대한기계학회 2001년도 춘계학술대회논문집 E pp. 783~788 KSME 01S650

비등온 난류 제트의 이상유동에 대한 수치모델

황득리엔* • 김명관** • 권오봉***

Numerical Modeling of Two-Phase Non-Isothermal Turbulent Jet

Hoang Duc Lien*, Myong Kwan Kim** and Oh Boong Kwon***

Key Words : Numerical Investigation, Model of Turbulence, Two-Phase, Non-Isothermal Turbulent Jet

Abstract

Choosing the most suitable mathematical model and relating this to turbulent tangential tensions model are very important in the investigations of turbulent two-phase flow. This paper considers two-fluid scheme. According to it, two phases have their own densities, velocities, and temperatures at any spatial point and at any moment. The equations of motion and heat transfer for each phase are linked with the forces of interaction between two phases. These forces are considered as predominant for the flow. As a closure in the system of motion equations, one modification of K - ε turbulent model is worked out. The modification uses two equations for turbulent kinetic energy of the phases and one - for the turbulent energy loss of main phase. This model can be set as a K_g - K_p - ε model. The modified model has been tested for both a two-phase non-isothermal flat jet and axially symmetrical jet. The numerical results are compared with the reference data revealing a good agreement between them.

Nomenclatures

$U_{i(i=go,po,gm,pm,g,p)}$ Initial, maximum and axial component of velocity of gas, admixture phase
$V_{i\,(i=g,p)}$ Radial component of velocity of gas, admixture phase
$T_{i(i=gm,pm,g,p,2)}$ Maximum temperature, temperature of gas, admixture, environment surrounding
$K_{i(i=g,p)}$ Energy kinetic of the motion of gas, admixture phase
Q Inter-phase thermal interaction
y_o Initial radius of jet
P Gas pressure
D_p size of fraction
R Gas constant
G Specific weight
Nu Nuselt number;
Re Reynold number
Pr Prandtl number
Sc Schmidt number

Greeks
λ Thermal conductivity coefficient
$\nu_{i(i=tg,tp)}$ Turbulent viscosity of gas, admixiture phase
$\rho_{i(i=go,po,gm,pm,g,p,2)}$ Initial, maximum and density of gas, admixture, environment surrounding

* 베트남 하노이 농업대학교 기계공학과
** 부경대학교 기계공학과
*** 부경대학교 기계공학부

1. Introduction

One of the exact methods for investigation of non-homogeneous, dispersed (two or multiphase) media is based on the conception of so called continuous change of multi-velocities. This methods often called two or multi-fluid, permit to build physically well-founded imagination for complicated fluid flows, such as two or multiphase flow [1,2]. We can suppose the existence of different fields of velocities, temperatures and densities of the carrier and the admixture phase. In this case, at every point of the flow the phases have own velocity, temperature and density.

The main purpose of this paper is a numerical modeling of two-phase non-isothermal jet, flowing in a surrounding of carrier phase with a temperature different from the temperature of the jet.

2. Basic Equations

The governing equations for two-phase non-isothermal turbulent jets consist of the equations for conservation of mass contents, quantity of motion, kinetic energy and state of gas phase[3], and they are as follows in the Cartesian-coordinate has a form:

$$\frac{\partial\left[y^j U_g \rho_g\right]}{\partial x}+\frac{\partial\left[y^j V_g \rho_g\right]}{\partial y}=0 \tag{1}$$

$$\frac{\partial\left[y^j U_p \rho_p\right]}{\partial x}+\frac{\partial\left[y^j V_p \rho_p\right]}{\partial y}=0 \tag{2}$$

$$\left[y^j U_p\right]\frac{\partial \rho_p}{\partial x}+\left[y^j V_p\right]\frac{\partial \rho_p}{\partial y}=-\frac{\partial\left[y^j \overline{\rho'_p V'_p}\right]}{\partial y}-\overline{\rho'_p V'_p} \tag{3}$$

$$\left[y^j \rho_g U_g\right]\frac{\partial U_g}{\partial x}+\left[y^j \rho_g V_g\right]\frac{\partial U_g}{\partial y}= =-\frac{\partial\left[y^j \rho_g \overline{U'_g V'_g}\right]}{\partial y}-F_x y^j \tag{4}$$

$$\left[y^j \rho_p U_p\right]\frac{\partial U_p}{\partial x}+\left[y^j (\rho_p V_p+\overline{\rho'_p V'_p})\right]\frac{\partial U_p}{\partial y}= =-\frac{\partial\left[y^j \rho_p \overline{U'_p V'_p}\right]}{\partial y}+F_x y^j \tag{5}$$

