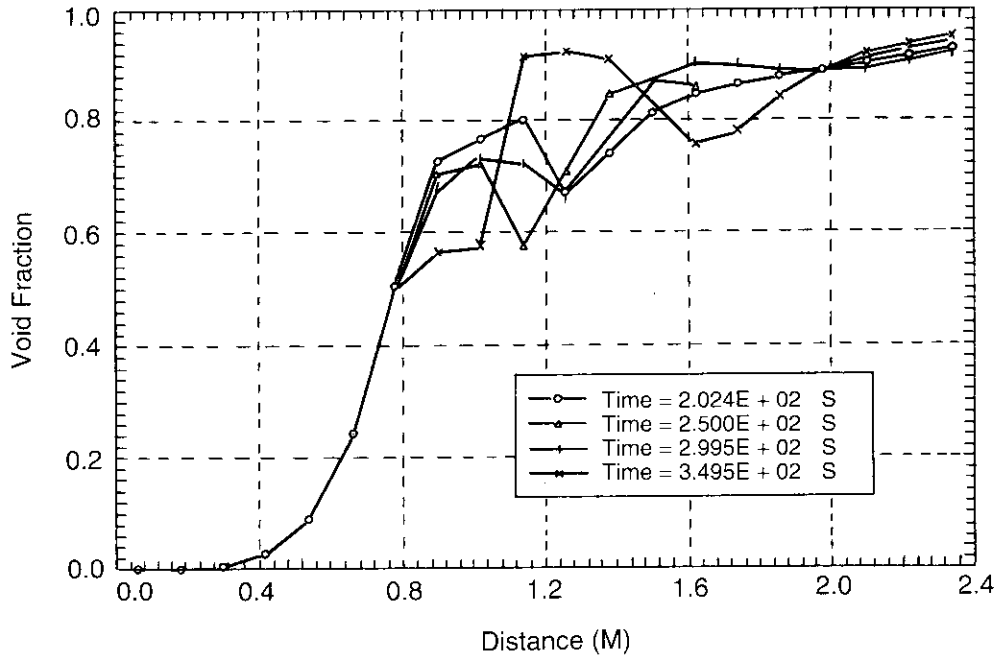


Fig. 6.1.2 Void Fraction Profiles

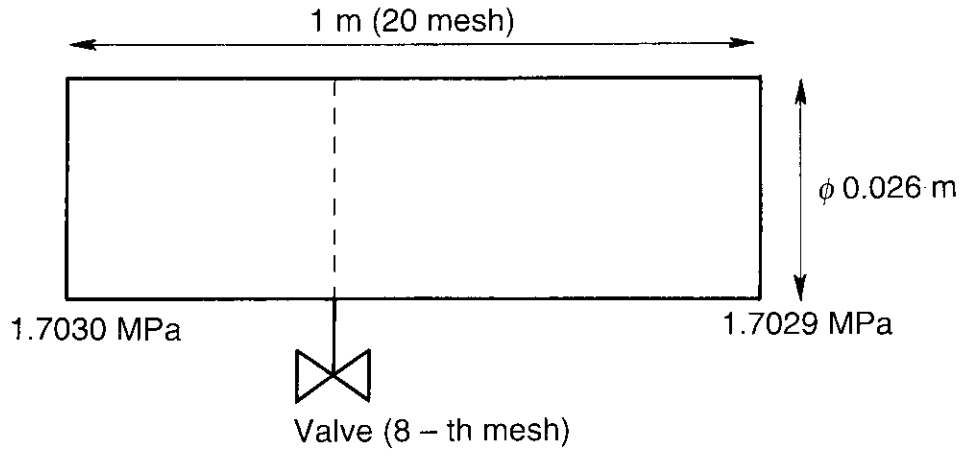


Fig. 6.2.1 Input Model of Sample Problem 6.2

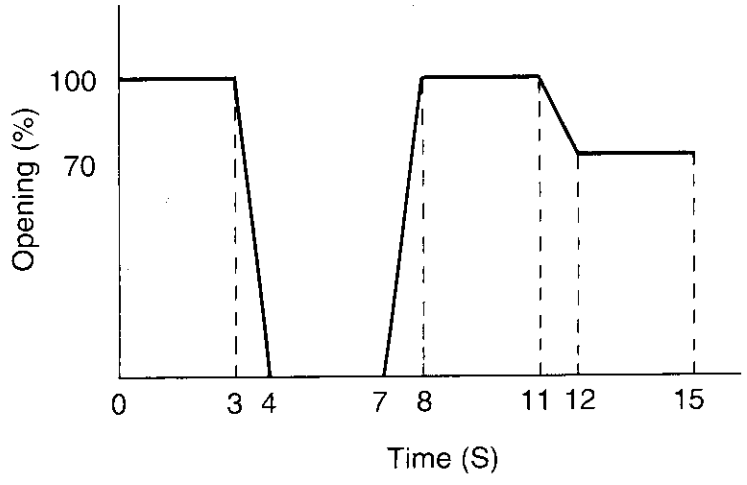


Fig. 6.2.2 Input Valve Condition

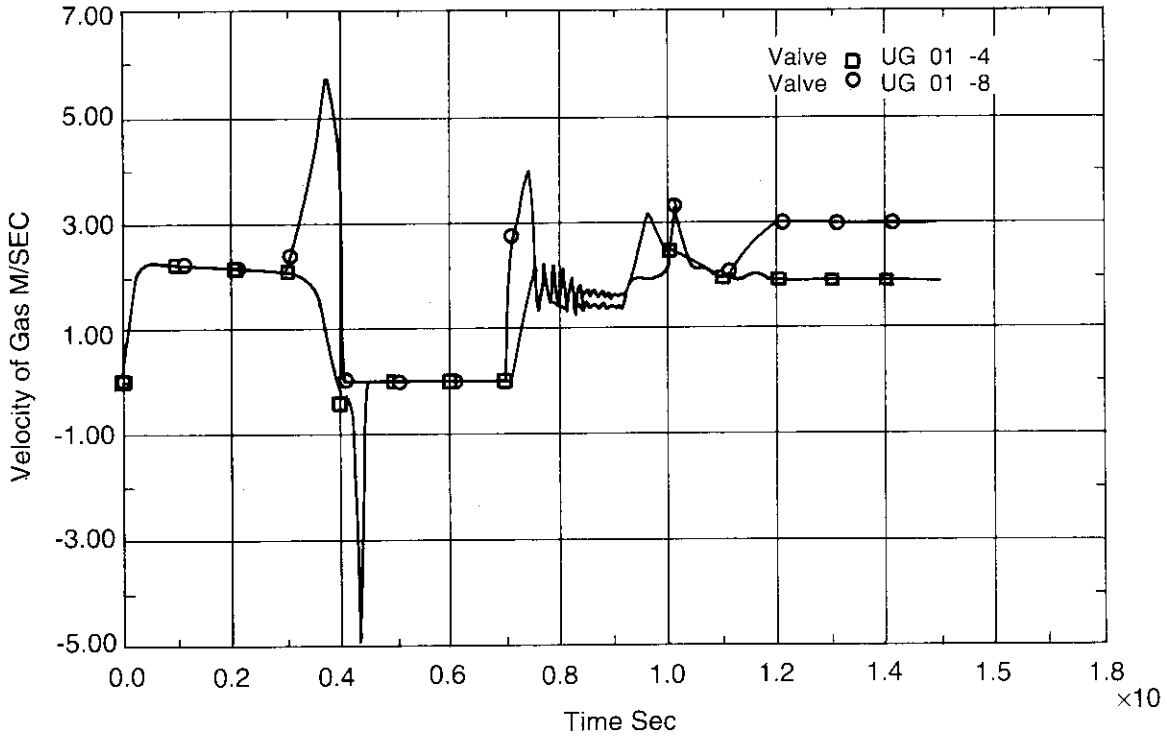


Fig. 6.2.3 Gas Velocity Transient

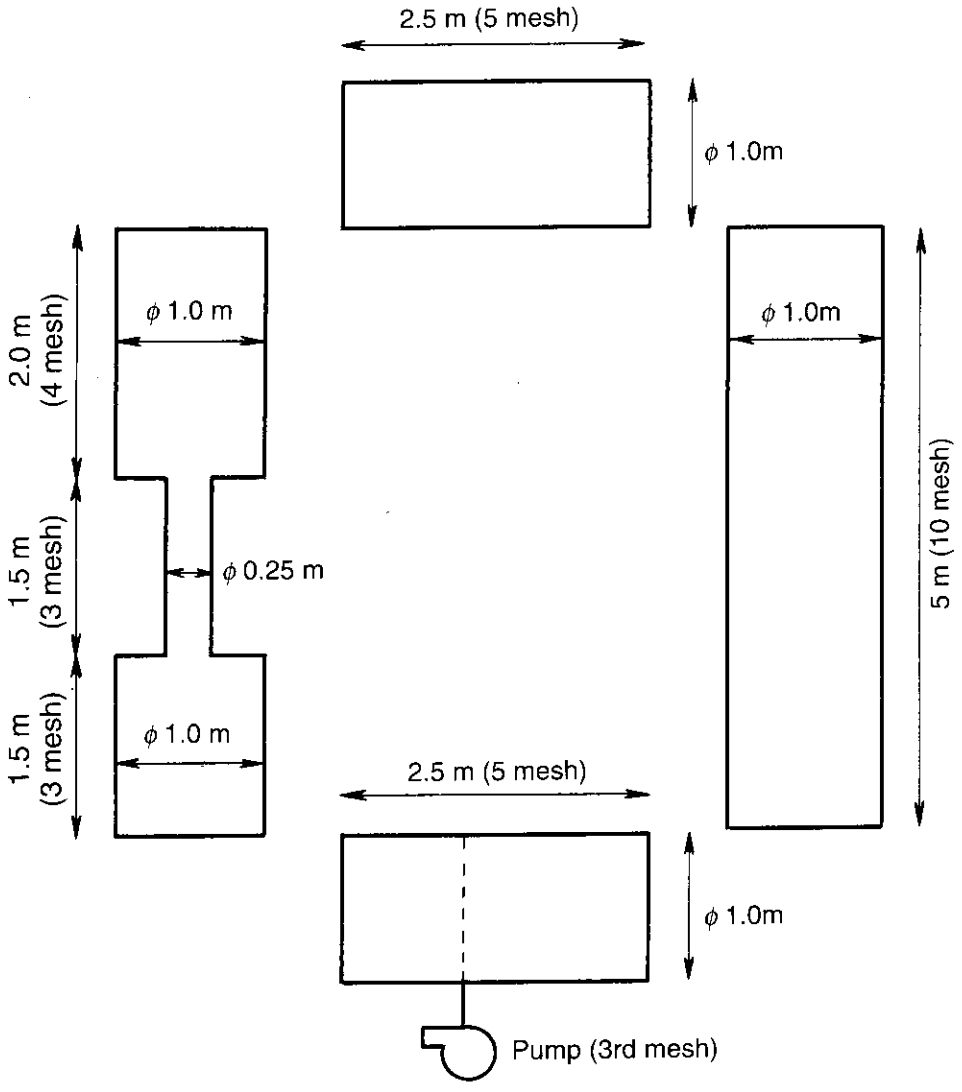


Fig. 6.3.1 Input Model of Sample Problem 6.3

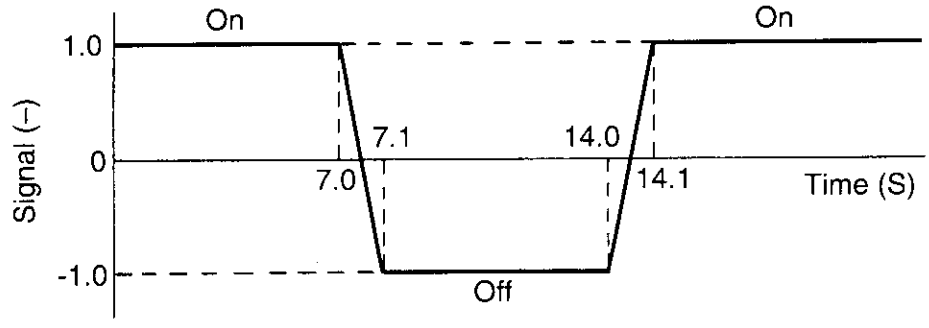


Fig. 6.3.2 Input Pump Condition

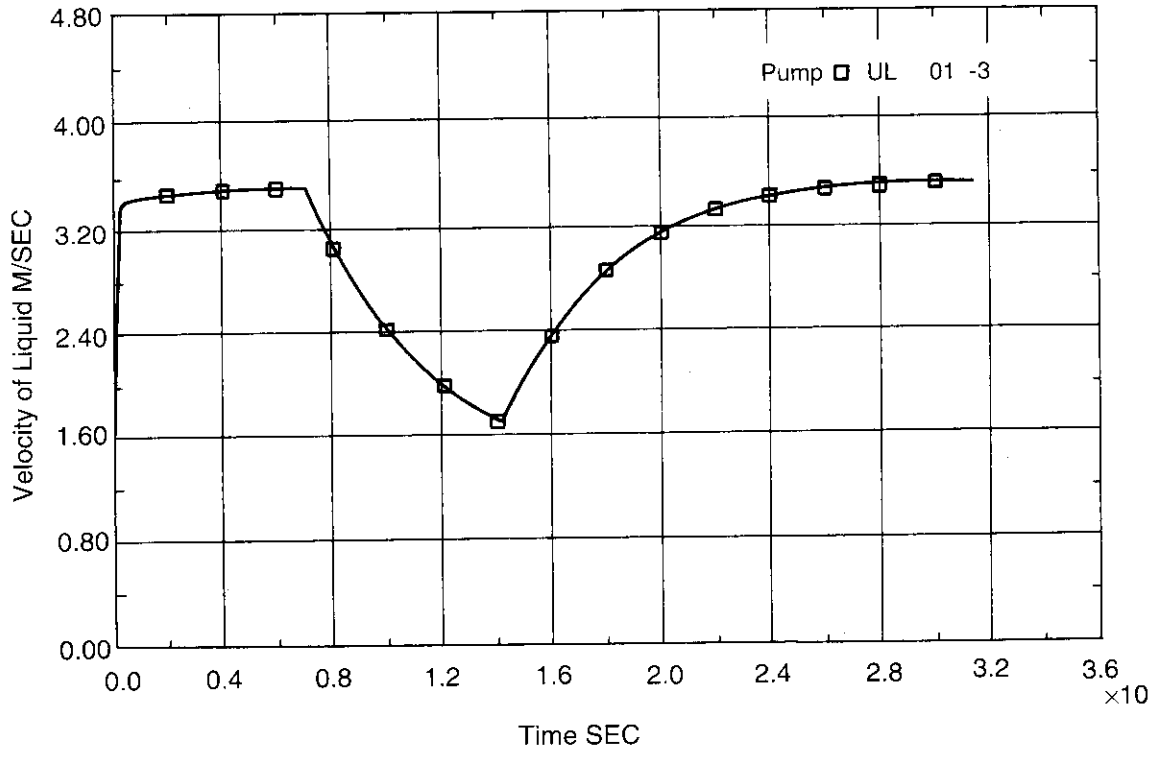


Fig. 6.3.3 Liquid Velocity Transient

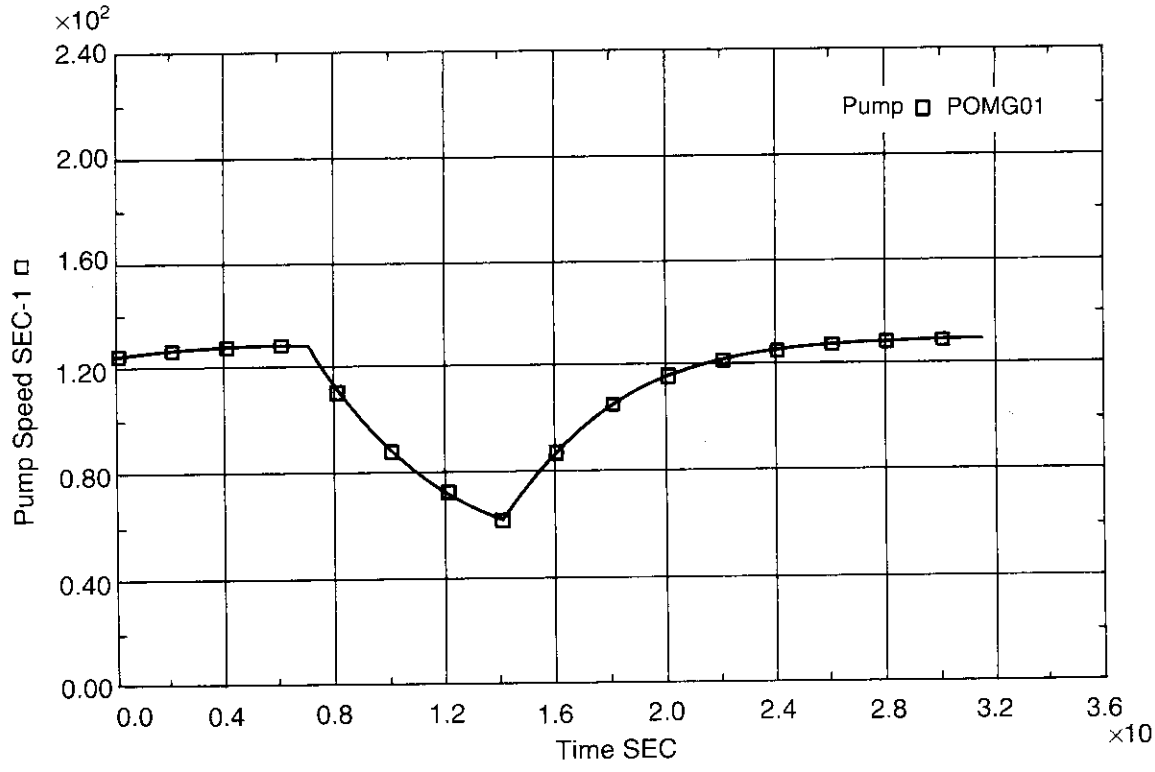


Fig. 6.3.4 Pump Speed Transient

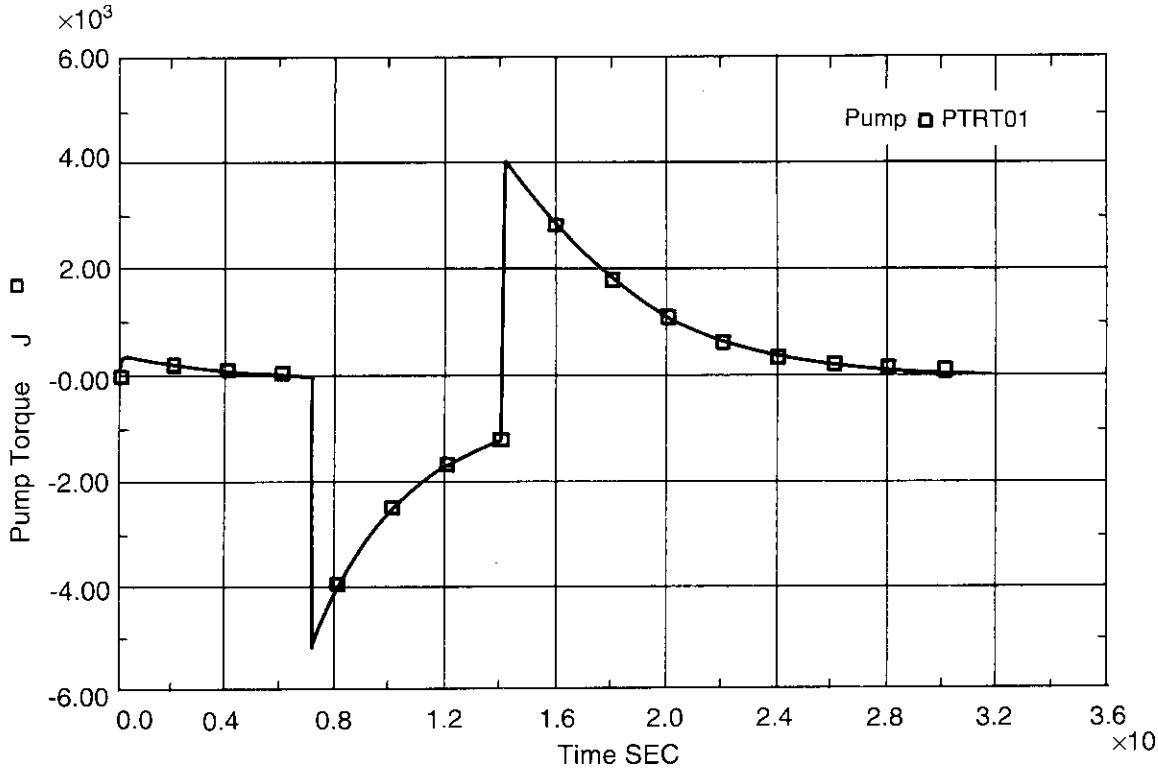


Fig. 6.3.5 Pump Torque Transient

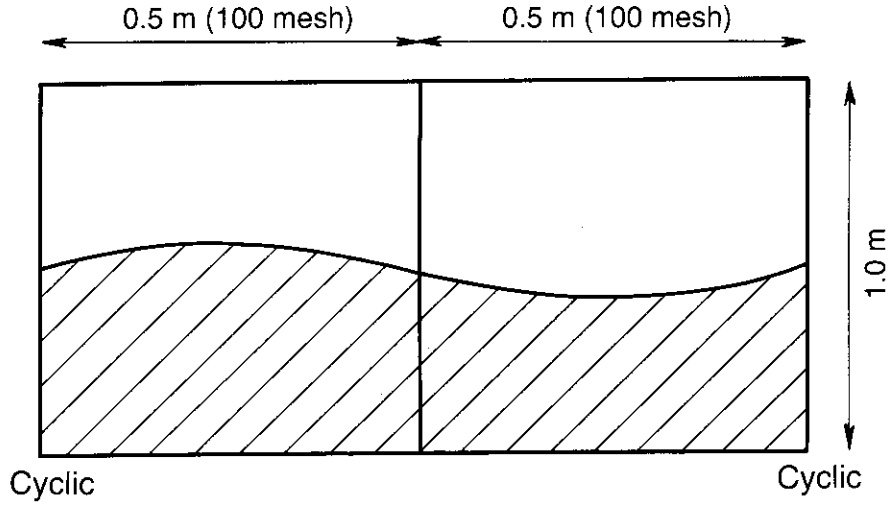


Fig. 6.4.1 Input Model of Sample Problem 6.4

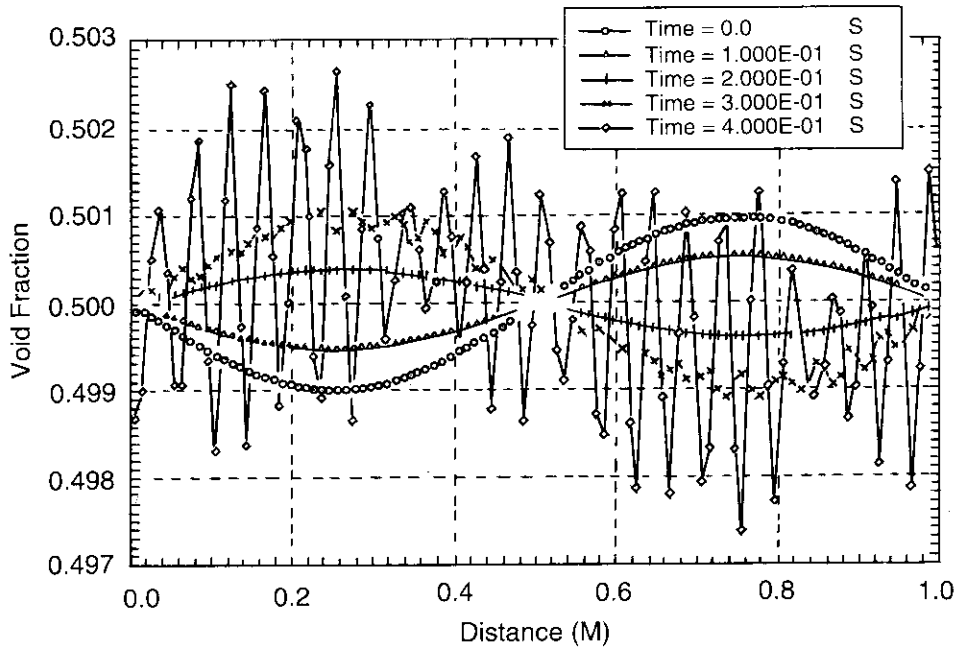


Fig. 6.4.2 Void Fraction Profiles

ACKNOWLEDGEMENT

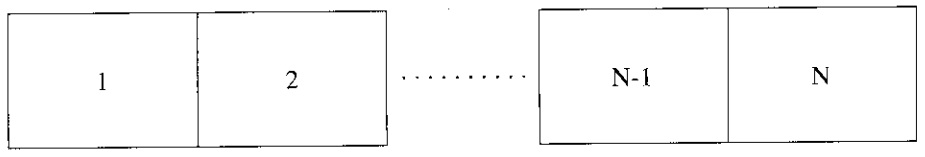
The authors wish to express their appreciation to Drs. H.KAMO, H.INOUE and H.OHSAKI of Japan Information Service Co. for their assistance in developing MINCS, and to Dr. Y.KUKITA, the head of Thermal-Hydraulics Safety Research Laboratory, for his encouragement and valuable advice.

APPENDIX 1. PROGRAM STRUCTURE AND FUNCTIONS

The program structures and functions are described for the important part of the code. The relation of subroutines and the role of each subroutine are as follows.

A1.1 PIPE COMPONENT

The PIPE component simulates the one-dimensional duct in which two-phase flows are flowing. In this component, all the combination of (1V,1VD,2V) and (1T,1.5T,2T) can be calculated.

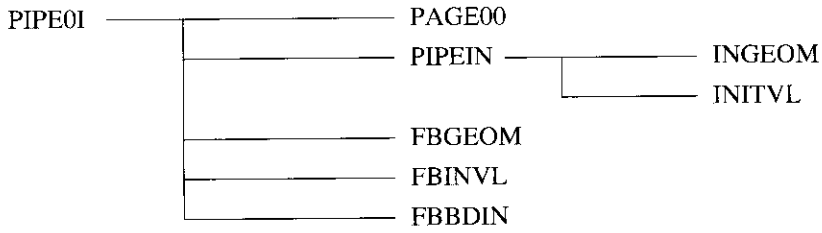


The direction is defined as positive from cell-1 to cell-N. The side of cell-1 is called the left side, while that of cell-N is called the right side. The left BOUNDARY component can be connected to the left side of the PIPE component and the right BOUNDARY component can be connected to the right side of it. Thus, the boundary conditions are set at both boundaries. The PIPE component can be connected to another PIPE components. In this case, the left side of one PIPE component must be connected to the right side of another PIPE components. The heat conductors can be used as the wall of the PIPE components. Thus, the heat transfers between fluid and heat sources or between fluid and surrounding structures can be calculated. The FILL-BREAK(FB) model can be used in any mesh-cells except for the first and N-th mesh-cells. Thus, branching junctions can be simulated. However, only one FB can be used in one mesh-cell. The VALVE and PUMP can be used at each cell edge. All functions mentioned above are used by specifying them in the input deck.

