A SUGGESTION FOR EFFICIENCY INCREASE OF FLARE TIPS BASED ON A MODEL OF SWIRLING TWO-COMPONENT NON-ISOTHERMAL TURBULENT JET

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ABSTRACT : Mathematical model describing a swirling two-component non-isothermal turbulent jet is based on the concept for so called, multi-fluid, non-equilibrium flow scheme, i.e. there are differences between velocity, density, temperature fields for both phases. This mathematical model is closer to the physical nature of the flow. Influences of Swirl Factor on the flow are evaluated and suggestions are made for designing flare tip for more complete burning of platform associated gas, that reduces environmental pollution.

SYMBOLS

$U_{i\,(i=p,g,o,m)}$ - Axial components of Velocity
$W_{i\,(i=p,g,o,m)}$ - Tangential components of Velocity
$P_{i\,(i=\infty,o,min)}$ - Pressures
$C_{pi(i=p,g)}$ - Specific heats

$R_{i\,(i=u,p,T)}$- Boundary layer (dynamic, diffusive & thermal)
$\chi_{i(o,m)}$ - Concentrates
I_o, M_o- Quantity & Moment of quantity of motion
$T_{i\,(i=p,g,o,m)}$ - Temperatures
x, r, θ- Coordinates of Cylindrical Coor. System.
ε - Dissipative Velocity of the motion
$l_{i\,(i=u,p)}$ - Mixing length (dynamic & diffusion)
D_p - Massiveness of fraction
Re, Sc - Reynold & Schmidth numbers
S_o - Initial swirling degree
Pr, Nu - Prandtl & Nussel numbers
λ - Thermal conductivity Coefficient
$\nu_{ti(i=p,g)}$ - Turbulent viscosity coefficients
$k_{i\,(i=p,g)}$ - Kinetic Energy of the motion
Q, Q_E - Inter-phase thermal interaction & heat sources
F_x - Inter-phase Force
$_{p,\,g,\,o,\,max}$ - symbols of fuel gas; air; in the initial section; max. values

INTRODUCTION

The swirling two-component non-isothermal turbulent jets find application in the modern technologies and technological devices as dust-suction, chemical industry, etc. Particularly in combustible technique the swirling two-component non-isothermal turbulent jet is widely used as control facility for the size of a flame, its' form, effective and clean combustion because it allows to increase speed injection air from environment, i.e. increasing intensity of the process mixing; to increase stability of a flame thanking to the good prepared products for combustion; to increase the life of equipment, to reduce environmental pollution.

On platforms, during oil production process, an associated gas is collected and time by time the superfluous associated gas must be burned on the flare tips for environmental sanitation. The above ejected gas for burning on the flare tip should be considered as a two-component (fuel gas - air) non-isothermal turbulent jet. In this work, beside introduction investigating methods we would like to do analysis on the effect of swirling factor to the flow, i.e. burning process.

Regarding methods applied for the flow's investigation, beside a long and very expensive experimental models, the mathematical & numerical models are recognised and become favourable method. The computer programmes are successfully applied in engineering practice because they need minimum preliminary input information.

When working out the mathematical model, such streams arise both in the case of out-flowing of an advance prepared two-component mixture and also when spraying a jet in a environment[1]. A two-fluid scheme of a stream is used, where the second, the transported component (air) is treated as a continuum by analogy with the transporting (fuel gas), i.e. anagogic equations of motion are used for transported component.

SYSTEM BASIC EQUATIONS

A swirling two-component non-isothermal axi-symmetrical turbulent jet is described by the following equations [3],[4]:

$$\frac{\partial(\bar{r}\,\bar{U}_g)}{\partial\bar{x}} + \frac{\partial(\bar{r}\,\bar{V}_g)}{\partial\bar{r}} = 0 \tag{1}$$

$$\frac{\partial(\bar{r}\,\bar{U}_p)}{\partial\bar{x}} + \frac{\partial(\bar{r}\,\bar{V}_p)}{\partial\bar{r}} = 0 \tag{2}$$

$$\frac{\partial\chi}{\partial\bar{x}}(\bar{r}\,\bar{U}_p) + \frac{\partial\chi}{\partial\bar{r}}(\bar{r}\,\bar{V}_g) = \frac{1}{\rho_g}\frac{\partial}{\partial\bar{r}}\left(\rho_g\,\bar{r}\frac{\bar{\nu}_{tp}}{S_c}\frac{\partial\chi}{\partial\bar{r}}\right) \tag{3}$$