$$\left[y^j \rho_p U_p\right]\frac{\partial h_p}{\partial x}+\left[y^j (\rho_p V_p+\overline{\rho'_p V'_p})\right]\frac{\partial h_p}{\partial x}= =-\frac{\partial}{\partial y}\left[y^j \rho_p \overline{h'_p V'_p}\right]+Q y^j \tag{6}$$

$$\left[y^j \rho_g U_g\right]\frac{\partial h_g}{\partial x}+\left[y^j \rho_g V_g\right]\frac{\partial h_g}{\partial x}=-\frac{\partial}{\partial y}\left[y^j \rho_g \overline{h'_g V'_g}\right]- \left[y^j \rho_g \overline{h'_g V'_g}\right]\frac{\partial U_g}{\partial y}-Q y^j + F_x y^j\left(U_g-U_p\right)+F_y y^j\left(V_g-V_p\right) \tag{7}$$

$$P=\rho_g R T_g \tag{8}$$

Using the upper index j, we can describe two-dimensional flat jets ($j=0$) and axially symmetrical jets ($j=1$). The link between phase in the equations of motion and heat transfer is the forces of phase interactions $\vec{F}_i$, which are considered predominated for the corresponding flow [3,4,5].

In the case of non-isothermal jets, the gas enthalpy and the enthalpy of admixture phase are as follows:

$$h_g = C_{pg}\,(T_g - T_2), \qquad h_p = C_{pp}\,(T_p) \tag{9}$$

where, $C_{pg} = f(T_g)$, $C_{pp} = f(T_p)$ are the specific thermal capacity at constant pressure of gas and admixture phase. Thermal interaction between phases is defined as [3,6]:

$$Q=\frac{6Nu\lambda}{D_p^2}\left(T_g-T_p\right) \tag{10}$$

where, $Nu=2+C\,\mathrm{Re}_p{}^n\,\mathrm{Pr}^m$ with C, n and m are functions of Re_p.

3. Turbulent Model

In the equations of movement, the double correlation of velocity, density and temperature take part. We can define these correlation, using turbulent viscosity and the field of mean parameters.

$$\overline{U'_g V'_g}=-\nu_{tg}\frac{\partial U_g}{\partial y};\ \overline{U'_p V'_p}=-\nu_{tp}\frac{\partial U_p}{\partial y};$$

$$\overline{V'_p \rho'_p}=-\frac{\nu_{tp}}{Sc_t}\frac{\partial \rho_p}{\partial y};$$

$$\overline{T'_g V'_g}=-\frac{\nu_{tg}}{Pr_t}\frac{\partial T_g}{\partial y};\quad \overline{T'_p V'_p}=-\frac{\nu_{tp}}{Pr_t}\frac{\partial T_p}{\partial y};$$

One modification of the k_g - k_p - ε turbulent model serves as a closure in the system of motion equations. This modification uses two equations for turbulent kinetic energy of the gas phase and the phase of admixture, and one for the turbulent dissipation rate of main gaseous phase. The modification was used by one of the authors for the investigation of isothermal jets in the previous works [7,8,11].

$$\left[y^j \rho_g U_g\right]\frac{\partial K_g}{\partial x}+\left[y^j \rho_g V_g\right]\frac{\partial K_g}{\partial y}=\frac{\partial}{\partial y}\left[y^j \rho_g \frac{\nu_{tg}\partial K_g}{\sigma_K \partial y}\right] +y^j \rho_g \nu_{tg}\left(\frac{\partial U_g}{\partial y}\right)^2-y^j \rho_g\left(\varepsilon+\varepsilon_p\right) \tag{11}$$

$$\left[y^j \rho_p U_p\right]\frac{\partial K_p}{\partial x}+\left[y^j \rho_p V_p\right]\frac{\partial K_p}{\partial y}=\frac{\partial}{\partial y}\left[y^j \rho_p \frac{\nu_{tp}\partial K_p}{\sigma_K \partial y}\right] +y^j \rho_p \nu_{tp}\left(\frac{\partial U_p}{\partial y}\right)^2+y^j \rho_p \varepsilon_p^* \tag{12}$$

$$\left[y^j \rho_g U_g\right]\frac{\partial \varepsilon}{\partial x}+\left[y^j \rho_g V_g\right]\frac{\partial \varepsilon}{\partial y}=\frac{\partial}{\partial y}\left[y^j \rho_g \frac{\nu_{tg}\partial \varepsilon}{\sigma_\varepsilon \partial y}\right]- -y^j \rho_g \phi_p+C_{\varepsilon 1} y^j \rho_g \frac{\varepsilon}{K_g}\left[\nu_{tg}\left(\frac{\partial U_g}{\partial y}\right)^2+G\right] -y^j \rho_g \frac{\varepsilon^2}{K_g}\left(C_{\varepsilon 2}-\chi C_{\varepsilon 3}\right) \tag{13}$$

