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Research Article

Integral Method for Flat Non-Isothermal Turbulent Jet

Hameed Khalaf Saleh* **and Read Abdalameer Saeed**

Engineering Techniques of Refrigeration and Air Conditioning Departments, Middle Technical University, Baghdad, Iraq

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Abstract

In the current work has developed an integrated solution on a flat vertical turbulent two-phase non-isothermal flow. It represents a model of ascending convective flow over the fire, which also brings smoke and combustion products.

Keywords: *Integral method; vertical, turbulent, two-phase*

Mathematical Model

An integral method for numerical study of the two-phase non-isothermal vertical jet is applied, as formulated below. At this method integral conditions for the amount of movement, for heat content and energy of the flow are used. This task is solved using two-phase flow where it is assumed that the two phases (the carrier and impurities) have different velocities, density and temperatures. This approximates to actual physical parameters of the flow and allows reporting of interfacial heat transfer i.e. withdrawal of the heat of the hot gases from the atmosphere, which is more essential in this case.

The types of the integral conditions are as follow:

- For conversation of purity

$$\int_0^\infty \rho_p U_p y^j dy = G_0 \quad (5)$$

- For quantity of movement of gas phase

$$\int_0^\infty \rho_g U_g \left(U_g - U_2\right) y^j dy + \int_0^\infty \rho_p U_p^2 y^j dy + \\ + \int_0^\infty \left(\rho_2 - \rho_g\right) g y^{2j} dy = I_0 \quad (6)$$

- For energy of gas phase

$$\frac{\partial}{\partial x}\left[\int_0^\infty \rho_g U_g \left(U_g - U_2\right)^2 y^j dy\right] = -2\int_0^\infty \rho_g v_{tg} \left(\frac{\partial U_g}{\partial y}\right)^2 y^j dy - \\ -2\int_0^\infty \left(U_g - U_2\right) F_x y^j dy - 2\int_0^\infty g\pi\left(\rho_2 - \rho_{gm}\right)\left(U_g - U_2\right) y^{2j} dy \quad (7)$$

For energy of phase of impurity

$$\frac{\partial}{\partial x}\int_0^\infty \rho_p U_p^3 y^j dy = -2\int_0^\infty \rho_p v_{tp}\left(\frac{\partial U_p}{\partial y}\right)^2 y^j dy + 2\int_0^\infty U_p F_x y^j dy \quad (8)$$

For concentration of impurity

$$\frac{\partial}{\partial x}\int_0^\infty \chi U_p y^j dy = -2\int_0^\infty \frac{v_{tp}}{Sc_t}\left[\frac{\partial \chi}{\partial y}\right]^2 y^j dy \quad (9)$$

For heat content of gas phase

$$\frac{\partial}{\partial x}\left[\int_0^\infty c_{pg}\rho_g U_g \left(T_g - T_2\right) y^j dy\right] = \\ = \int_0^\infty \left(U_g - U_p\right) y^j dy - \int_0^\infty Q y^j dy \quad (10)$$

For heat content of phase of impurity

$$\frac{\partial}{\partial x}\left[\int_0^\infty c_{pp}\rho_p U_p T_p y^j dy\right] = \int_0^\infty Q y^j dy \quad (11)$$

Assumed is affinity of the velocity and temperature field, which allows introduction of the similarity of the cross-section distribution of velocity, temperatures and concentrations. After processing and sizing with the initial values of the corresponding parameters, the following system of equations is reached:

$$A_{11}\overline{\rho_{pm}}\,\overline{U_{pm}}\,\overline{x}^{j+1} = G_1 \quad (12)$$

$$A_{21}\overline{\rho_{gm}}\left(\overline{U_{gm}} - \overline{U_2}\right)^2 \overline{x}^{j+1} + A_{22}\overline{U_2}\left(\overline{U_{gm}} - \overline{U_2}\right)\overline{x}^{j+1} + \\ + A_{23}\overline{\rho_{pm}}\,\overline{U}_{pm}^2 + \frac{\rho_2 \pi \overline{g}\,\overline{x}^{2j+1}}{2j+1} - A_{24}\rho_{gm}\pi\overline{g}\,\overline{x}^{2j+1} = I_1 \quad (13)$$