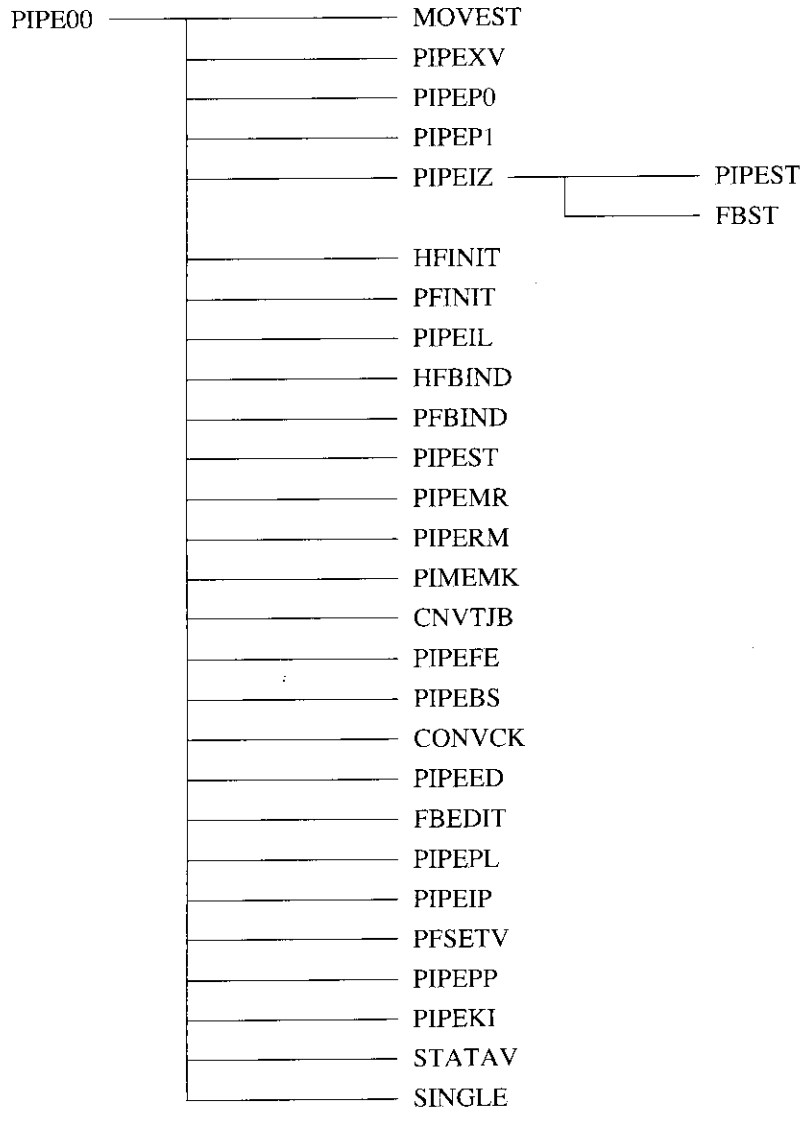
A1.1.1 PROGRAM STRUCTURE

The tree structure of subroutines related to PIPE components are shown below.

A1.1.1.1 INPUT SECTION



A1.1.1.2 CALCULATION SECTION



A1.1.2 FUNCTIONS

A1.1.2.1 INPUT SECTION

(1) PIPE0I

The integer data such as a number of mesh cells or some flags are read from the input deck. Using them, the address and the size of integer type array (IAR), real type array (RAR), character type array (CAR) and work area are calculated. The subroutine PAGE00 is called so as to print the problem title and the data. PIPEIN is then called, geometric data and the initial values of the basic variables are read. If the FB model is used,FBGEOM and FBINVL are called to read the geometric data and the initial values for the FB model. Further, if time dependent boundary conditions are used, FBBDIN is called to read the time table for the boundary condition. Finally, calculated address is stored in the array IAR.

(2) PAGE00

The problem title and the data are printed.

(3) PIPEIN

The subroutines INGEOM and INITVL are called.

(4) INGEOM

The geometric data are read and printed.

(5) INITVL

The initial values of basic variables are read and printed.

(6) FBGEOM

The geometric data for FB model are read and printed.

(7) FBINVL

The initial values of basic variables for FB model are read and printed.

(8) FBBDIN

The time table of boundary conditions for FB model are read and printed.

A1.1.2.2 CALCULATION SECTION

(1) PIPE00

The address and the important flags are retrieved from the array (IAR), and then all the subroutines needed for calculations are called according to the value of JOCODE.

(2) MOVEST

The variables at the location defined by ICNCJ in the array which has 'TJ' in the last of the array name are moved to the location defined by ICNCO in the array which has 'O' in the last of the array name.

(3) PIPEXV

When the right side end of the PIPE component is connected to the right BOUNDARY component in which velocities are fixed, the velocities are substituted into the rightmost internal terminal of the PIPE component and the relative velocity is calculated.

(4) PIPEP0

Initialization for plotting: sizes of fluid components are printed.

(5) PIPEP1

Initialization for plotting: tag lists for fluid components are printed.

(6) PIPEIZ

After initialization for some array, the subroutine PIPEST is called to initialize variables related to the steam table.

(7) PIPEST

If the flag INITLX is unity, variables related to the steam table are initialized using the subroutines INITL0, INITL1 and INITL2. If INITLX is other than unity, the subroutine STEAM0, STEAM1 and STEAM2 are used for initialization. The subroutine SETXV is then called to calculate the XV vector from the X vector.

(8) FBST

Variables in FB model related to the steam table are initialized using the subroutines INITL0 INITL1 and INITL2. The subroutine SETYV is then called to calculate the YV vector from the Y vector.

(9) HFINIT

Sequential numbers are given to the heat slab boundaries connected to the fluid components. Numbering is separately performed for each component. The array ITHT and IHT are set.

(10) PFINIT

The variable IPMBDT(M2USE,NOP) is set to unity if the PUMP model is used. NOP is the pump number.

(11) PIPEIL

After setting correlation parameters by calling the subroutine CORSET, the subroutine INTEGI is called to set the initial values of the inventory and the accumulation of mass and energy.

(12) HFBIND

The values in the steam table related to the fluid temperature are stored in the array HTBND.

(13) PFBIND

The fluid variables which is needed in the PUMP model are stored in the array PMPBDT.

(14) PIPEMR

The variables at the new time step (n+1) are stored in the array which is used to store the variables at the old time step (n). This array has 'X' in the last of the array name.

(15) PIPERM

The variables at the old time step (n) are stored in the array which is used to store the variables at the new time step (n+1).

(16) PIPEMK

The subroutine MAKEJB is called to calculate Jacobians and terminal matrices which are not modified by the boundary conditions. The subroutine DWLLHT is then called to differentiate the product of time step size and heat flux from the wall, $\delta t \times q_w$, by the wall temperature T_w, and the values are stored in the array TV. The subroutine JACOBV is then called, in which if the flow area in a valve is smaller than EPSVAL, the diagonal part of the Jacobian submatrix for the velocity is set to unity and the constant vector of equations for Newton method (F) is set to the negative values of variables (F=-X) so as to obtain the convergence of velocities to zero. Finally, some procedures are performed for terminal matrices when the flow area in the valve is smaller than EPSVAL and the component is the right-BOUNDARY type.

(17) CNVTJB

The Jacobian and the terminal matrix for the 2V2T model are converted to those for the non-2V2T models.

(18) PIPEFE

Forward elimination is performed and the matrix which is multiplied to the terminal vector is calculated.

(19) PIPEBS

Backward substitution is performed. The subroutine SETXVM is then called to set the array XV, HMIX and QAL using X vector during the iteration of Newton method.

(20) CONVCK

Convergence is checked for each component.

(21) PIPEED

Variables in fluid components are printed.

(22) FBEDIT

Variables in FB models are printed.

(23) PIPEPL

Transient values of variables in fluid components are output for plotting.

(24) PIPEIP

The subroutine SETGV0 is called to set the old value of the g-vector — terms including time derivatives in basic equations — which is needed to calculate Jacobians. If VALVEs are used, VALCON is called to obtain the degree of opening and the flow area of the VALVE by interpolation of the input table. ECFMLS is called to set form loss data according to the flow direction. The form loss for E/C section is calculated in the subroutine ECLOSS. The correlation parameters are obtained by calling CORSET. XV vector is set by using X vector, u_g and u_f in the subroutine SETXV. If the FB model is used and the FB is defined as the break, SETFB0 is called to set the old value which is needed to calculate Jacobians. If the FB model is used and the critical flow is defined at the FB, the critical velocity is set by the subroutine FBCHOK. If the FB model is used, FBBND is called to obtain the time dependent boundary values by interpolation of the input table.

(25) PFSETV

The pressure difference and the energy which are actually used in fluid calculation are calculated from the pump head, speed and torque.

(26) PIPEPP

If the FB model is used and the FB is defined as the break, FBBND is called to obtain the new value of mixture velocity. CHECKX is called to check whether or not the void fraction is in the range between zero and unity. Finally, the inventory and accumulation of mass and energy are calculated by the subroutine INTEGT.

(27) PIPEKI

For evaluating the correlations implicitly, the correlation parameters are calculated by using the subroutine CORSET. (this subroutine is not used at present)

(28) STATAV

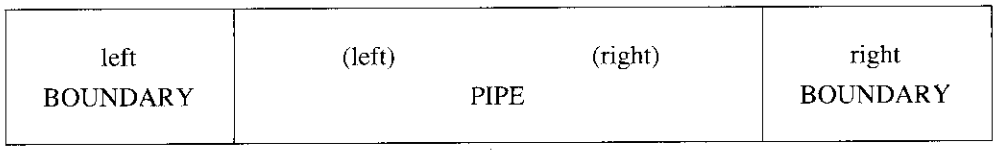
The minimum ratio of the new average value of variable change to the old one is obtained.

(29) SINGLE

(this subroutine is not used at present)

A1.2 BOUNDARY COMPONENT

The BOUNDARY components define the boundary conditions of the PIPE components.

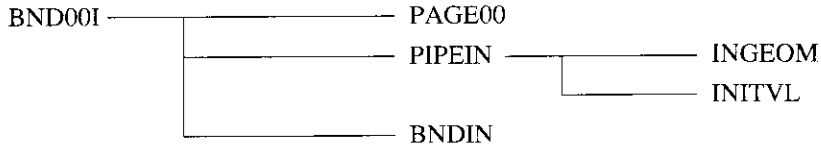


There are two types of BOUNDARY components: left-BOUNDARY and right-BOUNDARY components. The left-BOUNDARY component can be connected to the left side of the PIPE component, and the right-BOUNDARY component can be connected to the right side of the PIPE component. The left-BOUNDARY is usually used as an inflow boundary, while the right-BOUNDARY as an outflow boundary. Two types of boundary conditions can be supplied by BOUNDARY components: one is to fix all basic variables, the other is to calculate velocities and fix other variables. The input values of basic variables in the BOUNDARY components can be time dependent and are obtained by interpolation. All the combination of (1V,1VD,2V) and (1T,1.5T,2T) can also be calculated in this component. The FB model, heat slabs and PUMPs cannot be used in the BOUNDARY components, but the VALVE can be used at the cell edge of the left-BOUNDARY component.

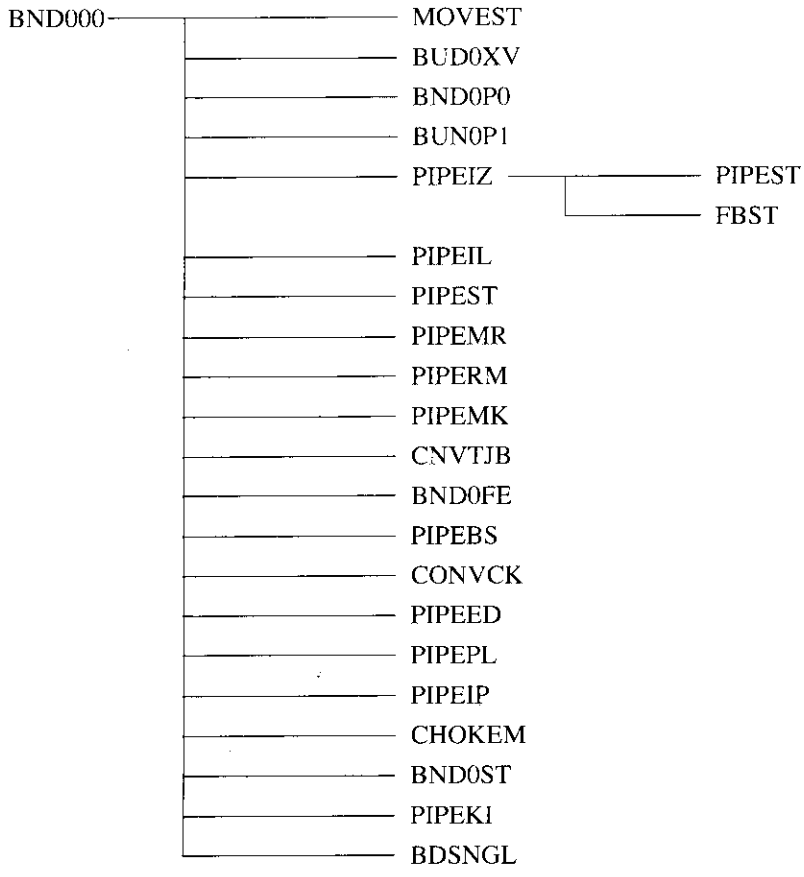
A1.2.1 PROGRAM STRUCTURE

The tree structure of subroutines related to BOUNDARY components are shown below.

A1.2.1.1 INPUT SECTION



A1.2.1.2 CALCULATION SECTION



A1.2.2 FUNCTIONS

A1.2.2.1 INPUT SECTION

(1) BND00I

The integer data such as some flags are read from the input deck. Using them, the address and the size of integer type array IAR, real type array RAR, character type array CAR and work area are calculated. The subroutine PAGE00 is called so as to print the problem title and the date. PIPEIN is then called, geometric data and the initial values of the basic variables are read. Further if time dependent boundary conditions are used, BNDIN is called to read the time table for the boundary condition. Finally, calculated address is stored in the array IAR.

(2) PAGE00

(see the description of PIPE component)

(3) PIPEIN

(see the description of PIPE component)

(4) INGEOM

(see the description of PIPE component)

(5) INITVL

(see the description of PIPE component)

(6) BNDIN

The time table of boundary conditions are read and printed.

A1.2.2.2 CALCULATION SECTION

(1) BND000

The address and the important flags are retrieved from the array IAR, and then, all the subroutines needed for calculation are called according to the value of JOCODE.

(2) MOVEST

(see the description of PIPE component)

(3) BND0XV

When the component is the right-BOUNDARY in which velocities are calculated, the calculated velocities in the external terminals are substituted into the internal terminals.

(4) BND0P0

This is an entry name in the subroutine PIPEP0. Initialization for plotting is performed: size of components are printed.

(5) BND0P1

This is an entry name in the subroutine PIPEP1. Initialization for plotting is performed: tag lists are printed.

(6) PIPEIZ

(see the description of PIPE component)

(7) PIPEST

(see the description of PIPE component)

(8) FBST

(see the description of PIPE component)

(9) PIPEIL

(see the description of PIPE component)

(10) PIPEMR

(see the description of PIPE component)

(11) PIPERM

(see the description of PIPE component)

(12) PIPEMK

(see the description of PIPE component)

(13) CNVTJB

(see the description of PIPE component)

(14) BND0FE

The Jacobian matrix is modified according to whether the velocities are calculated or not, then forward elimination is performed and the matrix, which is multiplied to the terminal vector, is calculated.

(15) PIPEBS

(see the description of PIPE component)

(16) CONVCK

(see the description of PIPE component)

(17) PIPEED

(see the description of PIPE component)

(18) PIPEPL

(see the description of PIPE component)

(19) PIPEIP

(see the description of PIPE component)

(20) CHOKEM

The critical flow velocity is calculated.

(21) BUND0ST

The boundary conditions at the new time level are calculated when the time dependent boundary conditions are used.

(22) PIPEKI

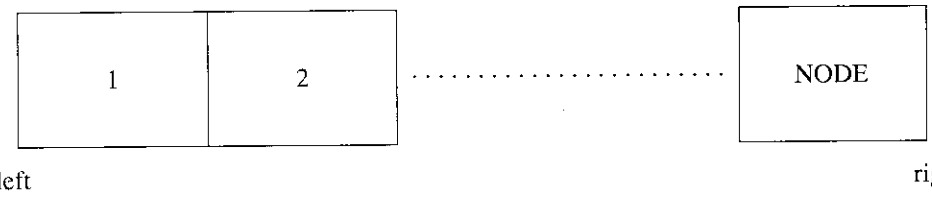
(see the description of PIPE component)

(23) BDSNGL

(this subroutine is not used at present)

A1.3 HEAT CONDUCTOR

The HEAT CONDUCTOR component simulates one-dimensional heat conduction in the wall of PIPE components. Cylindrical type or flat plate type heat slabs can be selected.



Different materials can be used in each mesh of the heat slab. When the heat slab has NODE mesh cells, the first mesh side is called the left side and the NODE-th mesh side the right side. The PIPE components can be connected to both sides. Several heat slabs can be used in one mesh cell of the PIPE component. Some characteristics and remarks are noted below.

(1) boundary conditions

The following 5 types of boundary conditions can be applied.

(a) implicit coupling between the heat slab and fluid
(b) explicit coupling between the heat slab and fluid
(c) fixed temperature
(d) adiabatic
(e) heat transfer coefficients and bulk temperatures

(2) time dependent values

the following values are defined as the time dependent values.

(a) power (heat source) being defined in each heat slab
(b) bulk temperature
(c) heat transfer coefficients at boundaries
(d) boundary temperature

(3) power fractions

Two types of power fractions are used.

(a) total power of one heat slab
Following two values are used to define the total power of one heat slab:
POWER(J) : power
FRAC(2,I,J) : table for (time versus power fraction)
The power fraction (FRAC) is obtained by interpolating the table of FRAC(2,I,J), and the total power is given as POWER(J)*FRAC.

(b) distribution of total power to each mesh
The total power of one hear slab is distributed to each mesh of the heat slab according to the fraction FPWR(K):

$$\frac{FRWR(K)\times VOLUME(K)}{\sum FPWR(L)\times VOLUME(L)}$$

which is the power fraction of K-th mesh in the heat slab.

(4) definition of the fluid cell to which the heat slab is connected

Two variables are used to define the connection between the heat slab and the fluid cell. IHTM is the number given to the fluid cell, and JHTM to the boundary of heat slab. The heat slab boundary and the fluid cell are connected if IHTM and JHTM are the same values.

(a) IHTM
It is defined in the geometric data of PIPE component. It is used as IAR(J,NOHTM) in the program, where J is the cell number of the PIPE component. It must be a positive integer. The value of IHTM is not necessary to be the same as the cell number of the PIPE component.

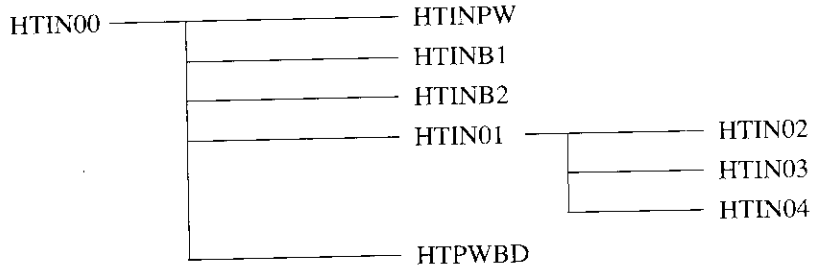
(b) JHTM

It is used as IHTBND(L1NODE,ISIDE, LHEAT) in the program. It is input when the boundary of heat slab is implicitly or explicitly coupled to the fluid cell. It must be a positive integer. The value of JHTM is not necessary to be the same as the cell number of the PIPE component.

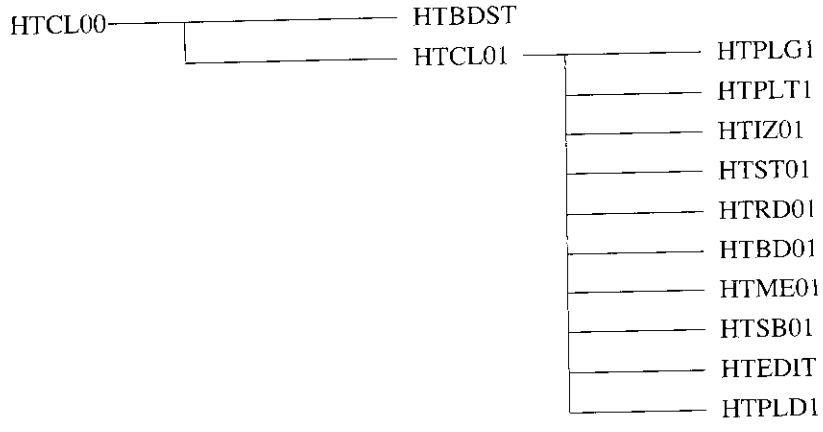
A1.3.1 PROGRAM STRUCTURE

The tree structure of subroutines related to HEAT CONDUCTOR components are shown below.

A1.3.1.1 INPUT SECTION



A1.3.1.2 CALCULATION SECTION



A1.3.2 FUNCTIONS

A1.3.2.1 INPUT SECTION

(1) HTIN00

Some flags, array numbers and dimensions related to all heat slabs are read from the input deck. The address of variables is calculated. The subroutine HTINPW is called to read power curve tables, HTINB1 to read bulk temperature tables and HTINB2 to read heat transfer coefficient tables. The variables in each heat slab are read and the address is calculated by calling HTIN01. Finally, HTPWB is called to read boundary conditions.

(2) HTINPW

The power curve tables are read.

(3) HTINB1

The bulk temperature tables are read.

(4) HTINB2

The heat transfer coefficients tables are read.

(5) HTIN01

The heat slab name (HNAME), the geometric flag (ICYL) and the number of mesh (NODE) are read. The address for JSLAB-th heat slab is then calculated. The subroutine HTIN02, HTIN03 and HTIN04 are called to read geometric data, initial temperatures, and power fraction tables, respectively. Finally, some parts of the array IHTBND and HTBND are set.

(6) HTIN02

The volume of the heat slab (TOTVOL), the distance between the PIPE center and each mesh edge (XR) and the identification number of the mesh material (MAT)are read, and then some values related to geometry are calculated to be stored in the array.

(7) HTIN03

The initial temperatures at mesh-cell edges are read and are checked whether or not they are within the temperature range of material properties' table.

(8) HTIN04

The power fractions (FPWR) are read, and then they are multiplied by the mesh cell volumes and are normalized.

(9) HTPWBD

Some values related to boundary conditions are read.

A1.3.2.2 CALCULATION SECTION

(1) HTCL00

If JHCODE, which is equivalent to JOCODE in this subroutine, is +1 or -1, the total power at time TIMEN is calculated by interpolating the table. The subroutine HTBDST is called to determine the boundary conditions according to the boundary type of each heat slab. Heat conduction calculations in each heat slab are performed by calling the subroutine HTCL01.

(2) HTBDST

The bulk temperatures and heat transfer coefficients are obtained by interpolating the table data or by using the fluid conditions, and then they are arranged into the array HTBND. If the boundary temperatures are to be fixed, the wall temperatures (T_w) are obtained by interpolating the bulk temperature tables.

(3) HTCL01

The address and flags are retrieved from the array IR, and then subroutines are called according to JHCODE to perform the calculation related to one hear slab.

(4) HTPLG1

Initialization for plotting is performed: geometric data are printed.

(5) HTPLT1

Initialization for plotting is performed: tag lists are printed.

(6) HTIZ01

The power in each mesh is calculated and the boundary temperatures, heat transfer coefficients and bulk temperatures are set into the appropriate variables.

(7) HTST01

If JHCODE is not equal to 10, the power in each mesh is calculated, and heat transfer coefficients and bulk temperatures are set into the appropriate variables. The boundary temperatures are set into the array HTBND.

(8) HTRD01

The coefficients of heat conduction equations are calculated by calling the subroutine MTPROP, and forward elimination is performed by MTSLOF.

(9) HTBD01

The source terms in heat conduction equations are calculated. The material properties are then calculated by calling the subroutine MTPROP, and the coefficient of boundary temperatures and bulk temperatures are obtained to complete the heat conduction equations at the left and right boundaries.

(10) HTME01

The coefficients in heat conduction equations at the boundary are calculated according to the three cases: the implicit coupling, the fixed boundary temperatures and others, and they are set into the array CWL.

(11) HTSB01

Backward substitution is performed, and new values are then substituted into the old variables.

(12) HTEDIT

If IDBG is not equal to zero, the variables are printed.

(13) HTPLD1

The time dependent data are printed for plotting.

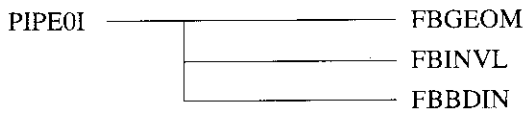
A1.4 FILL-BREAK MODEL

The FILL-BREAK (FB) model simulates the inflow and the outflow through the side walls of the the PIPE components. The FB model can be used in the PIPE component except for the first and the last mesh cells. It is used only in 2V model. There are two types of FB models: one is to fix all the flow variables (FILL) and the other is to calculate velocities (BREAK). The variables can be time dependent by interpolating the input tables. The critical flow model can be applied. The angle between the main PIPE and the FB is aribitrarily selected, and the location of the FB is chosen to be at the top, at the side or at the bottom of PIPE component.

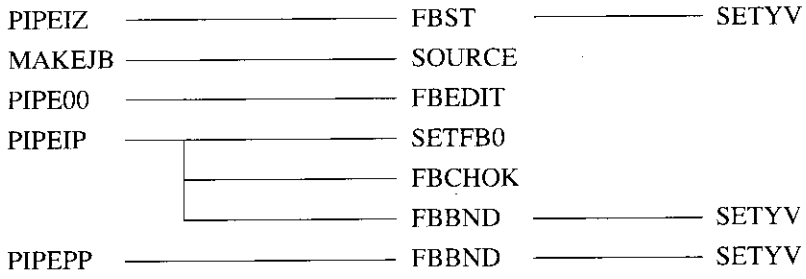
A1.4.1 PROGRAM STRUCTURE

The tree structure of subroutines related to FILL-BREAK model are shown below.

A1.4.1.1 INPUT SECTION



A1.4.1.2 CALCULATION SECTION



A1.4.2 FUNCTIONS

A1.4.2.1 INPUT SECTION

(1) FBGEOM

The geometric data are read from the input deck and are printed.

(2) FBINVL

The initial conditions are read from the input deck and are printed.

(3) FBBDIN

The time dependent boundary conditions are read from the input deck and are printed.

A1.4.2.2 CALCULATION SECTION

(1) FBST

Some variables related to the steam table are calculated by using the subroutines INITL0, INITL1 and INITL2. YV vector is then obtained from Y vector by calling the subroutine SETYV.

(2) SETYV

YV vector is calculated from the array DD3 and Y vector.

(3) SOURCE

The source terms and their derivatives are calculated.

(4) FBEDIT

The variables are printed.

(5) SETFB0

The old values of variables are set for Jacobian calculations.

(6) FBCHOK

The critical velocities are set.

(7) FBBND

If the flag IIORP is other than unity, the time dependent boundary values are obtained by interpolating the tables. When the flag is unity, the mixture velocity is set to new value.

A1.5 VALVE MODEL

The VALVE model simulates the valves in thermal-hydraulic systems. The VALVEs can be located at cell edges in the PIPE component or at the left-BOUNDARY component. The flow area is controlled by the VALVE. Two types of VALVEs can be used:

(1) normal valve

The flow area of the VALVE is time dependent and given by the input table data.

(2) check valve

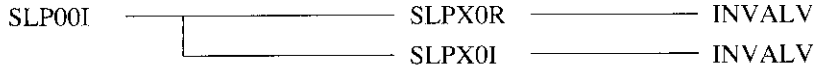
The flow area of the VALVE is determined from the pressure difference between both sides of the VALVE.

In the input stage, the flow area of the VALVE is defined as % of the full opening area for normal valves, while values between zero to unity are uses for check valves.

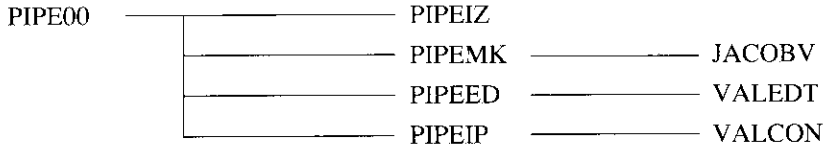
A1.5.1 PROGRAM STRUCTURE

The tree structure of subroutines related to VALVE models are shown below.