The additional dissipation terms ε_p, ε_p^* and ϕ_p, which appeared in Eqs. (11)-(13), consider the influence of the two phases into turbulent characteristics of the flow. These terms are calculated from stochastic part of the forces of the phase interaction F_i [3] and they give the connection between two phases in the equations of movement.

However, because of space limitations, the values of these dissipation terms are not presented here.

The turbulent viscosity is defined according to Kolmogorov's hypothesis by means of turbulent kinetic energy for the phase considered:

$$\nu_{tg} = C_\nu K_g^{0.5} L \quad , \quad \nu_{tp} = C_\nu K_p^{0.5} L \tag{14}$$

and the dissipation rate is as follows :

$$\varepsilon = C_D K_g^{0.5} L \tag{15}$$

where, $L = C_\lambda(y_{o.1} - y_{o.9})$, and $y_{o.1}$, $y_{o.9}$ are coordinates of the points with velocities equal 10% and 90% of the maximum velocity in the same section. The values of the empirical constants are as follows [9]:

$C_\nu = 0,078$ $\quad C_D = 1$ $\quad C_\lambda = 0,625$ $\quad C_{\varepsilon 1} = 1,44$
$C_{\varepsilon 2} = 1,92$ $\quad C_{\varepsilon 3} = 0,8$ $\quad \sigma_K = 1,0$ $\quad \sigma_\varepsilon = 1,3$

The K_g - K_p - ε model used by one of the authors for closing system equation of the two-phase non-isothermal turbulent jets on the basis of two-fluid scheme follows are as dimensionless forms:

$$\frac{\partial(\bar{y}^j \bar{\rho}_g \bar{U}_g)}{\partial \bar{x}} + \frac{\partial(\bar{y}^j \bar{\rho}_g \bar{V}_g)}{\partial \bar{y}} = 0 \tag{16}$$

$$\frac{\partial(\bar{y}^j \bar{\rho}_p \bar{U}_p)}{\partial \bar{x}} + \frac{\partial(\bar{y}^j \bar{\rho}_p \bar{V}_p)}{\partial \bar{y}} = 0 \tag{17}$$

$$(\bar{y}^j \bar{U}_p)\frac{\partial \bar{\rho}_p}{\partial \bar{x}} + (\bar{y}^j \bar{V}_p)\frac{\partial \bar{\rho}_p}{\partial \bar{y}} = \frac{\partial}{\partial \bar{y}}\left(\bar{y}^j \frac{\bar{\nu}_{tp} \partial \bar{\rho}_p}{Sc_t \partial \bar{y}}\right) \tag{18}$$

$$(\bar{y}^j \bar{\rho}_g \bar{U}_g)\frac{\partial \bar{U}_g}{\partial \bar{x}} + (\bar{y}^j \bar{\rho}_g \bar{V}_g)\frac{\partial \bar{U}_g}{\partial \bar{y}} = = \frac{\partial}{\partial \bar{y}}\left(\bar{y}^j \bar{\rho}_g \bar{\nu}_{tg} \frac{\partial \bar{U}_g}{\partial \bar{y}}\right) - \bar{F}_x \bar{y}^j \tag{19}$$

$$(\bar{y}^j \bar{\rho}_p \bar{U}_p)\frac{\partial \bar{U}_p}{\partial \bar{x}} + (\bar{y}^j \bar{\rho}_p \bar{V}_p)\frac{\partial \bar{U}_p}{\partial \bar{y}} = = \frac{\partial}{\partial \bar{y}}\left(\bar{y}^j \bar{\rho}_p \bar{\nu}_{tp} \frac{\partial \bar{U}_p}{\partial \bar{y}}\right) + \left(\bar{y}^j \frac{\bar{\nu}_{tp}}{Sc_t}\frac{\partial \bar{\rho}_p}{\partial \bar{y}}\right)\frac{\partial \bar{U}_p}{\partial \bar{y}} + \bar{F}_x \bar{y}^j \tag{20}$$

