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FLOW NETWORK CALCULATION CODE FOR HEAT,
MASS AND MOMENTUM TRANSFER
IN A MULTICOMPONENT GAS MIXTURE FLOW
WITH GRAPHITE CHEMICAL REACTIONS

November 1992

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Flow Network Calculation Code for Heat, Mass and Momentum Transfer
in A Multicomponent Gas Mixture Flow
with Graphite Chemical Reactions

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A flow network calculation code was developed to predict the thermo-hydraulic characteristics during a primary-cooling-pipe rupture accident in a high temperature gas cooled reactor such as the High Temperature Engineering Test Reactor (HTTR). The present calculation code deals with a natural convection of a multicomponent gas mixture (helium, nitrogen, oxygen, carbon monoxide and carbon dioxide) with graphite chemical reactions. One dimensional conservation equations of mass, momentum and energy for the gas mixture and equations of mass for gas species were solved by using a flow network model in the code. The calculation was performed for a flow channel system of an experimental apparatus simply simulating the cooling channels of the HTTR. The whole configuration of the flow channel is a reverse U shape, and the one vertical side of the reverse U shape consists of three parallel channels. Two of these channels are graphite ones. The entering flow rate, flow rates distributed to the parallel channels, generation volume of carbon monoxide and corrosion volume of the graphite could be calculated by the code.

Keywords: High Temperature Gas Cooled Reactor, Numerical Analysis, Flow Network Model, Reverse-U Shaped Flow Channel, Gas Mixture, Graphite Chemical Reactions, Pipe Rupture Accident

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黒鉛の化学反応を伴う場合の
多成分混合気体流れの熱・物質・流動管路網計算コード

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高温工学試験研究炉（HTTR）のような高温ガス炉における一次冷却系配管破断事故時の熱流動特性を予測するため、管路網計算コードを開発した。本計算コードでは、黒鉛の化学反応を伴う多成分混合気体（窒素、酸素、ヘリウム、一酸化炭素、二酸化炭素）の自然対流を扱う。一次元の混合気体の質量、運動量、エネルギー保存式と各成分気体の質量保存式を管路網モデルを用いて解いた。本計算では、HTTRの冷却流路を簡単に模擬した実験装置の試験流路体系を対象とした。この試験流路は、全体には逆U字型をしており、この逆U字の一方の垂直流路部は、3並列流路となっている。3並列流路のうち2流路は黒鉛流路である。この数値解析コードによって、空気侵入流量、冷却流路配分流量、一酸化炭素の発生量、黒鉛腐食量を計算することができた。

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1. Introduction

Japan Atomic Energy Research Institute (JAERI) is building the High Temperature Engineering Test Reactor⁽¹⁾ (HTTR) at Oarai Research Establishment. The HTTR is a high temperature gas cooled reactor with thermal output of 30MW and outlet coolant temperature of 950°C, employing the pin-in-block type fuel, and has the capability to demonstrate nuclear process heat utilization using an intermediate heat exchanger.

A primary pipe rupture accident is one of the most critical (important) design-base accident of the HTTR. The accident starts from a gullotine break of the primary coaxial double pipe in the primary cooling system as shown in Fig. 1. When the primary pipe rupture takes place, a gas mixture containing oxygen enters the inside of the reactor vessel (RV) through the breach of the inner pipe from the reactor containment vessel (RCV), and the oxygen reacts with high temperature graphite. The graphite chemical reactions may cause corrosion of graphite, temperature rise and generation of inflammable gas; carbon monoxide. It has already been assured by extensive safety analysis and evaluation under the conservative assumption that no serious damages are caused to the reactor core and the RCV during and after the accident⁽²⁾.

On the other hand, it is of great importance to know the real phenomena of the accident in order to understand the safety characteristics of the HTTR and in order to carry out a safety design with higher accuracy. In the analysis of the accident of the HTTR, the TAC-NC computer code was used to analyze the thermohydraulic characteristics and the GRACE computer code was used to analyze the graphite oxidation⁽³⁾. Thus, the thermohydraulics and the graphite corrosion were separately calculated by using the TAC-NC code and GRACE code, respectively. The assumptions were considerably conservative in the analysis. For example, it was assumed that only the reaction; $C + \frac{1}{2} O_2 \rightarrow CO$ was taken into account as the chemical reaction of the graphite oxidation and no combustion of carbon monoxide was considered.

Accordingly, we developed a flow network calculation code to deal with heat, mass and momentum transfer with homogeneous (carbon monoxide combustion) and heterogeneous (graphite oxidation and Boudouard reaction) chemical reactions. The entering flow rate of the gas mixture, the corrosion volume of graphite and the generation volume of carbon monoxide were calculated in the code.

2. Nomenclature

- A : Coefficient of Eq.(3.15)
 B : Coefficient of Eq.(3.15)
 c_p : Specific heat at constant pressure
 Da : Damköhler number
 d_k : Tube diameter of k th branch
 d_0 : Tube diameter of reference branch
 f : Friction factor
 f : Generation ratio of carbon monoxide mole fraction to carbon dioxide one
 G : Flow rate ($=\rho U$)
 g : Gravitational acceleration ($=9.807$)
 k^+ : Chemical reaction rate constant
 M : Molecular weight
 m : Solid/gas chemical reaction rate ($=$ mass flux)
 Nu : Nusselt number
 P : Dimensionless pressure
 p : Pressure
 Pr : Prandtl number
 Q : Generation heat due to carbon monoxide combustion
 R : Gas/gas chemical reaction rate
 Re : Reynolds number
 R_g : Gas constant ($=8.314$)
 Sc : Schmidt number
 Sh : Sherwood number
 T : Temperature
 T_K : Absolute temperature
 t : Time
 U : Dimensionless velocity
 u : Velocity
 ΔV : Volume of node
 X : Dimensionless axial distance
 x : Axial distance
 Δx : Length of branch

Suffix

- b : Bulk
- C : Graphite
- i : Gas species
- j : The number of the node
- k : The number of the branch
- n : The number of the time step
- w : Wall
- 0 : Reference (Inlet or Atmosphere)

Greeks

- α : Heat transfer coefficient
- β : Mass transfer coefficient
- ε_k : $=d_k/d_0$
- η : Pressure loss coefficient
- θ : Dimensionless temperature
- θ : Angle of branch from gravitational direction
- λ : Thermal conductivity
- ρ : Density
- τ : Dimensionless time
- ν : Kinematic viscosity
- ω : Mass fraction

Here, all units used are the International System of Units (SI units).

3. Numerical Analysis

3.1 Basic Equation

One-dimensional transient equations of mass, momentum and energy conservation for a gas mixture are as follows:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x} (\rho u) = S_k m_c, \quad (3.1)$$

$$\rho \frac{\partial u}{\partial t} + \rho u \frac{\partial u}{\partial x} = - \frac{\partial p}{\partial x} - \left(\frac{4}{d_k} f + \frac{1}{\Delta x} \sum_l \eta_l \right) \frac{\rho |u|}{2} u + \rho g \cos \theta_k, \quad (3.2)$$

$$\rho \frac{\partial}{\partial t} (c_p T) + u \frac{\partial}{\partial x} (c_p T) = S_k \alpha (T_w - T) + Q, \quad (3.3)$$

Suffix

- b : Bulk
- C : Graphite
- i : Gas species
- j : The number of the node
- k : The number of the branch
- n : The number of the time step
- w : Wall
- 0 : Reference (Inlet or Atmosphere)

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$$\rho \frac{\partial}{\partial t} (c_p T) + u \frac{\partial}{\partial x} (c_p T) = S_k \alpha (T_w - T) + Q, \quad (3.3)$$

here, k represents the number of the branch.

$$S_k = \frac{\pi d_k}{\frac{\pi}{4} d_k^2} = \frac{4}{d_k} \quad (3.4)$$

Ideal gas is assumed. The density of the gas mixture is given as:

$$\rho = \frac{pM}{R_g T_k} \quad (3.5)$$

A one-dimensional transient equation of mass conservation for each gas species is in the following;

$$\rho \frac{\partial \omega_i}{\partial t} + \rho u \frac{\partial \omega_i}{\partial x} = S_k \rho \beta_i (\omega_{wi} - \omega_i) + R_i \quad (3.6)$$

The gas mixture in the accident may consist of five gas species; helium, oxygen, carbon monoxide, carbon dioxide and nitrogen. In the above equations, $i=1, 2, 3, 4$ and 5 show helium, oxygen, carbon monoxide, carbon dioxide and nitrogen, respectively.

We convert above equations to dimensionless ones by the following normalization:

$$\left. \begin{aligned} X &= \frac{x}{d_0}, \\ \epsilon_k &= \frac{d_k}{d_0}, \\ \Delta X &= \frac{\Delta x_k}{d_k}. \end{aligned} \right\} \quad (3.7)$$

$$\left. \begin{aligned} U &= \frac{u}{u_0} \quad (u_0 = \sqrt{\frac{\Delta \rho g d_0}{\rho_0}}, \Delta \rho = \rho_0 - \rho_{min}) \\ G &= \rho^* U, \\ P &= \frac{P'}{\rho_0 u_0^2}, \quad (P' = p - p_0, \frac{\partial p_0}{\partial x} = \rho_0 g \cos \theta_k) \\ \theta &= \frac{T}{T_{max}}, \\ \tau &= \frac{t}{\frac{d_0}{u_0}}. \end{aligned} \right\} \quad (3.8)$$

$$\left. \begin{aligned}
 Da_{wC} &= \frac{4m_C}{\rho_0 u_0 \varepsilon_k} \frac{1}{\varepsilon_k}, & Sh_i &= \frac{\beta_i d_0}{D_{He/i}}, \\
 Da_i &= \frac{d_0 Ri}{\rho_0 u_0}, & Q^* &= \frac{d_0 Q}{\rho_0 u_0 c_{p0} T_{max}}, \\
 Re &= \frac{d_0 u_0}{\nu_0}, & \Delta\rho_k^* &= -\frac{\rho_0 - \rho}{\rho_0 - \rho_{min}} \cos\theta_k, \\
 Pr &= \frac{\rho_0 c_{p0} \nu_0}{\lambda_0}, & \rho^* &= \frac{\rho}{\rho_0}, \\
 Sc_i &= \frac{\nu_0}{D_{He/i}}, & c_p^* &= \frac{c_p}{c_{p0}}, \\
 Nu &= \frac{\alpha d_0}{\lambda_0}, & &
 \end{aligned} \right\} \quad (3.9)$$

The above normalization derives dimensionless equations from Eqs.(3.1)-(3.3), and (3.6);

$$\frac{\partial \rho^*}{\partial \tau} + \frac{\partial}{\partial X} (\rho^* U) = Da_{wC} \quad (3.10)$$

$$\rho^* \frac{\partial U}{\partial \tau} + \rho^* U \frac{\partial U}{\partial X} = -\frac{\partial P}{\partial X} - (4f + \frac{d_k}{\Delta x_k} \sum_l \eta_l) \frac{\rho^* |U|}{2 \varepsilon_k} U + \Delta\rho_k^* \quad (3.11)$$

$$\rho^* \frac{\partial}{\partial \tau} (c_p^* \theta) + \rho^* U \frac{\partial}{\partial X} (c_p^* \theta) = \frac{4}{\varepsilon_k} \frac{Nu}{Re Pr} (\theta_w - \theta) + Q^* \quad (3.12)$$

$$\rho^* \frac{\partial \omega_i}{\partial \tau} + \rho^* U \frac{\partial \omega_i}{\partial X} = \frac{4}{\varepsilon_k} \frac{Sh_i}{Re Sc_i} \rho^* (\omega_{wi} - \omega_i) + Da_i \quad (i = 1 \sim 5) \quad (3.13)$$

3.2 Flow Network Model

We can solve the differential equations of Eqs.(3.10)-(3.13) by using the finite difference method. However, much memory capacity and calculation time are necessary when the calculation is executed for the cooling channel system of the HTTR because of many cooling channels. Therefore a one-dimensional flow network model is applied to the problem. One cooling channel can be expressed by using a branch and the branch is connected to other branches at node in the flow network model. No distributions of variables are considered in the node, that is, the node is assumed as a point without volume. Thus, we can easily describe the complicated cooling channel system with these branches and nodes.

In the branch, we can obtain basic equations of momentum and energy

conservation for the gas mixture and of mass conservation for each gas species by integrating Eqs.(3.11) to (3.13) from the inlet of the branch to the outlet in the X axis direction.

$$G_{X+\Delta X} - G_X = Da_{wC} \Delta X + \{(\rho^*)^n - (\rho^*)^{n+1}\} \frac{\Delta X}{\Delta \tau} \quad (3.14)$$

$$\left. \begin{aligned} P_X - P_{X+\Delta X} &= A_k G_k + B_k \\ A_k &= (4 \Delta X f + \sum_l \eta_l) \frac{|G_k|}{2 \epsilon_k \rho^*} + \frac{\Delta X}{\Delta \tau} \\ B_k &= \left(\frac{G_{X+\Delta X}^2}{\rho_{X+\Delta X}^*} - \frac{G_X^2}{\rho_X^*} \right) + (\Delta \rho^* k - \frac{G_k}{\Delta \tau}) \Delta X \end{aligned} \right\} \quad (3.15)$$

$$\begin{aligned} \{(c_p^* \theta)_{X+\Delta X} - (c_p^* \theta)_X\} G_k & \quad (3.16) \\ &= \left\{ \frac{4 Nu}{\epsilon_k Re Pr} (\theta_w - \bar{\theta}) + Q^* \right\} \Delta X \\ & \quad + \{(c_p^* \theta)^n - (c_p \theta)^{n+1}\} \frac{\rho^* \Delta X}{\Delta \tau} \end{aligned}$$

$$\begin{aligned} \{(\omega_i)_{X+\Delta X} - (\omega_i)_X\} G_k & \quad (3.17) \\ &= \left\{ \frac{4 Sh_i \rho^*}{\epsilon_k Re Sc_i} (\omega_{wi} - \bar{\omega}_i) + Da_i \right\} \Delta X \\ & \quad + \{(\omega_i)^n - (\omega_i)^{n+1}\} \frac{\rho^* \Delta X}{\Delta \tau} \end{aligned}$$

If no chemical reaction takes place in the branch, Damköhler number in Eq.(3.14) is equal to zero. In the node, basic equations of mass and energy conservations for the gas mixture and of mass conservation for each gas species are expressed in the following.

$$\Sigma(d^2 G)_k = \Sigma(Da_{wC} \Delta X d^2)_k, \quad (3.18)$$

$$\Sigma(G c_p^* \theta)_k = 0 \quad (3.19)$$

$$\Sigma(G \omega_i)_k = 0 \quad (3.20)$$

Here, in Eq.(3.18), the gas flow rate entering the node is defined to be positive and the flow rate going out of the node to be negative. The signs of the heat flow rate of $(G c_p^* \theta)$ in Eq.(3.19) and the mass flow

rate of (G_w) in Eq.(3.20) are decided in the similar way as the flow rate. The node temperature and the node mass fraction are used as inlet values of the branch for the outflow from the node and the temperature and mass fraction of the branch outlet are used to calculate the node values.

An experimental apparatus has been manufactured to simulate the natural convection simply during the primary pipe rupture accident in the HTTR. The flow channel of the experimental apparatus is a reverse U shaped circular tube. The one side of the reverse U tube is a hot region and the other is a cold region as shown in Fig. 2. The cold and hot regions simulate the inlet cooling annular channel around the reactor core and the cooling channels in the reactor core, respectively. The hot region of the reverse U tube consists of three parallel vertical channels. One of the three channels is a cold channel and the rest are hot channels. The hot channel is a graphite circular tube placed in an electric furnace which is represented as Test section A or C as shown in Fig. 2. The temperature difference between the three channels simulates the one in the radial direction of the reactor core. Figure 3 shows the flow network used here for modeling the experimental apparatus. No.5 and 11 branches in Fig. 3 are graphite channels. The arrows in Fig. 3 denote the positive direction of the flow rate. The dimensions of the branches in Fig. 3 are shown in Table 3.

3.3 Algebraic Equation

In the present flow network shown in Fig. 3, the right-hand term in Eq.(3.21) is necessary only when the node connects to the No.5 or No.11 branch. The other nodes do not require the right-hand term in Eq.(3.21).

$$\Sigma(d^2G)_k = (Da_{wC} \Delta X d)_{k'} \quad (k' = 5 \text{ or } 11) \quad (3.21)$$

Here, the sign of G_k is defined as plus for the direction of the arrows shown in Fig. 3. For the pressure, in the closed circuit of the flow network model, the following equation is obtained from Eq.(3.15):

$$\Sigma(A_k G_k) = - \Sigma B_k \quad (3.22)$$

In the present calculation three closed circuits are chosen from the flow network in Fig. 3:

- (1) No.1 closed circuit: 2-3-4-5-6-7-13-12-11-10-9-8
- (2) No.2 closed circuit: 8-9-10-11-12-13-19-18-17-16-15-14
- (3) No.3 closed circuit: 1-14-15-16-17-18-19-20-21-22-23-24-25-26-27

(These figures denote the branch numbers in Fig. 3.)

The energy equations of the gas mixture at the branch and the node are written as follows:

$$G_k(c_p^* \theta)_{x+\Delta x} - G_k\{(c_p^* \theta)_{x_i} \delta_k^+ + (c_p^* \theta)_{x_{i+1}} \delta_k^-\} \quad (3.23)$$

$$= \left\{ \frac{4 \text{Nu}}{\varepsilon_k \text{Re Pr}} (\theta_w - \bar{\theta}) + Q^* \right\} \Delta X$$

$$+ \{(c_p^* \theta)^n - (c_p^* \theta)^{n+1}\} \frac{\rho^* \Delta X}{\Delta \tau}$$

$$(c_p^* \theta)_{x_i} \Sigma(G_k \delta_k^+) - \Sigma\{(c_p^* \theta)_{x+\Delta x_k} G_k \delta_k^-\} = 0 \quad (3.24)$$

$$\delta_k^+ = \max\left(\frac{G_k}{|G_k|}, 0\right), \quad \delta_k^- = \max\left(\frac{-G_k}{|G_k|}, 0\right) \quad (3.25)$$

respectively. In Eq.(3.23) the i th or $(i+1)$ th node in the k th branch is selected as the node of inlet side, judging from the flow direction in the k th branch. In the energy equation at the i th node, k ($k = 1, 2, 3, \dots$) branches connect to the i th node as shown in Fig. 4. In Eq. (3.24), $(c_p^* \theta)_{x+\Delta x}$ is the outlet value of the k th branch and $(c_p^* \theta)_{x_i}$ is the node value of the i th node. In Eq.(3.25), $\max(X1, X2)$ denotes the followings;

- if $X1 > X2$, then $\max(X1, X2) = X1$
- if $X1 < X2$, then $\max(X1, X2) = X2$.

The equations of the mass conservation for each gas species at the branch and the node can be expressed in the same manner as the energy equations.

$$G_k(\omega_i)_{x+\Delta x} - G_k\{(\omega_i)_{x_i} \delta_k^+ + (\omega_i)_{x_{i+1}} \delta_k^-\} \quad (3.26)$$

$$= \left\{ \frac{4 \text{Sh}_i \rho^*}{\varepsilon_k \text{Re Sc}_i} (\omega_{wi} - \bar{\omega}_i) + Da_i \right\}$$

$$+ \{(\omega_i)^n - (\omega_i)^{n+1}\} \frac{\rho^* \Delta X}{\Delta \tau}$$

$$(\omega_i)_{x_1} \Sigma(G_k \delta_k^+) - \Sigma\{(\omega_i)_{x+\Delta x_k} G_k \delta_k^-\} = 0 \quad (3.27)$$

In the above equations of Eqs.(3.21) to (3.27), unknown values are in the following:

- (a) Mass flow rate of gas mixture in the k th branch ; G_k
- (b) Outlet temperature of gas mixture in the k th branch ; $T_{0,k}$
- (c) Outlet mass fraction of each gas species in the k th branch ; $\omega_{0,k}$
- (d) Temperature of gas mixture at the i th node ; $T_{N,i}$
- (e) Mass fraction of each gas species at the i th node ; $\omega_{N,i}$

Three simultaneous linear equations for the mass flow rate, temperature and mass fraction are obtained from Eqs.(3.21) to (3.27) by assuming that factors like A_k in Eq.(3.22) are tentatively constant, although those factors are functions of the flow rate, temperature or mass fraction. First, the flow rate is solved by an iteration procedure, then the temperature of the gas mixture and the mass fraction of each gas species are solved. Figure 5 shows the flow chart of the code. The calculation at the certain time step is repeated until the converging conditions are satisfied, then it goes ahead to the next time step.

The present computer program is shown in Appendix.

3.4 Correlations of Heat and Mass Transfers and Pressure Loss

Friction factor, heat transfer and mass transfer coefficients are given by the following equations⁽⁴⁾:

$$f_{x_1-x_2} = \frac{x_2 f_{app}(x_2) - x_1 f_{app}(x_1)}{x_2 - x_1} \quad (3.28)$$

$$\Delta p \equiv \frac{4(x_2 - x_1)}{d} f_{x_1-x_2} \frac{\rho u^2}{2} \quad (3.29)$$

$$f_{app}(x)Re = \frac{3.44}{\sqrt{x^+}} + \frac{1.25/(4x^+) + 16 - 3.44/\sqrt{x^+}}{1 + 2.1 \times 10^{-4}(x^+)^{-2}} \quad (3.30)$$

$$\Delta p_{0-x} \equiv \frac{4x}{d} f_{app}(x) \frac{\rho u^2}{2} \quad (3.31)$$

$$\alpha_{x_1-x_2} = \frac{x_2 \Delta T_{0-x_2} \lambda_{0-x_2} \text{Nu}_{0-x_2} - x_1 \Delta T_{0-x_1} \lambda_{0-x_1} \text{Nu}_{0-x_1}}{d(x_2 - x_1) \Delta T_{x_1-x_2}} \quad (3.32)$$

$$\left. \begin{aligned} \text{Nu}_{0-x} &= 1.615(x^*)^{-\frac{1}{3}} - 0.7, & x^* \leq 0.005 \\ &1.615(x^*)^{-\frac{1}{3}} - 0.2, & 0.005 < x^* < 0.03 \\ &3.657 + 0.0499(x^*)^{-1}, & x \geq 0.03 \end{aligned} \right\} \quad (3.33)$$

$$x^* = \frac{\frac{x}{d}}{\text{Re Pr}} \quad (3.34)$$

$$\Delta T_{x_1-x_2} = \frac{\frac{T_{b_{x_2}} - T_{b_{x_1}}}{T_w - T_{b_{x_1}}}}{\ln \frac{T_w - T_{b_{x_1}}}{T_w - T_{b_{x_2}}}} \quad (3.35)$$

$$\beta_{x_1-x_2} = \frac{x_2 \beta_{0-x_2} \Delta \omega_{0-x_2} - x_1 \beta_{0-x_1} \Delta \omega_{0-x_1}}{(x_2 - x_1) \Delta \omega_{x_1-x_2}} \quad (3.36)$$

$$\left. \begin{aligned} \text{Sh}_{0-x} &= 1.615(x^{**})^{-\frac{1}{3}} - 0.7, & x^{**} \leq 0.005 \\ &1.615(x^{**})^{-\frac{1}{3}} - 0.2, & 0.005 < x^{**} < 0.03 \\ &3.657 + 0.0499(x^*)^{-1}, & x \geq 0.03 \end{aligned} \right\} \quad (3.37)$$

$$x^{**} = \frac{\frac{x}{d}}{\text{Re Sc}_i} \quad (3.38)$$

$$\Delta \omega_{x_1-x_2} = \frac{\frac{\omega_{b_{x_2}} - \omega_{b_{x_1}}}{\omega_w - \omega_{b_{x_1}}}}{\ln \frac{\omega_w - \omega_{b_{x_1}}}{\omega_w - \omega_{b_{x_2}}}} \quad (3.39)$$

$f_{x_1-x_2}$ in Eq.(3.28) is a friction factor for a developing laminar flow through a circular tube. Pressure loss coefficients are shown in Table 1. $\alpha_{x_1-x_2}$ in Eq.(3.32) is a heat transfer coefficient for a thermally developing laminar flow. $\beta_{x_1-x_2}$ in Eq.(3.36) is obtained from Eq.(3.32) on the assumption of analogy between heat and mass transfer. When we solve the algebraic equation, these factor and coefficients are implicitly dealt as constant values. These factor and coefficients are influenced by chemical reactions and are expressed by using dimensionless parameter in the following⁽⁵⁾.

$$f = F1(\text{Re}, X_1/d, X_2/d, \text{Da}, \text{Daw}) \quad (3.40)$$

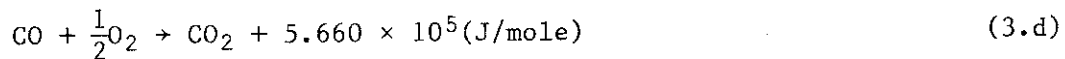
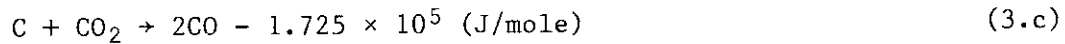
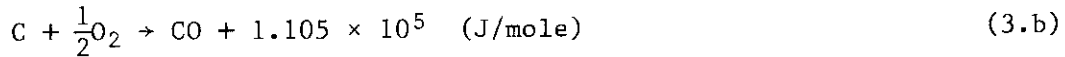
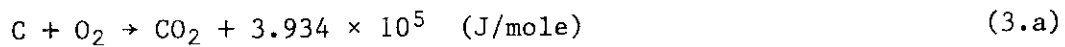
$$\alpha = F2(\text{Re}, \text{Pr}, X_1/d, X_2/d, \text{Da}, \text{Daw}) \quad (3.41)$$

$$\beta_i = F3(\text{Re}, \text{Sc}_i, X_1/d, X_2/d, \text{Da}_i, \text{Daw}_i) \quad (3.42)$$

In the calculation, only the parameters of Re, Pr, Sc_i and $(X_2 - X_1)$ are considered to check the calculation method:

3.5 Rate of Chemical Reaction

In the present numerical analysis, the following chemical reactions are considered:



Here, the positive sign represents an exothermic chemical reaction and the negative one an endothermic chemical reaction. It is said that the total chemical reactions of Eqs.(3.a) and (3.b) are the primary ones. The chemical reaction of Eq.(3.c) is called "Boudouard reaction". These three chemical reactions are solid(graphite)/gas reactions. The gas/gas reaction of Eq.(3.d) is the carbon combustion reaction.