A1.5.1.1 INPUT SECTION



A1.5.1.2 CALCULATION SECTION



A1.5.2 FUNCTIONS

A1.5.2.1 INPUT SECTION

(1) INVALV

Some input data are read from the input deck.

A1.5.2.2 CALCULATION SECTION

(1) PIPEIZ

The array CC2(J, N2AR2) and CC2(J,N2VOPN) are initialized.

(2) PIPEMK

The procedure, which is needed for the Jacobian matrix when the VALVE is closed, is performed by calling the subroutine JACOBV. The portion of the matrix SMTOX related to velocities are then set equal to zero so that this procedure is not affected by external terminals.

(3) JACOBV

If the flow area of the VALVE is smaller than EPSVAL, the diagonal elements for velocities in the Jacobian matrix are set to unity and the constant part of equations for Newton method (F) is set equal to the negative value of X vector (F=-X) so that the velocities are converged to zero.

(4) VALEDT

The condition of VALVE is printed.

(5) VALCON

The flow area is calculated by interpolating the VALTBL table.

A1.6 PUMP COMPONENT

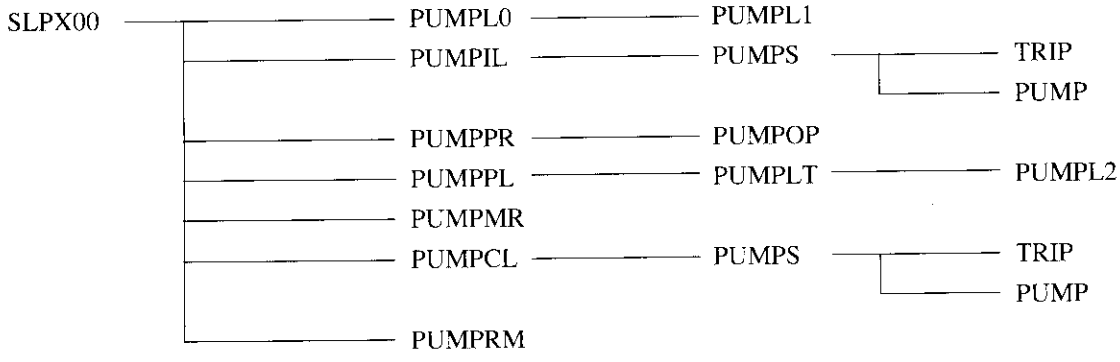
The PUMP component simulates the centrifugal pump. It produces the pressure difference due to the pump head and the energy dissipation due to the pump torque. The PUMPs can be located at cell edges in the PIPE component, and the direction of the PUMP component must coincide with that of the PIPE component.

A1.6.1 PROGRAM STRUCTURE

The tree structure of subroutines related to PUMP component are shown below.

A1.6.1.1 INPUT SECTION

A1.6.1.2 CALCULATION SECTION



A1.6.2 FUNCTIONS

A1.6.2.1 INPUT SECTION

(1) PUMPIN

Input data except for the trip data are read from the input deck, and the necessary array and address are prepared.

(2) TRIPIN

TRIPIN is the entry name in the subroutine TRIP, the trip data are read.

A1.6.2.2 CALCULATION SECTION

(1) PUMPL0

The component name is stored in the variable PNAME, and the subroutine PUMPL1, which is used to print the component name and the tag list for plotting, is called.

(2) PUMPL1

The component name and the tag list are printed out for plotting.

(3) PUMPIL

This is one of the entry names in the subroutine PUMPIN. The subroutine PUMPS is called for initialization.

(4) PUMPS

When the flag START is 'TRUE', initialization is performed. When the flag START is 'FALSE', the pump head and the pump torque are determined by interpolating the homologous curve tables, and then the pump speed is obtained by interpolating the pump speed table or by integrating the momentum equations.

(5) TRIP

The trip condition — 'on' or 'off' — is determined by interpolating the trip signal tables.

(6) PUMP

The type of homologous curve is determined according to the pump condition, and the pump head and the pump torque are obtained by interpolating the homologous curve tables.

(7) PUMPPR

This is one of the entry names of the subroutine PUMPIN. NSTEP, TIME and DT are printed, and the subroutine PUMPOP is called.

(8) PUMPOP

The calculated pump head, pump speed and pump torque are printed.

(9) PUMPPL

This is one of the entry names of the subroutine PUMPIN. The subroutine PUMPLT is called.

(10) PUMPLT

The component name is created for plotting, and the subroutine PUMPL2 is called.

(11) PUMPL2

The component name and the values of variables are printed for plotting.

(12) PUMPMR

This is one of the entry names of the subroutine PUMPIN. The pump speed at (n) step is stored in the array A(LOMEGX+NOP-1).

(13) PUMPCL

This is one of the entry names of the subroutine PUMPIN. The subroutine PUMPS is called.

(14) PUMPRM

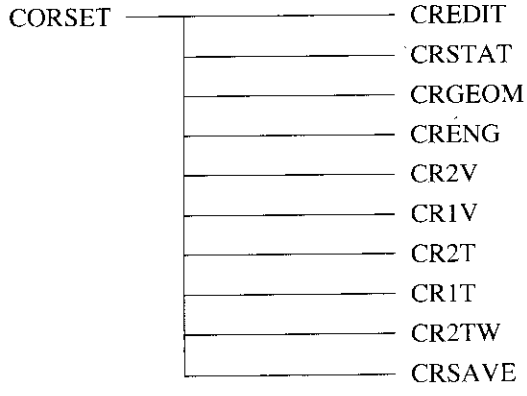
This is one of the entry names of the subroutine PUMPIN. The pump speed is retrieved from the array A(LOMEGX+NOP-1) to A(LOMEGA+NOP-1).

A1.7 CORSET

The correlations, which appear in the constitutive relations, are calculated in the subroutine CORSET and in its lower routines. The calculated values are stored in the array CC4.

A1.7.1 PROGRAM STRUCTURE

The tree structure of subroutines related to CORSET are shown below.



A1.7.2 FUNCTIONS

(1) CORSET

The calling sequence of the subroutines are controlled.

(2) CREDIT

When the flag IPRINT is greater than zero, the following variables are printed for debugging,

(a) values of basic variables,
(b) values related to the steam table,
(c) intermediate variables used to calculate correlations,
(d) calculated correlations.

(3) CRSTAT

State variables are prepared. If IPRINT is greater than zero, they are printed by calling the subroutine CREDIT. The state variables are

(a) basic dependent variables,
(b) values related to the steam table,
(temperature, density)
(c) flag ICHHV, which indicates whether the PIPE component is vertically or horizontally oriented,
(d) relative velocity,
(e) values related to the flow regime map,
(entrainment, volume fraction)
(f) mixture velocity, mass velocity.

(4) CRGEOM

Geometric data and material properties are prepared. If IPRINT is greater than zero, they are printed by calling the subroutine CREDIT. The geometric data and the material properties are

(a) diameter, cross-sectional area, cell length, cell height,
(b) specific heat, viscosity, heat conductivity, surface tension, compressibility, expansion coefficient,
(c) various hydraulic diameters,
(d) angle between the flow axis and the edges of interface,
(e) form loss data.

(5) CRENG

Engineering data are prepared. If IPRINT is greater than zero, they are printed by calling the subroutine CREDIT. The engineering data are

(a) Prandtl number,
(b) various Reynolds numbers.

(6) CR2V

This subroutine is called when METV is 2, that is, when 2V model is used. The wall area, the interfacial area, the wall friction factor, the interface friction factor and the added mass coefficients are calculated in this order.

(7) CR1V

This subroutine is called when METV is zero or unity, that is, when 1V or 1VD model is used. The wall area, the wall friction factor for the mixture and the two-phase multiplier are calculated in this order.

(8) CR2T

This subroutine is called when METT is 2, that is, when 2T model is used. The wall area and wall friction factor for heat conduction calculation and the interfacial heat transfer coefficient are calculated in this order.

(9) CR1T

This subroutine is called when METT is zero or unity, that is, when 1T or 1.5T model is used. The wall area for heat conduction calculation is calculated.

(10) CR2TW

This subroutine is called when the heat slab is used. Various wall heat transfer coefficients are calculated. The wall area for each heat slab is also calculated.

(11) CRSAVE

The wall area, the wall friction factors without form loss, the wall friction factors for 1V or 1VD models, interfacial area, the interfacial friction factors, the added mass coefficients, the mass transfer rate for subcool boiling, the interfacial heat transfer coefficients and the wall friction factors with form loss are stored in the array CC4 in this order.

A1.8 RELATIVE VELOCITY

The relative velocity used in 1VD model is calculated in the subroutine CRUR and in its lower routines.

A1.8.1 PROGRAM STRUCTURE

The tree structure of subroutines related to the relative velocity are shown below.

A1.8.2 FUNCTIONS

(1) CRUR

The relative velocity RELV is calculated by calling the subroutine VFLPLU and is stored in the array CC4(J,N4REV).

(2) VFLPLU

The flow regime is determined according to the flag IFLOW. If IFLOW is zero or unity, the flow regime is determined from the modified Bennet flow regime map by calling VFLMAP. The relative velocity is then calculated by calling DRIFT according to the flow regime.

(3) VFLMAP

The flow regime is determined using the modified Bennet flow regime map.

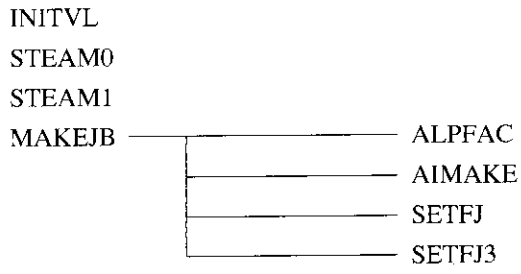
(4) DRIFT

The drift velocity αV_{gj} is calculated according to the flow regime.

A1.9 SINGLE PHASE TREATMENT

A1.9.1 PROGRAM STRUCTURE

The tree structure of subroutines related to the single phase treatment are shown below.



A1.9.2 FUNCTIONS

(1) INITVL

The void fraction read from the input deck is reset to ALPMIN when it is smaller than ALPMIN, and to ALPMAX when it is greater than ALPMAX.

(2) STEAM0

If HM is smaller than HLS or RM is larger than RHLS, XQ is reset to XQSMIN. If HM is larger than HLS or RM is smaller than RHGS, XQ is reset to XQSMAX. XQSMIN and XQSMAX are determined from ALPMIN and ALPMAX, respectively.

(3) STEAM1

When XQ is smaller than zero, XQ is reset to zero, and when XQ is larger than unity, XQ is reset to unity.

(4) MAKEJB

Two Jacobian matrices are combined into one matrix: one is the Jacobian matrix for the time derivatives in the basic equations, and the other is the Jacobian matrix for other terms than time derivatives calculated in the subroutine SETFJ and SETFJ3.

(5) ALPFAC

Some variables used for the single phase treatment are calculated: $s_g(\alpha)$, $s_f(\alpha)$, $s_{ig}(\alpha)$, $s_{if}(\alpha)$, $r_g(\alpha)$, $r_f(\alpha)$, and $r_i(\alpha)$. Their derivatives with respect to the void fraction are also calculated.

(6) AIMAKE

Modified interfacial area is calculated.

(7) SETFJ

The Jacobian matrices, which are not related to time derivatives, are calculated for the mass and energy equations.

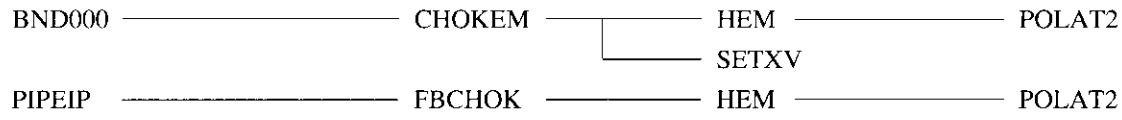
(8) SETFJ3

The Jacobian matrices, which are not related to time derivatives, are calculated for the momentum equations.

A1.10 CRITICAL FLOW MODEL

A1.10.1 PROGRAM STRUCTURE

The tree structure of subroutines related to the critical flow model are shown below.



A1.10.2 FUNCTIONS

(1) CHOKEM

The critical velocity is obtained using mass velocity G, and then it is stored in the array CC1 and X vector. The critical velocity is also stored in XV vector by calling the subroutine SETXV.

(2) SETXV

The basic variables in the array CC3 and CC1 and in X vector are set into XV vector.

(3) FBCHOK

The critical velocity is obtained using mass velocity G, and then it is stored in YV vector.

(4) HEM

The mass velocity G is obtained by interpolating the HEM table according to the pressure and the enthalpy.

(5) POLAT2

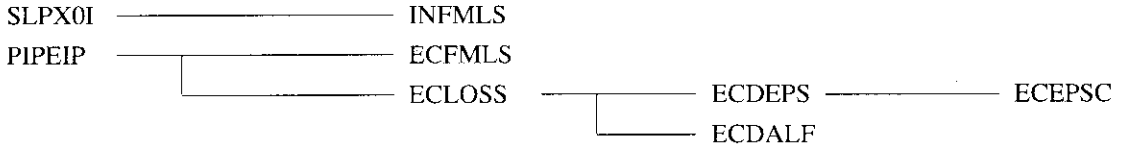
Some values are taken every IX and IY step from the array X and Y, and then the interpolated value is calculated.

A1.11 FORM LOSS MODEL

Two types of form loss are prepared: one is to give the form loss coefficients by the input and the other is to calculate the coefficients due to the variation of flow area. The form loss coefficients defined by the input are CC2(1,N2FLSG), CC2(1,N2FLSL) and CC2(1,N2FLSM) for the gas, liquid and mixture, respectively. The form loss coefficients calculated are CC2(1,N2FECG), CC2(1,N2FECL) and CC2(1,N2FECM) for the gas, liquid and mixture, respectively. These coefficients are combined with wall friction factors in the subroutine CORSET.

A1.11.1 PROGRAM STRUCTURE

The tree structure of subroutines related to the form loss model are shown below.



A1.11.2 FUNCTIONS

(1) INFMLS

The form loss data set is read IDF times from the input deck.

(2) ECFMLS

The form loss data are selected due to the flow direction.

(3) ECLOSS

The form loss is calculated according to the variation of flow area.

(4) ECDEPS

The variables ε_f and ε_c are calculated.

(5) ECEPSC

The variables ε_{gc} and ε_{lc} are calculated.

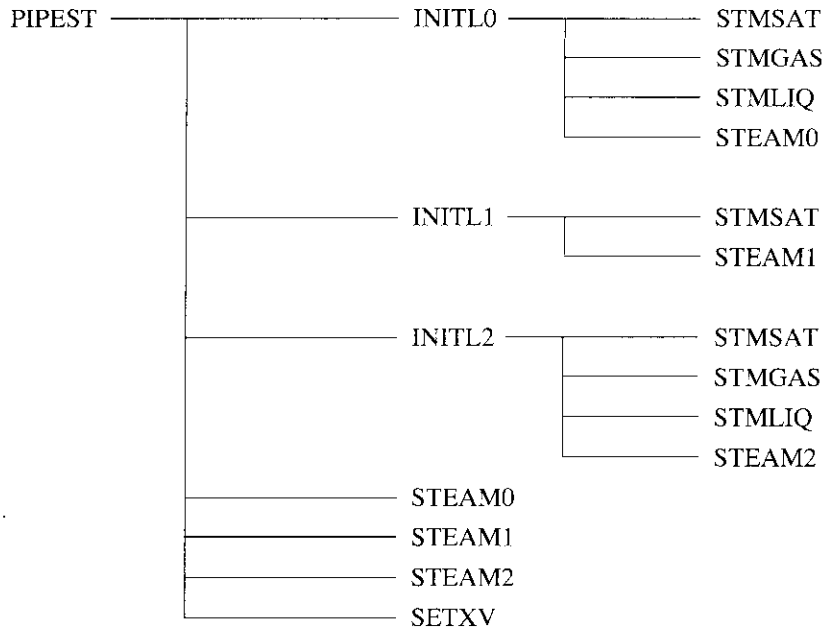
(6) ECDALF

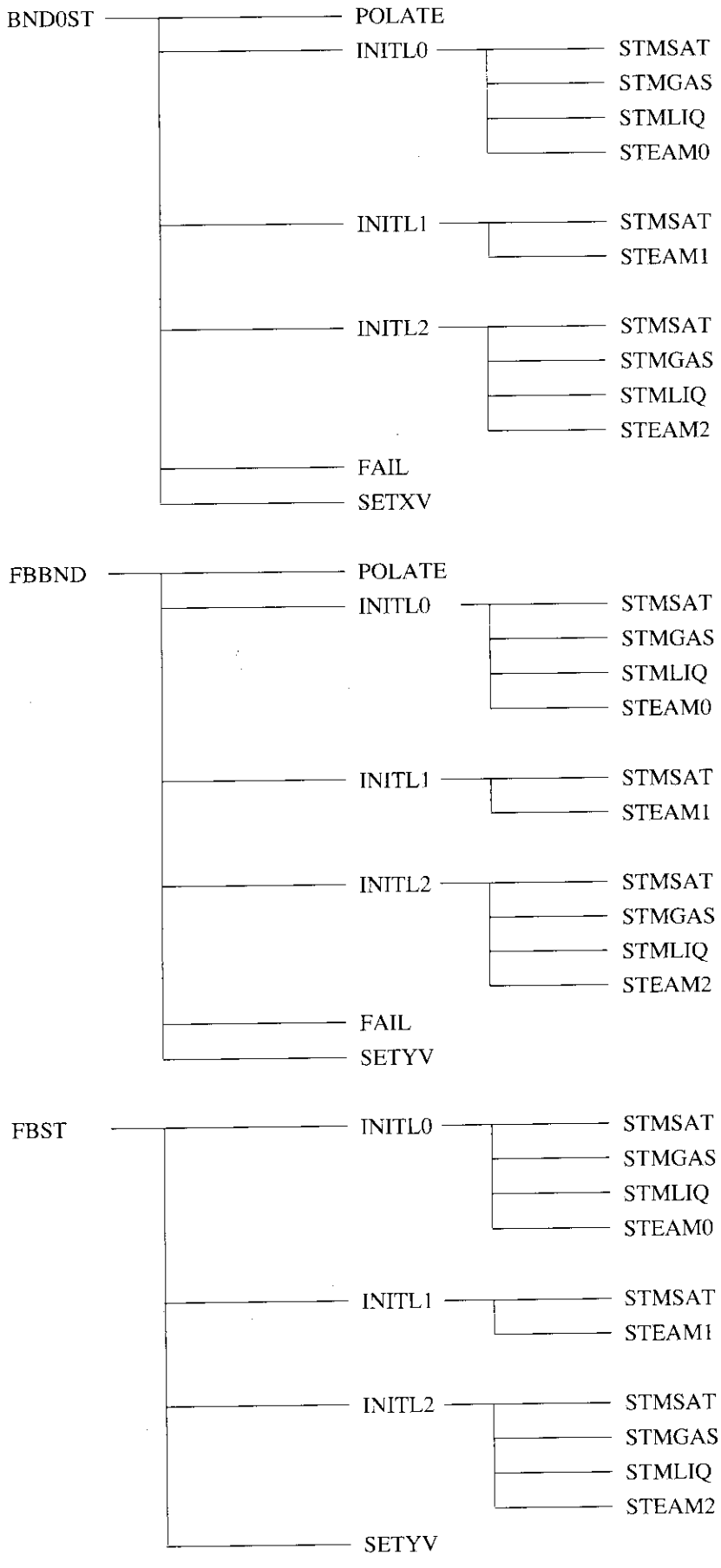
The void fraction and the holdup at (J+1/2) junction are calculated.

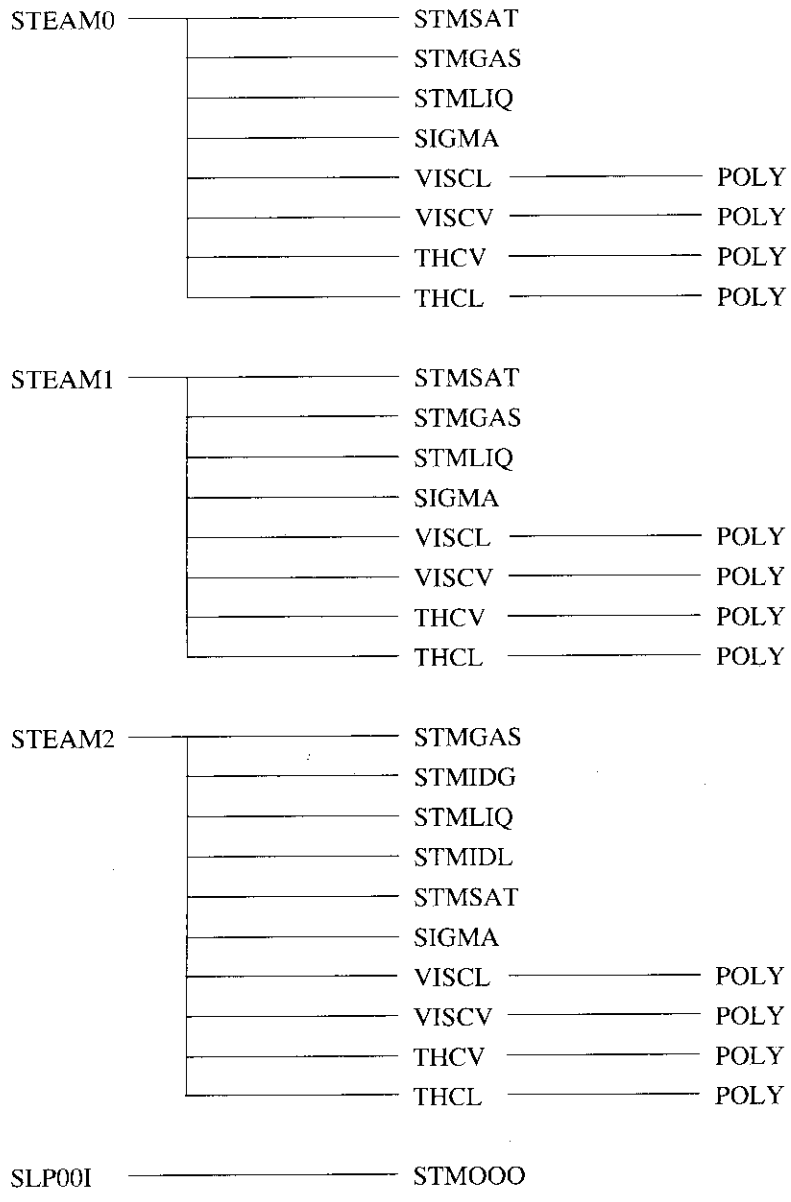
A1.12 STEAM TABLE

A1.12.1 PROGRAM STRUCTURE

The tree structure of subroutines related to the steam table are shown below.




BND0ST
POLATE
INITL0
STMSAT
STMGAS
STMLIQ
STEAM0
INITL1
STMSAT
STEAM1
INITL2
STMSAT
STMGAS
STMLIQ
STEAM2
FAIL
SETXV
FBBND
POLATE
INITL0
STMSAT
STMGAS
STMLIQ
STEAM0
INITL1
STMSAT
STEAM1
INITL2
STMSAT
STMGAS
STMLIQ
STEAM2
FAIL
SETYV
FBST
INITL0
STMSAT
STMGAS
STMLIQ
STEAM0
INITL1
STMSAT
STEAM1
INITL2
STMSAT
STMGAS
STMLIQ
STEAM2
SETYV



A1.12.2 FUNCTIONS

(1) STMOOO

The steam table data are read and stored into the common array STMDIM and STMDAT.

(2) STMSAT

The saturation enthalpies and their derivatives are calculated. The region in the steam table, where the given pressure is located, is determined for steam. The enthalpy h_g and its derivative are obtained by the spline function. The region in the steam table is also determined for water, and then h_l and its derivative are obtained.

(3) STMGAS

The region in the steam table, where the given pressure is located, is determined for single phase vapour. The region in the steam table, where the given enthalpy is located, is also determined for single phase vapour. The temperature T_g and its derivative are obtained by the spline function. The other properties are also calculated by the spline functions.

(4) STMLIQ

The region in the steam table. where the given pressure is located, is determined for single phase water. The region in the steam table, where the given enthalpy is located, is also determined for single phase water. The temperature T_l and its derivative are obtained by the spline function. The other properties are also calculated by the spline functions.

(5) STEAM0

The variables related to 1T model are calculated using the steam table, and stored in the array CC3. This subroutine consists of two parts: one is based on the basic variables p and h_m, the other is based on p and ρ_m.

(6) STEAM1

The variables related to 1.5T model are calculated using the steam table, and stored in the array CC3.

(7) STEAM2

The variables related to 2T model are calculated using the steam table and the hypothetical steam table, which is supplied by users, and stored in the array CC3.

(8) STMIDG

The variables related to the hypothetical steam table for gas are calculated.

(9) STMIDL

The variables related to the hypothetical steam table for liquid are calculated.

(10) SIGMA

The surface tension is calculated from the saturation temperature.

(11) VISCL

The viscosity of liquid is calculated from the liquid enthalpy and pressure.

(12) VISCV

The viscosity of gas is calculated from the gas temperature and density.

(13) THCV

The thermal conductivity of gas is calculated from the gas temperature and density.

(14) THCL

The thermal conductivity of liquid is calculated from liquid enthalpy.

(15) POLY

The products of coefficients and power of variables are summed up as $\Sigma A_i x^{i-1}$.

(16) INITL0

The mixture enthalpy is calculated if the input mixture enthalpy is negative or zero. The subroutine STEAM0 is then called to set the steam table values. The mixture density is stored in X(2,J).

(17) INITL1

The saturated mixture enthalpy is calculated if the input mixture enthalpy is negative or zero. The mixture enthalpy is stored in X(2,J). The subroutine STEAM1 is called to set the steam table values.

(18) INITL2

The enthalpy is calculated if the input enthalpy is negative or zero. The subroutine STEAM2 is called to set the steam table values.

A1.13 MATERIAL PROPERTIES

A1.13.1 PROGRAM STRUCTURE

The tree structure of subroutines related to the material properties are shown below.

SLPX0I ——— MTIN00
HTBD01 ——— MTPROP
HTRD01 ——— MTPROP
WALHTC ——— MTPROP

A1.13.2 FUNCTIONS

(1) SLPX0I

The subroutine CCP00I is called to read component data, and then MTIN00 is called to read material properties.

(2) MTIN00

The material properties data — the density, specific heat, thermal conductivity, emissivity — are read and checked.

(3) MTPROP

The material properties of heat slabs at a certain temperature are calculated by interpolation or by some calculations.

(4) HTBD01

The heat conduction equations are prepared at the left and right boundaries.

(5) HTRD01

Forward elimination is performed for heat conduction equations.

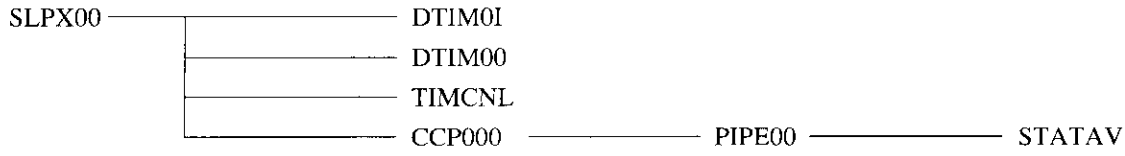
(6) WALHTC

The heat transfer coefficients for wall are calculated.

A1.14 TIME STEP CONTROL

A1.14.1 PROGRAM STRUCTURE

The subroutines related to the time step control are shown below.



A1.14.2 FUNCTIONS

(1) DTIM0I

The date for time step control are read from the input deck.