$$(\bar{y}^j \bar{\rho}_g \bar{U}_g \bar{C}_{pg})\frac{\partial \bar{T}_g}{\partial \bar{x}} + (\bar{y}^j \bar{\rho}_g \bar{V}_g \bar{C}_{pg})\frac{\partial \bar{T}_g}{\partial \bar{y}} = \bar{F}_x \bar{y}^j (\bar{U}_g - \bar{U}_p) + \frac{\partial}{\partial \bar{y}}\left(\bar{y}^j \bar{\rho}_g \bar{C}_{pg} \frac{\bar{\nu}_{tg}}{Pr_t}\frac{\partial \bar{T}_g}{\partial \bar{y}}\right) + \bar{F}_y \bar{y}^j (\bar{V}_g - \bar{V}_p) - \bar{Q}\bar{y}^j \tag{21}$$

$$(\bar{y}^j \bar{\rho}_p \bar{U}_p \bar{C}_{pp})\frac{\partial \bar{T}_p}{\partial \bar{x}} + (\bar{y}^j \bar{\rho}_p \bar{V}_p \bar{C}_{pp})\frac{\partial \bar{T}_p}{\partial \bar{y}} = \frac{\partial}{\partial \bar{y}}\left(\bar{y}^j \bar{\rho}_p \bar{C}_{pp} \frac{\bar{\nu}_{tp}}{Pr_t}\frac{\partial \bar{T}_p}{\partial \bar{y}}\right) + \left(\bar{y}^j \bar{C}_{pp} \frac{\bar{\nu}_{tp}}{Sc_t}\frac{\partial \bar{\rho}_p}{\partial \bar{y}}\right)\frac{\partial \bar{T}_p}{\partial \bar{y}} + \bar{Q}\bar{y}^j \tag{22}$$

$$(\bar{y}^j \bar{\rho}_g \bar{U}_g)\frac{\partial \bar{K}_g}{\partial \bar{x}} + (\bar{y}^j \bar{\rho}_g \bar{V}_g)\frac{\partial \bar{K}_g}{\partial \bar{y}} = \bar{y}^j \bar{\rho}_g \bar{\nu}_{tg}\left(\frac{\partial \bar{U}_g}{\partial \bar{y}}\right)^2 + + \frac{\partial}{\partial \bar{y}}\left[\bar{y}^j \bar{\rho}_g \frac{\bar{\nu}_{tg} \partial \bar{K}_g}{\sigma_k \partial \bar{y}}\right] - \bar{y}^j \bar{\rho}_g (\bar{\varepsilon} + \bar{\varepsilon}_p) \tag{23}$$

$$(\bar{y}^j \bar{\rho}_p \bar{U}_p)\frac{\partial \bar{K}_p}{\partial \bar{x}} + (\bar{y}^j \bar{\rho}_p \bar{V}_p)\frac{\partial \bar{K}_p}{\partial \bar{y}} = = \frac{\partial}{\partial \bar{y}}\left(\bar{y}^j \bar{\rho}_p \frac{\bar{\nu}_{tp} \partial \bar{K}_p}{\sigma_k \partial \bar{y}}\right) + \bar{y}^j \bar{\rho}_p \bar{\nu}_{tp}\left(\frac{\partial \bar{U}_p}{\partial \bar{y}}\right)^2 - \bar{y}^j \bar{\rho}_p \bar{\varepsilon}_p^* \tag{24}$$

$$(\bar{y}^j \bar{\rho}_g \bar{U}_g)\frac{\partial \bar{\varepsilon}}{\partial \bar{x}} + (\bar{y}^j \bar{\rho}_g \bar{V}_g)\frac{\partial \bar{\varepsilon}}{\partial \bar{y}} = \frac{\partial}{\partial \bar{y}}\left[\bar{y}^j \bar{\rho}_g \frac{\bar{\nu}_{tg} \partial \bar{\varepsilon}}{\sigma_\varepsilon \partial \bar{y}}\right] - - \bar{y}^j \bar{\rho}_g \bar{\Phi}_p + C_{\varepsilon 1} \bar{y}^j \bar{\rho}_g \frac{\bar{\varepsilon}}{\bar{K}_g}\left[\bar{\nu}_{tg}\left(\frac{\partial \bar{U}_g}{\partial \bar{y}}\right)^2 + G\right] - \bar{y}^j \bar{\rho}_g \frac{\bar{\varepsilon}^2}{\bar{K}_g}(C_{\varepsilon 2} + \chi C_{\varepsilon 3}) \tag{25}$$