$$\frac{\partial\bar{U}_g}{\partial\bar{x}}(\bar{r}\,\bar{U}_g) + \frac{\partial\bar{U}_g}{\partial\bar{r}}(\bar{r}\,\bar{V}_g) + \frac{\partial\bar{P}}{\partial\bar{x}} = \frac{1}{\rho_g}\frac{\partial}{\partial\bar{r}}\left(\rho_g\,\bar{r}\,\bar{\nu}_{tg}\frac{\partial\bar{U}_g}{\partial\bar{r}}\right) - \bar{F}_x\,\bar{r} \tag{4}$$

$$\frac{\partial\bar{U}_p}{\partial\bar{x}}(\bar{r}\,\bar{U}_p) + \frac{\partial\bar{U}_p}{\partial\bar{r}}\left(\bar{r}\,\bar{V}_p\,\frac{\bar{\nu}_{tp}\partial\chi}{S_c\,\partial\bar{x}}\right) = \frac{1}{\rho_p}\frac{\partial}{\partial\bar{r}}\left(\rho_p\,\bar{r}\,\bar{\nu}_{tp}\frac{\partial\bar{U}_p}{\partial\bar{r}}\right) + \bar{F}_x\,\bar{r} \tag{5}$$

$$\frac{\partial\bar{W}_g}{\partial\bar{x}}(\bar{r}^2\,\bar{U}_g) + \frac{\partial\bar{W}_g\,\bar{r}}{\partial\bar{r}}(\bar{r}\,\bar{V}_g) = \frac{1}{\rho_g}\frac{\partial}{\partial\bar{r}}\left(\rho_g\,\bar{r}^2\,\bar{\nu}_{tg}\left(\frac{\partial\bar{W}_g}{\partial\bar{r}} - \frac{\bar{W}_g}{\bar{r}}\right)\right) \tag{6}$$

$$\frac{\partial\bar{W}_p}{\partial\bar{x}}(\bar{r}^2\,\bar{U}_p) + \frac{\partial\bar{W}_p\,\bar{r}}{\partial\bar{r}}\left(\bar{r}\,\bar{V}_p\,\frac{\bar{\nu}_{tp}\,\partial\chi}{S_c\,\partial\bar{r}}\,\bar{r}\right) = \frac{1}{\rho_p}\frac{\partial}{\partial\bar{r}}\left(\rho_p\,\bar{r}^2\,\bar{\nu}_{tp}\left(\frac{\partial\bar{W}_p}{\partial\bar{r}} - \frac{\bar{W}_p}{\bar{r}}\right)\right) \tag{7}$$

$$\frac{\partial \bar{P}}{\partial \bar{x}} = \rho_g \frac{\bar{W}_g^2}{\bar{r}} \qquad (8)$$

$$\frac{\partial \bar{T}_g}{\partial \bar{x}}(\bar{r}\ \bar{U}_g C_{pg}) + \frac{\partial \bar{T}_g}{\partial \bar{r}}(\bar{r}\ \bar{V}_g C_{pg}) = \frac{1}{\rho_g}\left[\frac{\partial}{\partial \bar{r}}\left(\rho_g\ \bar{r} C_{pg} \frac{\nu_{tg}}{Pr_t}\frac{\partial \bar{T}_g}{\partial \bar{r}}\right) + \bar{Q}\,\bar{r} + \bar{F}_x\,\bar{r}(\bar{U}_g - \bar{U}_p)\right] \qquad (9)$$

$$\frac{\partial \bar{T}_p}{\partial \bar{x}}(\bar{r}\ \bar{U}_p C_{pp}) + \frac{\partial \bar{T}_p}{\partial \bar{r}}(\bar{r}\ \bar{V}_p C_{pp}) = \frac{1}{\rho_g}\left[\frac{\partial}{\partial r}\left(\rho_p\ \bar{r} C_{pp} \frac{\nu_{tp}}{Pr_t}\frac{\partial \bar{T}_p}{\partial \bar{r}}\right) + \left(\rho_p\ \bar{r} C_{pp} \frac{\nu_{tp}}{Sc_t}\frac{\partial \bar{\chi}}{\partial r}\right)\left(\frac{\partial T_p}{\partial \bar{r}}\right) + \bar{Q}\,\bar{r}\right] \qquad (10)$$