*Corresponding author: **Hameed Khalaf Saleh**

$$\frac{\partial}{\partial x}\left[A_{31}\overline{\rho_{gm}}\left(\overline{U_{gm}}-\overline{U_2}\right)^3\overline{x}^{j+1}+A_{32}\overline{\rho_{gm}}\overline{U_2}\left(\overline{U_{gm}}-\overline{U_2}\right)\overline{x}^{j+1}\right]= \\ =-A_{33}\overline{\rho_{gm}}\overline{R_u}\left(\overline{U_{gm}}-\overline{U_2}\right)^3\overline{x}^{j-1}-2\left(\overline{U_{pm}}-\overline{U_{gm}}\right)F_x+ \\ +A_{34}\overline{\rho_2}\left(\overline{U_{gm}}-\overline{U_2}\right)\pi\overline{g}\,\overline{x^{2j+1}}-A_{35}\overline{\rho_{gm}}\left(\overline{U_{gm}}-\overline{U_2}\right)\pi\overline{g}\,\overline{x^{2j+1}} \tag{14}$$

$$\frac{\partial}{\partial x}\left[A_{41}\overline{\rho_{pm}}\overline{U_{pm}}^3\overline{x}^{j+1}\right]=-A_{42}\overline{\rho_{pm}}\overline{R_u}\overline{U_{pm}}^3\overline{x}^{j-1}+\left(\overline{U_{pm}}-\overline{U_{gm}}\right)F_x \tag{15}$$

$$\frac{\partial}{\partial x}\left(A_{51}\overline{\rho_{pm}}\overline{U_{pm}}\overline{x}^{j+1}\right)=-A_{52}\overline{\rho_{pm}^2}\overline{Ru}\overline{U_{pm}^3}\overline{x^{j-1}} \tag{16}$$

$$\frac{\partial}{\partial x}\left[A_{61}\overline{\rho_{gm}}\left(\overline{U_{gm}^*}+m\right)\left(\overline{T_{gm}}-T\right)\overline{x}^{j+1}\right]=A_{63}\left(\overline{T_{gm}}-\overline{T_{pm}}\right)\overline{x}^{j+1}+ \\ +A_{62}\overline{\rho_{pm}}\left(\overline{U_{gm}^*}-\overline{U_{pm}}+m\right)^3\overline{x}^{j+1} \tag{17}$$

$$\frac{\partial}{\partial x}\left[A_{71}\overline{\rho_{pm}}\overline{U_{pm}}\overline{T_{pm}}\overline{x^{j+1}}\right]=A_{72}\left(\overline{T_{gm}}-\overline{T_{pm}}\right)\overline{x}^{j+1} \tag{18}$$

At the non-dimensionless system above of integrated conditions, the following equations are added:

$$R_u = Sc_t\overline{R_p} \tag{19}$$

$$R_u = \Pr_t\overline{R_T} \tag{20}$$

$$\overline{P}=\overline{\rho_g}\overline{R}\overline{T_g} \tag{21}$$

Where $Sc_t = Sc_g\left(1+\sqrt{1+v_0}\right)$-number of Scmid and $\Pr_t=\frac{\upsilon_t}{a_t}$ - turbulent number of Prandtl

Numerical Model

The system equation is processed by reducing it to one equation of the seventh degree on the velocity of the gas phase:

$$A\overline{U_{gm}^*}^7+B\overline{U_{gm}^*}^6+C\overline{U_{gm}^*}^5+D\overline{U_{gm}^*}^4+ \\ +E\overline{U_{gm}^*}^3+F\overline{U_{gm}^*}^2+G\overline{U_{gm}^*}+H=0 \tag{22}$$

Where

$$A=\left(L_{17}\overline{\rho_{gm}}^3+L_{18}\overline{\rho_{gm}}^2\right);\ B=\left(L_{19}\overline{\rho_{gm}}^3+L_{20}\overline{\rho_{gm}}^2\right)$$

$$C=\left(L_{23}\overline{\rho_{gm}}^3+L_{26}\overline{\rho_{gm}}^2+L_{27}\overline{\rho_{gm}}\right)$$

$$D=\left(L_{31}\overline{\rho_{gm}}^3+L_{36}\overline{\rho_{gm}}^2+L_{37}\overline{\rho_{gm}}\right)$$