$$\bar{P} = \bar{\rho}_g \bar{T}_g \tag{26}$$

where

$$\bar{x} = \frac{x}{y_o} \quad \bar{y} = \frac{y}{y_o} \quad \bar{U}_g = \frac{U_g}{U_{go}} \quad \bar{U}_p = \frac{U_p}{U_{go}}$$

$$\bar{V}_g = \frac{V_g}{U_{go}} \quad \bar{V}_p = \frac{V_p}{U_{go}} \quad \bar{\rho}_g = \frac{\rho_g}{\rho_{go}} \quad \bar{\rho}_p = \frac{\rho_p}{\rho_{go}}$$

$$\bar{T}_g = \frac{T_g R}{U_{go}^2} \quad \bar{T}_p = \frac{T_p R}{U_{go}^2} \quad \bar{K}_g = \frac{K_g}{U_{go}^2} \quad \bar{K}_p = \frac{K_p}{U_{go}^2}$$

$$\bar{\varepsilon}_g = \frac{\varepsilon y_o}{U_{go}^3} \quad \bar{C}_{pg} = \frac{C_{pg}}{R} \quad \bar{C}_{pp} = \frac{C_{pp}}{R} \quad \bar{\nu}_{tg} = \frac{\nu_{tg}}{y_o U_{go}}$$

$$\bar{\nu}_{tp} = \frac{\nu_{tp}}{y_o U_{go}} \quad \bar{F} = \frac{F y_o}{\rho_{go} U_{go}^2} \quad \bar{Q} = \frac{Q y_o}{\rho_{go} U_{go}^3} \quad \bar{\Phi}_p = \frac{\Phi_p y_o^2}{U_{go}^4}$$

4. Boundary conditions

We can study the flowing of the free two-phase non-isothermal jet in a stagnant surrounding of gas phase with temperature different from the jet temperature. The flow is symmetrical along the x axis. We can write down the boundary condition as follow:

- for the axis of symmetry at $y = 0$

$$\frac{\partial T_g}{\partial y} = \frac{\partial T_p}{\partial y} = 0 \qquad \frac{\partial U_g}{\partial y} = \frac{\partial U_p}{\partial y} = 0 \qquad \frac{\partial \rho_p}{\partial y} = 0$$

$$\frac{\partial K_g}{\partial y} = \frac{\partial K_p}{\partial y} = \frac{\partial \varepsilon}{\partial y} = 0 \quad \overline{U_g' V_g'} = \frac{\partial\left(\overline{U_g' V_g'}\right)}{\partial y} = 0 \quad V_g = V_p = 0$$

$$\overline{U_p' V_p'} = \frac{\partial\left(\overline{U_p' V_p'}\right)}{\partial y} = 0 \quad \overline{V_p' \rho_p'} = \frac{\partial\left(\overline{V_p' \rho_p'}\right)}{\partial y} = 0$$

- for the outer boundary of the jet :

$$\overline{U_g' V_g'} = \frac{\partial\left(\overline{U_g' V_g'}\right)}{\partial y} = 0 \quad \overline{U_p' V_p'} = \frac{\partial\left(\overline{U_p' V_p'}\right)}{\partial y} = 0 \quad U_g = U_p = 0$$

$$\frac{\partial T_g}{\partial y} = \frac{\partial T_p}{\partial y} = 0 \qquad \overline{V_p' \rho_p'} = \frac{\partial\left(\overline{V_p' \rho_p'}\right)}{\partial y} = 0 \quad V_g = V_p = 0$$

$$\rho_p = 0 \quad \rho_g = \rho_2 \quad T_g = T_p = T_2 \quad K_g = K_p = \varepsilon = 0$$

5. Characteristic equations and solving algorithm

After transforming the system of differential equations, we obtain one characteristic equation from the kind of:

$$A\frac{\partial \Phi}{\partial x} + B\frac{\partial \Phi}{\partial y} = C\frac{\partial^2 \Phi}{\partial y^2} + D \qquad (27)$$

where, Φ, A, B, C and D are adjusted to the variable quantities[5,4,10].