The reaction rates of the solid/gas chemical reactions are expressed as follows⁽⁶⁾:

$$m_{\text{O}_2} = m_{\text{C}}^{(1)} \frac{M_{\text{O}_2}}{M_{\text{C}}} \frac{2 + f}{2 + 2f} \quad (3.43)$$

$$m_{\text{CO}} = -m_{\text{C}}^{(1)} \frac{M_{\text{CO}}}{M_{\text{C}}} \frac{f}{1 + f} - 2m_{\text{C}}^{(2)} \frac{M_{\text{CO}}}{M_{\text{C}}} \quad (3.44)$$

$$m_{\text{CO}_2} = -m_{\text{C}}^{(1)} \frac{M_{\text{CO}_2}}{M_{\text{C}}} \frac{1}{1 + f} + m_{\text{C}}^{(2)} \frac{M_{\text{CO}_2}}{M_{\text{C}}} \quad (3.45)$$

$$m_{\text{C}}^{(1)} = -2560 \exp\left(-\frac{142000}{R_g T_K}\right) \left(\frac{p}{1.013 \times 10^5}\right)^{0.5} \left(\frac{M}{M_{\text{O}_2}} \frac{\omega_{\text{wO}_2}}{0.2095}\right)^{0.75} \quad (3.46)$$

$$m_{\text{C}}^{(2)} = -44.5 \exp\left(-\frac{162714}{R_g T_K}\right) \omega_{\text{wCO}_2} \quad (3.47)$$

$$f = 800 \exp\left(-\frac{6200}{T_K}\right) \quad (3.48)$$

$$Da_{w,i} = \frac{4}{\rho_0 u_0} \frac{d_0}{d_k} m_i \quad (3.49)$$

$m_C^{(1)}$ and $m_C^{(2)}$ are the graphite corrosion rates in the in-pore diffusion control regime. In the present numerical analysis, we deal with the mass transfer control regime and the in-pore diffusion control regime. Thus, we did not give the chemical reaction rates because the chemical reaction control regime lies in the temperature region lower than 400 to 500°C. f of Eq.(3.48) is the generation ratio of carbon monoxide mole fraction to carbon dioxide one.

The following reaction rates in the carbon monoxide combustion reaction are used.

$$R_{CO} = -R^+ \quad (3.50)$$

$$R_{O_2} = -0.5 R^+ \frac{M_{O_2}}{M_{CO}} \quad (3.51)$$

$$R_{CO_2} = R^+ \frac{M_{CO_2}}{M_{CO}} \quad (3.52)$$

$$R^+ = k^+ \rho \left(\frac{\rho}{M_{O_2}}\right)^{0.5} \omega_{CO} \omega_{O_2}^{0.5} \quad (3.53)$$

$$k^+ = 7 \times 10^9 \exp\left(-\frac{199720}{R_g T_K}\right) \quad (3.54)$$

The generation heat due to carbon monoxide combustion is considered in the present code by the equation:

$$Q = 5.660 \times 10^5 \frac{R_{CO_2}}{M_{CO_2}} \quad (3.55)$$

The graphite wall temperature is increased by the graphite/oxygen chemical reactions. The graphite wall temperature after this increase can be used as the input data of the code instead of providing the generation heat of the graphite chemical reactions to the code. Thus, the heat is assumed not to be generated by the graphite/oxygen chemical reactions in the code. The absorption heat due to the graphite/carbon-dioxide chemical reaction was ignored because this chemical reaction occurs scarcely under the present temperature conditions less than 1400°C.

Thermal properties of each gas species and gas mixture in Ref.(7) were used in the present calculation.

3.6 Average Value of Branch

The outlet temperature and outlet mass fraction of the branch would be obtained if the one-dimensional transient basic equation is analytically solved. The basic equation, however, can not be solved because of the non-linearity. Accordingly, the average value of the branch was assumed to be expressed by the inlet and the wall values of the branch as follows:

$$\bar{\theta} = \theta_w + (\theta_x - \theta_w)\{1 - \exp(-C_T)\} \frac{1}{C_T} \quad (3.56)$$

$$C_T = \frac{4 \text{ Nu}}{\varepsilon_k \text{ Re Pr}} \quad (3.57)$$

$$\bar{\omega}_i = \omega_{wi} + (\omega_{xi} - \omega_{wi})\{1 - \exp(-C_\omega)\} \frac{1}{C_\omega} \quad (3.58)$$

$$C_\omega = \frac{4 \text{ Sh}_i}{\varepsilon_k \text{ Re Sc}_i} \quad (3.59)$$

The above inlet and wall values used were obtained at one iterative step before. The inlet value of the branch is equal to the value at the node to which the inlet of the branch connects.

3.7 Initial and Boundary Conditions

When the primary pipe rupture takes place in the HTTR, the helium gas coolant of about 4 MPa spouts out of the RV to the RCV. After the balance of pressure between the RV and the RCV, the gas mixture of air and helium enters the RV from the RCV by molecular diffusion and by a special type of weak natural convection⁽⁸⁾. Then, the natural circulation starts suddenly throughout the reactor after the weak air ingress period continuing for a certain time. We deal with this natural circulation here. Therefore, the flow condition just before the natural circulation should be an initial condition for the calculation in the HTTR. On the other hand, when we carry out the experiment, the test is started by opening the slide valves at the inlet and outlet as shown in Fig. 2. Before the opening, the natural circulation is occurring in only the three parallel channels. The condition of this local natural circu-

lation is the initial condition in the calculation for the experimental apparatus. However, since the objective of the present study is to develop the analytical method, we gave a simple initial condition to the calculation as follows:

- (1) Nitrogen gas is filled in the all branches.
- (2) All flow rates are equal to zero.
- (3) Temperatures of only graphite branches are equal to, for example, 1000°C, and other temperatures are room ones.
- (4) All pressures are equal to atmospheric ones.

The following conditions are given as boundary conditions;

- (1) Two end branches connect separately to two infinite regions of a gas mixture of nitrogen and oxygen with atmospheric pressure and room temperature.
- (2) Wall mass fractions of oxygen, carbon monoxide and carbon dioxide in the graphite branch are obtained by solving the following equations.

$$-\frac{Sh_{O_2} \rho^*}{Re Sc_{CO_2}} (\bar{\omega}_{O_2} - \omega_{wO_2}) = \frac{m_{O_2}}{\rho_0 u_0} \quad (3.60)$$

$$-\frac{Sh_{CO} \rho^*}{Re Sc_{CO}} (\bar{\omega}_{CO} - \omega_{wCO}) = \frac{m_{CO}}{\rho_0 u_0} \quad (3.61)$$

$$-\frac{Sh_{CO_2} \rho^*}{Re Sc_{CO_2}} (\bar{\omega}_{CO_2} - \omega_{wCO_2}) = \frac{m_{CO_2}}{\rho_0 u_0} \quad (3.62)$$

It should be noted that the right hand sides of Eqs.(3.60) to (3.62) include wall mass fractions as expressed in Eqs.(3.43) to (3.47). Therefore, first, Eq.(3.60) of the wall mass fraction of oxygen is solved by Newton-Rapson method, then Eq.(3.62) is solved, and last the mass fraction of carbon monoxide can be obtained.

4. Result and Discussion

A steady state calculation was performed under the following conditions;

Graphite wall temperature	: 1000°C
Branch wall temperature	: 20°C
Gas temperature at inlet	: 20°C
Pressure at inlet and outlet	: 1.013×10^5 Pa
Oxygen mass fraction at inlet	: 0.233
Nitrogen mass fraction at inlet	: 0.767

The calculation results of Reynolds numbers in branches, temperatures at nodes, and mass fractions of oxygen, carbon monoxide and carbon dioxide at nodes are shown in Figs. 6-1 to 6-5. The Reynolds numbers in the branches with the same diameter and length differ from one another because of the difference of the bulk gas temperature. The flow rate at the outlet increased a little in comparison with the one at the inlet as shown in Fig. 6-1. This increase of the flow rate results from the gasification of the graphite due to the graphite/gas chemical reactions. The mass fraction of oxygen at the No.2 node (=0.207) is less than that at the No.1 node of the inlet (=0.233) because the flow goes down in the cold branches of the No.14 to No.19. The mass fractions of carbon monoxide and carbon dioxide at the No.2 node are not equal to zero as well as the mass fraction of oxygen at the No.2 node as shown in Figs. 6-4 and 6-5.

A transient calculation was carried out under the same conditions as the above ones. Figures 7 to 10 show the calculation results of the flow rates at the No.5, No.17 and No.27 branches, the gas temperatures at the No.6 and No.18 nodes and the mass fractions of oxygen, carbon monoxide and carbon dioxide at the No.6 and the No.26 nodes, respectively. The abscissa of Figs. 7 to 10 is elapsed time. The time increment was 0.2 seconds in the calculation. It is found that the values calculated reach steady state after about 5 seconds. The results in the steady state calculation agreed with those of steady state in the transient calculation. In these figures the overshooting is observed at the initial stage shorter than few seconds of the elapsed time.

The calculation results will be compared with the corresponding experimental results to verify the method of the numerical analysis.

5. Concluding Remarks

The flow network computer code was developed to calculate heat, mass and momentum transfer in a natural circulation of a multicomponent gas mixture with graphite chemical reaction due to air ingress. The entering flow rate, flow rates distributed to the parallel channels, generation volume of carbon monoxide and corrosion volume of the graphite were predicted by the present code. It was found that the numerical calculation method used in the code was basically effective for the analysis of heat, mass and momentum transfer in the gas mixture flow with solid(graphite)/gas(oxygen or carbon dioxide) and gas/gas(carbon monoxide/oxygen) chemical reactions.

We have already carried out the experiments on the graphite corrosion at high temperature in the experimental apparatus as shown in Fig. 2. The results calculated by the code will be compared with those obtained in the experiment.

References

- (1) S. Saito, T. Tanaka and Y. Sudo, Present Status of The High Temperature Engineering Test Reactor (HTTR), Nucl. Eng. Des., 132(1991), 85.
- (2) Japan Atomic Energy Research Institute, Present Status of HTGR Research And Development, (1991).
- (3) Japan Atomic Energy Research Institute, Present Status of HTGR Research And Development, (1989). (in Japanese)
- (4) R.K. Shah and A.L. London, Laminar Flow Forced Convection in Ducts, Academic Press, New York•San Francisco•London (1978), 103.
- (5) Y. Katto et al., Advances in Heat Transfer, Yokendou, Tokyo (1984), 183.
- (6) M. Ogawa, Mass Transfer with Graphite Oxidation in A Gas Mixture Laminar Flow through A Circular Tube, J. Atomic Energy Soc. Japan, to be published.
- (7) T. Takeda, B. Han and M. Ogawa, Thermal Properties of Multi-component Gas Mixture, JAERI-M 92-131 (1991).
- (8) M. Hishida and T. Takeda, Study on Air Ingress during An Early Stage of A Primary-pipe Rupture Accident of A High-temperature Gas-cooled Reactor, Nucl. Eng. Des., 126 (1991), 175.

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We have already carried out the experiments on the graphite corrosion at high temperature in the experimental apparatus as shown in Fig. 2. The results calculated by the code will be compared with those obtained in the experiment.

References

- (1) S. Saito, T. Tanaka and Y. Sudo, Present Status of The High Temperature Engineering Test Reactor (HTTR), Nucl. Eng. Des., 132(1991), 85.
- (2) Japan Atomic Energy Research Institute, Present Status of HTGR Research And Development, (1991).
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- (4) R.K. Shah and A.L. London, Laminar Flow Forced Convection in Ducts, Academic Press, New York•San Francisco•London (1978), 103.
- (5) Y. Katto et al., Advances in Heat Transfer, Yokendou, Tokyo (1984), 183.
- (6) M. Ogawa, Mass Transfer with Graphite Oxidation in A Gas Mixture Laminar Flow through A Circular Tube, J. Atomic Energy Soc. Japan, to be published.
- (7) T. Takeda, B. Han and M. Ogawa, Thermal Properties of Multi-component Gas Mixture, JAERI-M 92-131 (1991).
- (8) M. Hishida and T. Takeda, Study on Air Ingress during An Early Stage of A Primary-pipe Rupture Accident of A High-temperature Gas-cooled Reactor, Nucl. Eng. Des., 126 (1991), 175.

Table 1 Dimensions of branches and Pressure loss coefficients

Branch number	Length (m)	Diameter (m)	θ (deg)	Pressure coefficient
1	0.691	0.0549	0	1.5
2	0.7	0.0492	90	1.5
3	0.7025	0.0549	0	0
4	0.7025	0.0549	0	0
5	0.7	0.0549	0	0
6	1.085	0.0549	0	0
7	0.7	0.0492	90	1.5
8	0.7	0.0492	90	1.5
9	0.7025	0.0549	0	0
10	0.7025	0.0549	0	0
11	0.7	0.0549	0	0
12	1.085	0.0549	0	0
13	0.7	0.0492	90	1.5
14	0.7	0.0492	90	1.5
15	0.7975	0.0549	0	0
16	0.7975	0.0549	0	0
17	0.7975	0.0549	0	0
18	0.7975	0.0549	0	0
19	0.7	0.0492	90	1.5
20	0.246	0.0549	0	1.0
21	0.35	0.0549	90	1.0
22	0.688	0.0549	180	0
23	0.688	0.0549	180	0
24	0.688	0.0549	180	0
25	0.688	0.0549	180	0
26	0.688	0.0549	180	0
27	0.688	0.0549	180	0

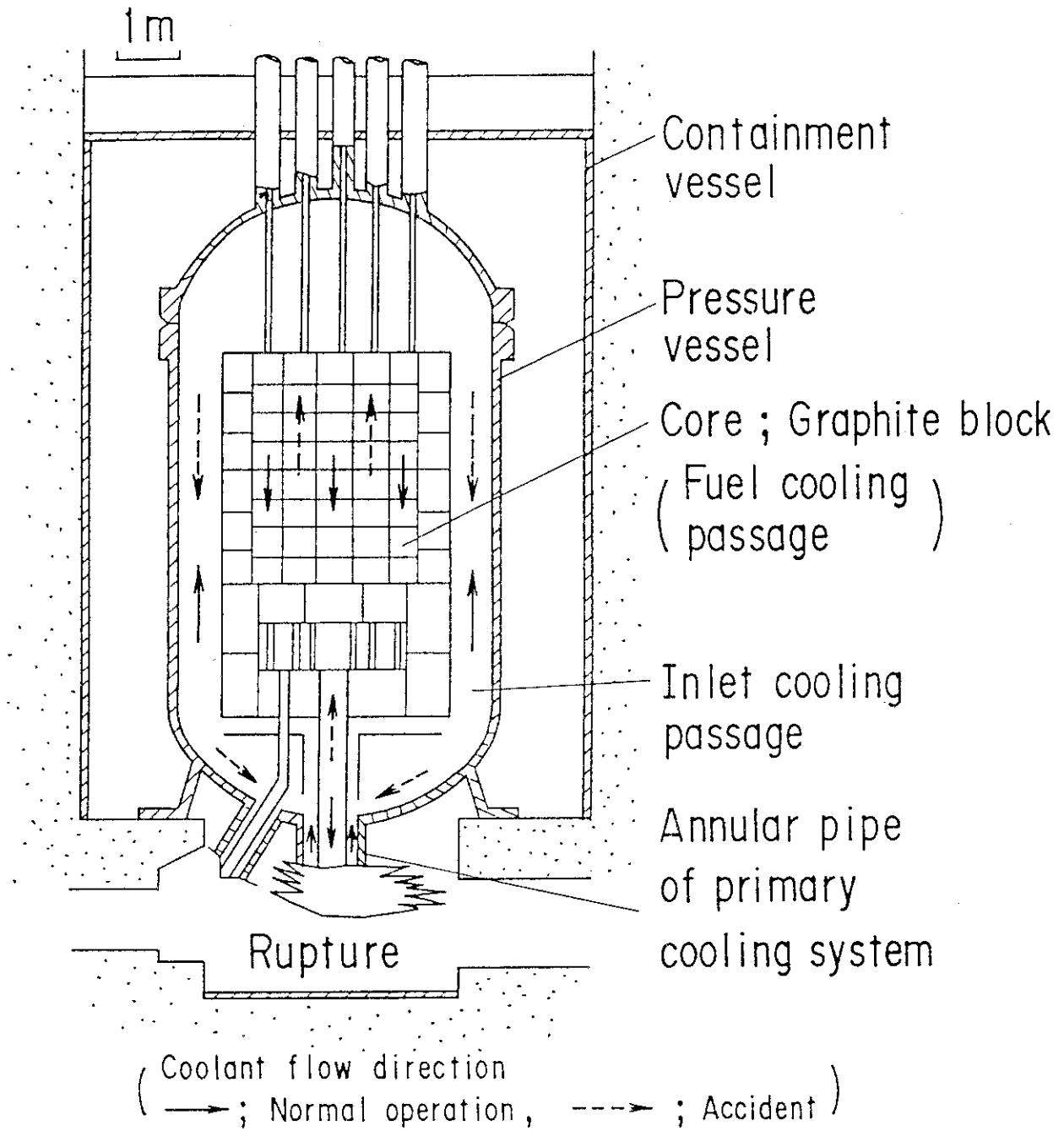


Fig. 1 Cross-sectional view of HTTR.

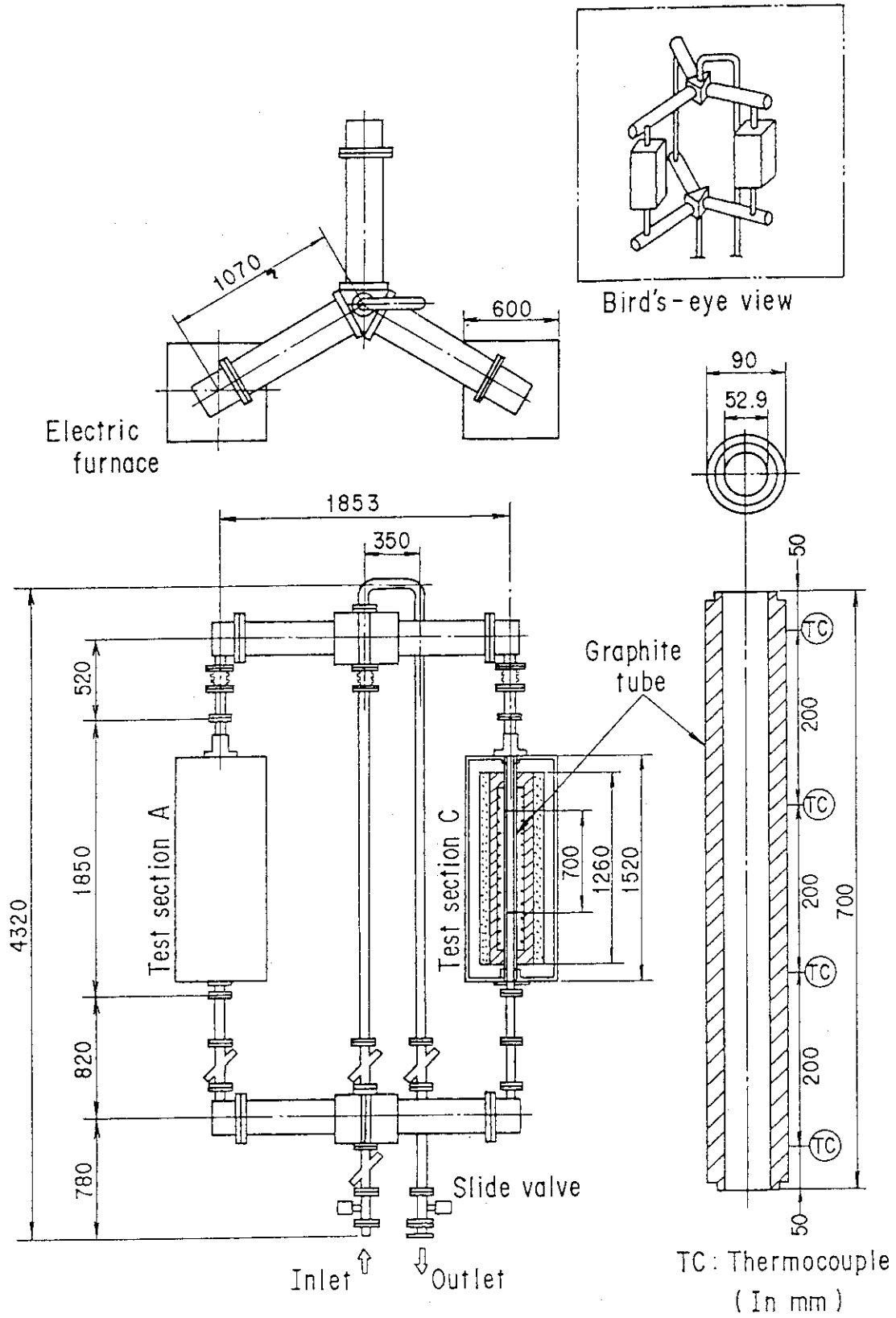


Fig. 2 Experimental apparatus for heat, mass and momentum transfer in a natural convection with graphite chemical reactions.