Where: $\bar{x} = x/r_o$; $\bar{U}_i = U_i/U_o$; $\bar{V}_i = V_i/V_o$; $\bar{T}_g = T_g/T_{go}$; $\bar{T}_p = T_p/T_{po}$; $\bar{P} = P/(\rho_g U_o^2)$;
$\bar{W}_i = W_i/W_o$; $\nu_{ti} = \nu_{ti}/(U_o r_o)$; $F_x = K_x \rho_p (U_g - U_p)^2$; $Q = 6Nu\ \lambda\ (T_g - T_p)/D_p^2 + Q_E$;
$\bar{F}_x = F_x\, r_o/(\rho_g U_o^2)$

Boundary Conditions:

- For the axis of the flow (r = 0):

$$\frac{\partial \bar{U}_g}{\partial \bar{r}} = \frac{\partial \bar{U}_p}{\partial \bar{r}} = 0\ ; \quad \frac{\partial \chi}{\partial \bar{r}} = 0\ ; \quad \frac{\partial \bar{T}_p}{\partial \bar{r}} = \frac{\partial \bar{T}_g}{\partial \bar{r}} = 0$$
$$\bar{W}_p = \bar{W}_g = 0\ ; \quad \bar{V}_p = \bar{V}_g = 0 \qquad (11)$$

- On the boundary layer ($U_i = 0$):

$$\bar{W}_g = \bar{W}_p = 0\ ; \quad \bar{U}_p = \bar{U}_g = 0\ ; \quad \bar{T}_p = T_g = T_2\ ; \bar{P} = 0 \qquad (12)$$

Initial Values:

$U_{io} = U_o$; $\chi_o = \rho_p/\rho_g$; $W_o = S_o r_o$; (13)

Where $\dot{S}_o$ is initial swirling factor (ration between momentum (M_o) and product of quantity of motion (J_o) & coordinate (r_o) [7]:

$$S_o = M_o / (J_o\, r_o) \qquad (14)$$

NUMERICAL RESULTS & ANALYSIS

The k_g-k_p-ε model is used by authors for closing system equations, describing the motion of the swirling axis-symmetrical two-component non-isothermal turbulent jet on the basis of two-fluid scheme and additional k_g-, k_p- & ε- equations are used as below[5]:

$$\frac{\partial \bar{k}_g}{\partial \bar{x}}(\bar{r}\ \bar{U}_g) + \frac{\partial \bar{k}_g}{\partial \bar{r}}(\bar{r}\ \bar{V}_g) = \frac{1}{\rho_g}\frac{\partial}{\partial \bar{r}}\left(\rho_g\ r \frac{\nu_{\bar{t}g}}{\sigma_k}\frac{\partial \bar{k}_g}{\partial \bar{r}}\right) + \bar{\nu}_{tg}\left(\frac{\partial \bar{U}_g}{\partial \bar{r}}\right) + C_R \bar{k}_g^{3/2} R_i - \bar{\varepsilon} - \bar{\varepsilon}_p^* \qquad (15)$$

$$\frac{\partial \bar{k}_p}{\partial \bar{x}}(\bar{r}\ \bar{U}_p) + \frac{\partial \bar{k}_p}{\partial \bar{r}}\left(\bar{r}\ \bar{V}_p \frac{\bar{\nu}_{tp}}{S_c}\frac{\partial \bar{k}_p}{\partial \bar{r}}\bar{r}\right) = \frac{1}{\rho_p}\frac{\partial}{\partial \bar{r}}\left(\rho_p \bar{r} \frac{\nu_{\bar{t}p}}{\sigma_k}\frac{\partial \bar{k}_p}{\partial \bar{r}}\right) + \bar{\nu}_{tp}\left(\frac{\partial \bar{U}_p}{\partial \bar{r}}\right) + C_R \bar{k}_p^{3/2} R_i + \bar{\varepsilon}_p^* \qquad (16)$$

$$\frac{\partial \bar{\varepsilon}}{\partial \bar{x}}(\bar{r}\,\bar{U}_g) + \frac{\partial \bar{\varepsilon}}{\partial \bar{r}}(\bar{r}\,\bar{V}_g) = \frac{1}{\rho_g}\frac{\partial}{\partial \bar{r}}\left(\rho_g \bar{r}\,\frac{\bar{\nu}_{tg}}{\sigma_\varepsilon}\frac{\partial \bar{\varepsilon}}{\partial \bar{r}}\right) + C_{\varepsilon 1}\,\bar{\nu}_{tp}\frac{\bar{\varepsilon}}{\bar{k}_g}\left(\frac{\partial \bar{U}_g}{\partial \bar{r}}\right)^2 +$$

$$+ C_{\varepsilon 1}\,\bar{\nu}_{tp}\frac{\bar{\varepsilon}}{\bar{k}_g}\left[\bar{r}\frac{\partial}{\partial \bar{r}}\left(\frac{\bar{W}_g}{\bar{r}}\right)\right]^2 - C_{\varepsilon 2}\frac{\bar{\varepsilon}^2}{\bar{k}_g} - \bar{\Phi}_p \qquad (17)$$