(2) DTIM00

The entry name of the subroutine DTIM0I. The maximum time step size at time TIME is selected.

(3) STATAV

The average variation of variables over the last (NMAX-1) time steps is calculated. The variation at the new time step is also calculated. The minimum ratio (RATE) of the two variations over all variables is obtained. The array STATE, in which old variables are stored, are updated.

(4) CCP000

The minimum of the ratio (RATE) in the component is obtained.

(5) TIMCNL

The average number of convergence in the past (AVN) is obtained. The ratio between the old and new time step size is calculated using RATE and AVN, and the new time step size is determined. The array NCOUNT, in which the number of convergence in the past is stored, is updated.

(6) SLPX00

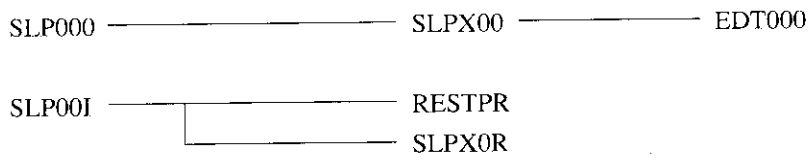
The subroutines DTIM00 (entry name of DTIM0I), TIMCNL and CCP000(STATAV) are called. The time step size is shortened if convergence is not accomplished.

A1.15 RESTART

The intermediate data are printed to the dump file every dump time intervals. The dump file is used as the input data for the restart calculation.

A1.15.1 PROGRAM STRUCTURE

The functions associated with the restart calculation are to print the intermediate data to the dump file and to read the data from the dump file for the restart. The subroutines related to the restart calculation are shown below.



A1.15.2 FUNCTIONS

(1) SLP000

The time independent data needed to the restart calculation are printed to the dump file.

(2) SLPX00

The time dependent data needed to the restart calculation are printed to the dump file every dump time intervals. When the dump file is printed out, the time and the time steps are printed on the output list.

(3) EDT000

This is the entry name of the subroutine EDT00I. It is checked whether or not the current time step is the dump time step.

(4) SLP00I

The time independent data in the dump file are read for the restart calculation.

(5) RESTPR

The statement indicating the restart calculation is printed on the output list.

(6) SLPX0R

The input data for the restart calculation and the time dependent data in the dump file are read.

APPENDIX 2. USER INFORMATION

A2.1 ARRAY STRUCTURE

The global array is divided into 3 parts: the integer array IAR, the double precision real array RAR and the character array CAR. The dimension is defined in the MAIN program. The address of the array itself is also stored in IAR.

A2.1.1 COMMON STRUCTURE

The array structure, which is common to IAR, RAR and CAR, consists of 5 parts.

1. system
2. pump
3. fluid component
4. heat conductor
5. work area

The storage of the system data into the array and the address allocation are performed by the subroutine SLP00I. The total array length except for work area are also calculated by SLP00I. The subroutine SLPX0I is called by SLP00I to obtain the array length for the pump component, fluid component, heat conductor and work area. SLPX0I calls the input routine for pump, the subroutine CCP00I and the input routine for heat conductor in this order, and calculate the length of each array.

The array structure of fluid components are as follows.

1. first fluid component
2. second fluid component

.....

N. NCOMP-th fluid component

The subroutine CCP00I is called by SLPX0I to obtain the array length for each fluid component. CCP00I calls the input routine for boundary and pipe, and calculate the length of each array.

A2.1.2 GENERAL STRUCTURE

The array structure for the system, pump and each fluid component are as follows. The array mentioned here are arranged by the subroutine SLP00I, PUMPIN, BND00I and PIPE0I.

(1) IAR: INTEGER*4

a. a region storing the address and the length of 'the region storing the address of single datum and array data'
b. a region storing the address of single datum and array data
c. some integer type array

(2) RAR: REAL*8

a. some double precision type real array

(3) CAR: CHARACTER*1

a. some character type array

The structure of 'the region storing the address of single datum and array data' consists of 7 parts.

1. single datum
2. address for integer type array
3. address for real type array
4. address for character type array
5. address for integer type array for work area
6. address for real type array for work area
7. address for character type array for work area

The variables used in address calculation are listed below.

1. length of 'the region storing the address of single datum and array data'

LADOP	:	number single datum
LADI	:	length of the region storing the address of integer type array data
LADR	:	length of the region storing the address of real type array data
LADC	:	length of the region storing the address of character type array data
LADIW	:	length of the region storing the address of integer type array data for work area
LADRW	:	length of the region storing the address of real type array data for work area
LADCW	:	length of the region storing the address of character type array data for work area

2. address of 'the region storing the address of single datum and array data'

NADOP	:	1 + (length of the region storing the address and length of 'the region storing the address of single datum and array data), address of the region storing single datum
NADI	:	NADOP + LADOP, address of the region storing the address of integer type array
NADR	:	NADI + LADI, address of the region storing the address of real type array
NADC	:	NADR + LADR, address of the region storing the address of character type array
NADIW	:	NADC + LADC, address of the region storing the address of integer type work area
NADRW	:	NADIW + LADIW, address of the region storing the address of real type work area
NADCW	:	NADRW + LADRW, address of the region storing the address of character type work area

3. address of integer type array

LMDCN : (NADOP-1) + LADOP + LADI + LADR + LADC + LADIW + LADRW + LADCW,
(LMDCN+1) is the first address of integer type array

* the first address of real type array is unity
* the first address of character type array is unity
* the first address of work area is unity

A2.1.3 HEAT CONDUCTOR

The array structure for the heat conductor is basically the same as fluid components. The single datum is followed by the array data. The address of array is stored in the region for single datum in the array IAR. The subroutine SLPX0I calls HTIN00, and HTIN00 calls HTIN01. The subroutine HTIN01 calculates the region size needed for each heat slab. The subroutine HTIN00 calculates the length of the array which is commonly used for all heat slabs. The total region for heat conductors is also calculated in HTIN00.

A2.2 DEFAULT VALUES

Some default values are used for important flags and data. The meaning and values are listed below.

(1) ISFLAG

Flag for calculation type. Unity for steady state calculations, and other values for transient calculations. But steady state calculations are not possible at present. The default value is zero, which is set in the subroutine SLPX00.

(2) IHTC

Flag for heat transfer coefficient. Interfacial heat transfer coefficients, which are calculated by using correlations, are used if IHTC is zero. Other than zero, interfacial heat transfer coefficients are set to zero. When the steam table indicator IEOS is zero or two, IHTC is set to zero. If IEOS is other than zero or two, IHTC is set to unity. IHTC is set in the subroutine SLP00I.

(3) EPSVAL

Valve flow area for stopping the flow. Default value is 0.0, which is set in the subroutine SLP00I.

(4) NSTORE

Maximum number of data point which are used to obtain the average value of variables and iterations for time step controlling. Default value is 20, which is set in the subroutine SLP00I.

(5) THETA

Degree of implicitness for heat conductor calculations. Default value is 1.0, which is set in the subroutine HTCL01.

(6) IPRINT

Flag for debug printing used in several subroutines. Default value is 0, which is set in the subroutine SLP00I for steam table data. Default value is also set in the subroutines PIPEIL, PIPEIP and PIPEKI for correlations.

(7) MXV, NMX

Dimension of the local array. MXV is the number of basic variables. NMX is the maximum number of mesh cells in one component. They are set by parameter statements as MXV=6 and NMX=52 in the subroutines MAKEJB, SETFJ and SETFJ3.

(8) MAXINP

Number of calculations for Jacobian. Jacobian is calculated for first MAXINP times in the iteration of Newton method. If the value smaller than zero is set in the input deck, MAXINP is set to 10000 in the subroutine SLP00I.

(9) DAMP1, DAMP2

Factor for time step size. If the iteration of Newton method is not converged, DAMP1 is multiplied to the time step size for the first and second time, but after the third time, DAMP2 is multiplied. They are set by data statement as DAMP1=0.7071067812D0 and DAMP2=0.5D0 in the subroutine SLPX00.

(10) WGHT (6, 3)

Factor for scaling of Jacobian. They are set by data statement as

WGHT/1.0D6, 1.0D6, 1.0D0, 1.0D0, 1.0D0, 1.0D0,

1.0D6, 1.0D6, 1.0D0, 1.0D0, 1.0D0, 1.0D0,

1.0D0, 1.0D6, 1.0D6, 1.0D6, 1.0D0, 1.0D0 / ,

in the common variable WEIGHT in the BLOCK DATA.

(11) THET1

Upwind degree of virtual mass force term. Default value is 1.0, which is set in the subroutine SETFJ3.

(12) IFAC

Flag for selecting correlations for the drift velocity in bubbly and droplet flows. Default value is 0, which is set in the subroutine CRUR.

(13) ISTDYX

Flag used in the subroutine WALHTC. Default value is 0, which is set in the subroutine SLP00I.

(14) ICHF

Flag used in the subroutine WALHTC. Default value is 1, which is set in the subroutine SLP00I.

(15) ITMIN

Flag used in the subroutine WALHTC. Default value is 0, which is set in the subroutine SLP00I.

(16) GRAV

Gravitational acceleration. If the value smaller than 10^{-10} is set in the input deck, GRAV is set to -9.80665 in the subroutine SLP00I.

(17) ISTDY, MXCNCO, NUMSG, NRSTP

ISTDY is the flag for selecting calculation type, zero for transient calculation and unity for steady state calculation. MXCNCO is the maximum number of terminals for each component. NUMSG is the number of steam generators. NRSTP is not used at present. These values are set in the input deck, but they are reset to default values in the subroutine SLP00I as ISTDY=0, NXCNCO=2, NUMSG=0 and NRSTP=0.

(18) ALP0, ALPW1, ALPW2

Parameters for determining the functions for single phase treatment. ALP0 is the minimum value of r_g, r_l and r_i. r_g, r_l and r_i are ALP0 at $\alpha = \alpha_{min}$, unity at $\alpha_{min} + ALPW1 \leq \alpha \leq \alpha_{max} - ALPW2$ and again ALP0 at $\alpha = \alpha_{max}$. In the region between α_{min} and $\alpha_{min} + ALPW1$ and $\alpha_{max} - ALPW2$ and α_{max}, r_g, r_l and r_i are obtained by linearly interpolating between ALP0 and unity. Default value are 0.0, 9.0D-5 and 9.0D-5 for ALP0, *ALPW*1 and *ALPW*2, respectively, which are set in the subroutine ALPFAC.

(19) EIFR, EIHG, EIHL

EIFR is the single phase limiting value of interfacial area for interfacial friction. EIHG is the single phase limiting value of AIHG, which is the interfacial area of gas for interfacial heat transfer. EIHL is the single phase limiting value of AIHL, which is the interfacial area of liquid for interfacial heat transfer. Default values are 1.0D-4, 1.0D-7 and 1.0D-7 for EIFR, EIHG and EIHL, respectively, which are set in the subroutine AIMAKE.

(20) NPHM, PHDM

The two-phase multiplier for the pump component is given as the table data: two-phase multiplier versus void fraction. NPHM is the dimension of the table, and PHDM is the table data. In the subroutine PUMPIN, NPHM is set equal to two, and PHDM is /-1.0, 0.0, 1.0, 0.0/, that is, the two-phase multiplier is always zero.

A2.3 IMPORTANT ARRAY

There are some important array which are not defined as the variable dimension.

(1) local array in MAKEJB, SETFJ, SETFJ3

The array MXV and NMX are set by parameter statements. It is noted that NMX must be larger than the maximum mesh cell number + 2.

(2) FMLOSS

The array FMLOSS is used for storing the input form loss data. It appears as the common block of FMTABL in the subroutine INFMLS and ECFMLS.

(3) VALTBL, IVKONT, IVTYPE, VNAME

The array VALTBL is used for storing the table data for valve, IVKONT is for the table length of VALTBL, IVTYPE is for the flag for valve type and VNAME is for the valve name. They are defined by the common VALTAB in the subroutine VALCON, INVALV and VALEDT.

A2.4 STOP NUMBERS

When some errors are detected during calculations, certain stop numbers are printed on the output list, and the calculation is stopped. The meaning of stop numbers is listed below.

(1) "STOP"

There are two cases in which "STOP" appears without stop numbers. When "STOP" is generated by the main routine, it corresponds to the normal end of calculations. If it is generated by the subroutine SLPX00, it corresponds to that the errors are detected in the heat conduction calculation routine HTCL00 when JHCODE=1 or =2.

(2) "STOP 200"

"STOP 200" is generated by the subroutine SLPX00 when the flag for system debug IDBS is 2.

(3) "STOP 2000"

"STOP 2000" is generated by the subroutine BND0ST or FBBND. In both cases, it means that some errors are detected in the subroutine INITL0, INITL1 or INITL2 during initialization of the steam table related variables.

(4) "STOP 4000"

"STOP 4000" is generated by the main routine. It corresponds to three cases, one case is that the error is detected in the subroutine SLP00I during input and initialization. Other case is that the necessary array size exceeds the size provided by the main routine. And the other case is that the error is detected during the transient calculations.

(5) "STOP 5000"

"STOP 5000" is generated by the subroutine POLATE during spline interpolation, in which the number of elements for the interpolation table exceeds 100.

(6) "STOP ***** SPLINE INTERPOLATION ERROR *****"

It is generated by the subroutine POLATE. It corresponds to the error in the lower routine INSPL.

A2.5 JOCODE

The subroutine CCP000 performs several procedures according to the value of JOCODE. The meaning of JOCODE is listed below.

(1) JOCODE = -3

Initialization for plotting: printing the geometric data of fluid components.

(2) JOCODE = -2

Initialization for plotting: printing the tag lists of fluid components.

(3) JOCODE = -1

Initialization: setting of steam table related variables.

(4) JOCODE = 0

If JOCODE is larger than or equal to zero, and is not equal to 10, the following procedure called 'procedure A' is performed. At first, variables are transferred from the array for the external terminal to the array for the fluid component. In the case of PIPE component with the velocity fixed boundary component at the right boundary, the boundary velocities are substituted into the right internal terminal of the PIPE component. In the case of right-BOUNDARY component with the velocity calculation option, the calculated velocities are substituted into the internal terminal of the right-BOUNDARY component. These procedures are 'procedure A'.

If JOCODE is equal to zero, the following procedures are performed after 'procedure A'. In the case of HEAT CONDUCTOR, the array ITHT or IHT are set by arranging the heat slab boundaries sequentially, which are connected to the fluid component.

In the case of PUMP component, the variable IPMBDT (M2USE, NOP) is set to unity corresponding to actually used PUMP components. Correlation parameters are calculated by the subroutine CORSET. The initial values for the inventory and accumulation of mass and energy are set.

In the case of HEAT CONDUCTOR, some steam table related variables are stored in the array HTBND. In the case of PUMP, variables transferred from fluid to pump are set in the array PMPBDT.

(5) JOCODE = 1

At first, 'procedure A' is performed. The values of steam table are set, then XV-vector is set by using X-vector. In the case of HEAT CONDUCTOR, steam table related variables are stored in the array HTBND. In the case of PUMP, variables transferred from fluid to pump are set in the array PMPBDT.

(6) JOCODE = 2

At first, 'procedure A' is performed. The values in the new time step are then stored in the array, which is used to store the values in the old time step.

(7) JOCODE = 3

At first, 'procedure A' is performed. The values in the old time step are then stored in the array, which is used to store the values in the new time step.

(8) JOCODE = 4

At first, 'procedure A' is performed. The Jacobian is calculated, then it is transformed into the non-2V2T Jacobian, if necessary. Forward elimination is performed.

(9) JOCODE = 5

At first, 'procedure A' is performed. Backward substitution is performed. By calling the subroutine SETXVM, the array XV, HMIX and QAL for the intermediate values of Newton iteration are set by using X-vector. Convergence is checked for each component and for all the fluid components.

(10) JOCODE = 6

At first, 'procedure A' is performed. Variables for the fluid component are printed on the output list.

(11) JOCODE = 7

At first, 'procedure A' is performed. Time dependent variables for the fluid component are printed for plotting.

(12) JOCODE = 8

At first, 'procedure A' is performed. The old values of g-vector are set.

In the case of VALVE, the flow area is calculated by interpolating the table data. The form loss data are set according to the flow direction, and the form loss data for E/C are calculated. Correlation parameters are set by the subroutine CORSET. XV-vector is set by using X-vector, u_g and u_f.

In the case of FB used as BREAK, old values are set for Jacobian calculation. Critical velocities are calculated, if necessary. Time dependent boundary values are then set.

In the case of PUMP, the pressure difference and the energy are calculated from the pump head, speed and torque.

In the case of BOUNDARY, critical velocities and time dependent boundary values at the new time level are calculated, if necessary.

(13) JOCODE = 9

At first 'procedure A' is performed. In the case of FB used as BREAK, u_{mix} is calculated. In the case of PIPE component, the void fraction is checked whether or not it remains between zero and unity, and then the inventory and the accumulation of mass and energy are calculated.

(14) JOCODE = 10

Some necessary values are transferred from the array for the fluid component to the array for internal terminals. Some necessary values are transferred from the array for internal terminals to the array for external terminals.

(15) JOCODE = 11

At first, 'procedure A' is performed. Parameters for implicit calculation of correlations are calculated. But it is not used at present.

(16) JOCODE = 12

Only 'procedure A' is performed.

(17) JOCODE = 13

At first, 'procedure A' is performed.

In the case of PIPE component, the minimum value of the ratio is calculated, which is defined as the ratio of the average variation of the old variables to the variation of the new variables.

(18) JOCODE = 14

It is not used at present.

A2.6 JHCODE

The subroutine HTCL00 performs several procedures according to the value of JHCODE. The meaning of JHCODE is listed below.

(1) JHCODE = -3

Initialization for plotting: printing the geometric data of HEAT CONDUCTOR.

(2) JHCODE = -2

Initialization for plotting: printing the tag lists of HEAT CONDUCTOR.

(3) JHCODE = -1

Initial power is calculated by interpolating the table data, and the boundary values are obtained according to the type of coupling between the fluid component and the heat conductor. The power of each mesh cell is calculated, and boundary temperatures, heat transfer coefficients and bulk temperatures are set.

(4) JHCODE = 1

The power at the next time level is calculated by interpolating the table data, and the boundary values are obtained according to the type of coupling between the fluid component and the heat conductor. The coefficients for heat conduction equations are calculated, and forward elimination is performed, then the coefficients at boundaries, which are transferred from the heat conductor to the fluid component, are stored in the array CWL.

(5) JHCODE = 2

Backward substitution is performed. The variables at the new time step are stored in the array, which is used to store the variables at the old time step.

A2.7 NETWORK DATA

Initial allocations for some network data - locations of boundary variables in the system matrix and conjunction of components - are described in the following.

A2.7.1 FLUID COMPONENT

The procedure is carried out in the subroutine CCP00I.

(1) allocation of the number of internal and external terminals, terminal identification number and polarity for each component.

(2) search for the component number from the component name in the network definition data, and distribution of the junction number in accordance with the component number.

(3) numbering the junctions.

(4) search for the external terminal 'A' to which the internal terminal of the component number ICOMP and the internal terminal number ICNCO is connected, and determination of the component number which has the terminal 'A' and the internal terminal number of 'A' in the component.

(5) determination of the location of terminal variables in the system matrix and the size of the system matrix.

- procedure (1) -

In the procedure (1), the number of internal and external terminal, the terminal number and the polarity are defined for each fluid component as

* left-BOUNDARY

NCNCT = 1
NCNCO = 1
NTABJN (K7CNC, 1, ICOMP) = 1
NTABJN (K7POLE, 1, ICOMP) = -1

* right-BOUNDARY

NCNCT = 1
NCNCO = 1
NTABJN (K7CNC, 1, ICOMP) = 1
NTABJN (K7POLE, 1, ICOMP) = 1

* PIPE

NCNCT = 2
NCNCO = 2
NTABJN (K7CNC, 1, ICOMP) = 1
NTABJN (K7CNC, 2, ICOMP) = 2
NTABJN (K7POLE, 1, ICOMP) = 1
NTABJN (K7POLE, 2, ICOMP) = -1

where the meaning of variables are

NCNCT : the number of internal terminals
NCNCO : the number of external terminals
NTABJN (K7CNC, 1, ICOMP) : the terminal number of ICOMP-th component (left terminal of pipe component)
NTABJN (K7CNC, 2, ICOMP) : the terminal number of ICOMP-th component (right terminal of pipe component)
NTABJN (K7POLE, 1, ICOMP) : the polarity of ICOMP-th component (left terminal of pipe component)
NTABJN (K7POLE, 2, ICOMP) : the polarity of ICOMP-th component (right terminal of pipe component)

Internal terminals are defined as the boundary cells of the component, while external terminals are the boundary cells of the neighboring component. The terminal which has a positive polarity must be connected to that with a negative one.

- procedure (2) -

The junction number, which is an arbitrary but unique number defining a junction between the internal and external terminals, is given to the variable

NTABJN (K7JUNC, I, ICOMP) (I = 1, NCNCO).

This number corresponds to the I-th terminal number of ICOMP-th component.

- procedure (3) -

After numbering all the component junctions, the terminal data of KC-th junction are set in the following variables:

* common data for both sides of the KC-th junction

NJNTN (K8JUNC, KC) : the junction number

NTABJN (K7JPOS, ICNCO, ICOMP) : the number KC, which is corresponding to the component number ICONP and the terminal number ICNCO

* data for right side terminal of the KC-th junction (polarity = 1)

NJNTN (K8CMPR, KC) : the component number to which the right-side terminal of KC-th junction belongs

NJNTN (K8CNCR, KC) : the right-side terminal number of KC-th junction looked at from the right-side component

* data for left side terminal of the KC-th junction (polarity = -1)

NJNTN (K8CMPL, KC) : the component number to which the left-side terminal of KC-th junction belongs

NJNTN (K8CNCL, KC) : the left-side terminal number of KC-th junction looked at from the left-side component

- procedure (4) -

The following variables are to be set:

NTABJN (K7CMPO, ICNCO, ICOMP) : the component number ICOMPX to which the external terminal 'A' belongs, internal terminal of the component number ICOMP and terminal number ICNCO are connected to 'A'

NTABJN (K7CNCO, ICNCO, ICOMP) : the terminal number of 'A' looked at from INCOMPX-th component

- procedure (5) -

The following variables are to be set:

MXSYSV : Dimension of system matrix when there are only fluid components

NTABJN (K7MPOS, ICNCT, ICOMP) : address of variable in ICNCT-th terminal of ICOMP-th fluid component in the system matrix

A2.7.2 HEAT CONDUCTOR

The location of following variables relating to the wall temperature in the system matrix is set by the subroutines SLPX0I and HFINIT.

(1) SLPX0I

IHTBND (L1MRX, K, I) : address of T_w, which is the temperature of K-th side (K=1 for left and K=2 for right) of I-th heat slab, in the system matrix

MXSYSV : dimension of the system matrix which is composed of fluid components and heat conductors

(2) HFINIT

IHT (L6MRX, L) : address of T_w, which is the boundary temperature of L-th heat slab connecting to ICOMP-th component

A2.8 SOLUTION METHOD FOR LINEAR EQUATIONS

Linear algebraic equation systems can be solved by several methods. The following four subroutines are prepared for solution methods:

1) INVGJ : calculating the inverse matrix of an arbitrary square matrix by the Gauss-Jordan method
2) MTSL0 : solving the equations which have tridiagonal coefficient matrix by the LU-decomposition method
3) MTSL1 : solving the equations which have block tridiagonal coefficient matrix by the LU-decomposition method
4) MTSLC : solving the equations which have an arbitrary coefficient matrix by the Crout method

(1) INVGJ

The inverse matrix is calculated.

N1 : dummy variable
N2 : dummy variable
N : dimension of matrices and vectors
A (N, N) : array for input and output matrices
NOSEQ (N) : work area for storage of the order of substitution
ISW : error flag: zero for normal end, unity for abnormal end

(2) MTSL0 (entry MTSL0F, MTSL0B)

Equations are solved by the LU-decomposition method when the coefficient matrix is tridiagonal. The vector, which is multiplied to the terminal variables, is obtained according to the KEY value.

KEY=1 : LU-decomposition is performed and equations without terminals are solved.
KEY=2 : LU-decomposition is performed.
KEY=3 : Equations without terminals are solved.
The vector, which is multiplied to the terminals, are obtained, and then the equations with terminals are solved.
KEY=12 : LU-decomposition is performed and equations without terminals are solved. The vector, which is multiplied to the terminals, are calculated.

KEY=13 : Equations with terminals are solved by using the solutions without terminals and the vector, which is multiplied to the terminals.

KEY= other value : LU-decomposition is performed and equations without terminals are solved. The vector, which is multiplied to the terminals, are calculated. Equations with terminals are solved.

N : dimension of matrix
A (N) : element for the lower diagonal part
B (N) : element for the diagonal part
C (N) : element for the upper diagonal part
D (N) : vector of constant terms
KEY : flag for calculations
ERR : flag for error information

(3) MTSL0F (entry of MTSL0)

MTSL0F is the entry name of MTSL0. It has the same functions as the subroutine MTSL0 except for the cases KEY=3 and KEY=13.

(4) MTSL0B (entry of MTSL0)

MTSL0B is the entry name of MTSL0. Equations with terminals are solved by using the terminal vector and the solutions without terminals.

X0 : values of left terminal
XN1 : values of right terminal

(5) MTSL1 (entry MTSL1F)

Equations are solved by the LU-decomposition method when the coefficient matrix is block tridiagonal. The terminal matrix for the system matrix is also obtained.

KEY=1 : LU-decomposition is performed.
KEY=2 : LU-decomposition is performed and equations without terminals are solved.
KEY=3 : Backward substitution is performed by using the matrix, which is obtained by LU-decompo sition.
KEY=11 : LU-decomposition is performed and coefficient matrices for backward substitution are obtained.
KEY=12 : LU-decomposition is performed and equations with terminals are solved.
KEY=13 : Backward substitution is performed by using the matrices, which are given.

N : number of cells
M : dimension of matrix and vector
MMAX : dimension of terminal matrix and terminal vector
NCNCO : number of terminals
A (M, M, N) : lower diagonal matrix
B (M, M, N) : diagonal part matrix
C (M, M, N) : upper diagonal matrix
Y (M, N) : vector of constant terms
MUSE (1) : degree of freedom of variables at the left external terminals
MUSE (2) : degree of freedom of variables at the right external terminals

XLR (MMAX, NCNCO) : terminal vector
ALCR (M, MMAX, NCNCO) : terminal matrix
S (M, MMAX, NCNCO, N) : matrix to be multiplied to terminal vector
KEY : flag for calculations
W (MMAX, MMAX) : work area
IW (M) : work area
ERR : flag for error information

(6) MTSL1F (entry of MTSL1)

MTSL1F is the entry name of MTSL1. It has the same functions as MTSL1, but the names of variables are different.

(7) MTSLC (entry MTSLCF, MTSLCB)

Equations are solved by the Crout method

KEY=1 : LU-decomposition is performed and equations are solved.
KEY=2 : LU-decomposition is performed.
KEY=3 : Backward substitution is performed by using the matrix, which is obtained by LU-decomposition.

(8) MTSLCF (entry of MTSLC)

MTSLCF is the entry name of MTSLC. It has the same functions as MTSLC except the case KEY=3.

(9) MTSLCB (entry of MTSLC)

MTSLCB is the entry name of MTSLC. It has the same function as the case KEY=3 in MTSLC.

(10) INNRPD

Inner product is calculated using the elements in an arbitrary range of an arbitrary vector, and added to certain constant.

N : dimension of array
W1 (N) : vector
W2 (N) : vector
FROM : starting number for element
TO : ending number for element
START : additive constant
ANS : sum of constant and inner product

A2.9 COMMON VARIABLES

Common blocks and variables are listed here. Almost all of variables used in MINCS appear in common blocks.