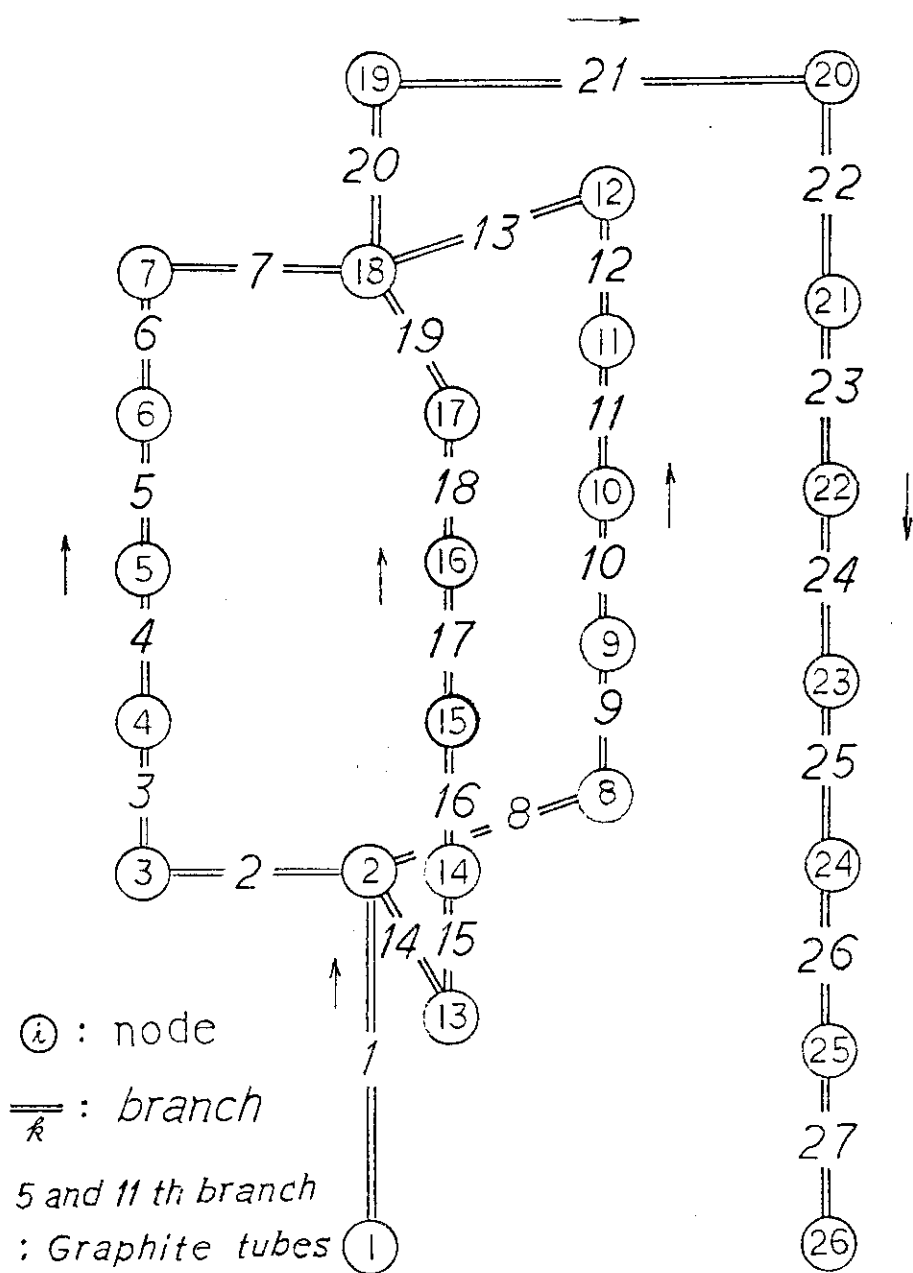


Fig. 3 Correction of branches and nodes in flow network corresponding to flow channels of experimental apparatus

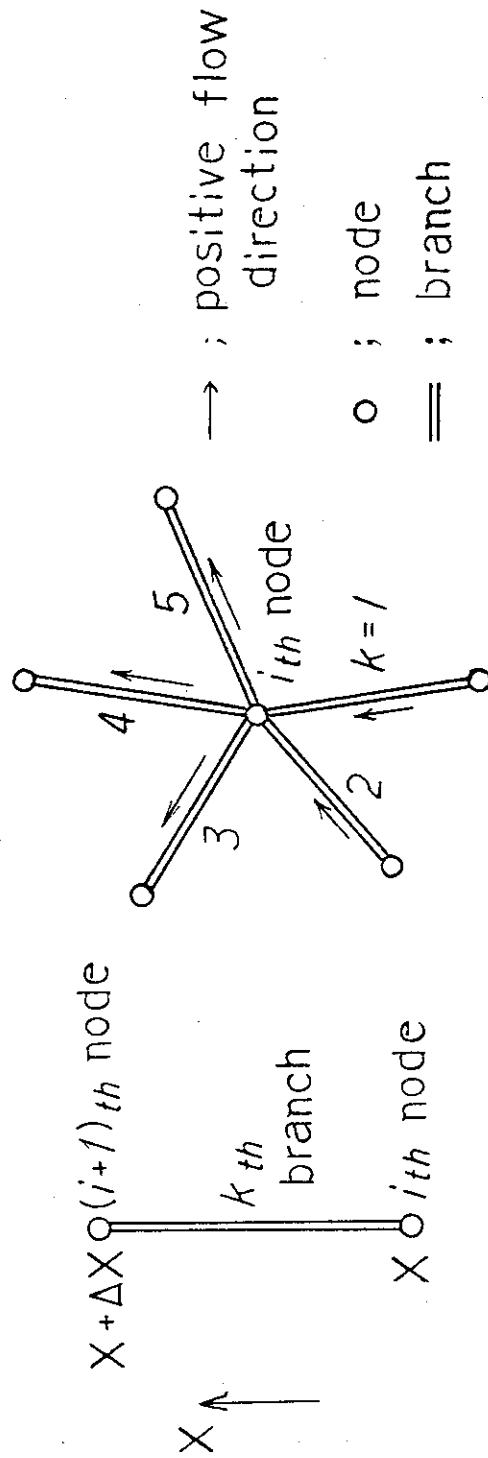


Fig. 4 An example of branch-node connection.

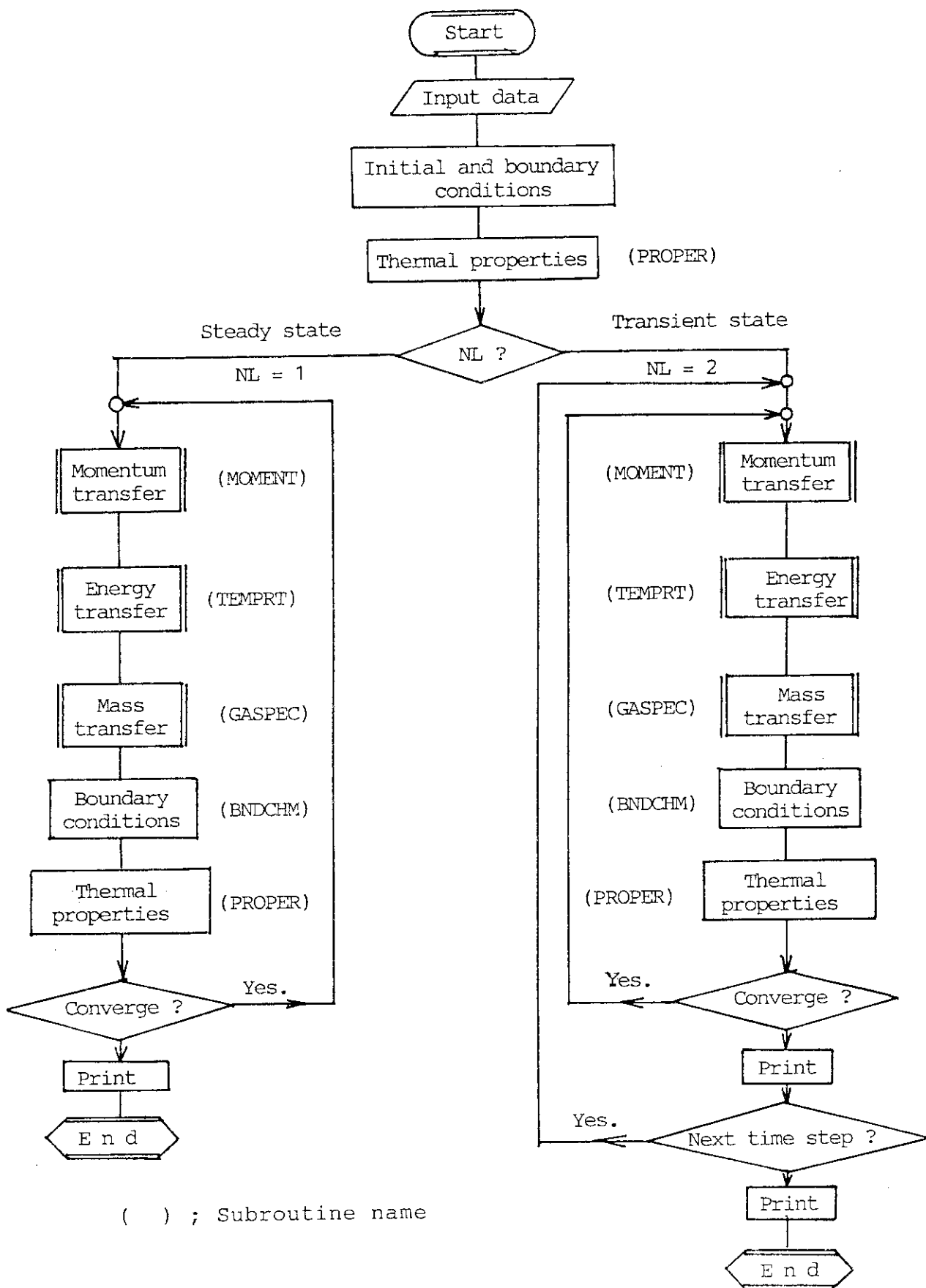


Fig. 5 Flow diagram of computer program.

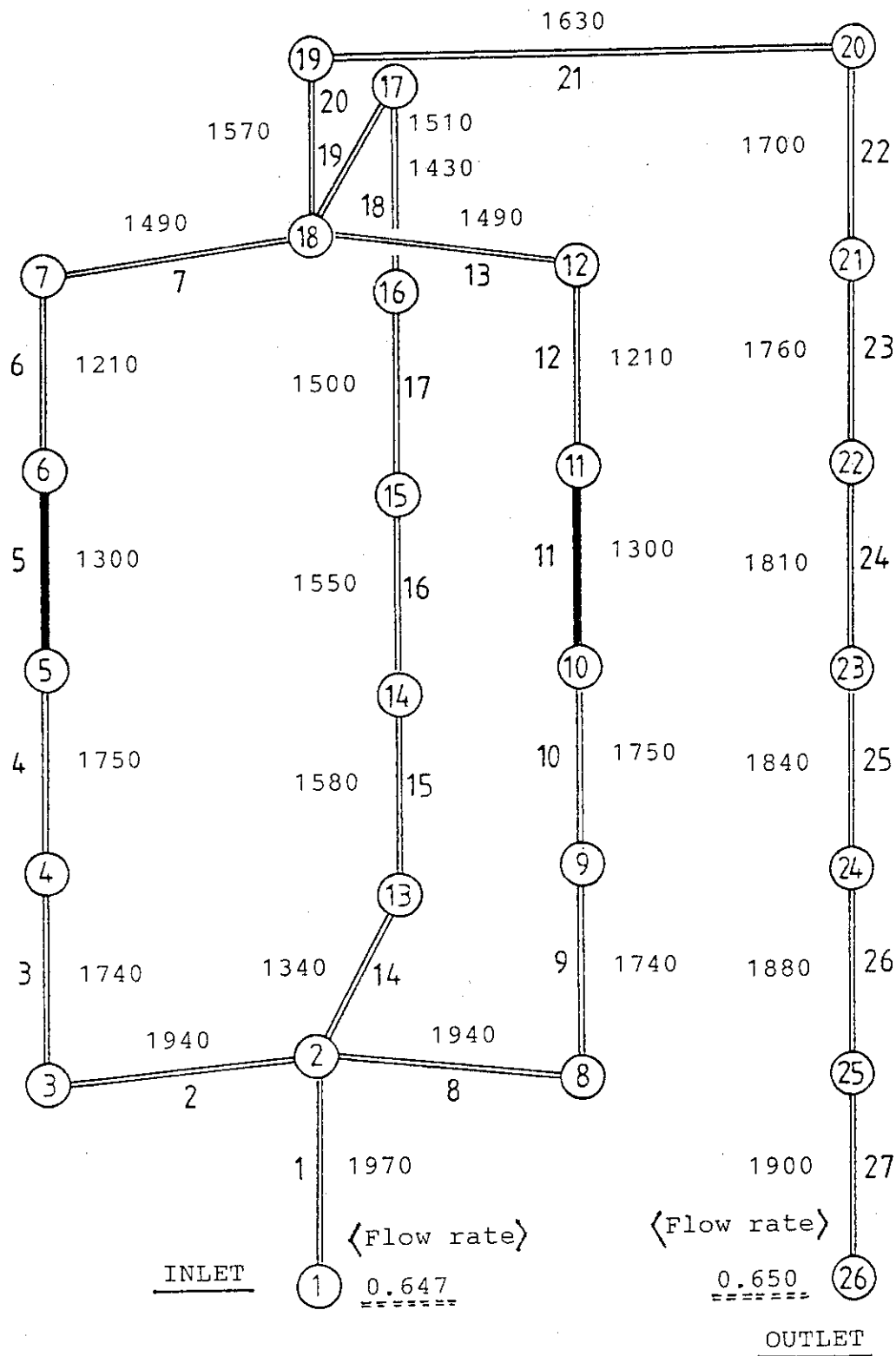


Fig. 6-1 Reynolds numbers of branches in steady state.

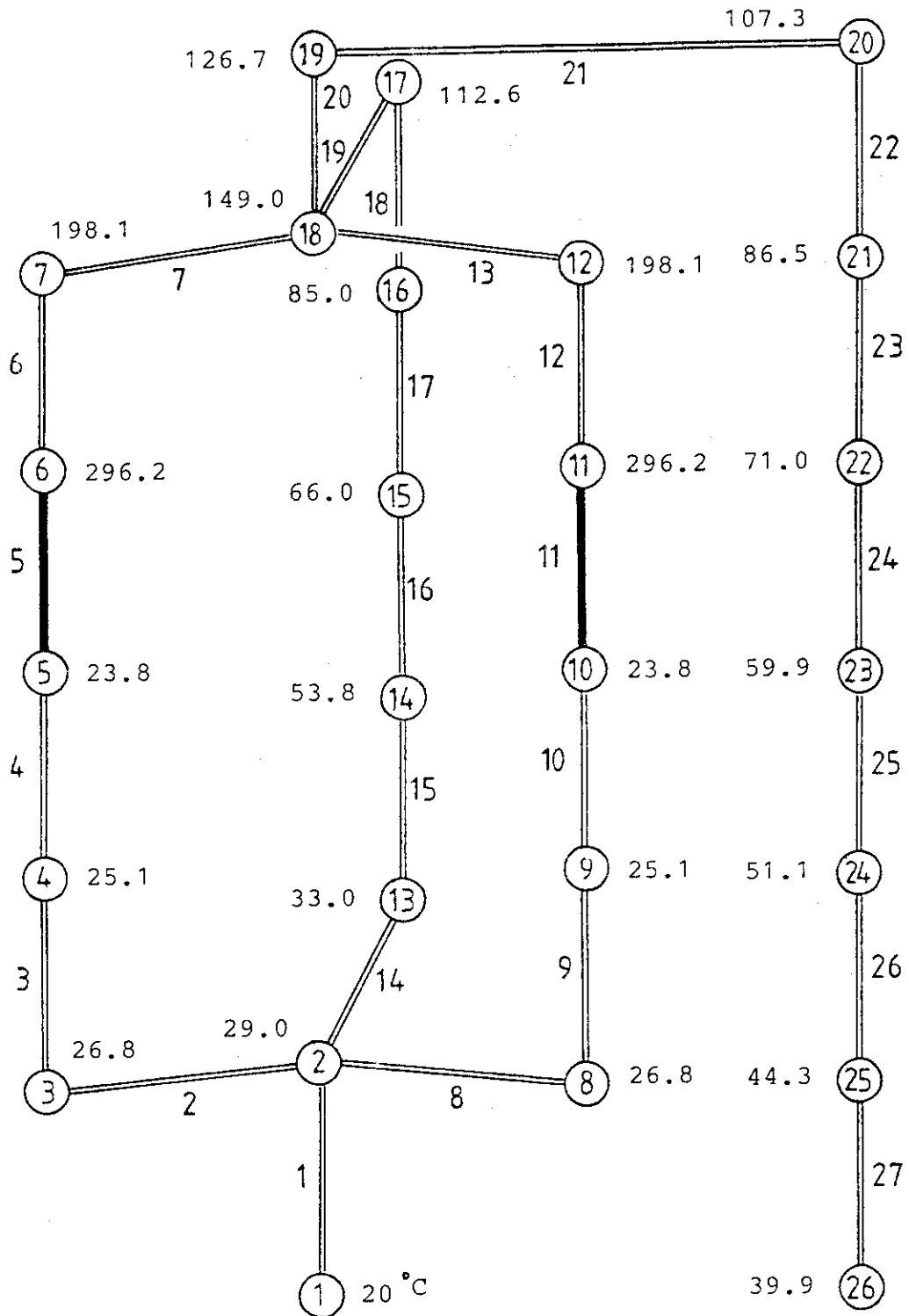


Fig. 6-2 Temperatures at nodes in steady state.

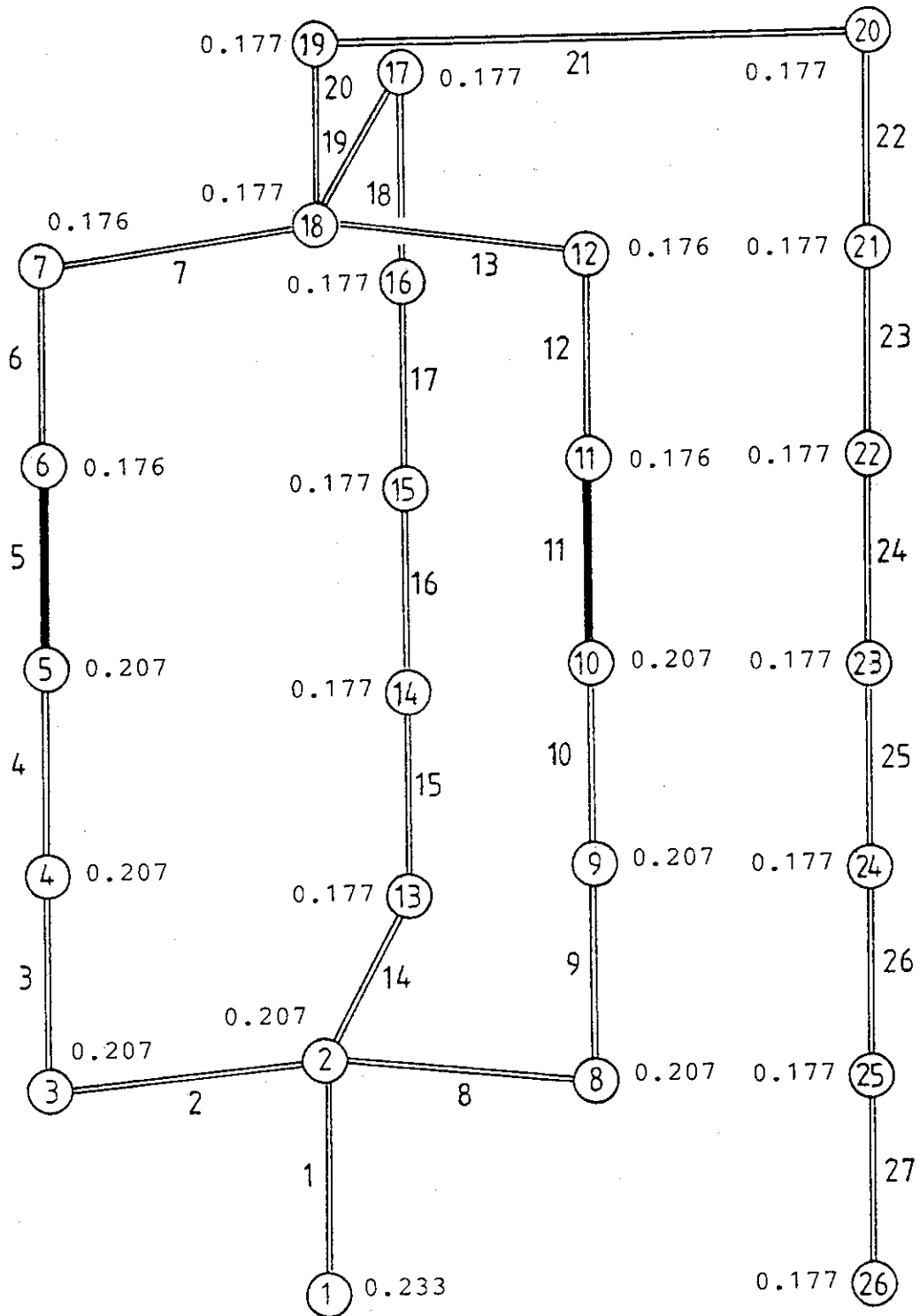


Fig. 6-3 Mass fractions of oxygen at nodes in steady state.

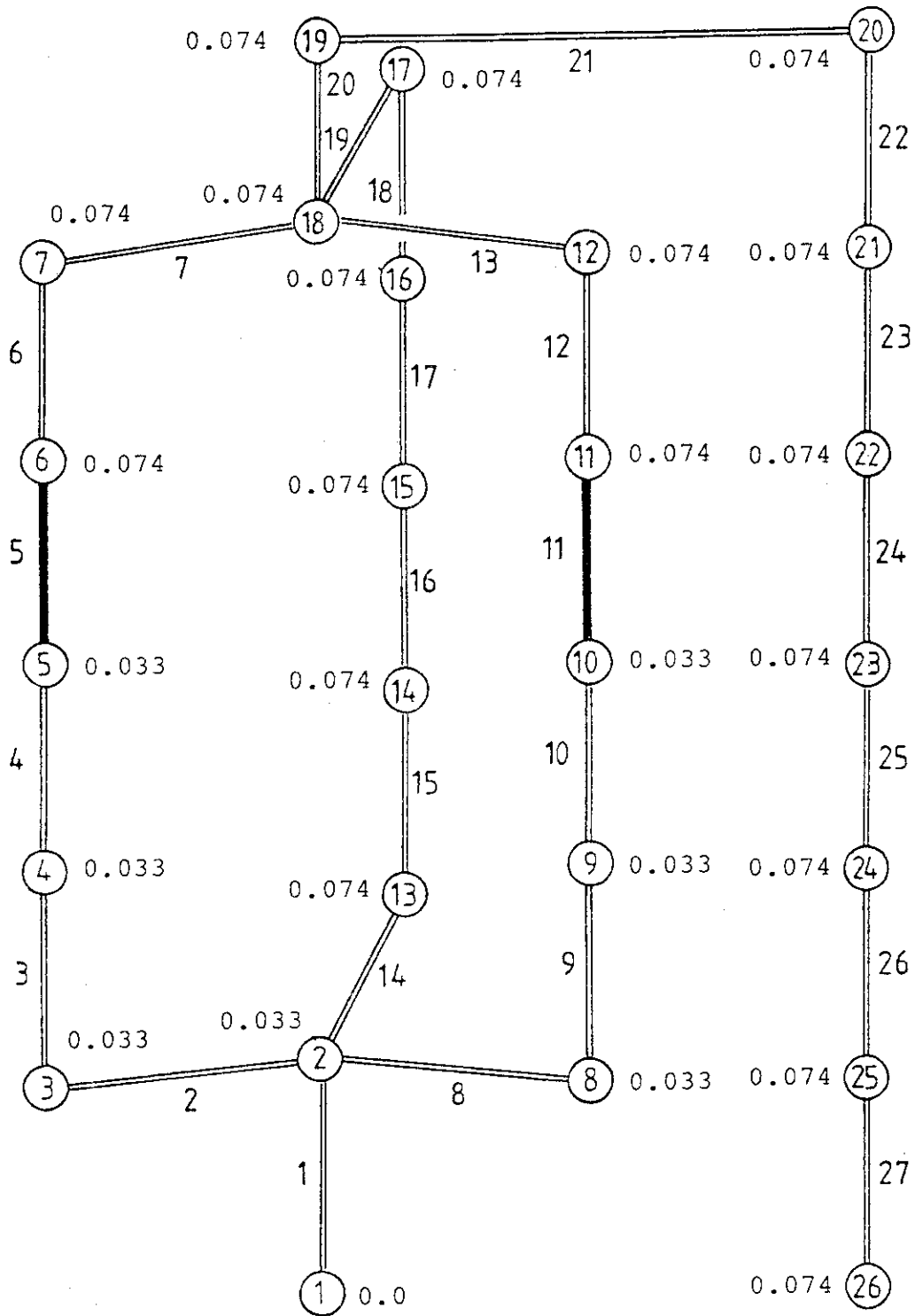


Fig. 6-4 Mass fractions of carbon monoxide at nodes in steady state.

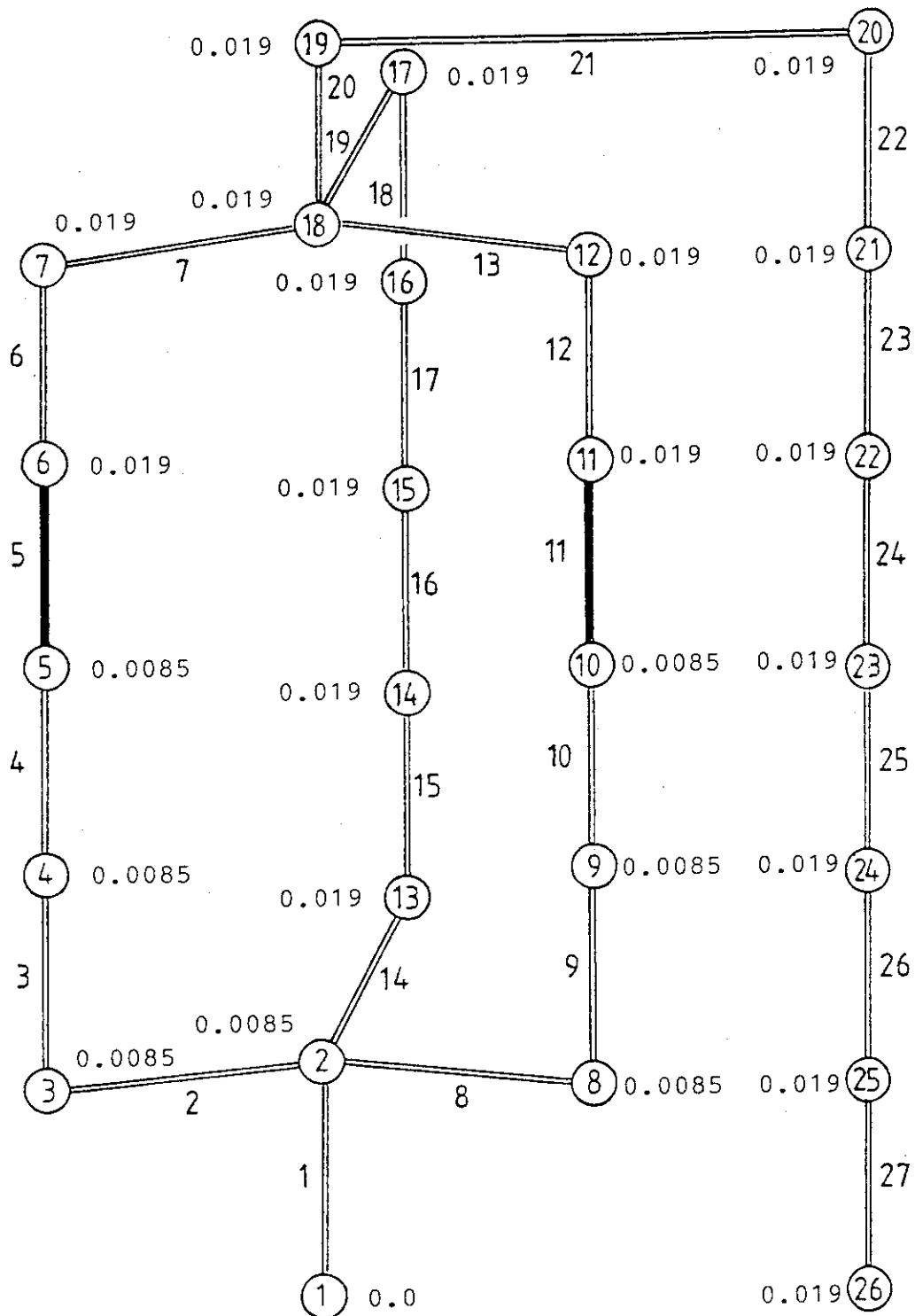


Fig. 6-5 Mass fractions of carbon dioxide at nodes in steady state.