Where: $\bar{k}_g = k_g/U_o^2$; $\bar{k}_p = k_p/u_o^2$; $\bar{\varepsilon} = \varepsilon r_o/U_o^3$; $\bar{\Phi}_p = \Phi_p r_o^2/U_o^4$; $\bar{F} = Fr_o/(\rho_g U_o^2)$

Additional boundary Conditions for k_g-, k_p- & ε- equations are applied:

- For the axis of the flow (r = 0):

$$\frac{\partial \bar{k}_p}{\partial \bar{r}} = \frac{\partial \bar{k}_g}{\partial \bar{r}} = \frac{\partial \bar{\varepsilon}}{\partial \bar{r}} = 0$$

- On the boundary layer ($U_i = 0$):

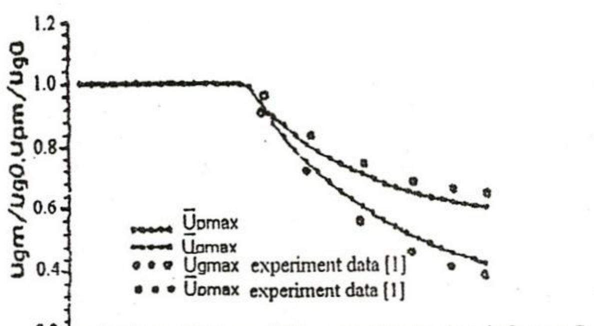
$\bar{k}_p = \bar{k}_g = \bar{\varepsilon} = 0$

Initial Values:

$k_{io} = (0.1U_{io})^2$; $V_{io} = 0$; $\varepsilon_o = C_D k_{go}^{1.5}/L$

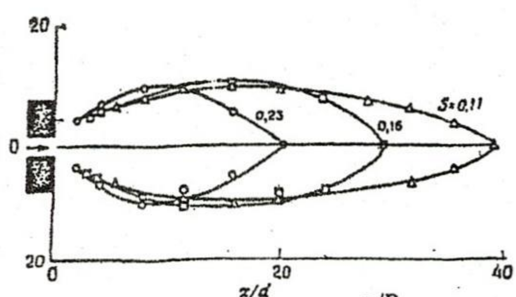
Numerical results of U_{pmax}, U_{pmax} and comparison with experimental data [1]

The system of 13 equations with 13 unknowns ($\bar{U}_i$; $\bar{V}_i$; $\bar{W}_i$; $\bar{T}_p$; $\bar{T}_g$; $\bar{k}_p$; $\bar{k}_g$; $\bar{\varepsilon}$; χ; $\bar{P}$...) is numerically solved with finite difference method using Duifort-Frankel differential scheme[5].



Distribution of U_{pmax}, U_{gmax} and R_g, R_p for deferent S_o

Fig. 1



x/R

T_{gmax} distribution & comparison with [1]

Distribution of the flame (profiles of max temperatures) for deferent initial swirl numbers[8]