(1) CCONST

COMMON/CCONST/FRGTYP

FRGTYP : array consists of 5 flow types defined by BLOCK DATA. Each of them has 18 characters.

(2) CORR

```
COMMON/CORR/AIL, AIG, AIC, AIB, AID, AILH, AIGH, AICH, AIBH, AIDH, AWG, AWL, AWM,
            AWGC, AWLC, AWGB, AWLD, AWGH, AWLH, AWMH, AWGCH, AWLCH,
            AWGBH, AWLDH, FIL, FIG, FIC, FIB, FID, FWG, FWL, FWM, FWGC, FWLC,
            FWGB, FWLD, HTCIL, HTCIG, HTCIGC, HTCIGD, HTCIGB, HTCILC, HTCILB,
            HTCILD, HTCWL, HTCWG, HTCNC, HTCWM, PHAI, CVM, RAM, GNCS
```

AIL	:	interfacial area of liquid for friction
AIG	:	interfacial area of gas for friction
AIC	:	interfacial area in continuous flow for friction
AIB	:	interfacial area in bubbly flow for friction
AID	:	interfacial area in droplet flow for friction
AILH	:	interfacial heat transfer area of liquid
AIGH	:	interfacial heat transfer area of gas
AICH	:	interfacial heat transfer area in continuous flow
AIBH	:	interfacial heat transfer are in bubbly flow
AIDH	:	interfacial heat transfer area in droplet flow
AWG	:	wall contact area of gas for friction
AWL	:	wall contact area of liquid for friction
AWM	:	wall contact area of mixture for friction
AWGC	:	wall contact area of gas in continuous flow for friction
AWLC	:	wall contact area of liquid in continuous flow for friction
AWGB	:	wall contact area of gas in bubbly flow for friction
AWLD	:	wall contact area of liquid in droplet flow for friction
AWGH	:	wall heat transfer area of gas
AWLH	:	wall heat transfer area of liquid
AWMH	:	wall heat transfer area of mixture
AWGCH	:	wall heat transfer area of gas in continuous flow
AWLCH	:	wall heat transfer area of liquid in continuous flow
AWGBH	:	wall heat transfer area of gas in bubbly flow
AWLDH	:	wall heat transfer area of liquid in droplet flow
FIG	:	interfacial friction coefficient of gas
FIL	:	interfacial friction coefficient of liquid
FIC	:	interfacial friction coefficient for continuous flow
FIB	:	interfacial friction coefficient for bubbly flow
FID	:	interfacial friction coefficient for droplet flow
FWG	:	wall friction coefficient of gas
FWL	:	wall friction coefficient of liquid
FWM	:	wall friction coefficient of mixture
FWGC	:	wall friction coefficient of gas in continuous flow
FWGB	:	wall friction coefficient of gas in bubbly flow
FWLD	:	wall friction coefficient of liquid in droplet flow
HTCIL	:	interfacial heat transfer coefficient of liquid
HTCIG	:	interfacial heat transfer coefficient of gas
HTCIGC	:	interfacial heat transfer coefficient of gas in continuous flow
HTCIGD	:	interfacial heat transfer coefficient of gas in droplet flow
HTCIGB	:	interfacial heat transfer coefficient of gas in bubbly flow

HTCILC : interfacial heat transfer coefficient of liquid in continuous flow
HTCILB : interfacial heat transfer coefficient of liquid in bubbly flow
HTCILD : interfacial heat transfer coefficient of liquid in droplet flow
HTCWL : wall heat transfer coefficient of liquid
HTCWG : wall heat transfer coefficient of gas
HTCNC : heat transfer coefficient for subcool boiling
HTCWM : not used at present
PHAI : two-phase multiplier for wall friction
CVM : virtual mass coefficient
RAM : parameter in virtual mass force term
GNCS : phase change rate for subcool boiling

(3) COUNT

COMMON/COUNT/NSTEPZ, KOUNTZ

NSTEPZ : total time step number
KOUNTZ : total iteration number

(4) CSLAND

COMMON/CSLAND/CAR (LENCAR)

CAR (LENCAR) : character type global array for all components

(5) ENGNER

COMMON/ENGNER/REW, REWGC, REWGB, REWLC, REWLD, REWM, REIGC, REIGC, REIGB, REILC, REILD, REIC, REIB, REID, PRIG, PRIL

REW : not used at present
REWGC : gas Reynolds number in continuous flow for wall correlation
REWGB : gas Reynolds number in bubbly flow for wall correlation
REWLC : liquid Reynolds number in droplet flow for wall correlation
REWM : Reynolds number in 1V and 1VD model for wall correlation
REIGC : not used at present
REIGB : not used at present
REILC : not used at present
REILD : not used at present
REIC : Reynolds number in continuous flow for interface
REIB : Reynolds number in bubbly flow for interface
REID : Reynolds number in droplet flow for interface
PRIG : gas Prandtl number
PRIL : liquid Prandtl number

(6) ERROR

COMMON/ERROR/NOGO

NOGO : error flag

(7) FMTABL

COMMON/FMTABL/FMLOSS (10, 6)

FMLOSS (10, 6) : input form loss coefficient

(8) ICONST

COMMON/ICONST/ICRDBG, NFF, ITRC, IHOR, IHORG, ICHVOL

ICRDBG : not used at present
NFF : not used at present
ITRC : not used at present
IHOR : not used at present
IHORG : not used at present
ICHVOL : not used at present

(9) IGEOM

COMMON/IGEOM/ICHHV, IDCPHX, IHTNO, ISIDE, KWL, VERT

ICHHV : flag for pipe, zero for horizontal, unity for vertical
IDCPHX : flag for discrete phase, zero for gas, unity for liquid
IHTNO : heat slab number to which IHEATC-th heat slab boundary belongs, same as ITHT (L2IHT,IHEATC)
ISIDE : flag for boundary type of IHEATC-th heat slab boundary, unity for left, two for right, same as ITHT (L2SDN, IHEATC)
KWL : material property number of ISIDE side boundary mesh in IHTNO-th heat slab, same as IHTBND (L1KWL, ISIDE, IHTNO)
VERT : indicator for pipe, '.FALSE.' for horizontal, '.TRUE.' for vertical

(10) INDJ3

COMMON/INDJ3/J3MAXN, J3TMI, J3TMG, J3TML, J3TEI, J3TEG, J3TEL, J3IMF, J3OMF, J3IEF, J3OEF, J3IMFT, J3OMFT, J3DIOF, J3IEFT, J3OEFT, J3DIOE, J3IMAS, J3IENG, J3RMAS, J3RENG, J3THI, J3THG, J3THL, J3THIT, J3THGT, J3THLT

J3MAXN : dimension of array CINV: total number of pointers in INDJ3 (= 26)
J3TMI : pointer indicating the location of total mass inventory in the array CINV
J3TMG : pointer indicating the location of mass inventory of gas in the array CINV
J3TML : pointer indicating the location of mass inventory of liquid in the array CINV
J3TEI : pointer indicating the location of total energy inventory in the array CINV
J3TEG : pointer indicating the location of energy inventory of gas in the array CINV
J3TEL : pointer indicating the location of energy inventory of liquid in the array CINV
J3IMF : pointer indicating the location of mass flow, which comes in from the left boundary of component, in the array CINV.
J3OMF : pointer indicating the location of mass flow, which goes out from the right boundary of component, in the array CINV
J3IEF : pointer indicating the location of energy flow, which comes in from the left boundary of component, in the array CINV
J3OEF : pointer indicating the location of energy flow, which goes out from the right boundary of component, in the array CINV

J3IMFT : pointer indicating the location of integrated mass flow, which comes in from the left boundary of component, in the array CINV

J3OMFT : pointer indicating the location of integrated mass flow, which goes out from the right boundary of component, in the array CINV

J3DIOF : pointer indicating the location of mass accumulation in the array CINV

J3IEFT : pointer indicating the location of integrated energy flow, which comes in from the left boundary of component, in the array CINV

J3OEFT : pointer indicating the location of integrated energy flow, which goes out from the right boundary of component, in the array CINV

J3DIOE : pointer indicating the location of energy accumulation in the array CINV

J3IMAS : pointer indicating the location of initial value of total mass inventory in the array CINV

J3IENG : pointer indicating the location of initial value of total energy inventory in the array CINV

J3RMAS : pointer indicating the location of relative error between total mass inventory and mass accumulation in the array CINV

J3RENG : pointer indicating the location of relative error between total energy inventory and energy accumulation in the array CINV

J3THI : pointer indicating the location of total heat flux, which comes in from the wall, in the array CINV

J3THG : pointer indicating the location of heat flux to gas, which comes in from the wall, in the array CINV

J3THL : pointer indicating the location of heat flux to liquid, which comes in from the wall, in the array CINV

J3THIT : point indicating the location of integrated total heat flux, which comes in from the wall, in the array CINV

J3THGT : pointer indicating the location of integrated heat flux to gas, which comes in from the wall, in the array CINV

J3THLT : point indicating the location of integrated heat flux to liquid, which comes in from the wall, in the array CINV

(11) INDK0

COMMON/INDK0/K0MAXN, K0AI, K0AR, K0AC, K0LI, K0LR, K0LC, K0LIW, K0LRW K0LCW

K0MAXN : first dimension of two-dimensional array NSBTAB: total number of pointers in INDK0 (= 9)

K0AI : pointer indicating the address location of integer type array IAR in the array NSBTAB

K0AR : pointer indicating the address location of real type array RAR in the array NSBTAB

K0AC : pointer indicating the address location of character type array CAR in the array NSBTAB

K0LI : pointer indicating the location of length of integer type array IAR in the array NSBTAB

K0LR : pointer indicating the location of length of real type array RAR in the array NSBTAB

K0LC : pointer indicating the location of length of character type array CAR in the array NSBTAB

K0LIW : pointer indicating the location of work area length of integer type array IAR in the array NSBTAB

K0LRW : pointer indicating the location of work area length of real type array RAR in the array NSBTAB

K0LCW : pointer indicating the location of work area length of character type array CAR in the array NSBTAB

(12) INDK1

COMMON/INDK1/K1MAXN, K1TIM, K1EDT, K1VAL, K1FRM, K1PMP, K1SGI, K1HTC, K1CCP, K1MTB

K1MAXN : second dimension of two-dimensional array NSBTAB: total number of pointers in INDK1 (= 9)
K1TIM : pointer indicating the location of time step control data in the array NSBTAB
K1EDT : pointer indicating the location of I/O control data in the array NSBTAB
K1VAL : pointer indicating the location of valve data in the array NSBTAB
K1FRM : pointer indicating the location of form loss data in the array NSBTAB
K1PMP : pointer indicating the location of pump data in the array NSBTAB
K1SGI : pointer indicating the location of SG component data in the array NSBTAB
K1HTC : pointer indicating the location of heat conductor data in the array NSBTAB
K1CCP : pointer indicating the location of fluid component data in the array NSBTAB
K1MTB : pointer indicating the location of physical property table data in the array NSBTAB

(13) INDK2

COMMON/INDK2/K2MAXN, K2USE, K2CMP, K2TYP, K2MXM, K2MTV, K2MTT, K2MBD, K2NCT, K2NCO, K2NHT, K2LI, K2LR, K2LC, K2LIT, K2LRT, K2LCT, K2LIW, K2LRW, K2LCW

K2MAXN : first dimension of two-dimensional array NTABOP: total number of pointers in INDK2 (= 19)
K2USE : not used at present
K2CMP : pointer indicating the location, in which the component number is stored in the array NTABOP
K2TYP : pointer indicating the location, in which the type of component is stored in the array NTABOP
K2MXM : pointer indicating the location, in which the number of basic variables MAXDM is stored in the array NTABOP
K2MTV : pointer indicating the location of flag, which denotes the velocity model: 1V, 1VD or 2V, in the array NTABOP
K2MTT : pointer indicating the location of flag, which denotes the temperature model: 1T, 1.5T or 2T, in the array NTABOP
K2MBD : pointer indicating the location of flag, which denotes the velocity condition of BOUNDARY component, in the array NTABOP
K2NCT : pointer indicating the location, in which the number of internal terminals is stored in the array NTABOP
K2NCO : pointer indicating the location, in which the number of external terminals is stored in the array NTABOP
K2NHT : pointer indicating the location, in which the number of heat slab boundaries is stored in the array NTABOP
K2LI : pointer indicating the location, in which the length for one component in the integer type array IAR is stored, in the array NTABOP
K2LR : pointer indicating the location, in which the length for one component in the real type array RAR is stored, in the array NTABOP
K2LC : pointer indicating the location, in which the length for one component in the character type array CAR is stored, in the array NTABOP

K2LIT : pointer indicating the location, in which the length for internal and external terminals of one component in the integer type array IAR is stored, in the array NTABOP

K2LRT : pointer indicating the location, in which the length for internal and external terminals of one component in the real type array RAR is stored, in the array NTABOP

K2LCT : pointer indicating the location, in which the length for internal and external terminals of one component in the character type array CAR is stored, in the array NTABOP

K2LIW : pointer indicating the location, in which the work area for one component in the integer type array IAR is stored, in the array NTABOP

K2LRW : pointer indicating the location, in which the work area for one component in the real type array RAR is stored, in the array NTABOP

K2LCW : pointer indicating the location, in which the work area for one component in the character type array CAR is stored, in the array NTABOP

(14) INDK3

COMMON/INDK3/K3MAXN, K3AI, K3IT, K3IO, K3IHT

K3MAXN : first dimension of two-dimensional array NTABI: total number of pointers in INDK3 (= 4)

K3AI : pointer indicating the location of address, which denotes the part used for other than terminals of one component in the integer type array IAR, in the array NTABI

K3IT : pointer indicating the location, in which the address of integer type array IART for internal terminals is stored, in the array NTABI

K3IO : pointer indicating the location, in which the address of integer type array IARO for external terminals is stored, in the array NTABI

K3IHT : pointer indicating the location, in which the address of array IHT for heat conductors is stored, in the array NTABI

(15) INDK4

COMMON/INDK4/K4MAXN, K4AR, K4RVT, K4SMTT, K4TVT, K4XT, K4XVT, K4CC1T, K4CC2T, K4CC3T, K4CC4T, K4RVO, K4SMTO, K4DTVO, K4XO, K4XVO, K4CC1O, K4CC2O, K4CC3O, K4CC4O

K4MAXN : first dimension of two-dimensional array NTABR: total number of pointers in INDK4 (= 19)

K4AR : pointer indicating the location of address, which denotes the part used for other than terminals of one component in the real type array RAR, in the array NTABR

K4RVT : pointer indicating the location, in which the address of array RVT used to store the solution of internal terminals without the effect of external terminals is stored, in the array NTABR

K4SMTT : pointer indicating the location, in which the address of matrix SMTT used for the effect of external terminals in the solution of internal terminals is stored, in the array NTABR

K4TVT : pointer indicating the location, in which the address of vector TVT used for the δT_w effect in the solution of internal terminals is stored, in the array NTABR

K4XT : pointer indicating the location, in which the address of vector XT for basic variables in internal terminals is stored, in the array NTABR

K4XVT : pointer indicating the location, in which the address of vector XVT for basic variables in internal terminals is stored, in the array NTABR

K4CC1T : pointer indicating the location, in which the address of array CC1T for internal terminals is stored, in the array NTABR

K4CC2T : pointer indicating the location, in which the address of array CC2T for geometric data of internal trminals is stored, in the array NTABR

K4CC3T : pointer indicating the location, in which the address of array CC3T for steam table related data of internal terminals is stored, in the array NTABR

K4CC4T : pointer indicating the location, in which the address of array CC4T for correlations for internal terminals is stored, in the array NTABR

K4RVO : pointer indicating the location, in which the address of array RVO for solutions of external terminals is stored, in the array NTABR

K4SMTO : pointer indicating the location, in which the address of array SMTO used to store derivatives of Jacobians of internal terminals by basic variables of external terminals is stored, in the array NTABR

K4DTVO : pointer indicating the location, in which the address of array DTVO used to store solutions (δT_w) of heat slab boundaries is stored, in the array NTABR

K4XO : pointer indicating the location, in which the address of vector XO for basic variables of external terminals is stored, in the array NTABR

K4XVO : pointer indicating the location, in which the address of vector XVO for basic variables of external terminals is stored, in the array NTABR

K4CC1O : pointer indicating the location, in which the address of array CC1O for external terminals is stored, in the array NTABR

K4CC2O : pointer indicating the location, in which the address of array CC2O for geometric data of external terminals is stored, in the array NTABR

K4CC3O : pointer indicating the location, in which the address of array CC3O for steam table related data of external terminals is stored, in the array NTABR

K4CC4O : pointer indicating the location, in which the address of array CC4O for correlations for external terminals is stored, in the array NTABR

(16) INDK5

COMMON/INDK5/K5MAXN, K5AC

K5MAXN : first dimension of two-dimensional array NTABC: total number of pointers in INDK5 (= 1)

K5AC : pointer indicating the location of address, which denotes the part used for other than terminals of one component in the character type array CAR, in the array NTABR

(17) INDK6

COMMON/INDK6/K6MAXN, K6TYP, K6MXM, K6MBD, K6MTV, K6MTT

K6MAXN : first dimension of two-dimensional array NTABOO: total number of pointers in INDK6 (= 5)

K6TYP : pointer indicating the location, where the type of component connected to one component is stored, in the array NTABOO

K6MXM : pointer indicating the location, where the number of basic variables in the component connected to one component is stored, in the array NTABOO

K6MBD : pointer indicating the location, where the flag for velocities in the BOUNDARY component is stored, in the array NTABOO

K6MTV : pointer indicating the location, where the flag for velocity model - 1V, 1VD or 2V - of the component connected to one component is stored, in the array NTABOO

K6MTT : pointer indicating the location, where the flag for temperature model - 1T, 1.5T or 2T - of the component connected to one component is stored, in the array NTABOO

(18) INDK7

COMMON/INDK7/K7MAXN, K7MPOS, K7CMPO, K7CNCO, K7JPOS, K7JUNC, K7CNC, K7POLE

K7MAXN : first dimension of three-dimensional array NTABJN: total number of pointers in INDK7 (= 7)

K7MPOS : pointer of the array NTABJN. NTABJN (K7MPOS, ICNCT, ICOMP) is the address of basic variable vector for ICNCT-th terminal of ICOMP-th component

K7CMPO : pointer of the array NTABJN. NTABJN (K7CMPO, ICNCO, ICOMP) is the component number, to which the terminal - connected to ICNCO-th terminal of ICOMP-th component - belongs

K7CNCO : pointer of the array NTABJN. NTABJN (K7CNCO, ICNCO, ICOMP) is the external terminal number of the component connected to ICNCO-th terminal of ICOMP-th compo nent

K7JPOS : pointer of the array NTABJN. NTABJN (K7JPOS, ICNCO, ICOMP) is the junction number corresponding to ICNCO-th terminal of ICOMP-th component

K7JUNC : pointer indicating the location, where the allotted junction number by the input is stored, in the array NTABJN

K7CNC : pointer indicating the location, where the terminal number of the component is stored, in the array NTABJN

K7POLE : pointer indicating the location, where the polarity of each terminal is stored, in the array NTABJN

(19) INDK8

COMMON/INDK8/K8MAXN, K8JUNC, K8CMPR, K8CNCR, K8CMPL, K8CNCL

K8MAXN : first dimension of two-dimensional array NJNTN: total number of pointers in INDK8 (= 5)

K8JUNC : pointer of the array NJNTN. NJNTN (K8JUNC, KC) is the allotted number for KC-th junction by input

K8CMPR : pointer of the array NJNTN. NJNTN (K8CMPR, KC) is the component number, which is connected to KC-th junction, with the terminal polarity of unity

K8CNCR : pointer of the array NJNTN. NJNTN (K8CNCR, KC) is the terminal number, which is connected to KC-th junction, in the component with the terminal polarity of unity

K8CMPL : pointer of the array NJNTN. NJNTN (K8CMPL, KC) is the component number, which is connected to KC-th junction, with the terminal polarity of -1

K8CNCL : pointer of the array NJNTN. NJNTN (K8CNCL, KC) is the terminal number, which is connected to KC-th junction, in the component with the terminal polarity of -1

(20) INDK9

COMMON/INDK9/K9MAXN, K9ALMI, K9ALMX, K9GRV, K9EPVL

K9MAXN : dimension of CONSTV: total number of pointers in INDK9 (= 4)

K9ALMI : pointer indicating the location of α_{min} in the array CONSTV

K9ALMX : pointer indicating the location of α_{max} in the array CONSTV

K9GRV : pointer indicating the location of gravitational acceleration in the array CONSTV

K9EPVL : pointer indicating the location of minimum valve flow area in the array CONSTV

(21) INDL0

COMMON/INDL0/L0MAXN, L0TW, L0AWG, L0AWL, L0HGW, L0HLW, L0HNC, L0TG, L0TL, L0TGP, L0TLP, L0TGH, L0TLH, L0TBL, L0HTC, L0AREA

L0MAXN : first dimension of three-dimensional array HTBND: total number of pointers in INDL0 (=15). The array HTBND is used to exchange variables between heat conductors and fluid components

L0TW : pointer of the array HTBND. HTBND (L0TW, I, J) is the temperature at I-th boundary of J-th heat slab

L0AWG : pointer of the array HTBND. HTBND (L0AWG, I, J) is the wall contact area of gas in the fluid cell connected to the I-th boundary of J-th heat slab

L0AWL : pointer of the array HTBND. HTBND (L0AWL, I, J) is the wall contact area of liquid in the fluid cell connected to the I-th boundary of J-th heat slab

L0HGW : pointer of the array HTBND. HTBND (L0HGW, I, J) is the wall heat transfer coefficient for gas in the fluid cell connected to the I-th boundary of J-th heat slab

L0HLW : pointer of the array HTBND. HTBND (L0HLW, I, J) is the wall heat transfer coefficient for liquid in the fluid cell connected to the I-th boundary of J-th heat slab

L0HNC : pointer of the array HTBND. HTBND (L0HLC, I, J) is the heat transfer coefficient for subcool boiling in the fluid cell connected to the I-th boundary of J-th heat slab

L0TG : pointer of the array HTBND. HTBND (L0TG, I, J) is the gas temperature in the fluid cell connected to the I-th boundary of J-th heat slab

L0TL : pointer of the array HTBND. HTBND (L0TL, I, J) is the liquid temperature in the fluid cell connected to the I-th boundary of J-th heat slab

L0TGP : pointer of the array HTBND. HTBND (L0TGP, I, J) is $\partial T_g/\partial p$ in the fluid cell connected to the I-th boundary of J-th heat slab

L0TLP : pointer of the array HTBND. HTBND (L0TLP, I, J) is $\partial T_f/\partial p$ in the fluid cell connected to the I-th boundary of J-th heat slab

L0TGH : pointer of the array HTBND. HTBND (L0TGH, I, J) is $\partial T_g/\partial h_g$ in the fluid cell connected to the I-th boundary of J-th heat slab

L0TLH : pointer of the array HTBND. HTBND (L0TLH, I, J) is $\partial T_f/\partial h_f$ in the fluid cell connected to the I-th boundary of J-th heat slab

L0TBL : pointer of the array HTBND. HTBND (L0TBL, I, J) is the bulk temperature for the I-th boundary of J-th heat slab

L0HTC : pointer of the array HTBND. HTBND (L0HTC, I, J) is the heat transfer coefficient for the I-th boundary of J-th heat slab

L0AREA : pointer of the array HTBND. HTBND (L0AREA, I, J) is the area of the I-th boundary of J-th heat slab

(22) INDL1

COMMON/INDL1/L1MAXN, L1MRX, L1KWL, L1TYPE, L1COMP, L1NODE, L1FLG, L1FBD

L1MAXN : first dimension of three-dimensional array IHTBND: total number of pointers in INDL1 (= 7).

L1MRX : pointer of the array IHTBND. IHTBND (L1MRX, I, J) is the number of total elements of system matrix up to the wall temperature of I-th boundary of J-th heat slab

L1KWL : pointer of the array IHTBND. IHTBND (L1KWL, I, J) is the material number of I-th boundary of J-th heat slab

L1TYPE : pointer of the array IHTBND. IHTBND (L1TYPE, I, J) is the boundary type of I-th boundary of J-th heat slab

L1COMP : pointer of the array IHTBND. IHTBND (L1COMP, I, J) is the component number, to which the I-th boundary of J-th heat slab is connected, or the table number of bulk temperature used as the boundary condition

L1NODE : pointer of the array IHTBND. IHTBND (L1NODE, I, J) is the cell number, to which the I-th boundary of J-th heat slab is connected, or the table number of heat transfer coefficient used as the boundary condition

L1FLG : pointer of the array IHTBND. IHTBND (L1FLG, I, J) is the flag, which is -1 if there is no component or cell when the I-th boundary of J-th heat slab is set to be connected to a fluid component. Otherwise, it is 0.

L1FBD : pointer of the array IHTBND. IHTBND (L1FBD, I, J) is the flag, which is L7IMB, L7EXB and L7NOT according to the coupling type, implicit, explicit and other, respectively.