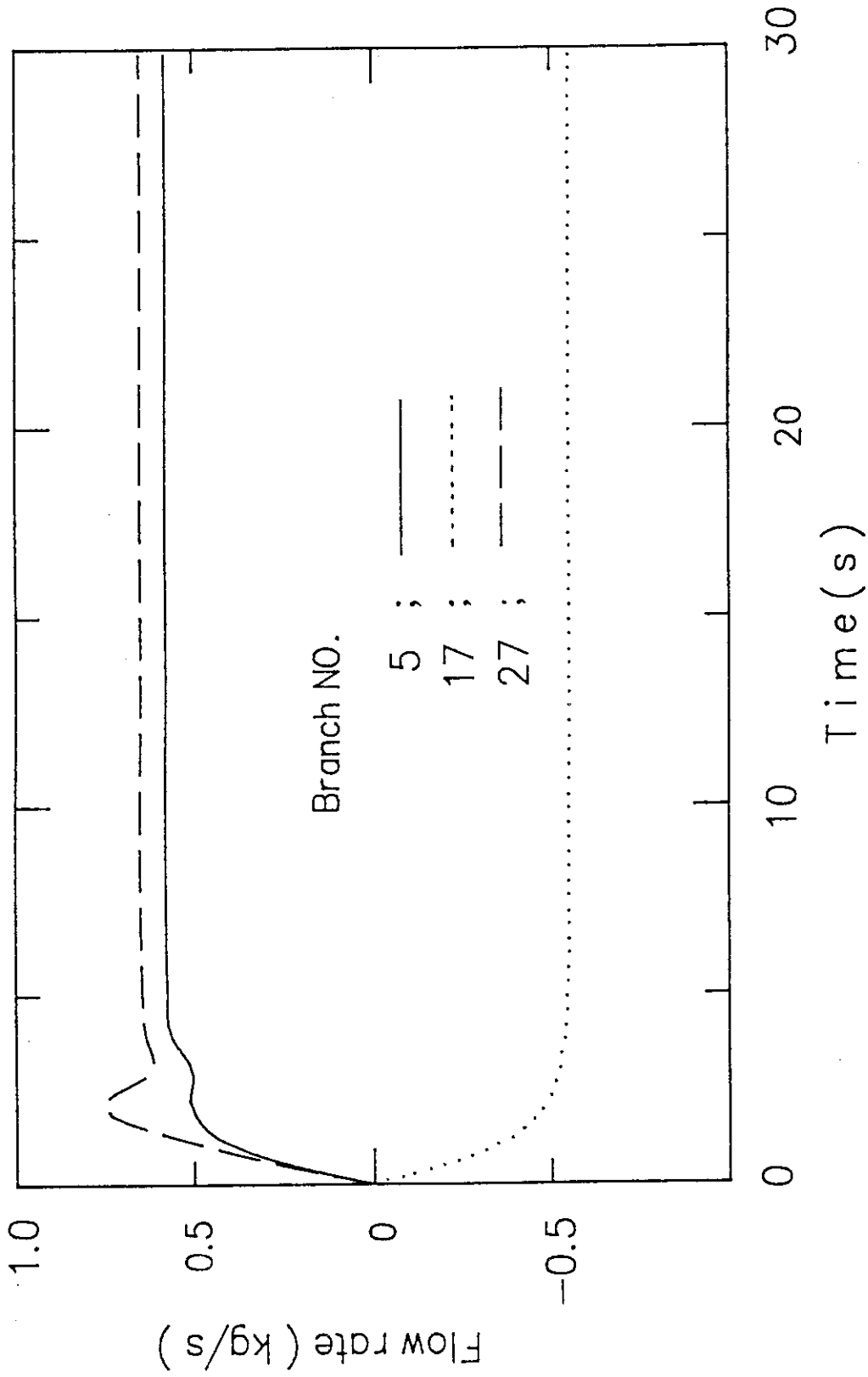


Fig. 7 Flow rates at the No.5, No.17 and No.27 branches in the transient calculation.

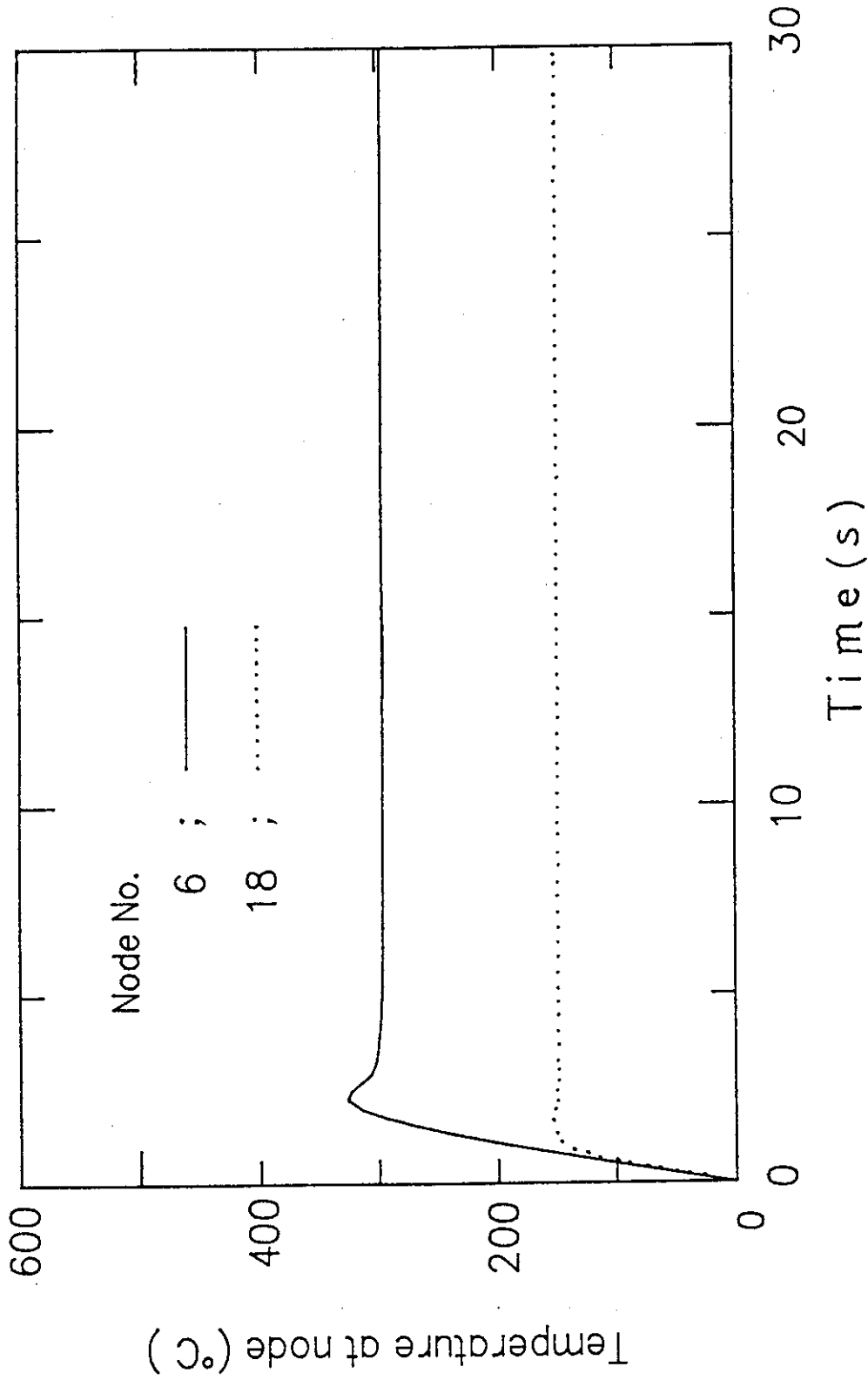


Fig. 8 Gas temperatures at the No.6 and No.18 nodes in the transient calculation.

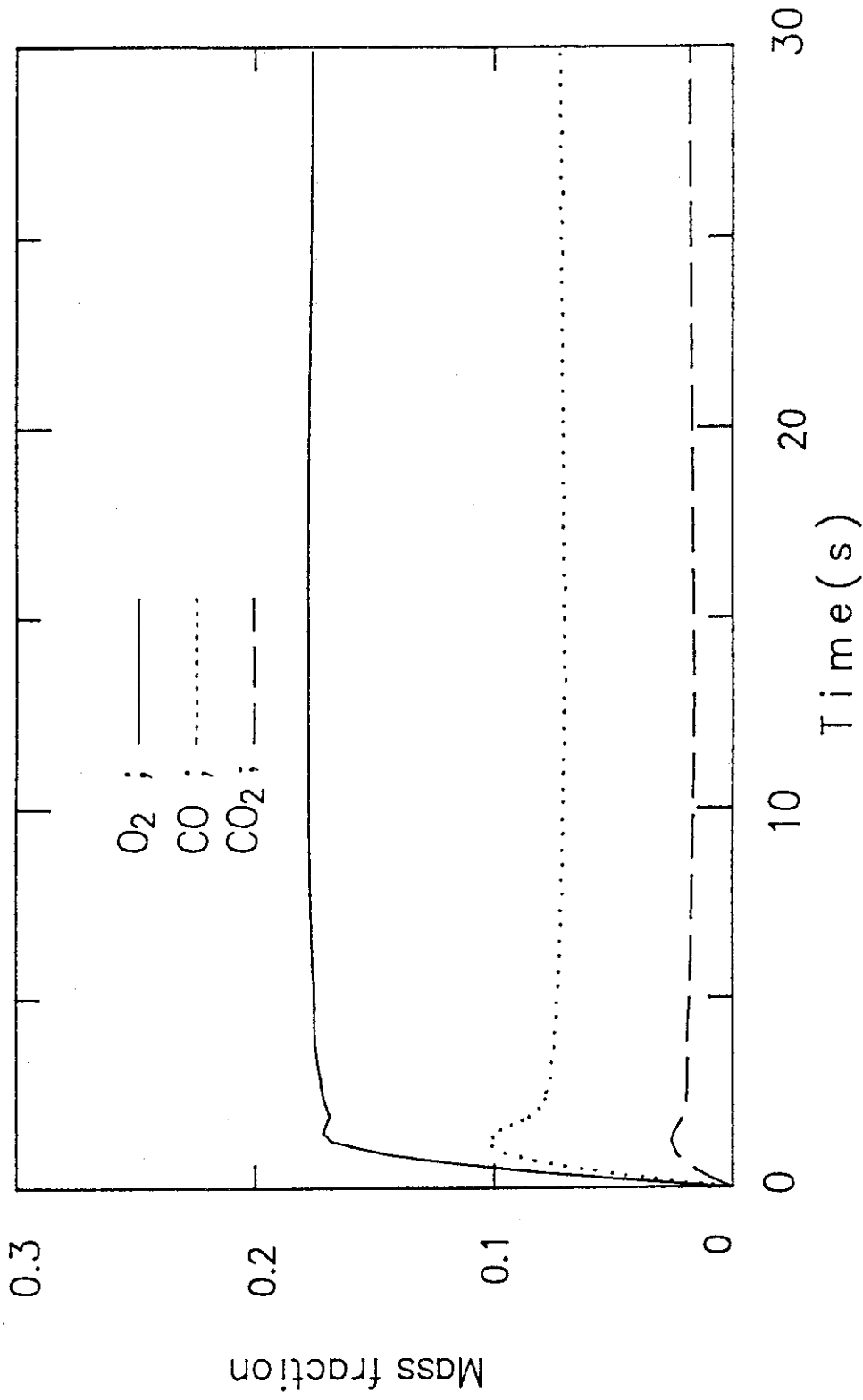


Fig. 9 Mass fractions at the No.6 node in the transient calculation.

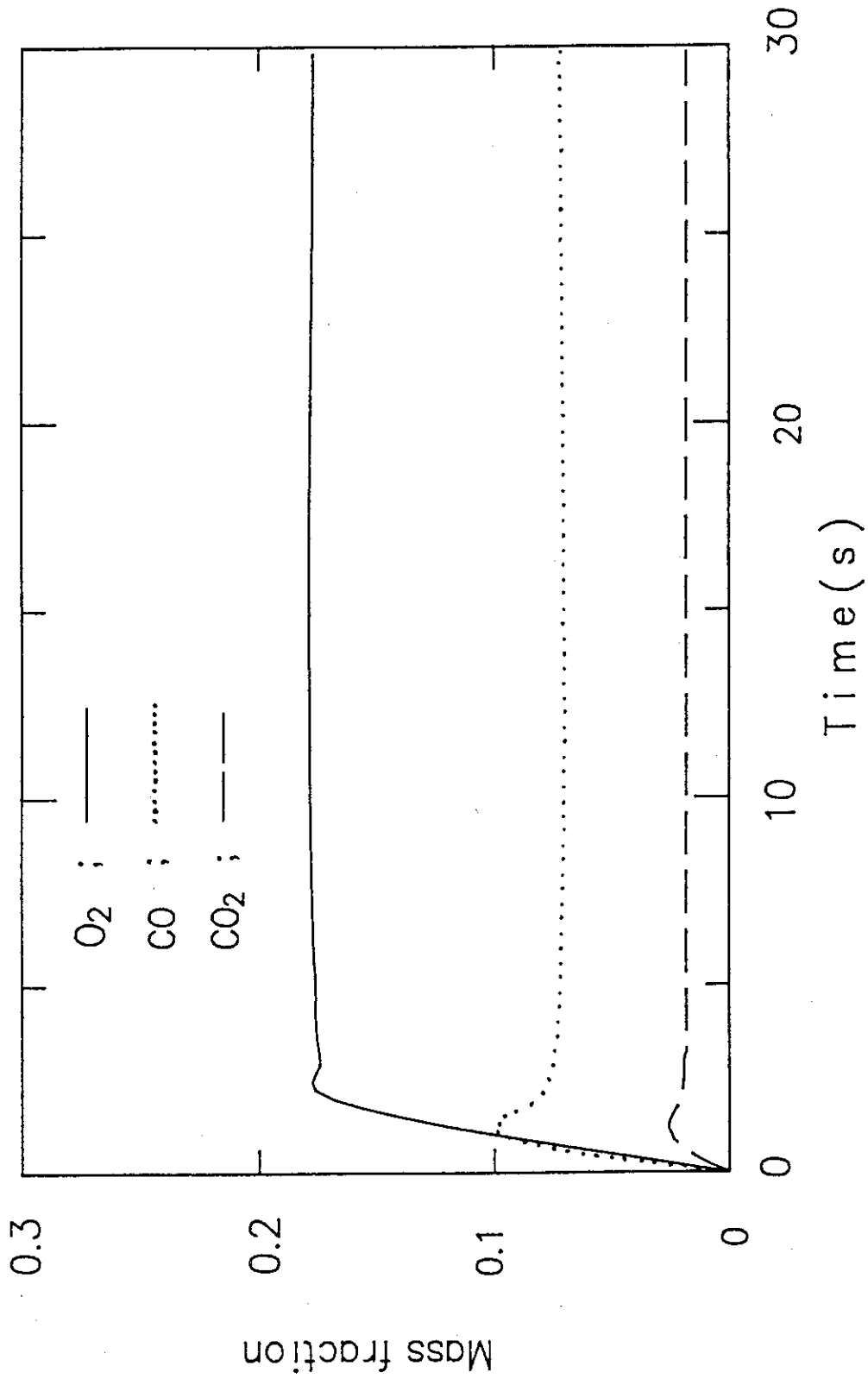


Fig. 10 Mass fraction at the No.26 node in the transient calculation.

APPENDIX Computer Program

FORTTRAN77 EX V12L10

DATE 92-09-21 TIME 20:42:03

```

C
00000001      IMPLICIT REAL*8 (A-H,O-Z)
00000002      PARAMETER ( N=26, M=27, K=5, J=200 )
C
00000003      DIMENSION H(M), D(M), Y(M), F(M), CAT(M),
*              TI1(M), TI2(M), TO1(M), TO2(M), TA1(M), TA2(M),
*              TN1(N), TN2(N), TWA(M), TTAT(M),
*              GA1(M), GA2(M), GA(M), GGT(M), GM1(M),
*              RE(M), GR(M), PR(M), SC(M,K), SH(M,K), Q(M),
*              DI(M,K), CP(M), CPT(M), CPO(M), CPN(M), DEI(M), DEO(M),
*              DEA1(M), DEAT(M),
*              AVEMOL(M), C(13),
*              P1(N), P2(N), PN1(N), PN2(N), PA1(M), PA2(M),
*              PP(N), PPT(N), PAT(M),
*              WI1(M,K), WI2(M,K), WO1(M,K), WO2(M,K), WA1(M,K),
*              WA2(M,K), WN1(N,K), WN2(N,K), WAAT(M,K), WWA(M,K),
*SCH(K), OMGB(K), OMGW(K), AMOL(K+1), CC(13),
*TTN(N), TTO(M), TTA(M), TTOT(M), TTNT(N),
*WAA(M,K), WWN(N,K), WWO(M,K), WWO2(M,K), WWNT(N,K), GG(M)
00000004      REAL*8 NNI(M), NNO(M), MU(M), LAM(M), NU(M), MOLW(K+1)
C
00000005      COMMON/SIZE/H,D,Y,F,NNI,NNO,CAT,DT
*              /TEMP/TI1,TI2,TO1,TO2,TA1,TA2,TN1,TN2,TWA,TTAT
*              /PRES/P1,P2,PN1,PN2,PA1,PA2,PP,PPT,PAT
*              /COMP/WI1,WI2,WO1,WO2,WA1,WA2,WN1,WN2,WAAT,WWA
*              /FLOW/GA1,GA2,GA,GGT,GM1
*              /QUAL/DI,CP,CPT,CPO,CPN,MU,LAM,DEI,DEO,DEA1,DEAT
*              /MLWG/MOLW,AVEMOL,C
*              /REFE/RE,GR,PR,NU,SC,SH,Q
C
00000006      DATA AMOL/4.003E-3, 32.000E-3, 28.010E-3, 44.010E-3, 28.016E-3,
*              12.010E-3/
*              CC/1.013E+5, 293.15, 1.1960, 3.8320E-2, 1.8497E-5, 25.7E-3,
*              1.006E3, 6.879E-5, 1.992E-5, 1.973E-5, 1.501E-5,
*              1.974E-5, 1.546572E-5/
00000007      DO 20 I=1,K+1
00000008 20      MOLW(I) = AMOL(I)
00000009      DO 30 I=1,13
00000010 30      C(I) = CC(I)
C
C***** INPUT DATA *****
C
00000011      READ(5,*) TIME, DTI, NL
00000012      READ(5,*) (NNI(I),I=1,M-3)
00000013      READ(5,*) (NNI(I),I=M-2,M)
00000014      READ(5,*) (NNO(I),I=1,M-7)
00000015      READ(5,*) (NNO(I),I=M-6,M)
00000016      READ(5,*) (P1(I),I=1,N)
00000017      READ(5,*) (H(I),I=1,M-9)
00000018      READ(5,*) (H(I),I=M-8,M)
00000019      READ(5,*) (D(I),I=1,M)
00000020      READ(5,*) (CAT(I),I=1,M)
00000021      READ(5,*) (Y(I),I=1,M)
00000022      READ(5,*) (TN1(I),I=1,N)
00000023      READ(5,*) (TWA(I),I=1,M)
00000024      DO 10 JJ=1,K
00000025      READ(5,*) (WA1(I,JJ),I=1,M)
00000026 10      CONTINUE
00000027      DO 11 JJ=1,K
00000028      READ(5,*) (WN1(I,JJ),I=1,N)

```

FORTRAN77 EX V12L10 MAIN DATE 92-09-21 TIME 20:42:03

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00000029 11 CONTINUE
C
00000030 WRITE(6,6100) TIME, DTI, NL
00000031 WRITE(6,6000) (NNI(I),I=1,M)
00000032 WRITE(6,6000) (NNO(I),I=1,M)
00000033 WRITE(6,6000) (P1(I),I=1,N)
00000034 WRITE(6,6000) (H(I),I=1,M)
00000035 WRITE(6,6000) (D(I),I=1,M)
00000036 WRITE(6,6000) (CAT(I),I=1,M)
00000037 WRITE(6,6000) (Y(I),I=1,M)
00000038 WRITE(6,3130) (I,TN1(I),I=1,N)
00000039 WRITE(6,3135) (I,TWA(I),I=1,M)
00000040 DO 12 JJ=1,K
00000041 WRITE(6,3150) JJ, (I,WN1(I,JJ),I=1,N)
00000042 12 WRITE(6,3180) (I,WA1(I,JJ),I=1,M)
C
00000043 6000 FORMAT(1H0,10(1PE12.5,1X),/,1X,10(E12.5,1X),/,1X,10(E12.5,1X))
00000044 6100 FORMAT(1H0,30('='),' INPUT DATA ',75('='),/,
* ' TIME = ',F8.3,' (SEC), DT = ',F7.3,' (SEC)',
* ' NL = ',I1,' ( NL=1 ; STEADY STATE, NL=2 ; ',
* 'TRANSIENT STATE. )' )
C
C***** INITIAL VALUES *****
C
00000045 DO 100 I=1,M
00000046 P2(NNI(I))=0.0
00000047 P2(NNO(I))=0.0
00000048 GA2(I)=0.0
00000049 TA2(I)=0.0
00000050 TO2(I)=0.0
00000051 TO1(I)=TWA(I)
00000052 TA1(I)=0.5*(TN1(NNI(I))+TO1(I))
00000053 PA1(I)=0.5*(P1(NNI(I))+P1(NNO(I)))
00000054 PAT(I)=PA1(I)
00000055 GA1(I)=0.100
00000056 GG(I)=GA1(I)
00000057 GGT(I)=GA1(I)
00000058 TTO(I)=TO1(I)
00000059 TTOT(I)=TTO(I)
00000060 TTA(I)=TA1(I)
00000061 TTAT(I)=TA1(I)
00000062 100 CONTINUE
00000063 P2(NNI(1))=C(1)
00000064 DO 110 I=1,N
00000065 PP(I)=P1(I)
00000066 PPT(I)=PP(I)
00000067 TN2(I)=0.0
00000068 TTN(I)=TN1(I)
00000069 TTNT(I)=TTN(I)
00000070 110 CONTINUE
00000071 DO 120 I=1,M
00000072 DO 120 JJ=1,K
00000073 WD2(I,JJ)=0.0
00000074 WA2(I,JJ)=0.0
00000075 WWA(I,JJ)=WA1(I,JJ)
00000076 W01(I,JJ)=WA1(I,JJ)
00000077 WWO(I,JJ)=WA1(I,JJ)
00000078 WAA(I,JJ)=WA1(I,JJ)
00000079 WWOT(I,JJ)=W01(I,JJ)
00000080 WAAT(I,JJ)=WAA(I,JJ)