$$E=\left(L_{41}\overline{\rho_{gm}}^3+L_{47}\overline{\rho_{gm}}^2+L_{51}\overline{\rho_{gm}}+L_{52}\right)$$

$$F=\left(L_{55}\overline{\rho_{gm}}^3+L_{61}\overline{\rho_{gm}}^2+L_{67}\overline{\rho_{gm}}+L_{68}\right)$$

$$G=\left(L_{69}\overline{\rho_{gm}}^3+L_{73}\overline{\rho_{gm}}^2+L_{79}\overline{\rho_{gm}}+L_{83}\right)$$

$$H=\left(L_{84}\overline{\rho_{gm}^3}+L_{85}\overline{\rho_{gm}^2}+L_{88}\overline{\rho_{gm}}+L_{91}\right)$$

The equation is solved by the method of Newton-Raphsan by consistently defining the parameters of the flow. A program of Delphi is made in which the following algorithm is used. After determining from "(22)" the other integrated parameters are determined as follows:

Velocity of phase of impurity is defined as:

$$\overline{U_{pm}}=L_{12}+L_{13}\overline{\rho_{gm}}\overline{U_{gm}^*}^2+L_{14}\overline{\rho_{gm}}\overline{U_{gm}^*}+L_{15}\overline{\rho_{gm}}+L_{16} \tag{23}$$

Temperature of phase of impurity is define as

$$\overline{T_{pm}}=e^{\frac{\left(\overline{x}-\overline{x_0}\right)}{L_{107}}}\left(\overline{T_{p01}}+L_{98}\right) \tag{24}$$

Velocity of gas phase is define as

$$\overline{T_{gm}}=L_{95}+L_{96}\overline{T_{pm}} \tag{25}$$

Boundary layer by velocity is defined as:

$$\overline{R_u}=L_4+L_3F_x\left(\frac{\overline{U_{pm}}-\overline{U_{gm}}}{\overline{U_{pm}^2}}\right) \tag{26}$$

Boundary layer by impurity is defines as

$$\overline{R_p}=\frac{R_u}{Sc_t} \tag{27}$$

Boundary layer by temperature is defined as

$$\overline{R_T}=\frac{R_T}{\Pr_t} \tag{28}$$

Results of a numerical investigation of vertical non-isothermal jet

On Fig 1-6 are given the numerical results set forth in [6] integral method under the following initial conditions: conditional diameter $D_p = 35\mu m$, width of the driving lane of the fire $B=5m$, ambient temperature $T_2 = 293K$, density of the gas phase $\rho_g = 1.205kg/m^3$ density of the phase of impurities $\rho_p = 900kg/m^3$.

The initial speed is determined by:

$$V_0 = 1{,}9Q^{0{,}25}, m/s \tag{29}$$

Distribution of the maximum value of the velocity of the gas phase and the phase of impurities in a dimensionless form, depending on the height above the center of the fire shown in Fig. 1 ÷ 4. The veloity of the phase of impurities decays more slowly than the velocity of the gas phase under the effect of buoyancy. Both veloity subside more slowly compared with isothermal jet due to buoyancy.

The maximum temperature above the location of the fire (Fig. 5 and 6, respectively, for T_g and T_p) is kept at a very large value at a height of 200 m for research mode. With great power of the fire this attenuation is negligible. At high power and the fire this attenuation is negligible from 1100K to 850K to 1100K and 950K to a temperature of impurities. Released at high altitude impurities at a high temperature can be carried around by the wind and cause new outbreaks of fire. This is especially dangerous given that wind speed arise by height.