An explicit method in finite differences is used for solving the task. The values of the parameters at i section are calculated using known values (or calculated) at two previous sections $(i-1)$ and $(i-2)$.

$$\Phi_{i,j} = \frac{E_2}{E_1}\Phi_{i-2,j} + \frac{E_3}{E_1}\Phi_{i-1,j+1} + \frac{E_4}{E_1}\Phi_{i-1,j-1} + \frac{E_5}{E_1} \qquad (28)$$

where

$$E_1 = \frac{A_{i-1,j}}{2K} + \frac{C_{i-1,j}}{H^2} \qquad E_2 = \frac{A_{i-1,j}}{2K} - \frac{C_{i-1,j}}{H^2}$$

$$E_3 = \frac{C_{i-1,j}}{H^2} - \frac{B_{i-1,j}}{2H} \qquad E_4 = \frac{B_{i-1,j}}{2H} + \frac{C_{i-1,j}}{H^2}$$

$$E_5 = D_{i-1,j}$$

K, H are steps in x, y coordinates, respectively. From the Eq. (28), we can find all the parameters $\overline{U}_{gi,j}$, $\overline{U}_{pi,j}$, $\overline{\rho}_{pi,j}$, $\overline{T}_{gi,j}$, $\overline{T}_{pi,j}$, $\overline{K}_{gi,j}$, $\overline{K}_{pi,j}$, $\overline{\varepsilon}_{i,j}$.

6. Numerical Results

The code is calibrated using the case of isothermal jet at the following conditions: $T_{go} = T_{po} = 300K$, $D_p = 45\mu m$, $U_{go} = U_{po} = 35 m/s$, $\rho_{go} = 1{,}16\ kg/m^3$, $\rho_{po} = 8340\ kg/m^3$. Comparison of the experimental data[6] with numerical results for the maximum velocity distribution $(\overline{U}_{gm}, \overline{U}_{pm})$ shown in Fig. 1. There is a relatively good agreement between the calculated results and the reference data. Comparisons of experimental data with numerical results (results from K-ε model and K_g - K_p - ε model) for incidence of the maximum temperature difference, T_{gm}, shown in Fig. 2 with two input initial conditions:

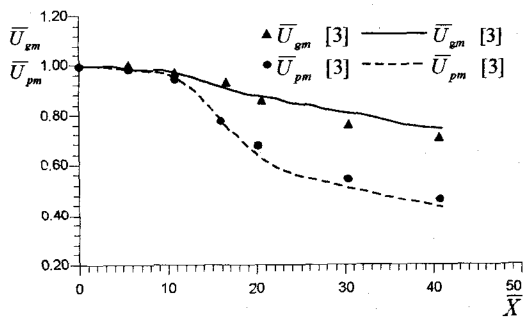

Fig. 1 Calibration for isothermal jet for the gas and admixture phase velocity

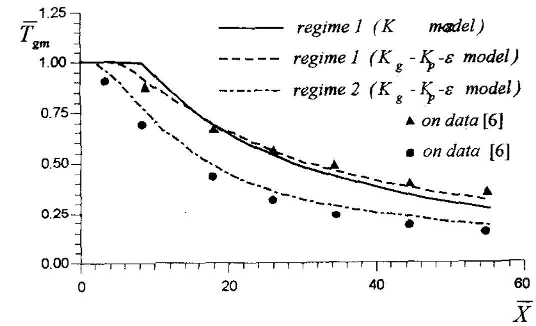

Fig. 2 Comparison with another model for temperature of the gas phase

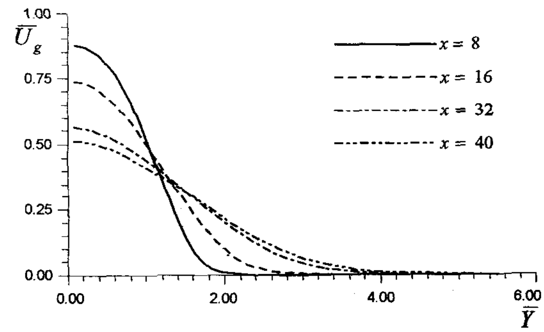

Fig. 3 Prediction for $\overline{U}_p$ - velocity distribution o f the Admixture phase

Case 1: D_p=32μm, U_{go}=36 m/s, U_{po}=56m/s, ρ_{go}=0,59 kg/m^3, ρ_{po} = 3950 kg/m^3, T_{go}= T_{po}=600K ≠ T_2=300K.
Case 2: for one phase jet under the same conditions of flow in the case 1.

The coincidence of the numerical results and experimental data is better when K_g - K_p - ε model of turbulence is used. The proposed model has been tested in a wide range of flow fields.