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00000081 120  CONTINUE                                00024100
00000082      DO 130 I=1,N                          00024200
00000083      DO 130 JJ=1,K                          00024300
00000084      WN2(I,JJ)=0.0                          00024400
00000085      WWN(I,JJ)=WN1(I,JJ)                   00024500
00000086      WWNT(I,JJ)=WN1(I,JJ)                   00024600
00000087 130  CONTINUE                                00024700
C                                                    00024800
00000088      CALL PROPER                             00024900
C                                                    00025000
00000089      NSORT = 1                                00025100
00000090      IF ( NL.GE.2 ) NSORT = 2                 00025200
00000091      IF(NL.EQ.1) GO TO 7100                   00025300
00000092      IF(NL.EQ.2) GO TO 7200                   00025400
C                                                    00025500
C***** G,P,T,W, OF STEADY STATE *****00025600
C                                                    00025700
00000093 7100  CONTINUE                                00025800
00000094      DO 200 LL=1,J                            00025900
00000095      CALL MOMENT ( 1 )                       00026000
00000096      CALL TEMPRT ( 1 )                       00026100
00000097      CALL GASPEC ( 1 )                       00026200
C                                                    00026300
00000098      EPS=0.0                                  00026400
00000099      DO 210 I=1,M                              00026500
00000100      IF (DABS((GA2(I)-GG(I))/GA2(I)).GT.EPS) EPS=DABS((GA2(I)
*-GG(I))/GA2(I))                                00026600
00000101      IF (DABS((TO2(I)-TTO(I))/TO2(I)).GT.EPS) EPS=DABS((TO2(I)
*-TTO(I))/TO2(I))                                00026700
00000102 210  CONTINUE                                00026800
00000103      DO 220 I=1,N                              00026900
00000104      IF (DABS((TN2(I)-TTN(I))/TN2(I)).GT.EPS) EPS=
*DABS((TN2(I)-TTN(I))/TN2(I))                    00027000
00000105 220  CONTINUE                                00027100
00000106      DO 230 I=1,N                              00027200
00000107      DO 230 JJ=1,K                              00027300
00000108      IF (DABS(WN2(I,JJ)-WWN(I,JJ)).GT.EPS) EPS=DABS(WN2(
*I,JJ)-WWN(I,JJ))                                00027400
00000109 230  CONTINUE                                00027500
00000110      DO 235 I=1,M                              00027600
00000111      DO 235 JJ=1,K                              00027700
00000112      IF (DABS(WO2(I,JJ)-WWO(I,JJ)).GT.EPS) EPS=DABS(WO2(I,JJ)
*-WWO(I,JJ))                                00027800
00000113 235  CONTINUE                                00027900
C                                                    00028000
00000114      IF (EPS.LE.1.0E-3) GO TO 400            00028100
C                                                    00028200
00000115      DO 250 I=1,M                              00028300
00000116      GA1(I)=0.7*GG(I)+0.3*GA2(I)            00028400
00000117      GG(I)=GA1(I)                            00028500
00000118      TO1(I)=0.7*TTO(I)+0.3*TO2(I)           00028600
00000119      TA1(I)=0.7*TTA(I)+0.3*TA2(I)           00028700
00000120      TTO(I)=TO1(I)                           00028800
00000121      TTA(I)=TA1(I)                           00028900
00000122 250  CONTINUE                                00029000
00000123      DO 260 I=1,N                              00029100
00000124      TN1(I)=0.7*TTN(I)+0.3*TN2(I)           00029200
00000125      TTN(I)=TN1(I)                           00029300
00000126 260  CONTINUE                                00029400
00000127      DO 280 I=1,N                              00029500

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00000128      DO 280 JJ=1,K                               00030100
00000129      WN1(I,JJ)=0.7*WWN(I,JJ)+0.3*WN2(I,JJ)    00030200
00000130      WWN(I,JJ)=WN1(I,JJ)                       00030300
00000131 280   CONTINUE                                00030400
00000132      DO 290 I=1,M                               00030500
00000133      DO 290 JJ=1,K                               00030600
00000134      W01(I,JJ)=0.7*W00(I,JJ)+0.3*W02(I,JJ)    00030700
00000135      W00(I,JJ)=W01(I,JJ)                       00030800
00000136      WA1(I,JJ)=0.7*WAA(I,JJ)+0.3*WA2(I,JJ)    00030900
00000137      WAA(I,JJ)=WA1(I,JJ)                      00031000
00000138 290   CONTINUE                                00031100
00000139      DO 292 JJ=1,K                               00031200
00000140      SCH(JJ)=SC(5,JJ)                             00031300
00000141 292   OMGB(JJ) = WA2(5,JJ)                   00031400
00000142      CALL BNDCHM ( RE(5), SCH, H(5)/D(5), D(5), C(3), C(13),
1             DEA1(5)/C(3), OMGB, TWA(5), PA2(5), AVEMOL(5),
2             OMGW, GM1(5) )                            00031500
00000143      DO 294 JJ=1,K                               00031600
00000144      WWA(5,JJ) = OMGW(JJ)                       00031700
00000145      SCH(JJ)=SC(11,JJ)                           00031800
00000146 294   OMGB(JJ) = WA2(11,JJ)                  00031900
00000147      CALL BNDCHM ( RE(11), SCH, H(11)/D(11), D(11), C(3), C(13),
1             DEA1(11)/C(3), OMGB, TWA(11), PA2(11), AVEMOL(11),
2             OMGW, GM1(11) )                          00032000
00000148      DO 298 JJ=1,K                               00032100
00000149 298   WWA(11,JJ) = OMGW(JJ)                  00032200
00000150      DO 240 I=1,M                               00032300
00000151      IF ( I.EQ.5.OR.I.EQ.11 ) GO TO 240         00032400
00000152      DO 245 JJ=1,K                               00032500
00000153 245   WWA(I,JJ) = WA2(I,JJ)                  00032600
00000154 240   CONTINUE                                00032700
C                                                     00032800
00000155      CALL PROPER                                00032900
00000156 200   CONTINUE                                00033000
C                                                     00033100
00000157      WRITE(6,*) '***** ITERATION TIME IS OVER AT STEADY STATE !!
1             , ' *****'                            00033200
C                                                     00033300
00000158 400   WRITE(6,3020) LL                        00033400
00000159      WRITE(6,3100) (I,P2(I),I=1,N)             00033500
00000160      WRITE(6,3110) (I,GA2(I),I=1,M)            00033600
00000161      WRITE(6,3120) (I,RE(I),I=1,M)            00033700
00000162      WRITE(6,3130) (I,TN2(I),I=1,N)          00033800
00000163      WRITE(6,3145) (I,TA2(I),I=1,M)           00033900
00000164      WRITE(6,3140) (I,TO2(I),I=1,M)          00034000
00000165      DO 405 KPRT=2,5                          00034100
00000166      WRITE(6,3150) KPRT, (I,WN2(I,KPRT),I=1,N) 00034200
00000167      WRITE(6,3180) (I,WA2(I,KPRT),I=1,M)      00034300
00000168      WRITE(6,3160) (I,W02(I,KPRT),I=1,M)      00034400
00000169 405   WRITE(6,3170) (I,WWA(I,KPRT),I=1,M)    00034500
00000170      STOP                                     00034600
C                                                     00034700
C***** G, P, T, W OF TRANSIENT STATE *****          00034800
C                                                     00034900
00000171 7200  ND=INT(TIME/DTI)                       00035000
00000172      ETIME = 0.0                              00035100
00000173      DT = DTI                                00035200
C                                                     00035300
00000174      DO 1000 KK=1,ND                          00035400
00000175      EPST=0.0                                 00035500

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00000176      ETIME=ETIME+DT                                00036100
C                                                     00036200
00000177      DO 500 L=1,J                                00036300
C                                                     00036400
00000178      CALL MOMENT ( NSORT )                        00036500
00000179      CALL TEMPRY ( 1 )                            00036600
00000180      CALL GASPEC ( 1 )                            00036700
C                                                     00036800
00000181      EPS=0.0                                       00036900
00000182      DO 510 I=1,M                                  00037000
00000183      IF (DABS((GA2(I)-GG(I))/GG(I)).GT.EPS) EPS=DABS((GA2(I)-GG(I))/
* GG(I))                                                    00037100
00000184      IF (DABS((TO2(I)-TTO(I))/TTO(I)).GT.EPS) EPS=DABS((TO2(I)-TTO(I))
*/TTO(I))                                                    00037200
00000185 510    CONTINUE                                     00037300
00000186      DO 520 I=1,N                                  00037400
00000187      IF (DABS((TN2(I)-TTN(I))/TTN(I)).GT.EPS) EPS=DABS((TN2(I)-TTN(I))
*/TTN(I))                                                    00037500
00000188 520    CONTINUE                                     00037600
00000189      DO 530 I=1,N                                  00037700
00000190      DO 530 JJ=1,K                                  00037800
00000191      IF (DABS(WN2(I,JJ)-WWN(I,JJ)).GT.EPS) EPS=DABS(WN2(I,JJ)
*-WWN(I,JJ))                                                  00037900
00000192 530    CONTINUE                                     00038000
00000193      DO 540 I=1,M                                  00038100
00000194      DO 540 JJ=1,K                                  00038200
00000195      IF (DABS(WO2(I,JJ)-WWO(I,JJ)).GT.EPS) EPS=DABS(WO2(I,JJ)
*-WWO(I,JJ))                                                  00038300
00000196 540    CONTINUE                                     00038400
C                                                     00038500
C----- JUDGEMENT OF CONVERGENCE -----                00038600
C                                                     00038700
00000197      IF (EPS.LE.1.0E-3) GO TO 300                 00038800
00000198      DO 650 I=1,M                                  00038900
00000199      GA1(I)=0.7*GG(I)+0.3*GA2(I)                 00039000
00000200      GG(I)=GA1(I)                                  00039100
00000201      TO1(I)=0.7*TTO(I)+0.3*TO2(I)                00039200
00000202      TA1(I)=0.7*TTA(I)+0.3*TA2(I)                00039300
00000203      TTO(I)=TO1(I)                                 00039400
00000204      TTA(I)=TA1(I)                                 00039500
00000205 650    CONTINUE                                     00039600
00000206      DO 660 I=1,N                                  00039700
00000207      TN1(I)=0.7*TTN(I)+0.3*TN2(I)                00039800
00000208      TTN(I)=TN1(I)                                 00039900
00000209 660    CONTINUE                                     00040000
00000210      DO 680 I=1,N                                  00040100
00000211      DO 680 JJ=1,K                                  00040200
00000212      WN1(I,JJ)=0.7*WWN(I,JJ)+0.3*WN2(I,JJ)      00040300
00000213      WWN(I,JJ)=WN1(I,JJ)                          00040400
00000214 680    CONTINUE                                     00040500
00000215      DO 690 I=1,M                                  00040600
00000216      DO 690 JJ=1,K                                  00040700
00000217      WO1(I,JJ)=0.7*WWO(I,JJ)+0.3*WO2(I,JJ)      00040800
00000218      WWO(I,JJ)=WO1(I,JJ)                          00040900
00000219      WA1(I,JJ)=0.7*WAA(I,JJ)+0.3*WA2(I,JJ)      00041000
00000220      WAA(I,JJ)=WA1(I,JJ)                          00041100
00000221 690    CONTINUE                                     00041200
00000222      DO 692 JJ=1,K                                  00041300
00000223      SCH(JJ)=SC(5,JJ)                              00041400
00000224 692    OMGB(JJ) = WA2(5,JJ)                      00041500

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00000225      CALL BNDCHM ( RE(5), SCH, H(5)/D(5), D(5), C(3), C(13),           00042100
1              DEA1(5)/C(3), OMGB, TWA(5), PA2(5), AVEMOL(5),           00042200
2              DMGW, GM1(5) )                                           00042300
00000226      DO 694 JJ=1,K                                             00042400
00000227      WWA(5,JJ) = OMGW(JJ)                                       00042500
00000228      SCH(JJ)=SC(11,JJ)                                           00042600
00000229 694   OMGB(JJ) = WA2(11,JJ)                                       00042700
00000230      CALL BNDCHM ( RE(11), SCH, H(11)/D(11), D(11), C(3), C(13),   00042800
1              DEA1(11)/C(3), OMGB, TWA(11), PA2(11), AVEMOL(11),     00042900
2              OMGW, GM1(11) )                                           00043000
00000231      DO 698 JJ=1,K                                             00043100
00000232 698   WWA(11,JJ) = OMGW(JJ)                                       00043200
00000233      DO 640 I=1,M                                             00043300
00000234      IF ( I.EQ.5.OR.I.EQ.11 ) GO TO 640                         00043400
00000235      DO 645 JJ=1,K                                             00043500
00000236 645   WWA(I,JJ) = WA2(I,JJ)                                       00043600
00000237 640   CONTINUE                                                    00043700
00000238      CALL PROPER                                               00043800
00000239 500   CONTINUE                                                    00043900
C                                                                 00044000
00000240      WRITE(6,*) '***** ITERATION TIME IS OVER AT TRANSIENT STATE !!' 00044100
1              , '*****'                                               00044200
C                                                                 00044300
00000241 300   WRITE(6,3000) ETIME, KK                                       00044400
00000242      WRITE(6,3100) (I,PA2(I),I=1,N)                               00044500
00000243      WRITE(6,3110) (I,GA2(I),I=1,M)                               00044600
00000244      WRITE(6,3120) (I,RE(I),I=1,M)                               00044700
00000245      WRITE(6,3130) (I,TA2(I),I=1,N)                               00044800
00000246      WRITE(6,3145) (I,TA2(I),I=1,M)                               00044900
00000247      WRITE(6,3140) (I,TO2(I),I=1,M)                               00045000
00000248      DO 415 KPRT=2,5                                             00045100
00000249      WRITE(6,3150) KPRT, (I,WN2(I,KPRT),I=1,N)                 00045200
00000250      WRITE(6,3180) (I,WA2(I,KPRT),I=1,M)                       00045300
00000251      WRITE(6,3160) (I,WO2(I,KPRT),I=1,M)                       00045400
00000252 415   WRITE(6,3170) (I,WWA(I,KPRT),I=1,M)                       00045500
C                                                                 00045600
00000253      DO 800 I=1,M                                             00045700
00000254      IF (DABS((GA2(I)-GGT(I))/GGT(I)).GT.EPST) EPST=DABS((GA2(I)
*-GGT(I))/GGT(I))
00000255      IF (DABS((TO2(I)-TTOT(I))/TTOT(I)).GT.EPST) EPST=DABS((TO2(I)
*-TTOT(I))/TTOT(I))
00000256      DO 800 JJ=1,K                                             00046200
00000257      IF(DABS(WO2(I,JJ)-WWOT(I,JJ)).GT.EPST) EPST=DABS(WO2(I,JJ)
*-WWOT(I,JJ))
00000258 800   CONTINUE                                                    00046500
00000259      DO 810 I=1,N                                             00046600
00000260      IF (DABS((TN2(I)-TTNT(I))/TTNT(I)).GT.EPST) EPST=DABS((TN2(I)
*-TTNT(I))/TTNT(I))
00000261      DO 810 JJ=1,K                                             00046900
00000262      IF (DABS(WN2(I,JJ)-WWNT(I,JJ)).GT.EPST) EPST=DABS(WN2(I,JJ)
*-WWNT(I,JJ))
00000263 810   CONTINUE                                                    00047000
C                                                                 00047100
00000264      IF (EPST.LE.1.0E-5) GO TO 2000                             00047200
C                                                                 00047300
00000265      DO 900 I=1,M                                             00047400
00000266      GGT(I)=GA2(I)                                               00047500
00000267      TTOT(I)=TO2(I)                                             00047600
00000268      TTAT(I)=TA2(I)                                             00047700
00000269      DO 900 JJ=1,K                                             00047800
00000269      DO 900 JJ=1,K                                             00047900
00000269      DO 900 JJ=1,K                                             00048000

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00000270      WWOT(I,JJ)=W02(I,JJ)
00000271      WAAT(I,JJ)=WA2(I,JJ)
00000272 900  CONTINUE
00000273      DO 910 I=1,N
00000274      DO 910 JJ=1,K
00000275      TTNT(I)=TTN(I)
00000276      WWNT(I,JJ)=WWN(I,JJ)
00000277 910  CONTINUE
C
00000278      CALL PROPER
C
00000279 1000 CONTINUE
00000280      STOP
C
00000281 2000 WRITE(6,3010) ETIME, KK
00000282      WRITE(6,3100) (I,P2(I),I=1,N)
00000283      WRITE(6,3110) (I,GA2(I),I=1,M)
00000284      WRITE(6,3120) (I,RE(I),I=1,M)
00000285      WRITE(6,3130) (I,TN2(I),I=1,N)
00000286      WRITE(6,3145) (I,TA2(I),I=1,M)
00000287      WRITE(6,3140) (I,TO2(I),I=1,M)
00000288      DO 425 KPRT=2,S
00000289      WRITE(6,3150) KPRT, (I,WN2(I,KPRT),I=1,N)
00000290      WRITE(6,3180) (I,WA2(I,KPRT),I=1,M)
00000291      WRITE(6,3160) (I,W02(I,KPRT),I=1,M)
00000292 425  WRITE(6,3170) (I,WWA(I,KPRT),I=1,M)
C
00000293 3000 FORMAT(1H0,/,/, ' ***** TIME =',F8.3,' (SEC) ITER.NO.=',
* 13,' ***** ')
00000294 3010 FORMAT(1H1,/,20('*'),' STEADY STATE IN TRANSIENT CALCULATION',
* ' TIME =',F8.3,' (SEC) ITER.NO.=',I3,' ',20('*'))
00000295 3020 FORMAT(1H1,/,20('*'),' STEADY STATE !!!',
* ' LL =',I3,' ',60('*'))
00000296 3100 FORMAT(1H0,' <PRESSURE AT NODE>', //,1X,8(I2,1PE14.7,1X)//,
* 1X,8(I2,E14.7,1X)//,1X,8(I2,E14.7,1X)//,1X,8(I2,E14.7,1X))
00000297 3110 FORMAT(1H0,' <FLOW RATE OF BRANCH>', //,1X,8(I2,1PE13.5,2X)//,
* 1X,8(I2,E13.5,2X)//,1X,8(I2,E13.5,2X)//,1X,8(I2,E13.5,2X))
00000298 3120 FORMAT(1H , ' <REYNOLDS NUMBER>', //,1X,10(I2,F8.2,3X)//,
* 1X,10(I2,F8.2,3X)//,1X,10(I2,F8.2,3X))
00000299 3130 FORMAT(1H0,' <TEMPERATURE AT NODE>', //,1X,10(I2,F8.2,3X)//,
* 1X,10(I2,F8.2,3X)//,1X,10(I2,F8.2,3X))
00000300 3135 FORMAT(1H , ' <TEMPERATURE AT WALL>', //,1X,10(I2,F8.2,3X)//,
* 1X,10(I2,F8.2,3X)//,1X,10(I2,F8.2,3X))
00000301 3140 FORMAT(1H , ' <TEMP. OF BRANCH OUTLET>',//,1X,10(I2,F8.2,3X)//,
* 1X,10(I2,F8.2,3X)//,1X,10(I2,F8.2,3X))
00000302 3145 FORMAT(1H , ' <AVERAGE TEMP. OF BRANCH>',//,1X,10(I2,F8.2,3X)//,
* 1X,10(I2,F8.2,3X)//,1X,10(I2,F8.2,3X))
00000303 3150 FORMAT(1H0,' <CONCENTRATION AT NODE> GAS =',I2,' : 1=HE, 2=O2',
* ' , 3=CO, 4=CO2, 5=N2 ---',//,
* 1X,10(I2,F9.5,2X)//,1X,10(I2,F9.5,2X)//,1X,10(I2,F9.5,2X))
00000304 3160 FORMAT(1H , ' <CONC. OF BRANCH OUTLET> ',//,
* 1X,10(I2,F9.5,2X)//,1X,10(I2,F9.5,2X)//,1X,10(I2,F9.5,2X))
00000305 3170 FORMAT(1H , ' <CONCENTRATION ON WALL> ',//,
* 1X,10(I2,F9.5,2X)//,1X,10(I2,F9.5,2X)//,1X,10(I2,F9.5,2X))
00000306 3180 FORMAT(1H , ' <AVERAGE CONCENTRATION OF BRANCH>',//,
* 1X,10(I2,F9.5,2X)//,1X,10(I2,F9.5,2X)//,1X,10(I2,F9.5,2X))
00000307      STOP
00000308      END

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C
C*****00053900
C*****00054000
C*****00054100
C***** TO CALCULATE MASS FLOW RATE AND PRESSURE *****00054200
C*****00054300
00000001 SUBROUTINE MOMENT ( KK ) 00054400
C*****00054500
C*****00054600
C 00054700
00000002 IMPLICIT REAL*8 (A-H,O-Z) 00054800
00000003 PARAMETER (N=26, M=27, K=5, J=200, PI=3.141592645, GRAV=9.807 ) 00054900
00000004 DIMENSION H(M),D(M),Y(M),F(M),TA1(M),GA1(M),GA2(M),PA1(M),PA2(M),
*PN1(N),PN2(N),DEA1(M),DI(M,K),CP(M),RE(M),GR(M),PR(M), 00055100
*SC(M,K),SH(M,K),C(13),AG(M),BG(M),AAG(M,M+1),P1(N),GA(M), 00055200
*WA1(M,K),DED(M),DEI(M),TN1(N),TI1(M),TI2(M),P2(N),GM1(M), 00055300
*TO1(M),TO2(M),TA2(M),WI1(M,K),WI2(M,K),WO1(M,K),WO2(M,K),TN2(N), 00055400
*WA2(M,K),S(M,M),CAT(M),Q(M), 00055500
*GX1(M),GX2(M),PX1(N),PX2(M),TWA(M),CPN(M),CPO(M), 00055600
*AVEMOL(M),WN1(N,K),WN2(N,K),WWA(M,K), 00055700
*TTAT(M),GGT(M),WAAT(M,K),PP(N),PPT(N),PAT(M),CPT(M),DEAT(M) 00055800
00000005 REAL*8 NNI(M),NNO(M),MU(M),LAM(M),NU(M),MOLW(K+1) 00055900
C 00056000
00000006 COMMON/SIZE/H,D,Y,F,NNI,NNO,CAT,DT 00056100
* /TEMP/TI1,TI2,TO1,TO2,TA1,TA2,TN1,TN2,TWA,TTAT 00056200
* /PRES/P1,P2,PN1,PN2,PA1,PA2,PP,PPT,PAT 00056300
* /COMP/WI1,WI2,WO1,WO2,WA1,WA2,WN1,WN2,WAAT,WWA 00056400
* /FLOW/GA1,GA2,GA,GGT,GM1 00056500
* /QUAL/DI,CP,CPT,CPO,CPN,MU,LAM,DEI,DED,DEA1,DEAT 00056600
* /MLWG/MOLW,AVEMOL,C 00056700
* /REFE/RE,GR,PR,NU,SC,SH,Q 00056800
C 00056900
00000007 DO 200 L=1,J 00057000
00000008 DO 30 I=1,M 00057100
00000009 AG(I) = 0.0 00057200
00000010 BG(I) = 0.0 00057300
00000011 DO 30 JJ=1,M+1 00057400
00000012 AAG(I,JJ)=0.0 00057500
00000013 30 CONTINUE 00057600
00000014 DO 80 I=1,M 00057700
00000015 PX1(NNI(I))=(P1(NNI(I))-C(1))*D(I)**2/C(3)/C(13)**2 00057800
00000016 IF(I.EQ.1) THEN 00057900
00000017 PX1(NNI(I))=0.0 00058000
00000018 END IF 00058100
00000019 IF(I.EQ.M) THEN 00058200
00000020 PX1(NNO(I))=0.0 00058300
00000021 END IF 00058400
00000022 PA1(I)=(P1(NNI(I))+P1(NNO(I)))/2.0 00058500
00000023 80 CONTINUE 00058600
C 00058700
C***** COEFFICIENTS OF MATRIX *****00058800
C 00058900
00000024 DO 150 I=1,M 00059000
00000025 GX1(I)=GA1(I)*D(I)/C(3)/C(13) 00059100
00000026 RE(I)=DABS(GA1(I)*D(I)/MU(I)) 00059200
00000027 F(I) = FRIC ( RE(I),H(I)/D(I) ) 00059300
00000028 GR(I)=(C(3)-C(4))*GRAV*D(I)**3/C(3)/C(13)**2 00059400
00000029 IF (KK.EQ.1) THEN 00059500
00000030 AG(I)=AG(I)+(4.0*F(I)+D(I)/H(I)*Y(I))*DABS(GX1(I))/2./DEA1(I) 00059600
* C(3)*H(I)/D(I) 00059700
00000031 AG(I)=AG(I)*C(3)*C(13)**2/D(I)**2 00059800