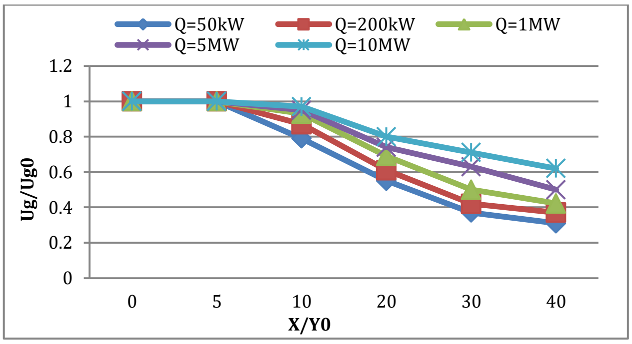

Fig.1

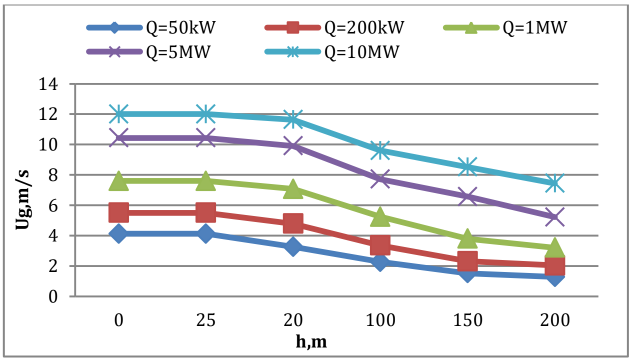

Fig.2

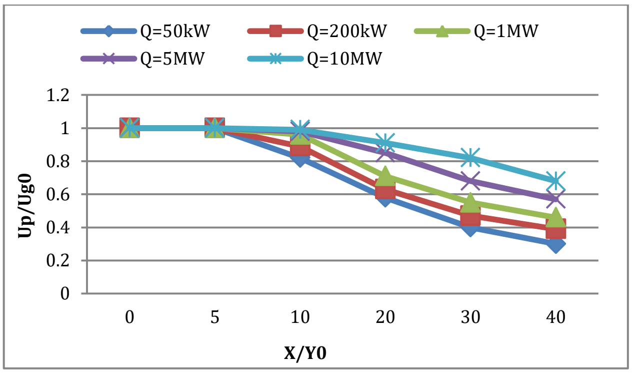

Fig.3

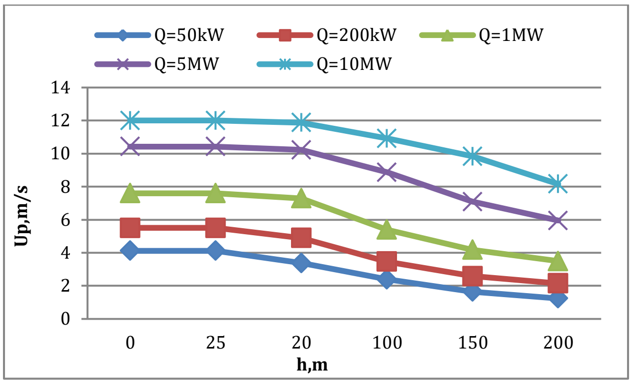

Fig.4

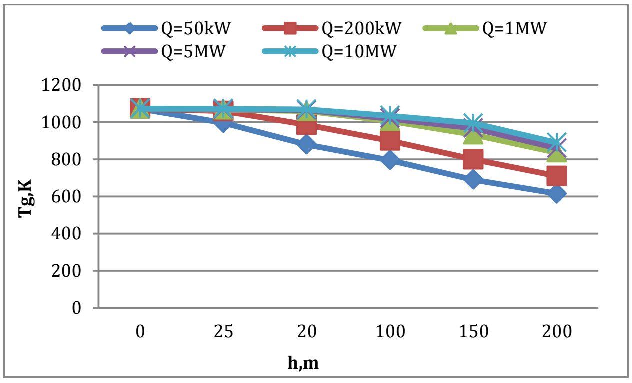

Fig.5

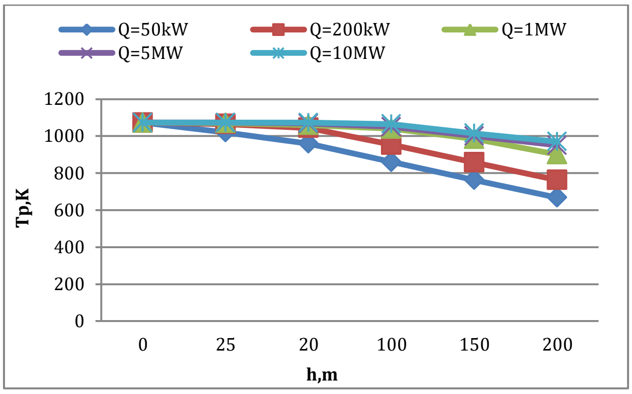

Fig.6

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