Fig. 2

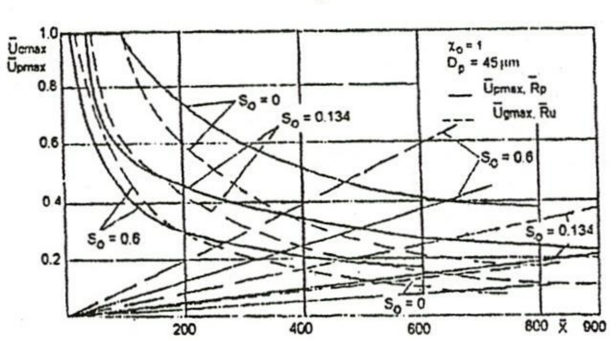


Fig. 3

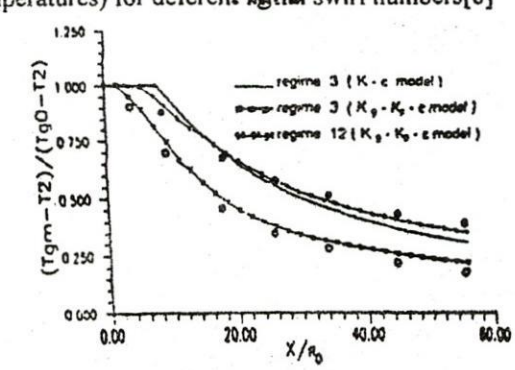
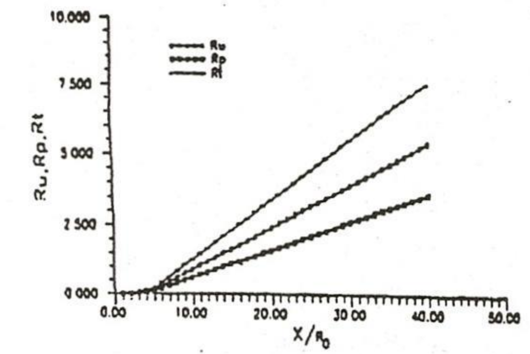
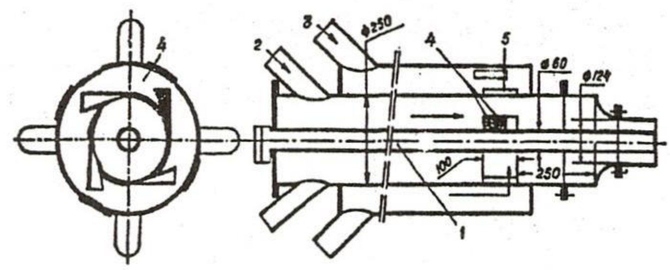


Fig. 4



Boundary layers R_p, R_u, R_t for the case χ_o =1.0; & D_p = 45μm

Fig. 5



Swirling burner with axial & tangential gas supply

1. Axial fuel gas supply; 2. Axial air supply; 3. Tangential air supply; 4. Directional control; 5. Cross profile 20x100mm, for tangential air supply.

Fig. 6

Results of the numerical investigation of a two-component stream with low initial concentration of the particles $\chi_o = 1$ and massiveness of the fractions D_p are shown on figures 1÷5. For the purpose of demonstration applicability of swirling two component non-isothermal turbulent jet, a comparison of numerical result for $\overline{U}_{gmax}$, $\overline{U}_{pmax}$ *and* $\overline{T}_{gmax}$ (χ_o=1.0; D_p=45μm; $U_{go}=U_{po}$=35m/s; ρ_{go}=0.59kg/m3; ρ_{po}=1,16kg/m^3; $T_{go}=T_{po}$=600°K) with experimental data [1] is made for S_o=0 on fig. 1&4. The good conformity between the values proves practical application of the numerical results.

The change in the swirling degree on fig. 2 & 3 shows that: while increasing S_o the velocity and temperature components of two phases decay faster and the jet boundary layers expand intensively (increasing speed injection air from environment and intensity of the mixing process). So, it is clear that with application of deferent swirling degrees (S_o), an associated gas burning process on the flare tips can be controlled, improved and the environmental pollution will be reduced.

CONCLUSION

- This summary of a part of the results of numerical investigation reveals a great opportunity to the suggested method for modelling of swirling two component non-isothermal turbulent jets.
- In case of forming swirling two-component non-isothermal turbulent flows on the flare tips of the oil production platform (for example by using swirling burner's structure as on Fig.6) we should increase efficiency of the process of mixing between platform associated gas and air from environment, i.e. increasing efficiency of burning process and reduced environmental pollution.

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MỘT KIẾN NGHỊ NHẰM GIA TĂNG HIỆU QUẢ QUÁ TRÌNH CHÁY Ở CÁC ĐẦU ĐUỐC DỰA TRÊN MÔ HÌNH LUỒNG RỐI XOÁY HAI THÀNH PHẦN KHÔNG ĐẲNG NHIỆT

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Mô hình toán của luồng rối xoáy hai thành phần không đẳng nhiệt được xây dựng trên cơ sở nhận thức tính chất không đồng nhất giữa các pha, có nghĩa là tồn tại sự khác biệt của vận tốc, mật độ và nhiệt độ giữa các pha. Mô hình toán học loại này có thể phản ánh một cách chính xác hơn bản chất vật lý của dòng tia. Báo cáo đánh giá tác động của hệ số xoáy lên sự phân

bố của luồng và đề cập tới khả năng ứng dụng chúng trong tính toán thiết kế các đầu đuốc tại các mỏ khai thác dầu khí nhằm đốt triệt để hơn khí đồng hành thải bỏ - tức là giảm ô nhiễm môi trường.

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