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00000032      BG(I)=BG(I)+GX1(I)*DABS(GX1(I))*(C(3)/DEO(I)-C(3)/DEI(I))      00059900
00000033      BG(I)=BG(I)+GR(I)*(DEA1(I)-C(3))/(C(3)-C(4))*H(I)*      00060000
      *DCOS(PI/180.0*CATT(I))/D(I)      00060100
00000034      BG(I)=BG(I)*C(3)*C(13)**2/D(I)**2      00060200
00000035      END IF      00060300
00000036      IF(KK.EQ.2) THEN      00060400
00000037      AG(I)=AG(I)+(4.0*F(I)+D(I)/H(I)*Y(I))*DABS(GX1(I))/2./DEA1(I)      00060500
      *C(3)*H(I)/D(I)      00060600
00000038      AG(I)=AG(I)+H(I)*D(I)/DT/C(13)      00060700
00000039      AG(I)=AG(I)*C(3)*C(13)**2/D(I)**2      00060800
00000040      BG(I)=BG(I)+GX1(I)*DABS(GX1(I))*(C(3)/DEO(I)-      00060900
      *C(3)/DEI(I))      00061000
00000041      BG(I)=BG(I)+GR(I)*(DEA1(I)-C(3))/(C(3)-C(4))*H(I)*      00061100
      *DCOS(PI/180.0*CATT(I))/D(I)      00061200
00000042      BG(I)=BG(I)-GG7(I)*D(I)/C(3)/C(13)*H(I)*D(I)/DT/C(13)      00061300
00000043      BG(I)=BG(I)*C(3)*C(13)**2/D(I)**2      00061400
00000044      END IF      00061500
00000045 130  CONTINUE      00061600
00000046 150  CONTINUE      00061700
C      00061800
C***** INPUT THE COEFFICIENTS OF THE MATRIX ***** 00061900
C      00062000
00000047      DO 100 I=1,M      00062100
00000048      DO 100 JJ=1,M      00062200
00000049      S(I,JJ)=PI/4.0*D(JJ)*C(3)*C(13)      00062300
00000050 100  CONTINUE      00062400
00000051      AAG(1,1)=S(1,1)      00062500
00000052      AAG(1,2)=-S(1,2)      00062600
00000053      AAG(1,8)=-S(1,8)      00062700
00000054      AAG(1,14)=-S(1,14)      00062800
00000055      DO 500 I=2,6      00062900
00000056      AAG(I,I)=S(I,I)      00063000
00000057      AAG(I,I+1)=-S(I,I+1)      00063100
00000058 500  CONTINUE      00063200
00000059      DO 510 I=8,12      00063300
00000060      AAG(I,I)=S(I,I)      00063400
00000061      AAG(I,I+1)=-S(I,I+1)      00063500
00000062 510  CONTINUE      00063600
00000063      AAG(7,7)=S(7,7)      00063700
00000064      AAG(7,13)=S(7,13)      00063800
00000065      AAG(7,19)=S(7,19)      00063900
00000066      AAG(7,20)=-S(7,20)      00064000
00000067      DO 520 I=2,7      00064100
00000068      AAG(13,I)=-AG(I)      00064200
00000069 520  CONTINUE      00064300
00000070      DO 525 I=8,13      00064400
00000071      AAG(13,I)=AG(I)      00064500
00000072 525  CONTINUE      00064600
00000073      DO 530 I=14,18      00064700
00000074      AAG(I,I)=S(I,I)      00064800
00000075      AAG(I,I+1)=-S(I,I+1)      00064900
00000076 530  CONTINUE      00065000
00000077      DO 540 I=8,13      00065100
00000078      AAG(19,I)=-AG(I)      00065200
00000079 540  CONTINUE      00065300
00000080      DO 550 I=14,19      00065400
00000081      AAG(19,I)=AG(I)      00065500
00000082 550  CONTINUE      00065600
00000083      DO 560 I=20,26      00065700
00000084      AAG(I,I)=S(I,I)      00065800

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00000085      AAG(I,I+1)=-S(I,I+1)                                00065900
00000086 560   CONTINUE                                          00066000
00000087      DO 570 I=14,27                                       00066100
00000088      AAG(27,1)=-AG(1)                                       00066200
00000089      AAG(27,I)=-AG(I)                                       00066300
00000090 570   CONTINUE                                          00066400
00000091      AAG(13,M+1)=BG(2)+BG(3)+BG(4)+BG(5)+BG(6)+BG(7)-BG(8) 00066500
* -BG(9)-BG(10)-BG(11)-BG(12)-BG(13) 00066600
00000092      AAG(19,M+1)=BG(8)+BG(9)+BG(10)+BG(11)+BG(12)+BG(13)-BG(14) 00066700
* -BG(15)-BG(16)-BG(17)-BG(18)-BG(19) 00066800
00000093      AAG(27,M+1)=BG(1)+BG(14)+BG(15)+BG(16)+BG(17)+BG(18)+BG(19) 00066900
* +BG(20)+BG(21)+BG(22)+BG(23)+BG(24)+BG(25)+BG(26)+BG(27) 00067000

C
00000094      DMLESS = PI/4.0*D(5)**2*H(5)                                00067200
00000095      DMLES1 = PI/4.0*D(11)**2*H(11)                             00067300
00000096      IF (GX1(5).LT.0.0) THEN                                    00067400
00000097      AAG(4,M+1)=-GM1(5) * DMLESS,                               00067500
00000098      AAG(5,M+1)=0.0                                             00067600
00000099      ELSE IF (GX1(5).GE.0.0) THEN                               00067700
00000100      AAG(4,M+1)=0.0                                             00067800
00000101      AAG(5,M+1)=-GM1(5) * DMLESS                               00067900
00000102      END IF                                                  00068000
00000103      IF (GX1(11).LT.0.0) THEN                                    00068100
00000104      AAG(10,M+1)=-GM1(11) * DMLES1                             00068200
00000105      AAG(11,M+1)=0.0                                             00068300
00000106      ELSE IF (GX1(11).GE.0.0) THEN                               00068400
00000107      AAG(10,M+1)=0.0                                             00068500
00000108      AAG(11,M+1)=-GM1(11) * DMLES1                             00068600
00000109      END IF                                                  00068700
C
C***** TO SOLVE MATRIX *****
C
00000110      CALL GAUELD (AAG,M,M,M+1,1.0E-10,ILL)                       00069100
00000111      IF(ILL.EQ.0) GO TO 1                                          00069200
00000112      WRITE(6,*) 'GAUELD AT MOMENT ; L, ILL ',L,ILL              00069300
00000113      STOP                                                         00069400
00000114 1   JJ=M+1                                                    00069500
00000115      DO 2 I=1,M                                                  00069600
00000116      GA1(I)=AAG(I,JJ)*C(3)*C(13)/D(I)                          00069700
00000117 2   CONTINUE                                                  00069800
C
C***** JUDGEMENT OF CONVERGENCE *****
C
00000118      EPS=1.0E-4                                                  00070000
00000119      DO 50 I=1,M-1                                               00070100
00000120      IF (DABS((AAG(I+1,M+1)-GX1(I+1))/DABS(GX1(I+1))).GT. 00070200
* DABS((AAG(I,M+1)-GX1(I))/DABS(GX1(I)))) 00070300
* TTA=DABS((AAG(I+1,M+1)-GX1(I+1))/GX1(I+1)) 00070400
CONTINUE 00070500
IF (TTA.LE.EPS) GO TO 40 00070600
DO 210 JJ=1,M 00070700
GX1(JJ)=GX1(JJ)+0.3*(AAG(JJ,M+1)-GX1(JJ)) 00070800
GA1(JJ)=GX1(JJ)*C(3)*C(13)/D(JJ) 00070900
CONTINUE 00071000
CONTINUE 00071100
CONTINUE 00071200
CONTINUE 00071300
WRITE(6,*) '***** ITERATION TIME IS OVER AT MOMENT SUBROUTINE' 00071400
1 ' !! *****' 00071500
C 00071600
C***** CONVERGED!!!!***** 00071700
C 00071800

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00000129	40	DO 60 I=1,M	00071900
00000130		GX2(I)=AAG(I,M+1)	00072000
00000131		GA2(I)=GX2(I)*C(3)*C(13)/D(I)	00072100
00000132		IF (ABS(GA2(I)).LT.1.0E-6) GA2(I)=1.0E-6	00072200
00000133		PX2(I)=0.0	00072300
00000134		P2(I)=1.0E+5	00072400
00000135		P2(NNO(I))=P2(NNI(I))-AG(I)*GX2(I)-BG(I)	00072500
00000136		PX2(NNO(I))=(P2(NNO(I))-C(1))*D(I)**2/C(3)/C(13)**2	00072600
00000137	60	CONTINUE	00072700
00000138		DO 65 I=1,M	00072800
00000139		PA2(I)=(P2(NNI(I))+P2(NNO(I)))/2.0	00072900
00000140	65	CONTINUE	00073000
00000141		DO 90 I=1,M	00073100
00000142		PX1(NNI(I))=PX2(NNI(I))	00073200
00000143		PX1(NNO(I))=PX2(NNO(I))	00073300
00000144		P1(NNI(I))=P2(NNI(I))	00073400
00000145		P1(NNO(I))=P2(NNO(I))	00073500
00000146		PA1(I)=PA2(I)	00073600
00000147		GX1(I)=GX2(I)	00073700
00000148		GA1(I)=GA2(I)	00073800
00000149	90	CONTINUE	00073900
00000150		RETURN	00074000
00000151		END	00074100

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C
C*****00074200
C*****00074300
C*****00074400
C*****00074500
C*****00074600
00000001 SUBROUTINE PROPER 00074700
C*****00074800
C*****00074900
C 00075000
C DI ; DIFFUSION FACTOR IN MIXTURE GAS (M**2/S) 00075100
C CP ; SPECIFIC HEAT OF MIXTURE GAS (J/KG.K) 00075200
C MU ; VISCOSITY OF MIXTURE GAS (PA.S) 00075300
C LAM ; THERMAL CONDUCTIVITY OF MIXTURE GAS (W/M.K) 00075400
C DEAI ; DENSITY OF MIXTURE GAS (KG/M**3) 00075500
C T ; TEMPRETURE OF MIXTURE GAS (K) 00075600
C PP ; PRESSURE OF MIXTURE GAS (PA) 00075700
C 00075800
00000002 IMPLICIT REAL*8 (A-H,O-Z) 00075900
00000003 PARAMETER (N=26, M=27, K=5) 00076000
00000004 DIMENSION H(M),D(M),Y(M),F(M),NNI(M),NNO(M),CP(M),
1 W2(K),W3(K),W4(K),W5(K),GA1(M),GA2(M),WN1(N,K),
2 CPOT(M),CPN(M),CPT(M),DEAT(M),AVEMOL(M),WN2(N,K),
* W(K),DIM(K),DDI(K,K),P1(N),P2(N),PN2(N),PP1(M),PPT(M),PAT(M),
* AMU(6), AD(8), TD(K,K), OMIKAD(K,K), FIB(K,K), FIA(K,K),EA(K),
* RA(K),CCP(K), CPA(K,4), TMU(K), OMIKAV(K), CPO(K), WFIA(K),
* TI1(M),TI2(M),TO1(M),TO2(M),TA1(M),TA2(M),TN1(N),PN1(N),
* PA1(M),PA2(M),WI1(M,K),WI2(M,K),WO1(M,K),WO2(M,K),WA1(M,K),
* WA2(M,K),DI(M,K),DEI(M),DEO(M),DEA1(M),WAAT(M,K),WWA(M,K),
* CPA1(K),TN2(N),TWA(M), TTAT(M)
00000005 REAL*8 LAS(K), MUS(K), LA(K), MU(M), LAM(M), MOLW(K+1), MUM,
* NNI, NNO, LAMM
00000006 COMMON/TEMP/TI1,TI2,TO1,TO2,TA1,TA2,TN1,TN2, TWA, TTAT
*/PRES/P1, P2, PN1, PN2, PA1, PA2, PP1, PPT, PAT
*/COMP/WI1,WI2,WO1,WO2,WA1,WA2,WN1,WN2,WAAT, WWA
*/QUAL/DI,CP,CPT,CPOT,CPN,MU,LAM,DEI,DEO,DEA1,DEAT
*/MLWG/MOLW,AVEMOL
*/FLOW/GA1,GA2
*/SIZE/H,D,Y,F,NNI,NNO
C
00000007 DATA AD/1.06036, 0.15610, 0.19300, 0.47635, 1.03587, 1.52996,
* 1.76474, 3.89411/
* EA/10.22, 106.7, 91.7, 195.2, 71.4/
* RA/2.551, 3.467, 3.690, 3.941, 3.798/
* AMU/1.16145, 0.14874, 0.52487, 0.77320, 2.16178, 2.43787/
00000008 DATA CPA1/4.9677, 6.713, 7.373, 4.728, 7.440/
00000009 DATA CPA/4.9677, 0.817026, 0.929207, 0.618542, 0.938314,
* 0.0, 3.87124E-4, 3.43656E-4, 9.43157E-4, 2.95732E-4,
* 0.0, -1.41476E-7, -1.00711E-7, -3.9229E-7, -7.31507E-8,
* 0.0, 1.99678E-11, 1.01493E-11, 5.44078E-11, 5.81796E-12/
C
00000010 DO 1000 II=1,M 00079200
00000011 T = TA1(II) + 273.15 00079300
00000012 T2 = TTAT(II) + 273.15 00079400
00000013 T4 = TO1(II) + 273.15 00079500
00000014 III = NNI(II) 00079600
00000015 IIO = NNO(II) 00079700
00000016 IF ( GA2(II).LT.0.0 ) THEN 00079800
00000017 III = NNO(II) 00079900
00000018 IIO = NNI(II) 00080000
00000019 ENDDIF 00080100

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00000020      PP = PA1(II)                                00080200
00000021      PP2 = PAT(II)                            00080300
00000022      IF ( II.GT.N.OR.III.GT.N ) GO TO 1010  00080400
00000023      T3 = TN1(II) + 273.15                    00080500
00000024      T5 = TN1(III) + 273.15                  00080600
00000025      PP3 = P1(II)                             00080700
00000026      PP4 = P1(II)                             00080800
00000027      PP5 = P1(II)                             00080900
00000028 1010    CONTINUE                              00081000
00000029      DO 1100 JJ=1,K                            00081100
00000030      W(JJ) = WA1(II,JJ)                       00081200
00000031      W2(JJ) = WAAT(II,JJ)                    00081300
00000032      W4(JJ) = W01(II,JJ)                     00081400
00000033      IF ( II.GT.N ) GO TO 1100                00081500
00000034      W3(JJ) = WN1(II,JJ)                      00081600
00000035      W5(JJ) = WN1(II,JJ)                      00081700
00000036 1100    CONTINUE                              00081800
C                                                     00081900
C***** DIFFUSION FACTOR IN MIXTURE GAS DIM(I) ***** 00082000
C                                                     00082100
00000037      DO 140 I=1,K                              00082200
00000038      DIM(I)=0.0                                00082300
00000039 140    CONTINUE                              00082400
00000040      DO 120 I=1,K                              00082500
00000041      DO 120 JJ=1,K                            00082600
00000042      IF(T.LE.0.0) THEN                        00082700
00000043      TD(I,JJ)=273.15/(EA(I)*EA(JJ))*0.5      00082800
00000044      END IF                                  00082900
00000045      IF (T.GT.0.0) THEN                        00083000
00000046      TD(I,JJ)=T/(EA(I)*EA(JJ))*0.5          00083100
00000047      END IF                                  00083200
00000048      DMIKAD(I,JJ)=AD(1)/TD(I,JJ)**AD(2)+AD(3)*DEXP(-AD(4)*TD(I,JJ)) 00083300
00000049      *+AD(5)*DEXP(-AD(6)*TD(I,JJ))            00083400
00000049      DDI(I,JJ)=1.858E-7*T**1.5*((MOLW(I)+MOLW(JJ))*1.0E+3)**0.5/ 00083500
00000049      *(MOLW(I)*1.0E+3)**0.5/(MOLW(JJ)*1.0E+3)**0.5/PP*0.98692E+5 00083600
00000049      */DMIKAD(I,JJ)/((RA(I)+RA(JJ))/2.)*2    00083700
00000050      DIM(I)=DIM(I)+W(JJ)/DDI(I,JJ)            00083800
00000051 120    CONTINUE                              00083900
00000052      DO 130 I=1,K                              00084000
00000053      DIM(I)=1.0/DIM(I)                        00084100
00000054 130    CONTINUE                              00084200
C                                                     00084300
C***** SPECIFIC HEAT OF MIXTURE GAS ; CPM ***** 00084400
C                                                     00084500
00000055      CPM=0.0                                  00084600
00000056      DO 210 I=1,K                              00084700
00000057      CCP(I)=(CPA(I,1)+CPA(I,2)*T+CPA(I,3)*T**2+CPA(I,4)*T**3)*1.0E+3 00084800
00000058      CPM=CPM+CCP(I)*W(I)                      00084900
00000059 210    CONTINUE                              00085000
00000060      CPM2=0.0                                  00085100
00000061      DO 220 I=1,K                              00085200
00000062      CCP(I)=(CPA(I,1)+CPA(I,2)*T2+CPA(I,3)*T2**2+CPA(I,4)*T2**3)*1.0E+3 00085300
00000063      CPM2=CPM2+CCP(I)*W2(I)                  00085400
00000064 220    CONTINUE                              00085500
00000065      CPM4=0.0                                  00085600
00000066      DO 230 I=1,K                              00085700
00000067      CCP(I)=(CPA(I,1)+CPA(I,2)*T4+CPA(I,3)*T4**2+CPA(I,4)*T4**3)*1.0E+3 00085800
00000068      CPM4=CPM4+CCP(I)*W4(I)                  00085900
00000069 230    CONTINUE                              00086000
00000070      CPM5=0.0                                  00086100

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00000071      DO 240 I=1,K                                00086200
00000072      CCP(I)=(CPA(I,1)+CPA(I,2)*T5+CPA(I,3)*T5**2+CPA(I,4)*T5**3)*1.0E+300086300
00000073      CPMS=CPMS+CCP(I)*W5(I)                    00086400
00000074-240  CONTINUE                                  00086500
C                                                     00086600
C***** VISCOSITY OF MIXTURE GAS ; MUM ***** 00086700
C                                                     00086800
00000075      MUM=0.0                                   00086900
00000076      DO 310 I=1,K                               00087000
00000077      IF(T.LE.0.0) THEN                          00087100
00000078      TMU(I)=273.15/EA(I)                       00087200
00000079      END IF                                    00087300
00000080      IF(T.GT.0.0) THEN                          00087400
00000081      TMU(I)=T/EA(I)                            00087500
00000082      END IF                                    00087600
00000083      OMIKAV(I)=AMU(1)/TMU(I)**AMU(2)+AMU(3)*DEXP(-AMU(4)*TMU(I)) 00087700
      *+AMU(5)*DEXP(-AMU(6)*TMU(I))                    00087800
00000084      MUS(I)=26.69*(MOLW(I)*1.0E+3*T)**0.5*1.0E-7/OMIKAV(I)/RA(I)**2 00087900
00000085      WFIA(I)=0.0                                00088000
00000086 310  CONTINUE                                  00088100
00000087      DO 320 I=1,K                               00088200
00000088      DO 330 JJ=1,K                             00088300
00000089      FIA(I,JJ)=(1.0+(MUS(I)/MUS(JJ))**0.5*(MOLW(JJ)/MOLW(I)) 00088400
      ***0.25)**2/(8.0*(1.0+MOLW(I)/MOLW(JJ))**0.5 00088500
00000090      WFIA(I)=WFIA(I)+W(JJ)*FIA(I,JJ)          00088600
00000091 330  CONTINUE                                  00088700
00000092      MUM=MUM+W(I)*MUS(I)/WFIA(I)              00088800
00000093 320  CONTINUE                                  00088900
C                                                     00089000
C***** THERMAL CONDUCTIVITY OF MIXTURE GAS ; LAMM **** 00089100
C                                                     00089200
00000094      LAMM=0.0                                   00089300
00000095      DO 410 I=1,K                               00089400
00000096      LAS(I)=0.0                                  00089500
00000097      CPO(I)=CPA1(I)-1.986                     00089600
00000098      LA(I)=4.186*(1.32*CPO(I)+3.52)*MUS(I)/MOLW(I) 00089700
00000099 410  CONTINUE                                  00089800
00000100      DO 430 I=1,K                               00089900
00000101      DO 420 JJ=1,K                             00900000
00000102      FIB(I,JJ)=(1.0+(LA(I)/LA(JJ))**0.5*(MOLW(JJ)/MOLW(I))**0.25) 00090100
      ***2/(8.0*(1.0+MOLW(I)/MOLW(JJ))**0.5 00090200
00000103      LAS(I)=LAS(I)+W(JJ)*FIB(I,JJ)            00090300
00000104 420  CONTINUE                                  00090400
00000105      LAMM=LAMM+W(I)*LA(I)/LAS(I)              00090500
00000106 430  CONTINUE                                  00090600
C                                                     00090700
C***** DENSITY OF MIXTURE GAS ; DEM ***** 00090800
C                                                     00090900
00000107      AVEM = 0.0                                 00091000
00000108      DO 510 I=1,K                               00091100
00000109 510  AVEM = AVEM + W(I) /MOLW(I)              00091200
00000110      AVEM = 1.0/AVEM                          00091300
00000111      DEM = AVEM *PP /8.314/T                  00091400
00000112      AVEM2 = 0.0                               00091500
00000113      DO 520 I=1,K                               00091600
00000114 520  AVEM2 = AVEM2 + W2(I)/MOLW(I)            00091700
00000115      AVEM2 = 1.0/AVEM2                        00091800
00000116      DEM2 = AVEM2*PP2/8.314/T2               00091900
00000117      AVEM3 = 0.0                               00092000
00000118      DO 530 I=1,K                               00092100

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00000119 530  AVEM3 = AVEM3 + W3(I)/MOLW(I)          00092200
00000120      AVEM3 = 1.0/AVEM3                    00092300
00000121      DEM3 = AVEM3*PP3/8.314/T3            00092400
00000122      AVEM4 = 0.0                          00092500
00000123      DO 540 I=1,K                          00092600
00000124 540  AVEM4 = AVEM4 + W4(I)/MOLW(I)        00092700
00000125      AVEM4 = 1.0/AVEM4                    00092800
00000126      DEM4 = AVEM4*PP4/8.314/T4            00092900
C                                                    00093000
C*****      REPLACEMENT OF EACH THERMAL PROPERTIES ***** 00093100
C                                                    00093200
00000127      DO 1200 JJ=1,K                          00093300
00000128 1200  DI(I,JJ) = DIM(JJ)                  00093400
00000129      CP(I) = CPM                            00093500
00000130      CPT(I) = CPM2                          00093600
00000131      CPOT(I) = CPM4                          00093700
00000132      CPN(I) = CPM5                          00093800
00000133      MU(I) = MUM                             00093900
00000134      LAM(I) = LAMM                          00094000
00000135      AVEMOL(I) = AVEM                       00094100
00000136      DEAI(I) = DEM                           00094200
00000137      DEAT(I) = DEM2                          00094300
00000138      DEI(I) = DEM3                          00094400
00000139      DEO(I) = DEM4                          00094500
00000140      IF ( GA2(I).LT.0.0 ) THEN              00094600
00000141      DEI(I) = DEM4                          00094700
00000142      DEO(I) = DEM3                          00094800
00000143      ENDIF                                  00094900
C                                                    00095000
00000144 1000  CONTINUE                             00095100
C                                                    00095200
00000145      RETURN                                  00095300
00000146      END                                    00095400