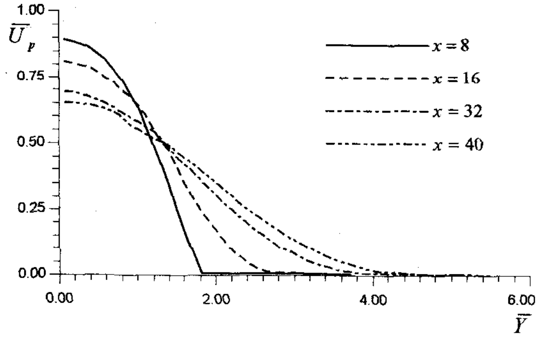

Fig. 4 Prediction for $\bar{U}_g$ - velocity distribution of the gas phase

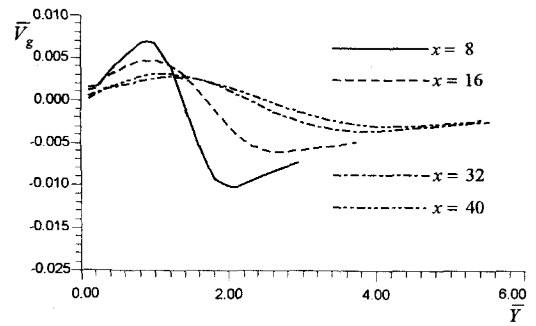

Fig. 5 Prediction for $\bar{V}_g$ - velocity distribution of the gas phase

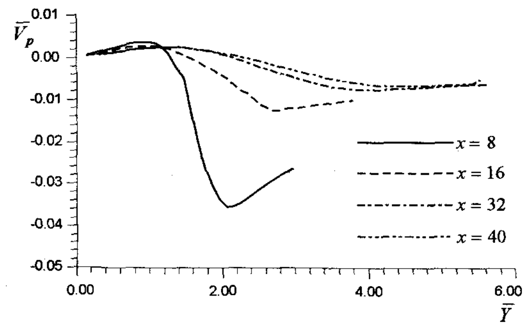

Fig. 6 Prediction for $\bar{V}_p$ - velocity distribution of the admixture phase admixture phase

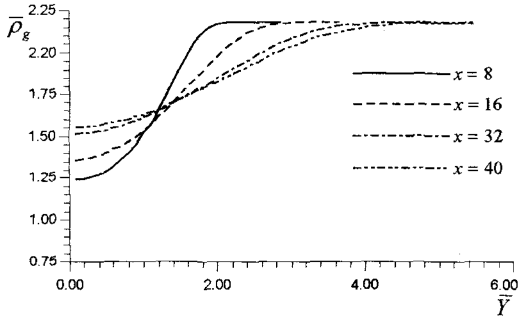

Fig. 7 Prediction for the density distribution of the gas phase

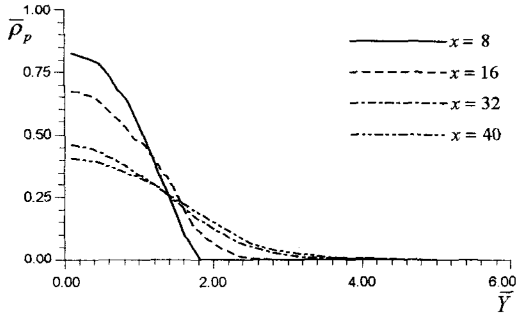

Fig. 8 Prediction for the density distribution of the admixture phase

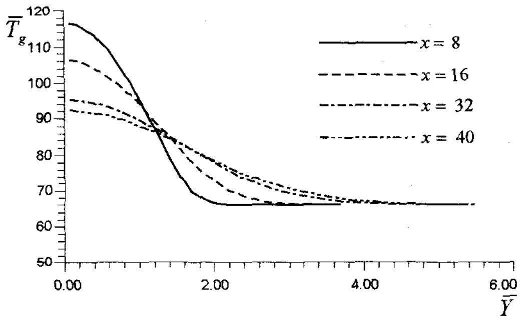

Fig. 9 Prediction for $\bar{T}_g$ - temperature distribution of the gas phase

Figs. 3-12 show the results of the numerical prediction of distribution of velocity components, densities, temperatures, turbulent kinetic energy and dissipation rate for the gas phase and the admixture phase. The initial conditions for the non-isothermal two-phase turbulent axially symmetrical jet in this investigation are : D_p = 32μm, U_{go}= U_{po}= 36m/s, ρ_{go} = 0,59 kg/m^3, ρ_{po} = 3950 kg/m^3, T_{go} = T_{po} = 600K, T_2 = 300 K . On the base of the numerical results, the distribution of turbulent viscosity and other parameters can be obtained.