(23) INDL2

COMMON/INDL2/L2MAXN, L2NDN, L2IHT, L2SDN, L2NIHT, L2FBD

L2MAXN : first dimension of two-dimensional array ITHT: total number of pointers in INDL2 (= 5)

L2NDN : pointer of the array ITHT. ITHT (L2NDN, I) is the fluid cell number, to which I-th boundary of heat slab is connected

L2IHT : pointer of the array ITHT. ITHT (L2IHT, I) is the heat slab number, to which I-th boundary belongs

L2SDN : pointer of the array ITHT. ITHT (L2SDN, I) is the flag of I-th boundary: unity for left, two for right

L2NIHT : pointer of the array ITHT. ITHT (L2NIHT, I) is the boundary number: I

L2FBD : pointer of the array ITHT. ITHT (L2FBD, I) is the flag for coupling: L7IMB for implicit, L7EXB for explicit

(24) INDL3

COMMON/INDL3/L3MAXN, L3WL, L3WR, L3TG, L3TL, L3CNST

L3MAXN : first dimension of three-dimensional array CWL: total number of pointers in INDL3 (= 5). CWL is the array for system matrix when coupling is implicit

L3WL : pointer of the array CWL. CWL (L3WL, I, J) is the coefficient for the left boundary temperature T_{wl} in the heat conduction equation of I-th boundary of J-th heat slab

L3WR : pointer of the array CWL. CWL (L3WR, I, J) is the coefficient or the right boundary temperature T_{wr} in the heat conduction equation of I-th boundary of J-th heat slab

L3TG : pointer of the array CWL. CWL (L3TG, I, J) is the coefficient for the gas temperature T_g in the heat conduction equation of I-th boundary of J-th heat slab

L3TL : pointer of the array CWL. CWL (L3TL, I, J) is the coefficient for the liquid temperature T_l in the heat conduction equation of I-th boundary of J-th heat slab

L3CNST : pointer of the array CWL. CWL (L3CNST, I, J) is the constant term in the heat conduction equation of I-th boundary of J-th heat slab

(25) INDL4

COMMON/INDL4/L4MAXN, L4TG, L4TL

L4MAXN : total number of pointers in INDL4 (= 2) for the array THGL, RVWL, SMTWL and TVWL

L4TG : element having this pointer is related to δT_g

L4TL : element having this pointer is related to δT_l

(26) INDL5

COMMON/INDL5/L5MAXN, L5IMB, L5EXB, L5TB, L5AB, L5TAB

L5MAXN : total number of flags in INDL5 (= 5)
L5IMB : flag indicating implicit coupling (= -100)
L5EXB : flag indicating explicit coupling (= -10)
L5TB : flag indicating temperature boundary (= -1)
L5AB : flag indicating adiabatic boundary (= 0)
L5TAB : flag indicating table data boundary (= 1)

(27) INDL6

COMMON/INDL6/L6MAXN, L6MRX, L6IHT, L6SDN, L6FBD

L6MAXN : first dimension of two-dimensional array IHT: total number of pointers in INDL6 (= 4)
L6MRX : pointer of the array IHT. IHT (L6MRX, I) is the number of total elements of system matrix up to the wall temperature of I-th boundary
L6IHT : pointer of the array IHT. IHT (L6IHT, I) is the heat slab number, to which I-th boundary belongs
L6SDN : pointer of the array IHT. IHT (L6SDN, I) is the flag of I-th boundary: unity for left, two for right
L6FBD : pointer of the array IHT. IHT (L6FBD, I) is the flag for coupling: L7IMB for implicit, L7EXB for explicit

(28) INDL7

COMMON/INDL7/L7MAXN, L7IMB, L7EXB, L7NOT

L7MAXN : total number of flags in INDL7 (= 3)
L7IMB : flag indicating implicit coupling
L7EXB : flag indicating explicit coupling
L7NOT : flag indicating other boundary condition

(29) INDM1

COMMON/INDM1/M1MAXN, M1ALP, M1UG, M1UL, M1RG, M1RL, M1AR2, M1HED, M1TRQ, M1OMG

M1MAXN : first dimension of two-dimensional array PMPBDT: total number of pointers in INDM1 (= 9)
M1ALP : pointer of the array PMPBDT. PMPBDT (M1ALP, I) is the void fraction in the cell, whose edge has I-th pump
M1UG : pointer of the array PMPBDT. PMPBDT (M1UG, I) is the gas velocity at the cell edge, which has I-th pump
M1UL : pointer of the array PMPBDT. PMPBDT (M1UL, I) is the liquid velocity at the cell edge, which has I-th pump
M1RG : pointer of the array PMPBDT. PMPBDT (M1RG, I) is the gas density at the cell, whose edge has I-th pump
M1RL : pointer of the array PMPBDT. PMPBDT (M1RL, I) is the liquid density at the cell, whose edge has I-th pump
M1AR2 : pointer of the array PMPBDT. PMPBDT (M1AR2, I) is the flow area of cell edge or valve, which has I-th pump

M1HED : pointer of the array PMPBDT. PMPBDT (M1HED, I) is the hydrodynamic head calculated in the I-th pump

M1TRQ : pointer of the array PMPBDT. PMPBDT (M1TRQ, I) is the hydrodynamic torque calculated in the I-th pump

M1OMG : pointer of the array PMPBDT. PMPBDT (M1OMG, I) is the rotation velocity calculated in the I-th pump

(30) INDM2

COMMON/INDM2/M2MAXN, M2ST, M2USE

M2MAXN : first dimension of two-dimensional array IPMBDT: total number of pointers in INDM2 (= 2)

M2ST : not used at present

M2USE : pointer of the array IPMBDT. IPMBDT (M2USE, I) is the flag indicating whether or not I-th pump is used in the fluid component (0: not used, 1: used)

(31) INDX0

COMMON/INDX0/N0KWAL, N0MSV, N0IDC, N0ISNG, N0MSVX, N0IDCX, N0IEC, N0IFM, N0IVL, N0IPM, N0HTM

N0KWAL : pointer of the integer array IAR for each component: IAR (J, N0KWAL) is the total number of heat slab boundaries, which are connected to J-th cell

N0MSV : pointer of the integer array IAR for each component: IAR (J, N0MSV) is the flag indicating the massive phase in J-th cell is gas or water (0: gas, 1: water)

N0IDC : pointer of the integer array IAR for each component: IAR (J, N0IDC) is the flag indicating the discrete phase in J-th cell is gas or water (0: gas, 1: water)

N0ISNG : pointer of the integer array IAR for each component: IAR (J, N0ISNG) is not used at present

N0MSVX : pointer of the integer array IAR for each component: IAR (J, N0MSVX) is not used at present

N0IDCX : pointer of the integer array IAR for each component: IAR (J, N0IDCX) is not used at present

N0IEC : pointer of the integer array IAR for each component: IAR (J, N0IEC) is the flag indicating whether or not calculated form loss coefficient is used in J-th cell (0: not used, 1: used)

N0IFM : pointer of the integer array IAR for each component: IAR (J, N0IFM) is the form loss coefficient table number used in J-th cell (0: no table is used)

N0IVL : pointer of the integer array IAR for each component: IAR (J, N0IVL) is the valve number connected to J-th cell edge (0: no valve is used)

N0IPM : pointer of the integer array IAR for each component: IAR (J, N0IPM) is the pump number connected to J-th cell edge (0: no pump is used)

N0HTM : pointer of the integer array IAR for each component: IAR (J, N0HTM) is the allotted number to the heat slab boundary, which is connected to J-th cell

(32) INDX1

COMMON/INDX1/N1QAL, N1RM, N1HM, N1UM, N1UG, N1UL, N1UGX, N1ULX

N1QAL : pointer of the array CC1: CC1 (J, N1QAL) is the quality in J-th cell

N1RM : pointer of the array CC1: CC1 (J, N1RM) is the mixture density in J-th cell

N1HM : pointer of the array CC1: CC1 (J, N1HM) is the mixture enthalpy in J-th cell

N1UM : pointer of the array CC1: CC1 (J, N1UM) is the mixture velocity at J-th cell edge

N1UG : pointer of the array CC1: CC1 (J, N1UG) is the gas velocity at J-th cell edge

N1UL : pointer of the array CC1: CC1 (J, N1UL) is the liquid velocity at J-th cell edge

N1UGX : pointer of the array CC1: CC1 (J, N1UGX) is the gas velocity at J-th cell edge at the old time level

N1ULX : pointer of the array CC1: CC1 (J, N1ULX) is the liquid velocity at J-th cell edge at the old time level

(33) INDX2

COMMON/INDX2/N2VOL, N2AR1, N2AR0, N2AR2, N2DLV, N2DLX, N2DHF, N2DHH, N2RGH, N2FECG, N2FECL, N2FECM, N2FLSG, N2FLSL, N2FLSM, N2VOPN, N2HED, N2TRQ, N2OMG

N2VOL : pointer of the array CC2: CC2 (J, N2VOL) is the volume of J-th cell

N2AR1 : pointer of the array CC2: CC2 (J, N2AR1) is the cross sectional area of J-th cell edge

N2AR0 : pointer of the array CC2: CC2 (J, N2AR0) is the cross sectional area of J-th cell center

N2DLV : pointer of the array CC2: CC2 (J, N2DLV) is the elevation between edges of J-th cell

N2DLX : pointer of the array CC2: CC2 (J, N2DLX) is the length of J-th cell

N2DHF : pointer of the array CC2: CC2 (J, N2DHF) is the equivalent diameter of J-th cell center

N2DHH : pointer of the array CC2: CC2 (J, N2DHH) is the equivalent diameter of J-th cell center for heat conduction calculation

N2RGH : pointer of the array CC2: CC2 (J, N2RGH) is the wall roughness of J-th cell

N2FECG : pointer of the array CC2: CC2 (J, N2FECG) is the calculated form loss coefficient of J-th cell for the gas phase in 2V model

N2FECL : pointer of the array CC2: CC2 (J, N2FECL) is the calculated form loss coefficient of J-th cell for the liquid phase in 2V model

N2FECM : pointer of the array CC2: CC2 (J, N2FECM) is the calculated form loss coefficient of J-th cell in 1V or 1VD models

N2FLSG : pointer of the array CC2: CC2 (J, N2FLSG) is the input form loss coefficient of J-th cell for the gas phase in 2V model

N2FLSL : pointer of the array CC2: CC2 (J, N2FLSL) is the input form loss coefficient of J-th cell for the liquid phase in 2V model

N2FLSM : pointer of the array CC2: CC2 (J, N2FLSM) is the input form loss coefficient of J-th cell in 1V or 1VD models

N2VOPN : pointer of the array CC2: CC2 (J, N2VOPN) is the opening degree of valve at J-th cell edge

N2HED : pointer of the array CC2: CC2 (J, N2HED) is the head of pump at J-th cell edge

N2TRQ : pointer of the array CC2: CC2 (J, N2TRQ) is the torque of pump at J-th cell edge

N2OMG : pointer of the array CC2: CC2 (J, N2OMG) is the rotation velocity of pump at J-th cell edge

(34) INDX3

COMMON/INDX3/ N3HM, N3QAL, N3ALP, N3RM, N3PG, N3PL, N3HG, N3HL, N3RG, N3RL, N3TG, N3TL, N3BETG, N3BETL, N3CAPG, N3CAPL, N3CIPG, N3CIPL, N3SPUG, N3SPUL, N3FMUG, N3FMUL, N3CNDG, N3CNDL, N3GP, N3LP, N3GH, N3LH, N3TGP, N3TLP, N3TGH, N3TLH, N3TS, N3HGS, N3HLS, N3RGS, N3RLS, N3FMLS, N3SIG, N3TSP, N3HGSP, N3HLSP, N3RGSP, N3RLSP

N3HM : pointer of the array CC3: CC3 (J, N3HM) is the mixture enthalpy in J-th cell

N3QAL : pointer of the array CC3: CC3 (J, N3QAL) is the quality in J-th cell

N3ALP : pointer of the array CC3: CC3 (J, N3ALP) is the void fraction in J-th cell

N3RM : pointer of the array CC3: CC3 (J, N3RM) is the mixture density in J-th cell

N3PG : pointer of the array CC3: CC3 (J, N3PG) is the gas pressure in J-th cell (same as the liquid pressure at present)

N3PL : pointer of the array CC3: CC3 (J, N3PL) is the liquid pressure in J-th cell
N3HG : pointer of the array CC3: CC3 (J, N3HG) is the gas enthalpy in J-th cell
N3HL : pointer of the array CC3: CC3 (J, N3HL) is the liquid enthalpy in J-th cell
N3RG : pointer of the array CC3: CC3 (J, N3RG) is the gas density in J-th cell
N3RL : pointer of the array CC3: CC3 (J, N3RL) is the liquid density in J-th cell
N3TG : pointer of the array CC3: CC3 (J, N3TG) is the gas temperature in J-th cell
N3TL : pointer of the array CC3: CC3 (J, N3TL) is the liquid temperature in J-th cell
N3BETG : pointer of the array CC3: CC3 (J, N3BETG) is the expansion coefficient of gas in J-th cell
N3BETL : pointer of the array CC3: CC3 (J, N3BETL) is the expansion coefficient of liquid in J-th cell
N3CAPG : pointer of the array CC3: CC3 (J, N3CAPG) is the compressibility of gas in J-th cell
N3CAPL : pointer of the array CC3: CC3 (J, N3CAPL) is the compressibility of liquid in J-th cell
N3CIPG : pointer of the array CC3: CC3 (J, N3CIPG) is the heat capacity of gas in J-th cell
N3CIPL : pointer of the array CC3: CC3 (J, N3CIPL) is the heat capacity of liquid in J-th cell
N3SPUG : pointer of the array CC3: CC3 (J, N3SPUG) is the internal energy of gas in J-th cell
N3SPUL : pointer of the array CC3: CC3 (J, N3SPUL) is the internal energy of liquid in J-th cell
N3FMUG : pointer of the array CC3: CC3 (J, N3FMUG) is the viscosity of gas in J-th cell
N3FMUL : pointer of the array CC3: CC3 (J, N3FMUL) is the viscosity of liquid in J-th cell
N3CNDG : pointer of the array CC3: CC3 (J, N3CNDG) is the heat conductivity of gas in J-th cell
N3CNDL : pointer of the array CC3: CC3 (J, N3CNDL) is the heat conductivity of liquid in J-th cell
N3GP : pointer of the array CC3: CC3 (J, N3GP) is the derivative $(\partial\rho_g/\partial p)_{hg}$ in J-th cell
N3LP : pointer of the array CC3: CC3 (J, N3LP) is the derivative $(\partial\rho_f/\partial p)_{hl}$ in J-th cell
N3GH : pointer of the array CC3: CC3 (J, N3GH) is the derivative $(\partial\rho_g/\partial h_g)_P$ in J-th cell
N3LH : pointer of the array CC3: CC3 (J, N3LH) is the derivative $(\partial\rho_f/\partial h_f)_P$ in J-th cell
N3TGP : pointer of the array CC3: CC3 (J, N3TGP) is the derivative $(\partial T_g/\partial p)_{hg}$ in J-th cell
N3TLP : pointer of the array CC3: CC3 (J, N3TLP) is the derivative $(\partial T_f/\partial p)_{hl}$ in J-th cell
N3TGH : pointer of the array CC3: CC3 (J, N3TGH) is the derivative $(\partial T_g/\partial h_g)_P$ in J-th cell
N3TLH : pointer of the array CC3: CC3 (J, N3TLH) is the derivative $(\partial T_f/\partial h_f)_P$ in J-th cell
N3TS : pointer of the array CC3: CC3 (J, N3TS) is the saturation temperature in J-th cell
N3HGS : pointer of the array CC3: CC3 (J, N3HGS) is the saturated enthalpy of gas in J-th cell
N3HLS : pointer of the array CC3: CC3 (J, N3HLS) is the saturated enthalpy of liquid in J-th cell
N3RGS : pointer of the array CC3: CC3 (J, N3RGS) is the saturated density of gas in J-th cell
N3RLS : pointer of the array CC3: CC3 (J, N3RLS) is the saturated density of liquid in J-th cell
N3FMLS : pointer of the array CC3: CC3 (J, N3FMLS) is the saturated viscosity of liquid in J-th cell
N3SIG : pointer of the array CC3: CC3 (J, N3SIG) is the surface tension in J-th cell
N3TSP : pointer of the array CC3: CC3 (J, N3TSP) is the derivative dT_{sat}/dp in J-th cell
N3HGSP : pointer of the array CC3: CC3 (J, N3HGSP) is the derivative $dH_{g,sat}/dp$ in J-th cell
N3HLSP : pointer of the array CC3: CC3 (J, N3HLSP) is the derivative $dH_{l,sat}/dp$ in J-th cell
N3RGSP : pointer of the array CC3: CC3 (J, N3RGSP) is the derivative $d\rho_{g,sat}/dp$ in J-th cell
N3RLSP : pointer of the array CC3: CC3 (J, N3RLSP) is the derivative $d\rho_{l,sat}/dp$ in J-th cell

(35) INDX4

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COMMON/INDX4/ N4TW,N4AWG,N4AWL,N4HGW,N4HLW,N4QWG,N4QWL,N4FGW,N4FLW,
              N4AGI,N4ALI,N4HGI,N4HLI,N4GAM,N4QGI,N4QLI,N4UKI,N4FGI,N4FLI,
              N4RAM,N4CVM,N4DYN,N4REV,N4AWM,N4FPH,N4TFGW,N4TFLW,
              N4TFMW,N4FIO,N4GNC,N4HNC,N4QNC,N4PHDG,N4PHDL,N4PHEG,
              N4PHEL
```

N4TW : pointer of the array CC4: CC4 (J, N4TW) is not used at present
N4AWG : pointer of the array CC4: CC4 (J, N4AWG) is the wall contact area of gas in J-th cell
N4AWL : pointer of the array CC4: CC4 (J, N4AWL) is the wall contact area of liquid in J-th cell
N4HGW : pointer of the array CC4: CC4 (J, N4HGW) is not used at present
N4HLW : pointer of the array CC4: CC4 (J, N4HLW) is not used at present
N4QWG : pointer of the array CC4: CC4 (J, N4QWG) is the heat flux from the wall to gas in J-th cell
N4QWL : pointer of the array CC4: CC4 (J, N4QWL) is the heat flux from the wall to liquid in J-th cell
N4FGW : pointer of the array CC4: CC4 (J, N4FGW) is the wall friction factor of gas in J-th cell
N4FLW : pointer of the array CC4: CC4 (J, N4FLW) is the wall friction factor of liquid in J-th cell
N4AGI : pointer of the array CC4: CC4 (J, N4AGI) is the interfacial area of gas in J-th cell
N4ALI : pointer of the array CC4: CC4 (J, N4ALI) is the interfacial area of liquid in J-th cell
N4HGI : pointer of the array CC4: CC4 (J, N4HGI) is the interfacial heat transfer coefficient of gas in J-th cell
N4HLI : pointer of the array CC4: CC4 (J, N4HLI) is the interfacial heat transfer coefficient of liquid in J-th cell
N4GAM : pointer of the array CC4: CC4 (J, N4GAM) is the vapour generation rate in J-th cell
N4QGI : pointer of the array CC4: CC4 (J, N4QGI) is the heat flux from the interface to gas in J-th cell
N4QLI : pointer of the array CC4: CC4 (J, N4QLI) is the heat flux from the interface to liquid in J-th cell
N4UKI : pointer of the array CC4: CC4 (J, N4UKI) is the velocity of interface in J-th cell
N4FGI : pointer of the array CC4: CC4 (J, N4FGI) is the interfacial friction factor of gas in J-th cell
N4FLI : pointer of the array CC4: CC4 (J, N4FLI) is the interfacial friction factor of liquid in J-th cell
N4RAM : pointer of the array CC4: CC4 (J, N4RAM) is the parameter λ in added mass force term in J-th cell
N4CVM : pointer of the array CC4: CC4 (J, N4CVM) is the coefficient C_{vm} in added mass force term in J-th cell
N4DYN : pointer of the array CC4: CC4 (J, N4DYN) and CC4 (J, N4DYN+1) are the pressure difference between gas and interface, and between liquid and interface, respectively, in J-th cell
N4REV : pointer of the array CC4: CC4 (J, N4REV) is the relative velocity between gas and liquid in J-th cell
N4AWM : pointer of the array CC4: CC4 (J, N4AWM) is the wall contact area in 1V or 1VD model in J-th cell
N4FPH : pointer of the array CC4: CC4 (J, N4FPH) is the product of wall friction coefficient in 1V or 1VD model and two-phase multiplier in J-th cell
N4TFGW : pointer of the array CC4: CC4 (J, N4TFGW) is the sum of wall friction coefficient and form loss coefficient of gas in J-th cell
N4TFLW : pointer of the array CC4: CC4 (J, N4TFLW) is the sum of wall friction coefficient and form loss coefficient of liquid in J-th cell
N4TFMW : pointer of the array CC4: CC4 (J, N4TFMW) is the sum of wall friction coefficient and form loss coefficient in 1V or 1VD model in J-th cell
N4FIO : pointer of the array CC4: CC4 (J, N4FIO) is not used at present
N4GNC : pointer of the array CC4: CC4 (J, N4GNC) is the vapour generation rate for subcool boiling in J-th cell
N4HNC : pointer of the array CC4: CC4 (J, N4HNC) is not used at present
N4QNC : pointer of the array CC4: CC4 (J, N4QNC) is the heat flux for subcool boiling in J-th cell

N4PHDG : pointer of the array CC4: CC4 (J, N4PHDG) is the pressure difference for gas by pump at J-th cell edge

N4PHDL : pointer of the array CC4: CC4 (J, N4PHDL) is the pressure difference for liquid by pump at J-th cell edge

N4PHEG : pointer of the array CC4: CC4 (J, N4PHEG) is the dissipation energy for gas by pump at J-th cell edge

N4PHEL : pointer of the array CC4: CC4 (J, N4PHEL) is the dissipation energy for liquid by pump at J-th cell edge

(36) ISLAND

COMMON/ISLAND/IAR (LENIAR)

IAR (LENIAR) : integer array used by all components

(37) RCONST

COMMON/RCONST/ZERO, ONE, TWO, HALF, TWOPI, CUTV

ZERO : constant of zero

ONE : constant of unity

TWO : constant of two

HALF : constant of 0.5

TWOPI : constant of 2π

CUTV : constant of 10^{-5}: the minimum value of wall contact area

(38) RGEOM

COMMON/RGEOM/ AREAV, AREAJ, GRAVC, HGS, HLS, TSAT, TCHF, SURFT, SURFA, SVLL, SVLG, SPUG, SPUL, RPD, RPB, DHWGC, DHWGB, DHWLC, DGWLD, DHIB, DHID, DHIC, THETA, DIA, DIAH, DELX, DELEV, ROUGH, CPIG, CPIL, FMUG, FMUL, CONDG, CONDL, VOL, FECLM, FECLG, FECLL, FLOSM, FLOSG, FLOSL, CAPG, CAPL, BETG, BETL, SIG, FMULS, RAITO

AREAV : cross sectional area at cell center

AREAJ : cross sectional area at cell edge

GRAVC : gravitational acceleration

HGS : saturated enthalpy of gas

HLS : saturated enthalpy of liquid

TSAT : saturation temperature

TCHF : critical heat flux temperature

SURFT : total side area of one cell

SURFA : boundary area of heat slab connected to fluid component

SVLL : not used at present

SVLG : not used at present

SPUG : internal energy of gas

SPUL : internal energy of liquid

RPD : radius of liquid droplet

RPB : radius of gas bubble

DHWGC : equivalent diameter of continuous gas phase for wall correlations

DHWGB : equivalent diameter of gas bubble for wall correlations

DHWLC : equivalent diameter of continuous liquid phase for wall correlations

DHWLD : equivalent diameter of liquid droplet for wall correlations
DHIB : equivalent diameter of bubbly flow for wall correlations
DHID : equivalent diameter of droplet flow for wall correlations
DHIC : equivalent diameter of continuous flow for wall correlations
THETA : angle between the center axis of pipe and both edges of interfacial area in stratified flow
DIA : equivalent diameter in the cell center
DIAH : equivalent diameter in the cell center for heat transfer
DELX : cell length
DELEV : elevation between both edges of one cell
ROUGH : wall roughness
CPIG : specific heat of gas
CPIL : specific heat of liquid
FMUG : viscosity of gas
FMUL : viscosity of liquid
CONDG : heat conductivity of gas
CONDL : heat conductivity of liquid
VOL : cell volume
FECLM : calculated form loss coefficient for 1V or 1VD model
FECLG : calculated form loss coefficient for gas in 2V model
FECLL : calculated form loss coefficient for liquid in 2V model
FLOSM : input form loss coefficient for 1V or 1VD model
FLOSG : input form loss coefficient for gas in 2V model
FLOSL : input form loss coefficient for liquid in 2V model
CAPG : compressibility of gas
CAPL : compressibility of liquid
BETG : expansion coefficient of gas
BETL : expansion coefficient of liquid
SIG : surface tension
FMULS : saturated viscosity of liqiud
RATIO : ratio of boundary area of heat slab to the total side area of one cell

(39) RSLAND

COMMON/RSLAND/RAR (LENRAR)

RAR (LENRAR) : real array used by all components

(40) STAT

COMMON/STAT/ ALPHA, XQ, XE, VOLFU, VOLFL, ALPC, ALPB, BETD, BETC, P, PG, PL, HG, HL, HM, VELG, VELL, VELM, VELGC, VELGB, VELLC, VELLD, RELVC, RELVB, RELVD, TG, TL, TM, TW, RHOL, RHOG, RHOM, GM, ALPU, ALPL, ED, EB

ALPHA : void fraction
XQ : quality
XE : not used at present
VOLFU : sum of volume fractions: continuous gas phase and droplets
VOLFL : sum of volume fractions: continuous liquid phase and bubbles
ALPC : volume fraction of continuous gas phase
ALPB : volume fraction of bubbles

BETD	:	volume fraction of droplets
BETC	:	volume fraction of continuous liquid phase
P	:	pressure
PG	:	same as P
PL	:	same as P
HG	:	specific enthalpy of gas
HL	:	specific enthalpy of liquid
HM	:	mixture enthalpy
VELG	:	gas velocity at the cell center
VELL	:	liquid velocity at the cell center
VELM	:	mixture velocity at the cell center
VELGC	:	same as VELG
VELGB	:	same as VELG
VELLC	:	same as VELL
VELLD	:	same as VELL
RELVC	:	difference between VELGC and VELLC
RELVB	:	same as RELVC
RELVD	:	same as RELVC
TG	:	gas temperature
TL	:	liquid temperature
TM	:	not used at present
TW	:	boundary temperature of heat slab connected to fluid cell
RHOL	:	liquid density
RHOG	:	gas density
RHOM	:	mixture density
GM	:	mass velocity
ALPU	:	ratio of ALPC to VOLFU
ALPL	:	ratio of ALPB to VOLFL
ED	:	entrainment of droplets in continuous gas phase
EB	:	entrainment of bubbles in continuous liquid phase

(41) STMDAT

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COMMON/STMDAT/DPGS(MXPRGS), PRGS(MXPRGS+1), PGS(MXPGS), CFHGS(M4, MXPGS),
              DPLS(MXPRLS), PRLS(MXPRLS+1), PLS(MXPLS), CFHLS(M4, MXPLS),
              DPG(MXPRG), PRG(MXPRG+1), PG(MXPG), DHG(MXHRG),
              HRG(MXHRG+1), HGP(MXHG), CFTG(M16, MXPG, MXHG),
              CFPVG(M16, MXPG, MXHG), AKAPG(MXPG, MXHG), DPL(MXPRL),
              PRL(MXPRL+1), PL(MXPL), DHL(MXHRL), HRL(MXHRL+1),
              HLP(MXHL), CFTL(M16, MXPL, MXHL), CFVL(M16, MXPL, MXHL),
              AKAPL(MXPL, MXHL)
```

DPGS (MXPRGS)	:	array for pressure intervals for detailed division of steam saturation line
PRGS (MXPRGS+1)	:	array for minimum pressures for each division of steam saturation line
PGS (MXPGS)	:	array for pressure values for rough division of steam saturation line
CFHGS (M4, MXPGS)	:	array for coefficients of spline function used to obtain the saturated steam enthalpy
DPLS (MXPRLS)	:	array for pressure intervals for detailed division of liquid saturation line

PRLS (MXPRLS+1) : array for minimum pressures for each division of liquid saturation line
PLS (MXPLS) : array for pressure values for rough division of liquid saturation line
CFHLS (M4, MXPLS) : array for coefficients of spline function used to obtain the saturated liquid enthalpy

DPG (MXPRG) : array for pressure intervals for detailed division of single phase steam
PRG (MXPRG+1) : array for minimum pressures for each division of single phase steam
PG (MXPG) : array for pressure values for rough division of single phase steam
DHG (MXHRG) : array for enthalpy intervals for detailed division of single phase steam
HRG (MXHRG+1) : array for minimum enthalpies for each division of single phase steam
HGP (MXHG) : array for enthalpy values for rough division of single phase steam
CFTG (M16, MXPG, MXHG) : array for coefficients of spline function used to obtain the temperature of single phase steam
CFPVG (M16, MXPG, MXHG) : array for coefficients of spline function used to obtain pv_g of single phase steam
AKAPG (MXPG, MXHG) : array for pK_g of single phase steam
DPL (MXPRL) : array for pressure intervals for the detailed division of single phase liquid

PRL (MXPRL+1) : array for minimum pressures for each division of single phase liquid
PL (MXPL) : array for pressure values for rough division of single phase liquid

DHL (MXHRL) : array for enthalpy intervals for detailed division of single phase liquid
HRL (MXHRL+1) : array for minimum enthalpies for each division of single phase liquid
HLP (MXHL) : array for enthalpy values for rough division of single phase liquid
CFTL (M16, MXPL, MXHL) : array for coefficients of spline function used to obtain the temperature of single phase liquid
CFVL (M16, MXPL, MXHL) : array for coefficients of spline function used to obtain v_l of single phase liquid
AKAPL (MXPL, MXHL) : array for $(2.5\times10^7\text{-}p)K_l$ of single phase liquid

(42) STMDIM

COMMON/STMDIM/ NXPRGS, NPGS, NPRGS (MXPRGS), NPRGST (MXPRGS), NXPRLS, NPLS, NPRLS (MXPRLS), NPRLST (MXPRLS), NXPRG, NPG, NPRG (MXPRG), NPRGT (MXPRG), NXHRG, NHG, NHRG (MXHRG), NHRGT (MXHRG), NXPRL, NPL, NPRL (MXPRL), NPRLT (MXPRL), NXHRL, NHL, NHRL (MXHRL), NHRLT (MXHRL)

NXPRGS : number of roughly divided regions of steam saturation line
NPGS : total number of pressure points for rough division of steam saturation line
NPRGS (MXPRGS) : array for the number of detailed division of steam saturation line
NPRGST (MXPRGS) : NPRGST (I) = ΣNPRGS (I-1)+1
NXPRLS : number of roughly divided regions of water saturation line
NPLS : total number of pressure points for rough division of water saturation line
NPRLS (MXPRLS) : array for the number of detailed division of water saturation line
NPRLST (MXPRLS) : NPRLST (I) = ΣNPRLS (I-1)+1
NXPRG : number of roughly divided pressure rergions of single phase steam
NPG : total number of pressure points for rough division of single phase steam
NPRG (MXPRG) : array for the number of detailed pressure division of single phase steam
NPRGT (MXPRG) : NPRGT (I) = ΣNPRG (I-1)+1

NXHRG : number of roughly divided enthalpy regions of single phase steam
NHG : total number of enthalpy points for rough division of single phase steam
NHRG (MXHRG) : array for the number of detailed enthalpy division of single phase steam
NHRGT (MXHRG) : NHRGT (I) = ΣNHRG (I-1)+1
NXPRL : number of roughly divided pressure regions of single phase water
NPL : total number of pressure points for rough division of single phase water
NPRL (MXPRL) : array for the number of detailed pressure division of single phase water
NPRLT (MXPRL) : NPRLT (I) = ΣNPRL (I-1)+1
NXHRL : number of roughly divided enthalpy regions of single phase water
NHL : total number of enthalpy points for rough division of single phase water
NHRL (MXHRL) : array for the number of detailed enthalpy division of single phase water
NHRLT (MXHRL) : NHRLT (I) = ΣNHRL (I-1)+1

(43) TRIPC

COMMON/TRIPC/TTRIP (100, 10), NTABTR (10)

TTRIP (100, 10) : array for the table of time and trip signal
NTABTR (10) : array for the number of trip data for each trip

(44) VALTAB

COMMON/VALTAB/VALTBL (50, 10), IVKONT (10), IVTYPE (10), VNAME (10)

VALTBL (50, 10) : array for the table of time and opening degree or that of pressure and opening degree, according to the valve type
IVKONT (10) : array for the table length in the array VALTBL
IVTYPE (10) : array for the flag of valve type
VNAME (10) : array for the valve name

(45) WEIGHT

COMMON/WEIGHT/WGHT (6, 3)

WGHT (6, 3) : array for the weighting factor for scaling of Jacobian

A2.10. FILE ALLOCATION

Following files are needed for MINCS calculations:

FT03F001 : convergence history for debugging,
FT05F001 : input data file,
FT06F001 : output list file,
FT11F001 : plot file,
FT20F001 : steam table,
FT30F001 : work area for RDCARD,
FT60F001 : output data for restart calculation,
FT61F001 : input data for restart calculation.