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C
C*****00095500
C*****00095600
C*****00095700
C***** TO SOLVE TEMPERATURE OF NODE AND BRANCH OUTLET *****00095800
C*****00095900
00000001 SUBROUTINE TEMPRT ( KK ) 00096000
C*****00096100
C*****00096200
C 00096300
00000002 IMPLICIT REAL*8 (A-H,O-Z) 00096400
00000003 PARAMETER (N=26, M=27, K=5, J=200, PI=3.14159264 ) 00096500
C 00096600
00000004 DIMENSION H(M),D(M),Y(M),F(M),CAT(M), 00096700
*TI1(M),TI2(M),TO1(M),TO2(M),TA1(M),TA2(M),TN1(N),TN2(N),TWA(M), 00096800
*TTAT(M), 00096900
*P1(N),P2(N),PN1(N),PN2(N),PA1(M),PA2(M),PP(N),PPT(N),PAT(M), 00097000
*GA1(M),GA2(M),GA(M),GGT(M), 00097100
*DI(M,K),CP(M),DEI(M),DEO(M),DEA1(M), 00097200
*CPN(M),CPO(M),CPT(M),DEAT(M),NI(M),NO(M), 00097300
*RE(M),GR(M),PR(M),SC(M,K),SH(M,K),Q(M), 00097400
*AAT(2*M-1,2*M),CS(2*M),TA(2*M-1), 00097500
*WI1(M,K),WI2(M,K),WO1(M,K),WO2(M,K),WA1(M,K),WA2(M,K), 00097600
*WN1(N,K),WN2(N,K),WAAT(M,K),AVEMOL(M),C(13), 00097700
*AT(M),CT(M),DDT(M),ET(M),ST(2*M),BT(M),GX2(M),TX1(N+M) 00097800
00000005 REAL*8 NNI(M),NNO(M),MU(M),LAM(M),NU(M),MOLW(K+1) 00097900
C 00098000
00000006 COMMON/SIZE/H,D,Y,F,NNI,NNO,CAT,DT 00098100
* /TEMP/TI1,TI2,TO1,TO2,TA1,TA2,TN1,TN2,TWA,TTAT 00098200
* /PRES/P1,P2,PN1,PN2,PA1,PA2,PP,PPT,PAT 00098300
* /COMP/WI1,WI2,WO1,WO2,WA1,WA2,WN1,WN2,WAAT 00098400
* /FLOW/GA1,GA2,GA,GGT 00098500
* /QUAL/DI,CP,CPT,CPO,CPN,MU,LAM,DEI,DED,DEA1,DEAT 00098600
* /MLWG/MOLW,AVEMOL,C 00098700
* /REFE/RE,GR,PR,NU,SC,SH,Q 00098800
C 00098900
00000007 DO 200 L=1,J 00099000
00000008 DO 30 JJ=1,2*M-1 00099100
00000009 DO 30 KJ=1,2*M 00099200
00000010 AAT(JJ,KJ)=0.0 00099300
00000011 30 CONTINUE 00099400
00000012 DO 150 I=1,M 00099500
00000013 AT(I) = 0.0 00099600
00000014 BT(I) = 0.0 00099700
00000015 CT(I) = 0.0 00099800
00000016 DDT(I) = 0.0 00099900
00000017 ET(I) = 0.0 01000000
00000018 IF (GA2(I)/DABS(GA2(I)).LT.0.0) THEN 01000100
00000019 NI(I)=NNO(I) 01000200
00000020 NO(I)=NNI(I) 01000300
00000021 END IF 01000400
00000022 IF (GA2(I)/DABS(GA2(I)).GE.0.0) THEN 01000500
00000023 NI(I)=NNI(I) 01000600
00000024 NO(I)=NNO(I) 01000700
00000025 END IF 01000800
00000026 150 CONTINUE 01000900
C 01010000
C***** HEAT TRANSFER AND OTHER COEFFICIENTS *****0101100
C 0101200
00000027 DO 350 I=1,M 0101300
00000028 PR(I)=MU(I)*CP(I)/LAM(I) 0101400

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00000029      NU(I) = HTC ( RE(I), PR(I), H(I)/D(I) )                00101500
00000030      CT(I)=4.0*NU(I)*LAM(I)*H(I)/D(I)/C(13)/C(3)/C(7)    00101600
00000031      ET(I)=ET(I)+D(I)**2/C(2)/C(6)/C(13)*H(I)/D(I)*Q(I)  00101700
00000032      GX2(I)=GA2(I)*D(I)/C(3)/C(13)                        00101800
C
00000033      IF (KK.EQ.1) THEN                                       00101900
00000034      DDT(I)=CT(I)                                           00102000
00000035      AT(I)=CT(I)*(TWA(I)-TA1(I))/C(2) + ET(I)             00102100
00000036      ELSE                                                                 00102200
00000037      DDT(I)=CT(I)+DEA1(I)/C(3)*CP(I)/C(7)*H(I)*D(I)/DT/C(13)  00102300
00000038      ET(I)=ET(I)+DEAT(I)/C(3)*CPT(I)/C(7)*(TTAT(I)+273.15)/C(2)*  00102400
      *H(I)*D(I)/DT/C(13)                                         00102500
00000039      AT(I)=AT(I)+CT(I)*(TWA(I)+273.15)/C(2)             00102600
00000040      AT(I)=AT(I)-DDT(I)*(TA1(I)+273.15)/C(2)           00102700
00000041      AT(I)=AT(I)+ET(I)                                       00102800
00000042      END IF                                                                 00102900
00000043 350  CONTINUE                                             00103000
C
C***** COEFFICIENTS OF MATRIX ***** 00103100
C
00000044      DO 100 I=1,M                                           00103200
00000045      ST(I)=PI/4.0*D(I)**2*DABS(GA2(I))*CPN(NI(I))*C(2)    00103300
00000046      IF(GA2(5)/DABS(GA2(5)).GE.0.0)                        00103400
      *ST(5)=PI/4.0*D(5)**2*DABS(GA2(4))*CPN(NI(5))*C(2)        00103500
00000047      IF(GA2(5)/DABS(GA2(5)).LT.0.0)                        00103600
      *ST(5)=PI/4.0*D(5)**2*DABS(GA2(6))*CPN(NI(5))*C(2)        00103700
00000048      IF(GA2(11)/DABS(GA2(11)).GE.0.0)                   00103800
      *ST(11)=PI/4.0*D(11)**2*DABS(GA2(10))*CPN(NI(11))*C(2)   00103900
00000049      IF(GA2(11)/DABS(GA2(11)).LT.0.0)                   00104000
      *ST(11)=PI/4.0*D(11)**2*DABS(GA2(12))*CPN(NI(11))*C(2)   00104100
00000050 100  CONTINUE                                             00104200
00000051      DO 120 I=M+1,2*M                                          00104300
00000052      ST(I)=-PI/4.0*D(I-M)**2*DABS(GA2(I-M))*CPD(I-M)*C(2)  00104400
00000053 120  CONTINUE                                             00104500
00000054      IF(GA2(1)/DABS(GA2(1)).LT.0.0) THEN                   00104600
00000055      AAT(1,1)=1.0                                           00104700
00000056      AAT(1,M)=-1.0                                         00104800
00000057      END IF                                                                 00104900
00000058      IF(GA2(1)/DABS(GA2(1)).GE.0.0) THEN                   00105000
00000059      AAT(1,1)=1.0                                           00105100
00000060      AAT(1,2*M)=1.0                                         00105200
00000061      END IF                                                                 00105300
00000062      IF(GA2(M)/DABS(GA2(M)).GE.0.0) THEN                   00105400
00000063      AAT(N,N)=1.0                                           00105500
00000064      AAT(N,N+M)=-1.0                                        00105600
00000065      END IF                                                                 00105700
00000066      IF(GA2(M)/DABS(GA2(M)).LT.0.0) THEN                   00105800
00000067      AAT(N,N)=1.0                                           00105900
00000068      AAT(N,2*M)=1.0                                        00106000
00000069      END IF                                                                 00106100
C
00000070      DO 390 I=1,2*M                                          00106200
00000071      CS(I)=1.0                                               00106300
00000072 390  CONTINUE                                             00106400
00000073      DO 400 I=2,14,6                                         00106500
00000074      IF(GA2(I)/DABS(GA2(I)).GE.0.0) CS(I+M)=0.0             00106600
00000075      IF(GA2(I)/DABS(GA2(I)).LT.0.0) CS(I)=0.0              00106700
00000076      IF(GA2(1)/DABS(GA2(1)).GE.0.0) CS(1)=0.0            00106800
00000077      IF(GA2(1)/DABS(GA2(1)).LT.0.0) CS(M+1)=0.0          00106900
00000078      AAT(2,2)=CS(1)*ST(1)+CS(2)*ST(2)+CS(8)*ST(8)+CS(14)*ST(14)  00107000

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00000079      AAT(2,I+N)=CS(I+M)*ST(I+M)                                00107500
00000080      AAT(2,M)=CS(M+1)*ST(M+1)                                00107600
00000081 400  CONTINUE                                                00107700
C
00000082      DO 410 I=3,7                                             00107800
00000083      IF(GA2(I)/DABS(GA2(I)).LT.0.0.OR.GA2(I-1)/DABS(GA2(I-1)).
*LT.0.0) THEN
00000084      AAT(I,I)=ST(I-1)                                           00107900
00000085      AAT(I,I+N)=ST(I+M)                                         00108000
00000086      GO TO 410
00000087      END IF
00000088      AAT(I,I)=ST(I)                                               00108100
00000089      AAT(I,I+N-1)=ST(I+M-1)                                     00108200
00000090 410  CONTINUE                                                00108300
C
00000091      DO 420 I=8,12                                            00108400
00000092      IF(GA2(I)/DABS(GA2(I)).LT.0.0.OR.GA2(I+1)/DABS(GA2(I+1)).
*LT.0.0) THEN
00000093      AAT(I,I)=ST(I)                                           00108500
00000094      AAT(I,I+1+N)=ST(I+1+M)                                     00108600
00000095      GO TO 420
00000096      END IF
00000097      AAT(I,I)=ST(I+1)                                           00108700
00000098      AAT(I,I+N)=ST(I+M)                                         00108800
00000099 420  CONTINUE                                                00108900
C
00000100      DO 430 I=13,17                                             00109000
00000101      IF(GA2(I+1)/DABS(GA2(I+1)).LT.0.0.OR.GA2(I+2)/DABS(GA2(I+2)).
*LT.0.0) THEN
00000102      AAT(I,I)=ST(I+1)                                           00109100
00000103      AAT(I,I+2+N)=ST(I+2+M)                                     00109200
00000104      GO TO 430
00000105      END IF
00000106      AAT(I,I)=ST(I+2)                                           00109300
00000107      AAT(I,I+1+N)=ST(I+1+M)                                     00109400
00000108 430  CONTINUE                                                00109500
C
00000109      IF(GA2(7)/DABS(GA2(7)).GE.0.0) CS(7)=0.0                    00109600
00000110      IF(GA2(7)/DABS(GA2(7)).LT.0.0) CS(7+M)=0.0                00109700
00000111      IF(GA2(13)/DABS(GA2(13)).GE.0.0) CS(13)=0.0             00109800
00000112      IF(GA2(13)/DABS(GA2(13)).LT.0.0) CS(13+M)=0.0          00109900
00000113      IF(GA2(19)/DABS(GA2(19)).GE.0.0) CS(19)=0.0            00110000
00000114      IF(GA2(19)/DABS(GA2(19)).LT.0.0) CS(19+M)=0.0          00110100
00000115      IF(GA2(20)/DABS(GA2(20)).GE.0.0) CS(20+M)=0.0          00110200
00000116      IF(GA2(20)/DABS(GA2(20)).LT.0.0) CS(20)=0.0            00110300
00000117      AAT(18,18)=CS(7)*ST(7)+CS(13)*ST(13)+CS(19)*ST(19)+CS(20)*ST(20) 00110400
00000118      AAT(18,7+N)=CS(7+M)*ST(7+M)                               00110500
00000119      AAT(18,13+N)=CS(13+M)*ST(13+M)                           00110600
00000120      AAT(18,19+N)=CS(19+M)*ST(19+M)                           00110700
00000121      AAT(18,20+N)=CS(20+M)*ST(20+M)                           00110800
C
00000122      DO 440 I=19,25                                             00110900
00000123      IF(GA2(I+1)/DABS(GA2(I+1)).LT.0.0.OR.GA2(I+2)/DABS(GA2(I+2)).
*LT.0.0) THEN
00000124      AAT(I,I)=ST(I+1)                                           00111000
00000125      AAT(I,I+2+N)=ST(I+2+M)                                     00111100
00000126      GO TO 440
00000127      END IF
00000128      AAT(I,I)=ST(I+2)                                           00111200
00000129      AAT(I,I+1+N)=ST(I+1+M)                                     00111300

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00000130 440 CONTINUE 00113500
C 00113600
00000131 DO 450 I=1,M 00113700
00000132 GX2(I)=GA2(I)*D(I)/C(3)/C(13) 00113800
00000133 AAT(I+N,I+N)=CPO(I)/C(7)*GX2(I) 00113900
00000134 AAT(I+N,NI(I))=-CPN(NI(I))/C(7)*GX2(I) 00114000
00000135 IF(GA2(5)/ABS(GA2(5)).GE.0.0) 00114100
* AAT(5+N,NI(5))=-CPN(NI(5))/C(7)*GX2(4) 00114200
IF(GA2(5)/ABS(GA2(5)).LT.0.0) 00114300
00000136 * AAT(5+N,NI(5))=-CPN(NI(5))/C(7)*GX2(6) 00114400
IF(GA2(11)/ABS(GA2(11)).GE.0.0) 00114500
* AAT(11+N,NI(11))=-CPN(NI(11))/C(7)*GX2(10) 00114600
IF(GA2(11)/ABS(GA2(11)).LT.0.0) 00114700
00000138 * AAT(11+N,NI(11))=-CPN(NI(11))/C(7)*GX2(12) 00114800
IF(GA2(I)/DABS(GA2(I)).LT.0.0) AAT(I+N,2*M)=-AT(I) 00114900
00000140 IF(GA2(I)/DABS(GA2(I)).GE.0.0) AAT(I+N,2*M)=AT(I) 00115000
00000141 450 CONTINUE 00115100
C 00115200
C***** TO SOLVE MATRIX ***** 00115300
C 00115400
00000142 CALL GAUELD (AAT,2*M-1,2*M-1,2*M,1.OE-10,ILL) 00115500
00000143 IF (ILL.EQ.0) GO TO 1 00115600
00000144 WRITE(6,*) 'GAUELD AT TEMPRT ; L, ILL ',L,ILL 00115700
00000145 STOP 00115800
00000146 1 DO 2 JJ=2*M,2*M 00115900
00000147 DO 3 I=1,N 00116000
00000148 TX1(I)=(TN1(I)+273.15)/C(2) 00116100
00000149 TN1(I)=AAT(I,JJ)*C(2) - 273.15 00116200
00000150 3 CONTINUE 00116300
00000151 DO 2 I=1,M 00116400
00000152 TX1(I+N)=(TO1(I)+273.15)/C(2) 00116500
00000153 TO1(I)=AAT(I+N,JJ)*C(2) - 273.15 00116600
00000154 2 CONTINUE 00116700
C 00116800
00000155 EPS=1.OE-3 00116900
00000156 TTA=0.0 00117000
00000157 DO 55 I=1,2*M-1 00117100
00000158 TA(I)=0.0 00117200
00000159 55 CONTINUE 00117300
00000160 DO 50 I=1,2*M-1 00117400
00000161 TA(I)=DABS((AAT(I,2*M)-TX1(I))/TX1(I)) 00117500
00000162 50 CONTINUE 00117600
00000163 DO 56 I=1,2*M-2 00117700
00000164 IF (TA(I+1).GE.TA(I)) TTA=TA(I+1) 00117800
00000165 IF (TA(I+1).LT.TA(I)) TTA=TA(I) 00117900
00000166 56 CONTINUE 00118000
00000167 IF (TTA.LE.EPS) GO TO 40 00118100
C 00118200
00000168 DO 210 JJ=1,2*M-1 00118300
00000169 TX1(JJ)=TX1(JJ)+0.1*(AAT(JJ,2*M)-TX1(JJ)) 00118400
00000170 210 CONTINUE 00118500
00000171 DO 215 I=1,N 00118600
00000172 TN1(I)=TX1(I)*C(2) - 273.15 00118700
00000173 215 CONTINUE 00118800
00000174 DO 225 I=1,M 00118900
00000175 TO1(I)=TX1(I+N)*C(2) - 273.15 00119000
00000176 225 CONTINUE 00119100
00000177 DO 240 JJ=1,M 00119200
00000178 SS=4.0*LAM(JJ)*NU(JJ)*H(JJ)/DABS(GA2(JJ))/D(JJ)**2/CP(JJ) 00119300
00000179 TA1(JJ)=TWA(JJ)+(TX1(NI(JJ))*C(2)-273.15-TWA(JJ))/SS 00119400

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*          *(1.0-1.0*EXP(-SS))
00000180 240 CONTINUE                                00119500
00000181 200 CONTINUE                                00119600
C                                                    00119700
C                                                    00119800
C*****          CONVERGED !!!          *****          00119900
C                                                    00120000
00000182 40 DO 60 I=1,N                              00120100
00000183 TN2(I)=AAT(I,2*M)*C(2) - 273.15              00120200
00000184 TN1(I)=TN2(I)                                00120300
00000185 60 CONTINUE                                  00120400
00000186 DO 65 I=1,M                                  00120500
00000187 T02(I)=AAT(I+N,2*M)*C(2) - 273.15          00120600
00000188 T01(I)=T02(I)                                00120700
00000189 SS=4.0*LAM(I)*NU(I)*H(I)/DABS(GA2(I))/D(I)**2/CP(I) 00120800
00000190 TA2(I)=TWA(I)+(TN2(NI(I))-TWA(I))/SS*(1.0-1.0*EXP(-SS)) 00120900
00000191 TA1(I)=TA2(I)                                00121000
00000192 65 CONTINUE                                  00121100
00000193 RETURN                                        00121200
00000194 END                                          00121300

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C
C*****00121400
C*****00121500
C*****00121600
C***** TO SOLVE CONCENTRATION OF NODE AND BRANCH OUTLET *****00121700
C*****00121800
00000001 C***** SUBROUTINE GASPEC ( KK ) 00121900
C*****00122000
C*****00122100
C*****00122200
C
00000002 IMPLICIT REAL*8 (A-H,O-Z) 00122300
00000003 PARAMETER (N=26, M=27, K=5, J=200, RG=8.314, PI=3.141592654 ) 00122400
C
00000004 DIMENSION H(M),D(M),Y(M),F(M),CAT(M), 00122500
*TI1(M),TI2(M),TO1(M),TO2(M),TA1(M),TA2(M),TN1(N),TN2(N),TWA(M), 00122600
*P1(N),P2(N),PN1(N),PN2(N),PA1(M),PA2(M), 00122700
*GA1(M),GA2(M),GA(M),GGT(M),TTAT(M),PP(N),PPT(N),PAT(M),WAAT(M,K), 00122800
*DI(M,K),CP(M),DEI(M),DEO(M),DEA1(M),DEAT(M),CPT(M), 00122900
*WN1(N,K),WN2(N,K),CS(2*M),Q(M),AVEMOL(M),CPO(M),CPN(M), 00123000
*RE(M),GR(M),PR(M),SC(M,K),SH(M,K),SI(M,K),WWA(M,K), 00123100
*WI1(M,K),WI2(M,K),WO1(M,K),WO2(M,K),WA1(M,K),WA2(M,K), 00123200
*AW(M,K),BW(M,K),CW(M,K),DW(M,K),AAW(2*M-1,2*M),SW(2*M,K), 00123300
*C(13),BAT(M,K),XW(K),GX2(M),NI(M),NO(M), 00123400
*WX1(2*M-1,K),WX2(2*M-1,K),TA(K) 00123500
00000005 REAL*8 NNI(M),NNO(M),MU(M),LAM(M),NU(M),MOLW(K+1) 00123600
00000006 COMMON/SIZE/H,D,Y,F,NN1,NNO,CAT,DT 00123700
* /TEMP/TI1, TI2, TO1, TO2, TA1, TA2, TN1, TN2, TWA, TTAT 00123800
* /PRES/P1, P2, PN1, PN2, PA1, PA2, PP, PPT, PAT 00123900
* /COMP/WI1, WI2, WO1, WO2, WA1, WA2, WN1, WN2, WAAT, WWA 00124000
* /FLOW/GA1, GA2, GA, GGT, 00124100
* /QUAL/DI, CP, CPT, CPO, CPN, MU, LAM, DEI, DEO, DEA1, DEAT 00124200
* /MLWG/MOLW, AVEMOL, C 00124300
* /REFE/RE, GR, PR, NU, SC, SH, Q 00124400
C
00000007 DO 200 L=1, J 00124500
00000008 DO 30 JJ=1, 2*M-1 00124600
00000009 DO 30 KJ=1, 2*M 00124700
00000010 AAW(JJ, KJ)=0.0 00124800
00000011 30 CONTINUE 00124900
00000012 DO 150 I=1, M 00125000
00000013 IF (GA2(I)/DABS(GA2(I)).LT.0.0) THEN 00125100
00000014 NI(I)=NNO(I) 00125200
00000015 NO(I)=NNI(I) 00125300
00000016 END IF 00125400
00000017 IF (GA2(I)/DABS(GA2(I)).GE.0.0) THEN 00125500
00000018 NI(I)=NNI(I) 00125600
00000019 NO(I)=NNO(I) 00125700
00000020 END IF 00125800
00000021 DO 150 JJ=1, K 00125900
00000022 AW(I, JJ) = 0.0 00126000
00000023 BW(I, JJ) = 0.0 00126100
00000024 CW(I, JJ) = 0.0 00126200
00000025 DW(I, JJ) = 0.0 00126300
00000026 WI2(I, JJ)=0.0 00126400
00000027 WO2(I, JJ)=0.0 00126500
00000028 WN2(NI(I), JJ)=0.0 00126600
00000029 IF (GA2(1)/DABS(GA2(1)).GE.0.0) THEN 00126700
00000030 WN1(1, 1)=0.0 00126800
00000031 WN1(1, 2)=0.233 00126900
00000032 WN1(1, 3)=0.0 00127000
00000033 WN1(1, 4)=0.0 00127100
00127200
00127300

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00000034      WN1(1,5)=0.767                                00127400
00000035      END IF                                       00127500
00000036      IF (GA2(M)/DABS(GA2(M)).LT.0.0) THEN        00127600
00000037      WN1(N,1)=0.0                                  00127700
00000038      WN1(N,2)=0.233                               00127800
00000039      WN1(N,3)=0.0                                  00127900
00000040      WN1(N,4)=0.0                                  00128000
00000041      WN1(N,5)=0.767                               00128100
00000042      END IF                                       00128200
00000043      W11(I,JJ)=WN1(NI(I),JJ)                     00128300
00000044 150  CONTINUE                                     00128400
C                                                       00128500
C***** MASS TRANSFER COEFFICIENT AND GENERATION/DISAPPEARANCE TERM **** 00128600
C                                                       00128700
00000045      DO 350 I=1,M                                  00128800
00000046      AKPLS = 7.0E+9*EXP(-199720.0/RG/(TA2(I)+273.15)) 00128900
00000047      RPLS  = AKPLS*DEA1(I)*(DEA1(I)/MOLW(2))*0.5*WA1(I,3) 00129000
1      *WA1(I,2)**0.5                                       00129100
00000048      SI(I,1) = 0.0                                  00129200
00000049      SI(I,2) = -0.5*RPLS                          00129300
00000050      SI(I,3) = -RPLS                              00129400
00000051      SI(I,4) = RPLS                               00129500
00000052      SI(I,5) = 0.0                                  00129600
00000053      Q(I)=D(I)**2/(C(2)*C(13)*C(3)*C(7))*5.660E5*RPLS/MOLW(4) 00129700
00000054      DO 350 JJ=1,K                                  00129800
00000055      SC(I,JJ)=MU(I)/DI(I,JJ)/DEA1(I)             00129900
00000056      SH(I,JJ) = AMTC ( RE(I), SC(I,JJ), H(I)/D(I) ) 00130000
00000057      BAT(I,JJ) = SH(I,JJ)*DI(I,JJ)/D(I)          00130100
00000058      BW(I,JJ) = 0.0                               00130200
00000059      CW(I,JJ) = 0.0                               00130300
00000060      IF ( I.EQ.5.OR.I.EQ.11 ) THEN                00130400
00000061      BW(I,JJ)=4.0*SH(I,JJ)*DI(I,JJ)*H(I)/D(I)/C(13) 00130500
00000062      IF(KK.EQ.1) CW(I,JJ)=BW(I,JJ)                00130600
00000063      ENDIF                                         00130700
00000064      IF(KK.EQ.2) CW(I,JJ)=BW(I,JJ)+H(I)*D(I)/DT/C(13) 00130800
00000065      DW(I,JJ)=SI(I,JJ)*D(I)*H(I)/C(3)/C(13)      00130900
00000066      IF(KK.EQ.2) DW(I,JJ)=DW(I,JJ)+H(I)*D(I)/DT/C(13)*DEAT(I)/C(3) 00131000
      *WAAT(I,JJ)                                           00131100
00000067      AW(I,JJ)=AW(I,JJ)+BW(I,JJ)*WWA(I,JJ)*DEA1(I)/C(3) 00131200
00000068      AW(I,JJ)=AW(I,JJ)-CW(I,JJ)*WA1(I,JJ)*DEA1(I)/C(3) 00131300
00000069      AW(I,JJ)=AW(I,JJ)+DW(I,JJ)                  00131400
00000070 350  CONTINUE                                     00131500
C                                                       00131600
C***** COEFFICIENTS OF MATRIX *****                    00131700
C                                                       00131800
00000071      DO 110 I=1,M                                  00131900
00000072      DO 110 JJ=1,K                                  00132000
00000073      SW(I,JJ)=PI/4.0*D(I)**2*DABS(GA2(I))          00132100
00000074      IF(GA2(5)/DABS(GA2(5)).GE.0.0)                00132200
      *SW(5,JJ)=PI/4.0*D(5)**2*DABS(GA2(4))              00132300
00000075      IF(GA2(5)/DABS(GA2(5)).LT.0.0)                00132400
      *SW(5,JJ)=PI/4.0*D(5)**2*DABS(GA2(6))              00132500
00000076      IF(GA2(11)/DABS(GA2(11)).GE.0.0)            00132600
      *SW(11,JJ)=PI/4.0*D(11)**2*DABS(GA2(10))           00132700
00000077      IF(GA2(11)/DABS(GA2(11)).LT.0.0)            00132800
      *SW(11,JJ)=PI/4.0*D(11)**2*DABS(GA2(12))           00132900
00000078 110  CONTINUE                                     00133000
00000079      DO 120 I=M+1,2*M                              00133100
00000080      DO 120 JJ=1,K                                  00133200
00000081      SW(I,JJ)=-PI/4.0*D(I-M)**2*DABS(GA2(I-M))    00133300