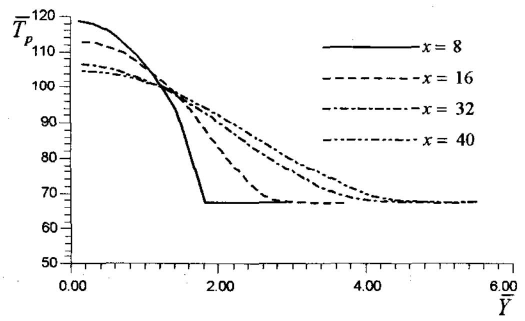

Fig. 10 Prediction for $\overline{T}_p$ - temperature distribution of the gas phase

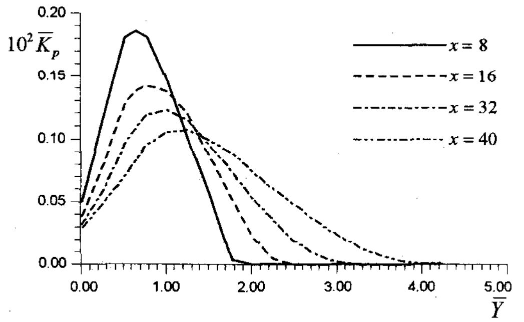

Fig. 11 Prediction for $\overline{K}_p$ – turbulent kinetic energy of the admixture phase

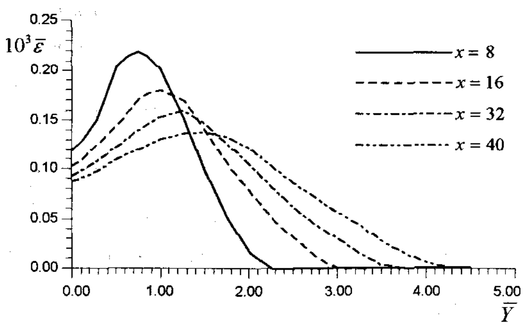

Fig. 12 Prediction for $\overline{\varepsilon}$ - energy dissipation rate of the gas phase

7. Conclusion remarks

A modification and improved model for a two-phase non-isothermal flat and axially symmetrical jet is realized and numerically tested. The method permits future investigation of flows with phase transformation and chemical reactions. The model described can be applied to channel flows when the boundary conditions are to be changed and the pressure changes of the gas phase are to be considered.

Acknowledgement

The authors would like to acknowledge the financial support and encouragement of Korea Science and Engineering Foundation (KOSEF) Postdoctoral Program and International Cooperation Program about Science and Technology of Ministry of Science, Technology and Environment (MSTE) of Vietnam.

Referenes

(1) Loyitzyjansky L.G., 1987, Mechanics of Fluid and Gas, Nauka, Moscow, Russian

(2) Nigmatulin R.I., 1978, Foundations of hetero Geneo mechanics, Moscow, Nauka, Russian

(3) Schreiber A. A., L.B. Gavin, V.N. Naumov, and V.P. Latsenko., 1987, "Turbulent Flows in Gas-Particle Mixtures", Naukova dumka, Kiev, Russian

(4) Lien H.D., 1996, "Two-phase Non-isothermal Turbulent Jets", Ph.D. thesis, Sofia, Bulgaria

(5) Antonov I.S., 1995, "Modeling of Two-phase Turbulent Jets", D.Sc. Thesis, Sofia, Bulgaria

(6) Gavin L.B., A.S. Mulgi, and V.V. Sor, 1986, "Numerical and Experimental Research about Non-isothermal turbulent jets with Mixture Particles", IFJ, vol. 5, pp. 735-742, Russian

(7) Gorbis E.R., F.E. Spokoinui, and R..Zagainova, 1976, "Influence of Powerful factors on the Transverse Speed of small particles which Moving in the Turbulent Gas Flow", IFJ. Vol. 30, 4, pp. 657-664, Russian

(8) Lien H.D., I.S. Antonov, and N.T. Nam, 1998, "One Modification of K - ε Turbulent Model of Two-phase Flows", Vietnam Journal of Mechanics, No 2, Hanoi, pp.37-45

(9) Patankar C.V., and D.B. Spolding, 1971, Heat and Mass-Transfer in Boundary Layer. "Energy", Moscow, Russian

(10) Lien H.D., and I.S. Antonov, 1996, "Numerical Modeling of Non-isothermal Flat Two-phase Turbulent Jets", Proceeding of Jubilee Scientific Conference, Air Force Academy, D. Metropolya, Bulgaria, pp.72-78

(11) Antonov I.S., N.T. Nam, and H.D. Lien, 1994, "Two-phase Turbulent Jets, K - ε Model", Proceeding of the 4th Workshop of Applied Mech., Cent. of Comp. Mech., HUT, HoChiMinh city, Vietnam, pp.IX/1-IX/8