An example for file allocation in JCL is thus:

```
//FT03F001 DD DUMMY
//FT05F001 DD DISP=SHR, DSN=J4042.MINCS.DATA (SAMPLE1)
//FT06F001 DD UNIT=TSSWK, SPACE=(TRK, (50, 50), RLSE),
//        DISP=(NEW, CATLG), DCB=(LRECL=137, RECFM=FBA, BLKSIZE=27400),
//        DSN=J4042.SAMPLE1.OUT
//FT11F001 DD UNIT=TSSWK, SPACE=(TRK, (50, 50), RLSE),
//        DISP=(NEW, CATLG), DCB=(LRECL=6208, RECFM=VBS, BLKSIZE=6212),
//        DSN=J4042.SAMPLE1.PLOT
//FT20F001 DD DSN=J4042.¥STMTAB.DATA, DISP=SHR
//FT30F001 DD UNIT=TSSWK, SPACE=(TRK, (10, 5)), DISP=(NEW, DELETE)
//FT60F001 DD UNIT=TSSWK, SPACE=(TRK, (50, 50), RLSE),
//        DISP=(NEW, CATLG), DCB=(LRECL=6208, RECFM=VBS, BLKSIZE=6212),
//        DSN=J4042.RESTART.OUT
//FT61F001 DD DSN=J4042.RESTART.IN, DISP=SHR
```

A simple example is:

```
//FT03F001 DD DUMMY
//FT05F001 DD DISP=SHR, DSN=J4042.MINCS. DATA (SAMPLE1)
//FT06F001 DD SYSOUT=*
//FT11F001 DD DUMMY
//FT20F001 DD DSN=J4042.¥STMTAB.DATA, DISP=SHR
//FT30F001 DD UNIT=TSSWK, SPACE=(TRK, (10, 5)), DISP=(NEW, DELETE)
//FT60F001 DD DUMMY
//FT61F001 DD DUMMY
```

APPENDIX 3. SAMPLE INPUT

Four sample problems are shown in Section 6: the annular flow evaporation, the valve controlled flow, the pump controlled flow and the Kelvin-Helmholtz instability problems. All the input decks are listed here.

A3.1 ANNULAR FLOW EVAPORATION

```
 SAMPLE-1 ANNULAR   FLOW EVAPORATION
**********************************************************************
*
*   SAMPLE PROBLEM 1  -  ANNULAR FLOW EVAPORATION
*
*         VERTICAL HEATED PIPE  =   2.438 M  LONG
*                                   9.296 MM I.D.
*                                   1.651 MM WALL THICKNESS
*
*         BOTTOM INLET FLOW     =   297.0 KG/S/M2
*                                   111.1 DEG-C
*                                   377.1 KPA
*
*         WALL HEAT FLUX        =   207.3 KW/M2
*
*          -- THIS PROBLEM IS BASED ON DATA SET NO.12 IN
*             PHYSICAL BENCHMARK PROBLEM PRESENTED AT
*             INTERNATIONAL WORKSHOP ON TWO-PHASE FLOW FUNDAMENTALS,
*             SEE 'MULTIPHASE SCIENCE AND TECHNOLOGY VOL.3',
*                  HEMISPHERE CORP. 1987.
*
*             ( BUT HEAT FLUX IS ABOUT A HALF OF THE ORIGINAL ONE )
*
*     TEST SECTION IS SIMULATED BY 20-MESH PIPE
*               - EACH MESH HAS 6-MESH HEAT CONDUCTOR
*               - CONSTANT INLET VELOCITY BOUNDARY CONDITION
*               - HEAT FLUX IS LINEARLY INCREASED
*
**********************************************************************
*    SYSTEM CONTROL DATA
**********************************************************************
* IRST, ISTDY
    0     0
* NONCMP
```

```
    0
* NUC,  MOMEN,  IEOS
    1     1       0
* NCOMP, MXCNCO, IDV, NHEAT, MXHEAT, NUMPMP, NUMSG,IDF,MAXTB,MATNUM
    3     2       0     20      20       0        0      0     0      0
* MAXITR, MAXIMP,  EPS,  EPSC, EPCR
   40       0      0.01  0.01   1.0
* IDBS
   0
* THET
  1.0
* GRAV
  0.0
* DELTI, DELT, ENDTIM, NTIM
   0.1   10.0   500.0   0
* MPRT, NTPRT, MPLT, NTPLT,  MRST, NTRST
  100     0     10       0    10000    0
*************************************************************************
*    COMPONENT DEFINITION DATA
*************************************************************************
* MDLNAM, IMTYP, METV, METT
PIPE        1     2     2
*   N    ,  NVAL,  NFB
    20       0     0
*  IDB   , ICUTS, ICUTE
     0       0     0
*  ICJO , IHCON, IADMP, IREC , IECFG, IFLOW
     1       0     0       0      0      2
* I,IEC,IFM,IVL,IPM,IHTM,
*              AREA0 ,  DELX,   AREA1,  DELEV,  DHF,     DHH,  ROGH
  1 0 0 0 0  1 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
  2 0 0 0 0  2 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
  3 0 0 0 0  3 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
  4 0 0 0 0  4 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
  5 0 0 0 0  5 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
  6 0 0 0 0  6 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
  7 0 0 0 0  7 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
```

```
  8 0 0 0 0  8 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
  9 0 0 0 0  9 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
 10 0 0 0 0 10 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
 11 0 0 0 0 11 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
 12 0 0 0 0 12 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
 13 0 0 0 0 13 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
 14 0 0 0 0 14 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
 15 0 0 0 0 15 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
 16 0 0 0 0 16 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
 17 0 0 0 0 17 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
 18 0 0 0 0 18 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
 19 0 0 0 0 19 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
 20 0 0 0 0 20 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
* I,  VOID,  PRES,   ENTH-G,  ENTH-L,   VEL-G,  VEL-L,  ENTH-M,  QUAL
  1   0.0    2.82D5   0.0      4.6616D5  0.3127  0.3127   0.0      0.0
 20   0.0    2.82D5   0.0      4.6616D5  0.3127  0.3127   0.0      0.0
**************************************************************************
* MDLNAM,  IMTYP, METV, METT
BOUNDARY-L  -2     2     2
* IBNDY, ITB(K),K=1,8
    2       8*0
*  IDB  , ICUTS, ICUTE
    0        0     0
*  ICJO , IHCON, IADMP, IREC , IECFG, IFLOW
    1        1     0     0       0      2
* I,IEC,IFM,IVL,IPM,IHTM,
*              AREA0 ,  DELX,   AREA1,  DELEV,  DHF,     DHH,  ROGH
  1 0 0 0 0  0 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
* I,  VOID,  PRES,   ENTH-G,  ENTH-L,   VEL-G,  VEL-L,  ENTH-M,  QUAL
  1   0.0   3.771D5   0.0      4.6616D5  0.3127  0.3127   0.0      0.0
**************************************************************************
* MDLNAM,  IMTYP, METV, METT
BOUNDARY-R  -1     2     2
* IBNDY, ITB(K),K=1,8
    1       8*0
*  IDB  , ICUTS, ICUTE
    0        0     0
```

```
*  ICJO , IHCON, IADMP, IREC , IECFG, IFLOW
    1       1      0     0       0      2
* I,IEC,IFM,IVL,IPM,IHTM,
*              AREA0 ,  DELX,   AREA1,  DELEV,  DHF,     DHH,  ROGH
  1 0 0 0 0  0 6.787D-5 0.1219 6.787D-5 0.1219 9.296D-3 9.296D-3 0.0
* I,  VOID,  PRES,   ENTH-G,  ENTH-L,   VEL-G,  VEL-L,  ENTH-M,  QUAL
  1   1.0   2.82D5    0.0       0.0        0.0      0.0      0.0      0.0
**************************************************************************
*    NETWORK DEFINITION DATA
**************************************************************************
* MDLNAM, JUNC1, JUNC2
PIPE        1      2
BOUNDARY-L  1
BOUNDARY-R  2
**************************************************************************
*    HEAT CONDUCTOR DEFINITION DATA
**************************************************************************
* IDBG,
   0
* NPOW, NPWMAX, NTBLK, MAXBLK, NHTC, MAXHTC
   1      7        0       0       0       0
* NPWLEN, POWER
   7      1.D3
* FRAC1,  FRAC2
    0.0     0.0
   20.0     0.3
   30.0     0.3
   60.0     0.6
   70.0     0.6
  100.0     1.0
 1000.0     1.0
* HNAME
HEAT01
* ICYL, NODE
   1     6
* TOTVOL
  8.556D-6
```

```
* XR(I),I=1,NODE+1
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
* MAT(I),I=1,NODE
       6*6
* TEMPO(I),I=1,NODE+1
       7*384.26
* FPWR(I),I=1,NODE
     5*0.0  1.0
HEAT02
  1  6
  8.556D-6
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
  7*384.26
  5*0.0  1.0
HEAT03
  1  6
  8.556D-6
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
  7*384.26
  5*0.0  1.0
HEAT04
  1  6
  8.556D-6
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
  7*384.26
  5*0.0  1.0
HEAT05
  1  6
  8.556D-6
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
  7*384.26
  5*0.0  1.0
HEAT06
```

```
  1  6
  8.556D-6
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
  7*384.26
  5*0.0  1.0
HEAT07
  1  6
  8.556D-6
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
  7*384.26
  5*0.0  1.0
HEAT08
  1  6
  8.556D-6
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
  7*384.26
  5*0.0  1.0
HEAT09
  1  6
  8.556D-6
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
  7*384.26
  5*0.0  1.0
HEAT10
  1  6
  8.556D-6
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
  7*384.26
  5*0.0  1.0
HEAT11
  1  6
  8.556D-6
```

```
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
  7*384.26
  5*0.0  1.0
HEAT12
  1  6
  8.556D-6
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
  7*384.26
  5*0.0  1.0
HEAT13
  1  6
  8.556D-6
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
  7*384.26
  5*0.0  1.0
HEAT14
  1  6
  8.556D-6
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
  7*384.26
  5*0.0  1.0
HEAT15
  1  6
  8.556D-6
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
  7*384.26
  5*0.0  1.0
HEAT16
  1  6
  8.556D-6
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
```

```
  7*384.26
  5*0.0  1.0
HEAT17
  1  6
  8.556D-6
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
  7*384.26
  5*0.0  1.0
HEAT18
  1  6
  8.556D-6
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
  7*384.26
  5*0.0  1.0
HEAT19
  1  6
  8.556D-6
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
  7*384.26
  5*0.0  1.0
HEAT20
  1  6
  8.556D-6
  4.648D-3 4.9782D-3 5.3084D-3 5.6386D-3 5.9688D-3 6.299D-3 6.6292D-3
  6*6
  7*384.26
  5*0.0  1.0
* HNAME, IPOWX, ITYPL, COMP1, NODEL, ITYPR, COMP2, NODER
HEAT01     1     -10   PIPE     1       0       0       0
HEAT02     1     -10   PIPE     2       0       0       0
HEAT03     1     -10   PIPE     3       0       0       0
HEAT04     1     -10   PIPE     4       0       0       0
HEAT05     1     -10   PIPE     5       0       0       0
HEAT06     1     -10   PIPE     6       0       0       0
```

HEAT07	1	-10	PIPE	7	0	0	0
HEAT08	1	-10	PIPE	8	0	0	0
HEAT09	1	-10	PIPE	9	0	0	0
HEAT10	1	-10	PIPE	10	0	0	0
HEAT11	1	-10	PIPE	11	0	0	0
HEAT12	1	-10	PIPE	12	0	0	0
HEAT13	1	-10	PIPE	13	0	0	0
HEAT14	1	-10	PIPE	14	0	0	0
HEAT15	1	-10	PIPE	15	0	0	0
HEAT16	1	-10	PIPE	16	0	0	0
HEAT17	1	-10	PIPE	17	0	0	0
HEAT18	1	-10	PIPE	18	0	0	0
HEAT19	1	-10	PIPE	19	0	0	0
HEAT20	1	-10	PIPE	20	0	0	0

A3.2 VALVE CONTROLLED FLOW

```
 SAMPLE-2   VALVE   CONTROLLED FLOW
**********************************************************************
*
*  SAMPLE PROBLEM 2  -  VALVE CONTROLLED FLOW
*
*     HORIZONTAL PIPE WITH FIXED PRESSURE AT BOTH ENDS
*                          =  1.0    M  LENGTH
*                             0.026  M  DIA.
*
*     PIPE IS SIMULATED BY 20-MESH PIPE COMPONENT
*     VALVE IS LOCATED AT 8-TH MESH
*
*     VALVE CONDITION   :  0.0   3.0   SEC   100% OPEN
*                          3.0   4.0   SEC   LINEARLY DECREASE
*                          4.0   7.0   SEC     0% OPEN ( CLOSE )
*                          7.0   8.0   SEC   LINEARLY INCREASE
*                          8.0  11.0   SEC   100% OPEN
*                         11.0  12.0   SEC   LINEARLY DECREASE
*                         12.0  15.0   SEC    70% OPEN
*
**********************************************************************
*   SYSTEM CONTROL DATA
**********************************************************************
* IRST, ISTDY
    0     0
* NONCMP
    0
* NUC,  MOMEN,  IEOS
    1     1       0
* NCOMP, MXCNCO, IDV, NHEAT, MXHEAT, NUMPMP, NUMSG,IDF,MAXTB,MATNUM
    3     3       1     0      0        0        0     0     0      0
* MAXITR, MAXIMP,  EPS,  EPSC, EPCR
   40       0       0.1   0.1   1.0
* IDBS
```

```
   0
* THET
  0.5
* GRAV
  0.0
* DELTI, DELT, ENDTIM, NTIM
  0.01   0.01   15.0    0
* MPRT, NTPRT, MPLT, NTPLT,  MRST, NTRST
  100     0      5      0     10000    0
*************************************************************************
*  VALVE DEFINITION DATA
*************************************************************************
* VNAME,  IVTYPE, IVKONT
'VALVE01'   1       8
* VALTAB(1),  (2),   (3),  (4),   (5), (6),  (7), (8),  (9), (10),
    0.0     100.0    3.0  100.0   4.0  0.0   7.0  0.0   8.0 100.0
* VALTAB(11), (12), (13),  (14), (15), (16)
   11.0     100.0   12.0   70.0  15.0 70.0
*************************************************************************
*  COMPONENT DEFINITION DATA
*************************************************************************
* MDLNAM, IMTYP, METV, METT
PIPE        1     2     2
*   N   ,  NVAL,  NFB
   20       0     0
*  IDB  , ICUTS, ICUTE
    0       0     0
*  ICJO , IHCON, IADMP, IREC , IECFG, IFLOW
    1       0     0       0      0      0
* I,IEC,IFM,IVL,IPM,IHTM,
*                AREA0 ,  DELX,   AREA1,   DELEV, DHF,   DHH,  ROGH
 1  0 0 0 0 0  5.3236D-4  0.05  5.3236D-4  0.0  0.026  0.026  0.0
 8  0 0 1 0 0  5.3236D-4  0.05  5.3236D-4  0.0  0.026  0.026  0.0
 9  0 0 0 0 0  5.3236D-4  0.05  5.3236D-4  0.0  0.026  0.026  0.0
20  0 0 0 0 0  5.3236D-4  0.05  5.3236D-4  0.0  0.026  0.026  0.0
* I, VOID,   PRES,  ENTH-G, ENTH-L, VEL-G, VEL-L, ENTH-M, QUAL
  1   0.5  1.7029D6  0.0      0.0      0.0    0.0     0.0    0.0
```

```
 20   0.5  1.7029D6  0.0       0.0       0.0     0.0       0.0     0.0
*************************************************************************
* MDLNAM, IMTYP, METV, METT
BOUNDARY-L  -2    2     2
* IBNDY, ITB(K),K=1,8
    1       8*0
*  IDB   , ICUTS, ICUTE
    0        0     0
*  ICJO , IHCON, IADMP, IREC , IECFG, IFLOW
    1        0     0     0       0      0
* I,IEC,IFM,IVL,IPM,IHTM,
*               AREA0 ,  DELX,   AREA1,   DELEV, DHF,   DHH,  ROGH
 1  0 0 0 0 0  5.3236D-4  0.05  5.3236D-4  0.0  0.026  0.026  0.0
* I, VOID,   PRES,  ENTH-G, ENTH-L, VEL-G, VEL-L, ENTH-M, QUAL
  1  0.5  1.7030D6    0.0       0.0      0.0     0.0       0.0     0.0
*************************************************************************
* MDLNAM, IMTYP, METV, METT
BOUNDARY-R  -1    2     2
* IBNDY, ITB(K),K=1,8
    1       8*0
*  IDB   , ICUTS, ICUTE
    0        0     0
*  ICJO , IHCON, IADMP, IREC , IECFG, IFLOW
    1        0     0     0       0      0
* I,IEC,IFM,IVL,IPM,IHTM,
*               AREA0 ,  DELX,   AREA1,   DELEV, DHF,   DHH,  ROGH
 1  0 0 0 0 0  5.3236D-4  0.05  5.3236D-4  0.0  0.026  0.026  0.0
* I, VOID,   PRES,  ENTH-G, ENTH-L, VEL-G, VEL-L, ENTH-M, QUAL
  1  0.5  1.7029D6    0.0       0.0      0.0     0.0       0.0     0.0
*************************************************************************
*   NETWORK DEFINITION DATA
*************************************************************************
* MDLNAM, JUNC1, JUNC2
PIPE        1      2
BOUNDARY-L  1
BOUNDARY-R  2
```

A3.3 PUMP CONTROLLED FLOW

```
 SAMPLE-3    PUMP   CONTROLLED   FLOW
**********************************************************************
*
*    SAMPLE PROBLEM 3  -  PUMP CONTROLLED FLOW
*
*        LOOP WITH A PUMP  =  LOOP : 15  M  LONG
*                                     1  M  DIA.
*
*        2 VERTICAL ( 5 M ) AND 2 HORIZONTAL ( 2.5 M ) PIPES
*
*        ONE VERTICAL PIPE HAS CONTRACTION
*                  ( PRESSURE DROP = PUMP HEAD )
*
*        PUMP CONDITION  :  0.0  -  7.0  SEC  ON
*                           7.0  -  7.1  SEC  LINEARLY DECREASE
*                           7.1  - 14.0  SEC  OFF
*                          14.0  - 14.1  SEC  LINEARLY INCREASE
*                          14.1  - 35.0  SEC  ON
*
**********************************************************************
*    SYSTEM CONTROL DATA
**********************************************************************
* IRST, ISTDY
    0     0
* NONCMP
    0
* NUC,  MOMEN,  IEOS
    1     1       0
* NCOMP, MXCNCO, IDV, NHEAT, MXHEAT, NUMPMP, NUMSG,IDF,MAXTB,MATNUM
    4      3       0     0       0       1       0      0     0      0
* MAXITR, MAXIMP,  EPS,  EPSC, EPCR
   40       0      0.1   0.1   1.0
* IDBS
   0
```

```
* THET
  0.5
* GRAV
  0.0
* DELTI, DELT, ENDTIM, NTIM
   0.01  0.01   35.0    0
* MPRT, NTPRT, MPLT, NTPLT,  MRST, NTRST
  200     0     5      0    10000    0
**************************************************************************
*   PUMP DEFINITION DATA
**************************************************************************
* NPMPD, NPCHRC, NMOTRC, NPSTP, NPSPED, NINERT
    1      1       1       1      1       1
* IPUMP
    1
* IPC, ITPUMP, IRP, IPM, IMT, IPSPD,INERT, ISTOP
   1     1       1    1     1     0     0      0
* POMGAR, PSRAT, PFLOWR, PHEADR, PTORKR, PINRTA,   VRHOI, TORKMR
   124.1   1.0   16.7486   97.54   4410.4   264.6244   747.5   0.0
* TORKMR(1), (2), (3), (4)
    0.0      0.0  0.0  0.0
* NTMO
   2
* PTMO(1),  (2),    (3),   (4)
   0.0      1.0    1000.0  1.0
* NOIN
   2
* CAVCON, FPUMP, SPUMP
   10.0    0.0    0.0
* ITPSP, NPSP
    1      5
* PSPEED(1), (2),  (3), (4),  (5), (6),  (7), (8),  (9), (10)
    0.0      1.0   2.0  1.0   4.0  1.0   6.0  1.0   40.0  1.0
* RTRIP, VARIN(1), (2), (3), (4)
   10.0    0.0     0.0  0.0  0.0
* KTRIP
    1
```

```
* NTABTR
    6
*TTRIP(1), (2), (3), (4), (5), (6), (7),  (8), (9), (10), (11), (12)
   0.0     1.0  7.0  1.0  7.1 -1.0  14.0 -1.0  14.1  1.0  40.0  1.0
**************************************************************************
*  COMPONENT DEFINITION DATA
**************************************************************************
* MDLNAM, IMTYP, METV, METT
PIPE-T      1     2     2
*   N    ,  NVAL,  NFB
    5       0     0
*  IDB   , ICUTS, ICUTE
    0       0     0
*  ICJO  , IHCON, IADMP, IREC  , IECFG, IFLOW
    1       0     0       0      0      0
* I,IEC,IFM,IVL,IPM,IHTM,
*                  AREA0, DELX, AREA1, DELEV, DHF, DHH, ROGH
 1  0  0  0  0  0  0.785   0.5   0.785   0.0    1.0   1.0  0.0
 5  0  0  0  0  0  0.785   0.5   0.785   0.0    1.0   1.0  0.0
* I, VOID,  PRES, ENTH-G, ENTH-L, VEL-G, VEL-L, ENTH-M, QUAL
  1   0.0  1.0D6   0.0      0.0     0.0     0.0    0.0     0.0
  5   0.0  1.0D6   0.0      0.0     0.0     0.0    0.0     0.0
* MDLNAM, IMTYP, METV, METT
PIPE-R      1     2     2
*   N    ,  NVAL,  NFB
   10       0     0
*  IDB   , ICUTS, ICUTE
    0       0     0
*  ICJO  , IHCON, IADMP, IREC  , IECFG, IFLOW
    1       0     0       0      0      0
* I,IEC,IFM,IVL,IPM,IHTM,
*                  AREA0, DELX, AREA1, DELEV, DHF, DHH, ROGH
 1  0  0  0  0  0  0.785   0.5   0.785   -0.5   1.0  1.0  0.0
10  0  0  0  0  0  0.785   0.5   0.785   -0.5   1.0  1.0  0.0
* I, VOID,  PRES, ENTH-G, ENTH-L, VEL-G, VEL-L, ENTH-M, QUAL
 1    0.0  1.0D6   0.0      0.0     0.0     0.0    0.0     0.0
10    0.0  1.0D6   0.0      0.0     0.0     0.0    0.0     0.0
```

```
* MDLNAM, IMTYP, METV, METT
PIPE-B      1     2     2
*   N    ,  NVAL,  NFB
    5       0      0
*  IDB   , ICUTS, ICUTE
    0       0      0
*  ICJO  , IHCON, IADMP, IREC  , IECFG, IFLOW
    1       0      0      0      0      0
* I,IEC,IFM,IVL,IPM,IHTM,
*                  AREA0, DELX, AREA1, DELEV, DHF, DHH, ROGH
 1  0  0  0  0  0  0.785   0.5   0.785   0.0    1.0   1.0   0.0
 3  0  0  0  1  0  0.785   0.5   0.785   0.0    1.0   1.0   0.0
 4  0  0  0  0  0  0.785   0.5   0.785   0.0    1.0   1.0   0.0
 5  0  0  0  0  0  0.785   0.5   0.785   0.0    1.0   1.0   0.0
* I, VOID,  PRES, ENTH-G, ENTH-L, VEL-G, VEL-L, ENTH-M, QUAL
 1    0.0  1.0D6   0.0      0.0     0.0     0.0     0.0     0.0
 5    0.0  1.0D6   0.0      0.0     0.0     0.0     0.0     0.0
* MDLNAM, IMTYP, METV, METT
PIPE-L      1     2     2
*   N    ,  NVAL,  NFB
   10       0     0
*  IDB   , ICUTS, ICUTE
    0       0     0
*  ICJO  , IHCON, IADMP, IREC  , IECFG, IFLOW
    1       0     0      0       0      0
* I,IEC,IFM,IVL,IPM,IHTM,
*                  AREA0, DELX, AREA1, DELEV, DHF, DHH, ROGH
 1  0  0  0  0  0  0.785   0.5  0.785   0.5    1.0  1.0   0.0
 3  1  0  0  0  0  0.785   0.5  0.785   0.5    1.0  1.0   0.0
 4  0  0  0  0  0  0.04909 0.5  0.04909 0.5    0.25 0.25  0.0
 6  1  0  0  0  0  0.04909 0.5  0.04909 0.5    0.25 0.25  0.0
 7  0  0  0  0  0  0.785   0.5  0.785   0.5    1.0  1.0   0.0
10  0  0  0  0  0  0.785   0.5  0.785   0.5    1.0  1.0   0.0
* I, VOID,  PRES, ENTH-G, ENTH-L, VEL-G, VEL-L, ENTH-M, QUAL
 1    0.0  1.0D6   0.0      0.0     0.0     0.0     0.0     0.0
10    0.0  1.0D6   0.0      0.0     0.0     0.0     0.0     0.0
*************************************************************************
```

```
*   NETWORK DEFINITION DATA
*************************************************************************
* MDLNAM, JUNC1, JUNC2
PIPE-T      1      2
PIPE-R      2      3
PIPE-B      3      4
PIPE-L      4      1
```