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00000082 120 CONTINUE
00000083 DO 500 JJ=2,4
00000084 DO 550 II=1,2*M-1
00000085 DO 550 IJ=1,2*M
00000086 AAW(II,IJ)=0.0
00000087 550 CONTINUE
00000088 IF(GA2(1)/DABS(GA2(1)).GE.0.0) THEN
00000089 IF(JJ.EQ.1) AAW(1,2*M)=0.0
00000090 IF(JJ.EQ.2) AAW(1,2*M)=0.233
00000091 IF(JJ.EQ.3) AAW(1,2*M)=0.0
00000092 IF(JJ.EQ.4) AAW(1,2*M)=0.0
00000093 IF(JJ.EQ.5) AAW(1,2*M)=0.767
00000094 AAW(1,1)=1.0
00000095 END IF
00000096 IF(GA2(1)/DABS(GA2(1)).LT.0.0) THEN
00000097 AAW(1,1)=1.0
00000098 AAW(1,M)=-1.0
00000099 END IF
00000100 IF(GA2(M)/DABS(GA2(M)).LT.0.0) THEN
00000101 IF(JJ.EQ.1) AAW(N,2*M)=0.0
00000102 IF(JJ.EQ.2) AAW(N,2*M)=0.233
00000103 IF(JJ.EQ.3) AAW(N,2*M)=0.0
00000104 IF(JJ.EQ.4) AAW(N,2*M)=0.0
00000105 IF(JJ.EQ.5) AAW(N,2*M)=0.767
00000106 AAW(N,N)=1.0
00000107 END IF
00000108 IF(GA2(M)/DABS(GA2(M)).GE..0) THEN
00000109 AAW(N,N)=1.0
00000110 AAW(N,N+M)=-1.0
00000111 END IF
00000112 DO 395 I=1,2*M
00000113 CS(I)=1.0
00000114 395 CONTINUE
00000115 DO 405 I=2,14,6
00000116 IF(GA2(I)/DABS(GA2(I)).GE.0.0) CS(I+M)=0.0
00000117 IF(GA2(I)/DABS(GA2(I)).LT.0.0) CS(I)=0.0
00000118 IF(GA2(1)/DABS(GA2(1)).GE.0.0) CS(1)=0.0
00000119 IF(GA2(1)/DABS(GA2(1)).LT.0.0) CS(M+1)=0.0
00000120 AAW(2,2)=CS(1)*SW(1, JJ)+CS(2)*SW(2, JJ)+CS(8)*SW(8, JJ)
*+CS(14)*SW(14, JJ)
00000121 AAW(2, I+N)=CS(I+M)*SW(I+M, JJ)
00000122 AAW(2, M)=CS(M+1)*SW(M+1, JJ)
00000123 405 CONTINUE
00000124 DO 415 I=3,7
00000125 IF(GA2(I)/DABS(GA2(I)).LT.0.0.OR.GA2(I-1)/DABS(GA2(I-1)).LT.0.0
*) THEN
00000126 AAW(I, I)=SW(I-1, JJ)
00000127 AAW(I, I+N)=SW(I+M, JJ)
00000128 GO TO 415
00000129 END IF
00000130 AAW(I, I)=SW(I, JJ)
00000131 AAW(I, I+N-1)=SW(I+M-1, JJ)
00000132 415 CONTINUE
00000133 DO 425 I=8,12
00000134 IF(GA2(I)/DABS(GA2(I)).LT.0.0.OR.GA2(I+1)/DABS(GA2(I+1)).
*LT.0.0) THEN
00000135 AAW(I, I)=SW(I, JJ)
00000136 AAW(I, I+1+N)=SW(I+1+M, JJ)
00000137 GO TO 425
00000138 END IF
00133400
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00000139      AAW(I,I)=SW(I+1,JJ)                                00139400
00000140      AAW(I,I+N)=SW(I+M,JJ)                            00139500
00000141 425    CONTINUE                                        00139600
00000142      DO 435 I=13,17                                    00139700
00000143      IF(GA2(I+1)/DABS(GA2(I+1)).LT.0.0.OR.GA2(I+2)/DABS(GA2(I+2)).
*LT.0.0) THEN                                                00139800
00000144      AAW(I,I)=SW(I+1,JJ)                                00139900
00000145      AAW(I,I+2+N)=SW(I+2+M,JJ)                        00140000
00000146      GO TO 435                                          00140100
00000147      END IF                                            00140200
00000148      AAW(I,I)=SW(I+2,JJ)                                00140300
00000149      AAW(I,I+1+N)=SW(I+1+M,JJ)                        00140400
00000150 435    CONTINUE                                        00140500
C                                                        00140600
00000151      IF(GA2(7)/DABS(GA2(7)).GE.0.0) CS(7)=0.0         00140700
00000152      IF(GA2(7)/DABS(GA2(7)).LT.0.0) CS(7+M)=0.0       00140800
00000153      IF(GA2(13)/DABS(GA2(13)).GE.0.0) CS(13)=0.0     00140900
00000154      IF(GA2(13)/DABS(GA2(13)).LT.0.0) CS(13+M)=0.0   00141000
00000155      IF(GA2(19)/DABS(GA2(19)).GE.0.0) CS(19)=0.0     00141100
00000156      IF(GA2(19)/DABS(GA2(19)).LT.0.0) CS(19+M)=0.0  00141200
00000157      IF(GA2(20)/DABS(GA2(20)).GE.0.0) CS(20)=0.0    00141300
00000158      IF(GA2(20)/DABS(GA2(20)).LT.0.0) CS(20+M)=0.0  00141400
00000159      AAW(18,18)=CS(7)*SW(7,JJ)+CS(13)*SW(13,JJ)+CS(19)*SW(19,JJ)
*CS(20)*SW(20,JJ)                                           00141500
00000160      AAW(18,7+N)=CS(7+M)*SW(7+M,JJ)                  00141600
00000161      AAW(18,13+N)=CS(13+M)*SW(13+M,JJ)              00141700
00000162      AAW(18,19+N)=CS(19+M)*SW(19+M,JJ)              00141800
00000163      AAW(18,20+N)=CS(20+M)*SW(20+M,JJ)              00141900
C                                                        00142000
00000164      DO 445 I=19,25                                    00142100
00000165      IF(GA2(I+1)/DABS(GA2(I+1)).LT.0.0.OR.GA2(I+2)/DABS(GA2(I+2)).
*LT.0.0) THEN                                                00142200
00000166      AAW(I,I)=SW(I+1,JJ)                                00142300
00000167      AAW(I,I+2+N)=SW(I+2+M,JJ)                        00142400
00000168      GO TO 445                                          00142500
00000169      END IF                                            00142600
00000170      AAW(I,I)=SW(I+2,JJ)                                00142700
00000171      AAW(I,I+1+N)=SW(I+1+M,JJ)                        00142800
00000172 445    CONTINUE                                        00142900
00000173      DO 455 I=1,M                                      00143000
00000174      GX2(I)=GA2(I)*D(I)/C(3)/C(13)                    00143100
00000175      AAW(I+N,I+N)=GX2(I)                                00143200
00000176      AAW(I+N,NI(I))=-GX2(I)                            00143300
00000177      IF(GA2(5)/ABS(GA2(5)).GE.0.0)                    00143400
*AAW(5+N,NI(5))=-GX2(4)                                       00143500
00000178      IF(GA2(5)/ABS(GA2(5)).LT.0.0)                    00143600
*AAW(5+N,NI(5))=-GX2(6)                                       00143700
00000179      IF(GA2(11)/ABS(GA2(11)).GE.0.0)                 00143800
*AAW(11+N,NI(11))=-GX2(10)                                    00143900
00000180      IF(GA2(11)/ABS(GA2(11)).LT.0.0)                 00144000
*AAW(11+N,NI(11))=-GX2(12)                                    00144100
00000181      IF(GA2(I)/DABS(GA2(I)).LT.0.0) AAW(I+N,2*M)=-AW(I,JJ)
00000182      IF(GA2(I)/DABS(GA2(I)).GE.0.0) AAW(I+N,2*M)=AW(I,JJ)
00000183 455    CONTINUE                                        00144200
C                                                        00144300
00000184      DO 90 I=1,M-1                                      00144400
00000185      IF(DABS(WA1(I,JJ)).GT.DABS(WA1(I+1,JJ)))
*XW(JJ)=DABS(WA1(I,JJ))                                       00144500
00000186 90    CONTINUE                                        00144600
00000187      IF(XW(JJ).EQ.0.0) GO TO 500                      00144700

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C
C***** TO SOLVE MATRIX *****
C
00000188 CALL GAUELD (AAW,2*M-1,2*M-1,2*M,1.0E-10,ILL)
00000189 IF (ILL.EQ.0) GO TO 1
00000190 WRITE(6,*) 'GAUELD AT GASPEC ; L, ILL ',L,ILL
00000191 STOP
00000192 1 DO 2 JK=2*M,2*M
00000193 DO 3 I=1,N
00000194 WX1(I,JJ)=WN1(I,JJ)
00000195 WX2(I,JJ)=AAW(I,JK)
00000196 WN1(I,JJ)=AAW(I,JK)
00000197 AAW(I,JK)=0.0
00000198 3 CONTINUE
00000199 DO 2 I=N+1,N+M
00000200 WX1(I,JJ)=W01(I-N,JJ)
00000201 WX2(I,JJ)=AAW(I,JK)
00000202 W01(I-N,JJ)=AAW(I,JK)
00000203 AAW(I,JK)=0.0
00000204 2 CONTINUE
C
00000205 EPS=1.0E-5
00000206 DO 50 I=1,2*M-2
00000207 IF (DABS(WX2(I+1,JJ)-WX1(I+1,JJ)).GT.
* DABS(WX2(I,JJ)-WX1(I,JJ))) THEN
00000208 TA(JJ)=DABS(WX2(I+1,JJ)-WX1(I+1,JJ))
00000209 ENDIF
00000210 50 CONTINUE
00000211 500 CONTINUE
00000212 DO 70 JJ=1,K-1
00000213 IF(TA(JJ+1).GT.TA(JJ)) TTA=TA(JJ+1)
00000214 70 CONTINUE
00000215 IF (TTA.LE.EPS) GO TO 40
C
00000216 DO 215 I=1,2*M-1
00000217 DO 215 JJ=1,K
00000218 IF(WX2(I,JJ).LT.0.0) WX2(I,JJ)=0.0
00000219 215 CONTINUE
00000220 DO 210 I=1,2*M-1
00000221 WX2(I,1)=0.0
00000222 WX2(I,5)=1.0-WX2(I,2)-WX2(I,3)-WX2(I,4)
00000223 DO 210 JJ=1,K
00000224 WX1(I,JJ)=WX1(I,JJ)+0.3*(WX2(I,JJ)-WX1(I,JJ))
00000225 IF(GA2(1)/DABS(GA2(1)).GE.0.0) THEN
00000226 WX1(1,1)=0.0
00000227 WX1(1,2)=0.233
00000228 WX1(1,3)=0.0
00000229 WX1(1,4)=0.0
00000230 WX1(1,5)=0.767
00000231 END IF
00000232 IF(GA2(M)/DABS(GA2(M)).LT.0.0) THEN
00000233 WX1(N,1)=0.0
00000234 WX1(N,2)=0.233
00000235 WX1(N,3)=0.0
00000236 WX1(N,4)=0.0
00000237 WX1(N,5)=0.767
00000238 END IF
00000239 210 CONTINUE
00000240 DO 230 I=1,N
00000241 DO 230 JJ=1,K

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00000242      WN1(I,JJ)=WX1(I,JJ)                                00151400
00000243      WN1(I,1)=0.0                                    00151500
00000244      WN1(I,5)=1.0-WX1(I,2)-WX1(I,3)-WX1(I,4)      00151600
00000245 230    CONTINUE                                       00151700
00000246      DO 245 I=N+1,N+M                                  00151800
00000247      DO 245 JJ=1,K                                    00151900
00000248      W01(I-N,JJ)=WX1(I,JJ)                            00152000
00000249      W01(I-N,1)=0.0                                    00152100
00000250      W01(I-N,5)=1.0-W01(I-N,2)-W01(I-N,3)-W01(I-N,4) 00152200
00000251 245    CONTINUE                                       00152300
00000252      DO 255 I=1,M                                      00152400
00000253      DO 255 JJ=1,K                                    00152500
00000254      SS=4.0*BAT(I,JJ)*H(I)*DEA1(I)/ABS(GA2(I))/D(I)  00152600
00000255      WA1(I,JJ)=WWA(I,JJ)+(WN1(NI(I),JJ)-WWA(I,JJ))/SS*
*(1.0-1.0*EXP(-SS))
00000256 255    CONTINUE                                       00152900
00000257 200    CONTINUE                                       00153000
00000258      WRITE(6,*) '***** ITERATION TIME IS OVER'
1              , ' AT GASPEC SUBROUTINE !! ; ERR = ',TTA,' *****'
C
C***** CONVERGED !!! *****
C
00000259 40    DO 60 I=1,2*M-1                                  00153600
00000260      DO 60 JJ=1,K                                       00153700
00000261      IF(WX2(I,JJ).LT.0.0) WX2(I,JJ)=0.0              00153800
00000262 60    CONTINUE                                       00153900
00000263      DO 65 I=1,2*M-1                                  00154000
00000264      WX2(I,1)=0.0                                        00154100
00000265      WX2(I,5)=1.0-WX2(I,1)-WX2(I,2)-WX2(I,3)-WX2(I,4) 00154200
00000266      IF (GA2(1)/DABS(GA2(1)).GE.0.0) THEN              00154300
00000267      WX2(1,1)=0.0                                        00154400
00000268      WX2(1,2)=0.233                                    00154500
00000269      WX2(1,3)=0.0                                        00154600
00000270      WX2(1,4)=0.0                                        00154700
00000271      WX2(1,5)=0.767                                    00154800
00000272      END IF                                           00154900
00000273      IF (GA2(M)/DABS(GA2(M)).LT.0.0) THEN              00155000
00000274      WX2(N,1)=0.0                                        00155100
00000275      WX2(N,2)=0.233                                    00155200
00000276      WX2(N,3)=0.0                                        00155300
00000277      WX2(N,4)=0.0                                        00155400
00000278      WX2(N,5)=0.767                                    00155500
00000279      END IF                                           00155600
00000280 65    CONTINUE                                       00155700
00000281      DO 75 I=1,N                                       00155800
00000282      DO 75 JJ=1,K                                       00155900
00000283      WN2(I,JJ)=WX2(I,JJ)                                00156000
00000284 75    WN1(I,JJ)=WN2(I,JJ)                              00156100
00000285      DO 95 I=1,M                                       00156200
00000286      DO 95 JJ=1,K                                       00156300
00000287      W02(I,JJ)=WX2(I+N,JJ)                            00156400
00000288      W01(I,JJ)=W02(I,JJ)                                00156500
00000289      SS=4.0*BAT(I,JJ)*H(I)*DEA1(I)/DABS(GA2(I))/D(I)  00156600
00000290      WA2(I,JJ)=WWA(I,JJ)+(WN2(NI(I),JJ)-WWA(I,JJ))/SS*
*(1.0-1.0*EXP(-SS))
00000291 95    WA1(I,JJ)=WA2(I,JJ)                              00156800
C
00000292      RETURN                                           00157000
00000293      END                                             00157100
00000293      END                                             00157200

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C
C*****00157300
C*****00157400
C*****00157500
C***** SUBROUTINE PROGRAM FOR MASS FRACTION ON GRAPHITE WALL *****00157600
C*****00157700
00000001 SUBROUTINE BNDCHM ( RE, SC, XBYD, D, RHOO, AMUO, RHO, 00157800
1 OMGB, TW, P, AM, OMGW, GM1 ) 00157900
C*****00158000
C*****00158100
C 00158200
00000002 IMPLICIT REAL*8 (A-H,O-Z) 00158300
00000003 PARAMETER ( RG=8.314, K=5, EPS=1.0E-6, XIO=1.0E-2, XIMIN=1.0E-8 ) 00158400
00000004 DIMENSION SH(3), SC(K), OMGB(K), OMGW(K), AMOL(K+1) 00158500
00000005 COMMON /MLWG/AMOL 00158600
C 00158700
00000006 SH(1) = AMTC ( RE, SC(2), XBYD ) 00158800
00000007 SH(2) = AMTC ( RE, SC(3), XBYD ) 00158900
00000008 SH(3) = AMTC ( RE, SC(4), XBYD ) 00159000
00000009 TWK = TW + 273.15 00159100
00000010 F = 800.0*EXP(-6200.0/TWK) 00159200
00000011 AN = 0.75 00159300
C 00159400
00000012 C1 = -2560.0*EXP(-142000.0/RG/TWK)*(P/1.013E5)**0.5 00159500
1 *(AM/0.2095/AMOL(2))**AN 00159600
00000013 C2 = -44.5*EXP(-162710.0/RG/TWK) 00159700
00000014 AO2L = -SH(1)*RHO/SC(2) 00159800
00000015 ACO2L = -SH(2)*RHO/SC(3) 00159900
00000016 ACO2L = -SH(3)*RHO/SC(4) 00160000
00000017 AO2R = AMOL(2)/AMOL(6)*D/RHOO/AMUO*(2.0+F)/(2.0+2.0*F)*C1 00160100
00000018 ACOR1 = -AMOL(3)/AMOL(6)*D/RHOO/AMUO*F/(1.0+F)*C1 00160200
00000019 ACOR2 = -2.0*AMOL(3)/AMOL(6)*C2*D/RHOO/AMUO 00160300
00000020 ACO2R1 = -AMOL(4)/AMOL(6)/RHOO/AMUO*D/(1.0+F)*C1 00160400
00000021 ACO2R2 = AMOL(4)/AMOL(6)*C2*D/RHOO/AMUO 00160500
C 00160600
00000022 XI = XIO 00160700
00000023 DO 100 I=1,20 00160800
00000024 FNC = AO2R*XI**AN + AO2L*XI - AO2L*OMGB(2) 00160900
00000025 FNCD = AO2R*AN*XI**(AN-1.0) + AO2L 00161000
00000026 XIP1 = XI - FNC/FNCD 00161100
00000027 ERR = ABS( (XIP1-XI)/XI ) 00161200
00000028 IF ( ERR.LT.EPS ) GO TO 200 00161300
00000029 IF ( XIP1.LT.0.0 ) XIP1 = XIMIN 00161400
00000030 XI = XIP1 00161500
00000031 100 CONTINUE 00161600
C 00161700
00000032 200 OMGW(2) = XIP1 00161800
00000033 OMGW(4) = (-ACO2R1*OMGW(2)**AN + ACO2L*OMGB(4))/(ACO2R2+ACO2L) 00161900
00000034 OMGW(3) = (ACOL*OMGB(3)-ACOR1*OMGW(2)**AN-ACOR2*OMGW(4))/ACOL 00162000
00000035 OMGW(1) = OMGB(1) 00162100
00000036 OMGW(5) = OMGB(5) 00162200
00000037 GM1 = -C1*OMGW(2)**AN - C2*OMGW(4) 00162300
C 00162400
00000038 RETURN 00162500
00000039 END 00162600

```

FORTRAN77 EX V12L10

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C                                     00162700
C*****00162800
C*****00162900
C***** FUNCTION PROGRAM FOR CALCULATION OF FRICTION FACTOR *****00163000
C*****00163100
00000001          FUNCTION FRIC ( RE, XBYD )                                00163200
C*****00163300
C*****00163400
C                                     00163500
00000002          IMPLICIT REAL*8 (A-H,O-Z)                                00163600
C                                     00163700
00000003          FAPP(X,Y)=( 3.44/X**0.5 + (1.25/4.0/X+16.0-3.44/X**0.5)  00163800
1                / (1.0+2.1E-4/X/X) ) / Y                                00163900
C                                     00164000
00000004          X1 = 0.000001                                           00164100
00000005          X2 = XBYD                                               00164200
00000006          FRIC = ( X2*FAPP(X2,RE) - X1*FAPP(X1,RE) ) / ( X2-X1 ) 00164300
C                                     00164400
00000007          RETURN                                                  00164500
00000008          END                                                    00164600

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FORTRAN77 EX V12L10

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C
C*****00164700
C*****00164800
C*****00164900
C***** FUNCTION PROGRAM FOR CALCULATION OF HEAT TRANSFER. *****00165000
C*****00165100
00000001          FUNCTION HTC ( RE, PR, XBYD )          00165200
C*****          *****00165300
C*****          *****00165400
C          00165500
00000002          IMPLICIT REAL*8 (A-H,O-Z)          00165600
C          00165700
00000003          ANU1 (X) = 1.615*X**(-0.333333) - 0.7          00165800
00000004          ANU2 (X) = 1.615*X**(-0.333333) - 0.2          00165900
00000005          ANU3 (X) = 3.657 + 0.0499/X          00166000
C          00166100
00000006          X1 = 0.00001          00166200
00000007          X2 = XBYD          00166300
00000008          IF ( RE.LE.1.0.OR.PR.LE.1.0E-4 ) THEN          00166400
00000009          HTC = 1.0          00166500
00000010          RETURN          00166600
00000011          ENDIF          00166700
00000012          XAST1 = X1/RE/PR          00166800
00000013          XAST2 = X2/RE/PR          00166900
00000014          IF ( XAST1.LE.0.005 )          ANUX1=ANU1(XAST1)          00167000
00000015          IF ( XAST1.GT.0.005.AND.XAST1.LT.0.03 ) ANUX1=ANU2(XAST1)          00167100
00000016          IF ( XAST1.GE.0.03 )          ANUX1=ANU3(XAST1)          00167200
00000017          IF ( XAST2.LE.0.005 )          ANUX2=ANU1(XAST2)          00167300
00000018          IF ( XAST2.GT.0.005.AND.XAST2.LT.0.03 ) ANUX2=ANU2(XAST2)          00167400
00000019          IF ( XAST2.GE.0.03 )          ANUX2=ANU3(XAST2)          00167500
C          00167600
00000020          CND1 = 1.0          00167700
00000021          CND2 = 1.0          00167800
00000022          CND = 1.0          00167900
00000023          DT1 = 1.0          00168000
00000024          DT2 = 1.0          00168100
00000025          DT = 1.0          00168200
00000026          HTC = ( X2*ANUX2*DT2*CND2 - X1*ANUX1*DT1*CND1 )/( X2 - X1 )          00168300
1          /DT/CND          00168400
C          00168500
00000027          RETURN          00168600
00000028          END          00168700

```

FORTRAN77 EX V12L10

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C
C*****00168800
C*****00168900
C*****00169000
C*****00169100
C*****00169200
00000001      FUNCTION AMTC ( RE, SC, XBYD )      00169300
C*****00169400
C*****00169500
C
00000002      IMPLICIT REAL*8 (A-H,O-Z)      00169600
C
00000003      SH1 (X) = 1.615*X**(-0.333333) - 0.7      00169700
00000004      SH2 (X) = 1.615*X**(-0.333333) - 0.2      00169800
00000005      SH3 (X) = 3.657 + 0.0499/X      00169900
C
00000006      X1 = 0.00001      00170000
00000007      X2 = XBYD      00170100
00000008      IF ( RE.LE.1.0.OR.SC.LE.1.0E-4 ) THEN      00170200
00000009      AMTC = 1.0      00170300
00000010      RETURN      00170400
00000011      ENDIF      00170500
00000012      XAST1 = X1/RE/SC      00170600
00000013      XAST2 = X2/RE/SC      00170700
00000014      IF ( XAST1.LE.0.005 )      SHX1=SH1(XAST1)      00170800
00000015      IF ( XAST1.GT.0.005.AND.XAST1.LT.0.03 )      SHX1=SH2(XAST1)      00170900
00000016      IF ( XAST1.GE.0.03 )      SHX1=SH3(XAST1)      00171000
00000017      IF ( XAST2.LE.0.005 )      SHX2=SH1(XAST2)      00171100
00000018      IF ( XAST2.GT.0.005.AND.XAST2.LT.0.03 )      SHX2=SH2(XAST2)      00171200
00000019      IF ( XAST2.GE.0.03 )      SHX2=SH3(XAST2)      00171300
C
00000020      DIF1 = 1.0      00171400
00000021      DIF2 = 1.0      00171500
00000022      DIF = 1.0      00171600
00000023      DW1 = 1.0      00171700
00000024      DW2 = 1.0      00171800
00000025      DW = 1.0      00171900
00000026      AMTC = ( X2*SHX2*DW2*DIF2 - X1*SHX1*DW1*DIF1 )/( X2 - X1 )      00172000
1      /DW/DIF      00172100
C
00000027      RETURN      00172200
00000028      END      00172300
END OF COMPILATION,HIGHEST SEVERITY CODE=00      00172400
00172500
00172600
00172700
00172800

```