A3.4 KELVIN-HELMHOLTZ INSTABILITY

```
 SAMPLE-4 KELVIN-   HELMHOLTZ INSTABILITY
**********************************************************************
*
*   SAMPLE PROBLEM 4  -  KELVIN-HELMHOLTZ INSTABILITY
*
*     HORIZONTAL RECTANGULAR DUCT   =   1.0 M LONG
*                                       1.0 M * 1.0 M CROSS SECTION
*
*     INLET AND OUTLET ARE CONNECTED -- CYCLIC BOUNDARY CONDITION
*
*     INITIAL CONDITION  :  UG    =  50.0   M/S
*                           UL    =   0.001 M/S
*                           VOID  =   0.5
*                                  WITH SINUSOIDAL PERTURBATION
*                                  1.0   M  WAVELENGTH
*                                  0.001    AMPLITUDE
*
*     INVISCID , INCOMPRESSIBLE
*
*          -- THIS PROBLEM IS BASED ON NUMERICAL BENCHMARK TEST
*             NO. 2.5 PRESENTED AT INTERNATIONAL WORKSHOP ON
*             TWO-PHASE FLOW FUNDAMENTALS,
*             SEE 'MULTIPHASE SCIENCE AND TECHNOLOGY VOL.3',
*                  HEMISPHERE CORP. 1987.
*
*             ( BUT SEVERAL VALUES USED ARE SLIGHTLY DIFFERENT
*               FROM THE ORIGINAL ONE )
*
*     DUCT IS SIMULATED BY 2 PIPE COMPONENTS
*               -  DX = 0.005 M  :  EACH HAS 100 MESH CELLS
*               -  DT = 0.001 S
*
*     DYNAMIC PRESSURE FORCE IS CONSIDERED
*
```

```
*     SUBROUTINE CORSET MUST BE MODIFIED FOR INVISCID CALCULATION
*
*     SUBROUTINE SETFJ , SETFJ3 , MAKEJB AND MAIN PROGRAM
*     MUST BE MODIFIED FOR 200 MESH-CELL CALCULATION
*
*************************************************************************
*    SYSTEM CONTROL DATA
*************************************************************************
* IRST, ISTDY
    0     0
* NONCMP
    1
* NUC,  MOMEN,  IEOS
    1     1       2
* RHOG00, CG00,  RHOL00,  CL00,  P00, HGS00, HLS00, CPG00, CPL00
    1.0   1.E-8  1000.0   0.E0   0.0   1.E6   1.E5  1.0E3  4.2E3
* NCOMP, MXCNCO, IDV, NHEAT, MXHEAT, NUMPMP, NUMSG,IDF,MAXTB,MATNUM
    2     2       0     0       0        0        0     0     0      0
* MAXITR, MAXIMP,  EPS,  EPSC, EPCR
   40       0       0.01   0.01  1.0
* IDBS
  0
* THET
  1.0
* GRAV
 10.0
* DELTI,  DELT,  ENDTIM,  NTIM
  0.001   0.001     1.      0
* MPRT, NTPRT, MPLT, NTPLT,  MRST, NTRST
  500     0     100    0       10000    0
*************************************************************************
*    COMPONENT DEFINITION DATA
*************************************************************************
* MDLNAM, IMTYP, METV, METT
PIPE1       1     2     2
*   N   , NVAL,  NFB
   100      0     0
```

```
*  IDB   , ICUTS, ICUTE
     0       0      0
*  ICJO  , IHCON, IADMP, IREC  , IECFG, IFLOW
     1       1      1       1       0      1
* I,IEC,IFM,IVL,IPM,IHTM,
*                AREA0 ,  DELX,    AREA1,  DELEV,  DHF,     DHH,   ROGH
  1 0 0 0 0  0   1.0      0.005      1.0     0.0     1.0       1.0    0.0
100 0 0 0 0  0   1.0      0.005      1.0     0.0     1.0       1.0    0.0
*    I,    VOID,     PRES,EN-G,EN-L,    VEL-G,       VEL-L,     EN-M, QUAL
     1  0.499984D+00 0.0 0.0 0.0  0.500016D+02  0.999969D-03 0.0  0.0
     2  0.499953D+00 0.0 0.0 0.0  0.500047D+02  0.999906D-03 0.0  0.0
     3  0.499922D+00 0.0 0.0 0.0  0.500078D+02  0.999843D-03 0.0  0.0
     4  0.499890D+00 0.0 0.0 0.0  0.500110D+02  0.999781D-03 0.0  0.0
     5  0.499859D+00 0.0 0.0 0.0  0.500141D+02  0.999718D-03 0.0  0.0
     6  0.499828D+00 0.0 0.0 0.0  0.500172D+02  0.999656D-03 0.0  0.0
     7  0.499797D+00 0.0 0.0 0.0  0.500203D+02  0.999595D-03 0.0  0.0
     8  0.499767D+00 0.0 0.0 0.0  0.500234D+02  0.999533D-03 0.0  0.0
     9  0.499736D+00 0.0 0.0 0.0  0.500264D+02  0.999473D-03 0.0  0.0
    10  0.499706D+00 0.0 0.0 0.0  0.500294D+02  0.999412D-03 0.0  0.0
    11  0.499676D+00 0.0 0.0 0.0  0.500324D+02  0.999353D-03 0.0  0.0
    12  0.499647D+00 0.0 0.0 0.0  0.500354D+02  0.999294D-03 0.0  0.0
    13  0.499617D+00 0.0 0.0 0.0  0.500383D+02  0.999235D-03 0.0  0.0
    14  0.499588D+00 0.0 0.0 0.0  0.500412D+02  0.999178D-03 0.0  0.0
    15  0.499560D+00 0.0 0.0 0.0  0.500440D+02  0.999121D-03 0.0  0.0
    16  0.499532D+00 0.0 0.0 0.0  0.500468D+02  0.999065D-03 0.0  0.0
    17  0.499505D+00 0.0 0.0 0.0  0.500496D+02  0.999010D-03 0.0  0.0
    18  0.499478D+00 0.0 0.0 0.0  0.500523D+02  0.998956D-03 0.0  0.0
    19  0.499451D+00 0.0 0.0 0.0  0.500550D+02  0.998903D-03 0.0  0.0
    20  0.499425D+00 0.0 0.0 0.0  0.500576D+02  0.998851D-03 0.0  0.0
    21  0.499400D+00 0.0 0.0 0.0  0.500601D+02  0.998801D-03 0.0  0.0
    22  0.499375D+00 0.0 0.0 0.0  0.500626D+02  0.998751D-03 0.0  0.0
    23  0.499351D+00 0.0 0.0 0.0  0.500650D+02  0.998703D-03 0.0  0.0
    24  0.499327D+00 0.0 0.0 0.0  0.500674D+02  0.998656D-03 0.0  0.0
    25  0.499304D+00 0.0 0.0 0.0  0.500697D+02  0.998610D-03 0.0  0.0
    26  0.499282D+00 0.0 0.0 0.0  0.500719D+02  0.998566D-03 0.0  0.0
    27  0.499260D+00 0.0 0.0 0.0  0.500741D+02  0.998523D-03 0.0  0.0
    28  0.499240D+00 0.0 0.0 0.0  0.500762D+02  0.998481D-03 0.0  0.0
```

```
29 0.499220D+00 0.0 0.0 0.0 0.500782D+02 0.998442D-03 0.0 0.0
30 0.499200D+00 0.0 0.0 0.0 0.500801D+02 0.998403D-03 0.0 0.0
31 0.499182D+00 0.0 0.0 0.0 0.500819D+02 0.998366D-03 0.0 0.0
32 0.499164D+00 0.0 0.0 0.0 0.500837D+02 0.998331D-03 0.0 0.0
33 0.499147D+00 0.0 0.0 0.0 0.500854D+02 0.998298D-03 0.0 0.0
34 0.499131D+00 0.0 0.0 0.0 0.500870D+02 0.998266D-03 0.0 0.0
35 0.499116D+00 0.0 0.0 0.0 0.500885D+02 0.998236D-03 0.0 0.0
36 0.499102D+00 0.0 0.0 0.0 0.500900D+02 0.998207D-03 0.0 0.0
37 0.499089D+00 0.0 0.0 0.0 0.500913D+02 0.998181D-03 0.0 0.0
38 0.499076D+00 0.0 0.0 0.0 0.500926D+02 0.998156D-03 0.0 0.0
39 0.499065D+00 0.0 0.0 0.0 0.500937D+02 0.998133D-03 0.0 0.0
40 0.499054D+00 0.0 0.0 0.0 0.500948D+02 0.998111D-03 0.0 0.0
41 0.499044D+00 0.0 0.0 0.0 0.500958D+02 0.998092D-03 0.0 0.0
42 0.499035D+00 0.0 0.0 0.0 0.500966D+02 0.998075D-03 0.0 0.0
43 0.499028D+00 0.0 0.0 0.0 0.500974D+02 0.998059D-03 0.0 0.0
44 0.499021D+00 0.0 0.0 0.0 0.500981D+02 0.998045D-03 0.0 0.0
45 0.499015D+00 0.0 0.0 0.0 0.500987D+02 0.998034D-03 0.0 0.0
46 0.499010D+00 0.0 0.0 0.0 0.500992D+02 0.998024D-03 0.0 0.0
47 0.499006D+00 0.0 0.0 0.0 0.500996D+02 0.998016D-03 0.0 0.0
48 0.499003D+00 0.0 0.0 0.0 0.500999D+02 0.998010D-03 0.0 0.0
49 0.499001D+00 0.0 0.0 0.0 0.501001D+02 0.998006D-03 0.0 0.0
50 0.499000D+00 0.0 0.0 0.0 0.501002D+02 0.998004D-03 0.0 0.0
51 0.499000D+00 0.0 0.0 0.0 0.501002D+02 0.998004D-03 0.0 0.0
52 0.499001D+00 0.0 0.0 0.0 0.501001D+02 0.998006D-03 0.0 0.0
53 0.499003D+00 0.0 0.0 0.0 0.500999D+02 0.998010D-03 0.0 0.0
54 0.499006D+00 0.0 0.0 0.0 0.500996D+02 0.998016D-03 0.0 0.0
55 0.499010D+00 0.0 0.0 0.0 0.500992D+02 0.998024D-03 0.0 0.0
56 0.499015D+00 0.0 0.0 0.0 0.500987D+02 0.998034D-03 0.0 0.0
57 0.499021D+00 0.0 0.0 0.0 0.500981D+02 0.998045D-03 0.0 0.0
58 0.499028D+00 0.0 0.0 0.0 0.500974D+02 0.998059D-03 0.0 0.0
59 0.499035D+00 0.0 0.0 0.0 0.500966D+02 0.998075D-03 0.0 0.0
60 0.499044D+00 0.0 0.0 0.0 0.500958D+02 0.998092D-03 0.0 0.0
61 0.499054D+00 0.0 0.0 0.0 0.500948D+02 0.998111D-03 0.0 0.0
62 0.499065D+00 0.0 0.0 0.0 0.500937D+02 0.998133D-03 0.0 0.0
63 0.499076D+00 0.0 0.0 0.0 0.500926D+02 0.998156D-03 0.0 0.0
64 0.499089D+00 0.0 0.0 0.0 0.500913D+02 0.998181D-03 0.0 0.0
65 0.499102D+00 0.0 0.0 0.0 0.500900D+02 0.998207D-03 0.0 0.0
```

```
  66  0.499116D+00 0.0 0.0 0.0  0.500885D+02  0.998236D-03 0.0  0.0
  67  0.499131D+00 0.0 0.0 0.0  0.500870D+02  0.998266D-03 0.0  0.0
  68  0.499147D+00 0.0 0.0 0.0  0.500854D+02  0.998298D-03 0.0  0.0
  69  0.499164D+00 0.0 0.0 0.0  0.500837D+02  0.998331D-03 0.0  0.0
  70  0.499182D+00 0.0 0.0 0.0  0.500819D+02  0.998366D-03 0.0  0.0
  71  0.499200D+00 0.0 0.0 0.0  0.500801D+02  0.998403D-03 0.0  0.0
  72  0.499220D+00 0.0 0.0 0.0  0.500782D+02  0.998442D-03 0.0  0.0
  73  0.499240D+00 0.0 0.0 0.0  0.500762D+02  0.998481D-03 0.0  0.0
  74  0.499260D+00 0.0 0.0 0.0  0.500741D+02  0.998523D-03 0.0  0.0
  75  0.499282D+00 0.0 0.0 0.0  0.500719D+02  0.998566D-03 0.0  0.0
  76  0.499304D+00 0.0 0.0 0.0  0.500697D+02  0.998610D-03 0.0  0.0
  77  0.499327D+00 0.0 0.0 0.0  0.500674D+02  0.998656D-03 0.0  0.0
  78  0.499351D+00 0.0 0.0 0.0  0.500650D+02  0.998703D-03 0.0  0.0
  79  0.499375D+00 0.0 0.0 0.0  0.500626D+02  0.998751D-03 0.0  0.0
  80  0.499400D+00 0.0 0.0 0.0  0.500601D+02  0.998801D-03 0.0  0.0
  81  0.499425D+00 0.0 0.0 0.0  0.500576D+02  0.998851D-03 0.0  0.0
  82  0.499451D+00 0.0 0.0 0.0  0.500550D+02  0.998903D-03 0.0  0.0
  83  0.499478D+00 0.0 0.0 0.0  0.500523D+02  0.998956D-03 0.0  0.0
  84  0.499505D+00 0.0 0.0 0.0  0.500496D+02  0.999010D-03 0.0  0.0
  85  0.499532D+00 0.0 0.0 0.0  0.500468D+02  0.999065D-03 0.0  0.0
  86  0.499560D+00 0.0 0.0 0.0  0.500440D+02  0.999121D-03 0.0  0.0
  87  0.499588D+00 0.0 0.0 0.0  0.500412D+02  0.999178D-03 0.0  0.0
  88  0.499617D+00 0.0 0.0 0.0  0.500383D+02  0.999235D-03 0.0  0.0
  89  0.499647D+00 0.0 0.0 0.0  0.500354D+02  0.999294D-03 0.0  0.0
  90  0.499676D+00 0.0 0.0 0.0  0.500324D+02  0.999353D-03 0.0  0.0
  91  0.499706D+00 0.0 0.0 0.0  0.500294D+02  0.999412D-03 0.0  0.0
  92  0.499736D+00 0.0 0.0 0.0  0.500264D+02  0.999473D-03 0.0  0.0
  93  0.499767D+00 0.0 0.0 0.0  0.500234D+02  0.999533D-03 0.0  0.0
  94  0.499797D+00 0.0 0.0 0.0  0.500203D+02  0.999595D-03 0.0  0.0
  95  0.499828D+00 0.0 0.0 0.0  0.500172D+02  0.999656D-03 0.0  0.0
  96  0.499859D+00 0.0 0.0 0.0  0.500141D+02  0.999718D-03 0.0  0.0
  97  0.499890D+00 0.0 0.0 0.0  0.500110D+02  0.999781D-03 0.0  0.0
  98  0.499922D+00 0.0 0.0 0.0  0.500078D+02  0.999843D-03 0.0  0.0
  99  0.499953D+00 0.0 0.0 0.0  0.500047D+02  0.999906D-03 0.0  0.0
 100  0.499984D+00 0.0 0.0 0.0  0.500016D+02  0.999969D-03 0.0  0.0
* MDLNAM, IMTYP, METV, METT
PIPE2       1      2      2
```

```
*   N    ,  NVAL,  NFB
   100       0       0
*  IDB   , ICUTS, ICUTE
     0       0       0
*  ICJO , IHCON, IADMP, IREC , IECFG, IFLOW
     1       1       1       1       0       1
* I,IEC,IFM,IVL,IPM,IHTM,
*                AREA0 ,  DELX,    AREA1,  DELEV,  DHF,      DHH,   ROGH
  1 0 0 0 0  0   1.0      0.005      1.0      0.0      1.0       1.0     0.0
100 0 0 0 0  0   1.0      0.005      1.0      0.0      1.0       1.0     0.0
*   I,    VOID,     PRES,EN-G,EN-L,    VEL-G,        VEL-L,     EN-M, QUAL
    1  0.500016D+00 0.0 0.0 0.0  0.499984D+02  0.100003D-02 0.0  0.0
    2  0.500047D+00 0.0 0.0 0.0  0.499953D+02  0.100009D-02 0.0  0.0
    3  0.500078D+00 0.0 0.0 0.0  0.499922D+02  0.100016D-02 0.0  0.0
    4  0.500110D+00 0.0 0.0 0.0  0.499890D+02  0.100022D-02 0.0  0.0
    5  0.500141D+00 0.0 0.0 0.0  0.499859D+02  0.100028D-02 0.0  0.0
    6  0.500172D+00 0.0 0.0 0.0  0.499828D+02  0.100034D-02 0.0  0.0
    7  0.500203D+00 0.0 0.0 0.0  0.499797D+02  0.100041D-02 0.0  0.0
    8  0.500233D+00 0.0 0.0 0.0  0.499767D+02  0.100047D-02 0.0  0.0
    9  0.500264D+00 0.0 0.0 0.0  0.499736D+02  0.100053D-02 0.0  0.0
   10  0.500294D+00 0.0 0.0 0.0  0.499706D+02  0.100059D-02 0.0  0.0
   11  0.500324D+00 0.0 0.0 0.0  0.499676D+02  0.100065D-02 0.0  0.0
   12  0.500353D+00 0.0 0.0 0.0  0.499647D+02  0.100071D-02 0.0  0.0
   13  0.500383D+00 0.0 0.0 0.0  0.499618D+02  0.100077D-02 0.0  0.0
   14  0.500412D+00 0.0 0.0 0.0  0.499589D+02  0.100082D-02 0.0  0.0
   15  0.500440D+00 0.0 0.0 0.0  0.499560D+02  0.100088D-02 0.0  0.0
   16  0.500468D+00 0.0 0.0 0.0  0.499533D+02  0.100094D-02 0.0  0.0
   17  0.500495D+00 0.0 0.0 0.0  0.499505D+02  0.100099D-02 0.0  0.0
   18  0.500522D+00 0.0 0.0 0.0  0.499478D+02  0.100105D-02 0.0  0.0
   19  0.500549D+00 0.0 0.0 0.0  0.499452D+02  0.100110D-02 0.0  0.0
   20  0.500575D+00 0.0 0.0 0.0  0.499426D+02  0.100115D-02 0.0  0.0
   21  0.500600D+00 0.0 0.0 0.0  0.499400D+02  0.100120D-02 0.0  0.0
   22  0.500625D+00 0.0 0.0 0.0  0.499376D+02  0.100125D-02 0.0  0.0
   23  0.500649D+00 0.0 0.0 0.0  0.499351D+02  0.100130D-02 0.0  0.0
   24  0.500673D+00 0.0 0.0 0.0  0.499328D+02  0.100135D-02 0.0  0.0
   25  0.500696D+00 0.0 0.0 0.0  0.499305D+02  0.100139D-02 0.0  0.0
   26  0.500718D+00 0.0 0.0 0.0  0.499283D+02  0.100144D-02 0.0  0.0
```

27	0.500740D+00	0.0	0.0	0.0	0.499261D+02	0.100148D-02	0.0	0.0
28	0.500760D+00	0.0	0.0	0.0	0.499241D+02	0.100152D-02	0.0	0.0
29	0.500780D+00	0.0	0.0	0.0	0.499221D+02	0.100156D-02	0.0	0.0
30	0.500800D+00	0.0	0.0	0.0	0.499202D+02	0.100160D-02	0.0	0.0
31	0.500818D+00	0.0	0.0	0.0	0.499183D+02	0.100164D-02	0.0	0.0
32	0.500836D+00	0.0	0.0	0.0	0.499166D+02	0.100167D-02	0.0	0.0
33	0.500853D+00	0.0	0.0	0.0	0.499149D+02	0.100171D-02	0.0	0.0
34	0.500869D+00	0.0	0.0	0.0	0.499133D+02	0.100174D-02	0.0	0.0
35	0.500884D+00	0.0	0.0	0.0	0.499118D+02	0.100177D-02	0.0	0.0
36	0.500898D+00	0.0	0.0	0.0	0.499104D+02	0.100180D-02	0.0	0.0
37	0.500911D+00	0.0	0.0	0.0	0.499090D+02	0.100183D-02	0.0	0.0
38	0.500924D+00	0.0	0.0	0.0	0.499078D+02	0.100185D-02	0.0	0.0
39	0.500935D+00	0.0	0.0	0.0	0.499066D+02	0.100187D-02	0.0	0.0
40	0.500946D+00	0.0	0.0	0.0	0.499056D+02	0.100190D-02	0.0	0.0
41	0.500956D+00	0.0	0.0	0.0	0.499046D+02	0.100192D-02	0.0	0.0
42	0.500965D+00	0.0	0.0	0.0	0.499037D+02	0.100193D-02	0.0	0.0
43	0.500972D+00	0.0	0.0	0.0	0.499030D+02	0.100195D-02	0.0	0.0
44	0.500979D+00	0.0	0.0	0.0	0.499023D+02	0.100196D-02	0.0	0.0
45	0.500985D+00	0.0	0.0	0.0	0.499017D+02	0.100197D-02	0.0	0.0
46	0.500990D+00	0.0	0.0	0.0	0.499012D+02	0.100198D-02	0.0	0.0
47	0.500994D+00	0.0	0.0	0.0	0.499008D+02	0.100199D-02	0.0	0.0
48	0.500997D+00	0.0	0.0	0.0	0.499005D+02	0.100200D-02	0.0	0.0
49	0.500999D+00	0.0	0.0	0.0	0.499003D+02	0.100200D-02	0.0	0.0
50	0.501000D+00	0.0	0.0	0.0	0.499002D+02	0.100200D-02	0.0	0.0
51	0.501000D+00	0.0	0.0	0.0	0.499002D+02	0.100200D-02	0.0	0.0
52	0.500999D+00	0.0	0.0	0.0	0.499003D+02	0.100200D-02	0.0	0.0
53	0.500997D+00	0.0	0.0	0.0	0.499005D+02	0.100200D-02	0.0	0.0
54	0.500994D+00	0.0	0.0	0.0	0.499008D+02	0.100199D-02	0.0	0.0
55	0.500990D+00	0.0	0.0	0.0	0.499012D+02	0.100198D-02	0.0	0.0
56	0.500985D+00	0.0	0.0	0.0	0.499017D+02	0.100197D-02	0.0	0.0
57	0.500979D+00	0.0	0.0	0.0	0.499023D+02	0.100196D-02	0.0	0.0
58	0.500972D+00	0.0	0.0	0.0	0.499030D+02	0.100195D-02	0.0	0.0
59	0.500965D+00	0.0	0.0	0.0	0.499037D+02	0.100193D-02	0.0	0.0
60	0.500956D+00	0.0	0.0	0.0	0.499046D+02	0.100192D-02	0.0	0.0
61	0.500946D+00	0.0	0.0	0.0	0.499056D+02	0.100190D-02	0.0	0.0
62	0.500935D+00	0.0	0.0	0.0	0.499066D+02	0.100187D-02	0.0	0.0
63	0.500924D+00	0.0	0.0	0.0	0.499078D+02	0.100185D-02	0.0	0.0

```
 64  0.500911D+00 0.0 0.0 0.0  0.499090D+02  0.100183D-02 0.0  0.0
 65  0.500898D+00 0.0 0.0 0.0  0.499104D+02  0.100180D-02 0.0  0.0
 66  0.500884D+00 0.0 0.0 0.0  0.499118D+02  0.100177D-02 0.0  0.0
 67  0.500869D+00 0.0 0.0 0.0  0.499133D+02  0.100174D-02 0.0  0.0
 68  0.500853D+00 0.0 0.0 0.0  0.499149D+02  0.100171D-02 0.0  0.0
 69  0.500836D+00 0.0 0.0 0.0  0.499166D+02  0.100167D-02 0.0  0.0
 70  0.500818D+00 0.0 0.0 0.0  0.499183D+02  0.100164D-02 0.0  0.0
 71  0.500800D+00 0.0 0.0 0.0  0.499202D+02  0.100160D-02 0.0  0.0
 72  0.500780D+00 0.0 0.0 0.0  0.499221D+02  0.100156D-02 0.0  0.0
 73  0.500760D+00 0.0 0.0 0.0  0.499241D+02  0.100152D-02 0.0  0.0
 74  0.500740D+00 0.0 0.0 0.0  0.499261D+02  0.100148D-02 0.0  0.0
 75  0.500718D+00 0.0 0.0 0.0  0.499283D+02  0.100144D-02 0.0  0.0
 76  0.500696D+00 0.0 0.0 0.0  0.499305D+02  0.100139D-02 0.0  0.0
 77  0.500673D+00 0.0 0.0 0.0  0.499328D+02  0.100135D-02 0.0  0.0
 78  0.500649D+00 0.0 0.0 0.0  0.499351D+02  0.100130D-02 0.0  0.0
 79  0.500625D+00 0.0 0.0 0.0  0.499376D+02  0.100125D-02 0.0  0.0
 80  0.500600D+00 0.0 0.0 0.0  0.499400D+02  0.100120D-02 0.0  0.0
 81  0.500575D+00 0.0 0.0 0.0  0.499426D+02  0.100115D-02 0.0  0.0
 82  0.500549D+00 0.0 0.0 0.0  0.499452D+02  0.100110D-02 0.0  0.0
 83  0.500522D+00 0.0 0.0 0.0  0.499478D+02  0.100105D-02 0.0  0.0
 84  0.500495D+00 0.0 0.0 0.0  0.499505D+02  0.100099D-02 0.0  0.0
 85  0.500468D+00 0.0 0.0 0.0  0.499533D+02  0.100094D-02 0.0  0.0
 86  0.500440D+00 0.0 0.0 0.0  0.499560D+02  0.100088D-02 0.0  0.0
 87  0.500412D+00 0.0 0.0 0.0  0.499589D+02  0.100082D-02 0.0  0.0
 88  0.500383D+00 0.0 0.0 0.0  0.499618D+02  0.100077D-02 0.0  0.0
 89  0.500353D+00 0.0 0.0 0.0  0.499647D+02  0.100071D-02 0.0  0.0
 90  0.500324D+00 0.0 0.0 0.0  0.499676D+02  0.100065D-02 0.0  0.0
 91  0.500294D+00 0.0 0.0 0.0  0.499706D+02  0.100059D-02 0.0  0.0
 92  0.500264D+00 0.0 0.0 0.0  0.499736D+02  0.100053D-02 0.0  0.0
 93  0.500233D+00 0.0 0.0 0.0  0.499767D+02  0.100047D-02 0.0  0.0
 94  0.500203D+00 0.0 0.0 0.0  0.499797D+02  0.100041D-02 0.0  0.0
 95  0.500172D+00 0.0 0.0 0.0  0.499828D+02  0.100034D-02 0.0  0.0
 96  0.500141D+00 0.0 0.0 0.0  0.499859D+02  0.100028D-02 0.0  0.0
 97  0.500110D+00 0.0 0.0 0.0  0.499890D+02  0.100022D-02 0.0  0.0
 98  0.500078D+00 0.0 0.0 0.0  0.499922D+02  0.100016D-02 0.0  0.0
 99  0.500047D+00 0.0 0.0 0.0  0.499953D+02  0.100009D-02 0.0  0.0
100  0.500016D+00 0.0 0.0 0.0  0.499984D+02  0.100003D-02 0.0  0.0
```

```
**************************************************************************
*    NETWORK DEFINITION DATA
**************************************************************************
* MDLNAM, JUNC1, JUNC2
PIPE1       1      2
PIPE2       2      1
```