EFFECTS OF VARIABLE DENSITY ON MIXING EFFECIENCY IN AXISYMMETRIC TURBULENT CONFINED JETS

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ABSTRACT

The paper presents an application of two-equations k-ε model to the problem of axisymmetric confined jets with variable density. The continuity, momentum, mass fraction and turbulence equations are solved using the finite control volume methode of Patankar and Splading for two dimensional elliptique flows. The results are presented for differents velocity ratios, m=Ue/Uj, and density ratio, $R\rho=\rho_e/\rho_j$, where ρ_e and Ue are the density and velocity of the coflow and ρ_j and Uj are the jet density and jet velocity. The efficiency of mixing of mass originating from the jet with coflow is studied for varying Rρ. Finally, the comparisons with measurements are presented and discussed.

INTRODUCTION:

The turbulent flows where the density strongly varies occur in various industrial applications, related on energetics and propulsion. This type of complex flows (strong coupling between dynamic and scalar fields), were studied within the framework of many numerical and experimental work. The impact of strong variable density in turbulent jets has been reported by Pitts (1991), Panchapakesan, and Lumley (1993) , Sanders et al. (1997) for the jets issuing in stagnant surrounding, Stewart and Guruz (1977), Pagé et al. (1997), Dong and Mankbadi (1999), Saudreau et al. (2000) for the confined jets, and Elzey et al. (1991) for confined diffusion flames. The results indicate that the variable density effect on the structure of turbulent jet has not been fully elucidated.

In the present study, the objective is to isolate and analyse the main physical mechanisms governing the development and the structure of the jet and the efficiency of mixing. The variable density effects are investigated by varying the density ratio, Rρ, between 0.66 (CO_2/air) and 14.4 (H_2/air), and velocity ratio, m, between 0 and 3 (m=0, 0.075, 0.3, 0.5, 0.975, 1.5 and 3).

TURBULENCE MODEL

The standard k-ε model developed by Launder and Spalding (1974) is used. The Reynolds stresses are calculated via the effective viscosity concept. The effective viscosity ν_t is related to turbulent kinetic energy, k, and the rate of its dissipation, ε, by the Kolmogorov-Prandtl expression : $\nu_t = C_\mu k^2/\varepsilon$, where C_μ is the empirical constant. The turbulent kinetic energy and its dissipation rate are obtained from their respective transport equations. To model scalar mixing, an equation for the mean mixture fraction F is solved. The turbulent diffusion term in this equation is modelled by

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using a turbulent diffusivity (ν_t / σ_f) where σ_f is a turbulent Schmidt number. The constants in the model are given below:

C_μ	C1	C2	σ_k	σ_e	σ_f	σ_g
0.09	1.44	1.92	1	1.3	0.7	0.7

All variables, except for the density, are Favre-averaged.

COMPUTATIONAL PROCEDURE

We consider the flow configuration shown in figure 1. The primary nozzle diameter is D and its inlet velocity is Uj. The velocity and density of coflow is Ue and ρ_e. The finite-difference equations have been obtained by integrating the basic equations over the control volume. A staggered non uniform grid was employed and the solution algorithm is the SIMPLER (Patankar, 1980). The wall functions where used for the boundary condition of all the walls. The inlet conditions of the computational domain were given based on the measurement (Pagé at al. 1997).

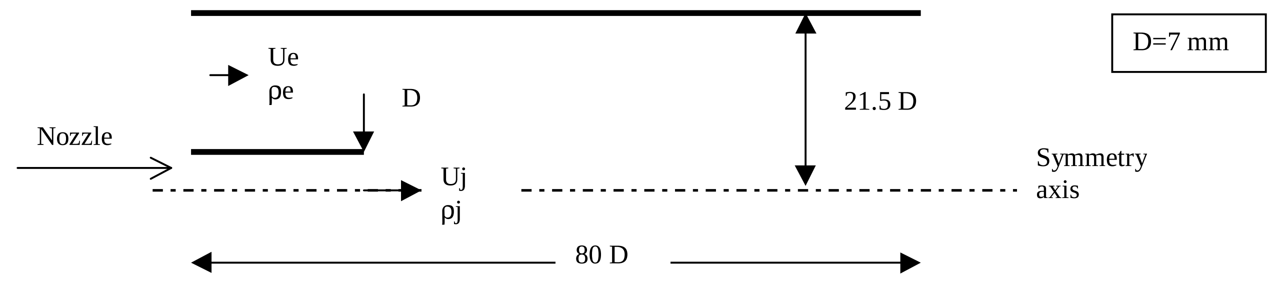

Figure 1 : Computational domaine

RESULT

In the calculation of variable density jets for constant m, only the jet density ρ_j has been changed to vary Rρ. The centreline velocity in the nozzle, Uj, was 70 m/s

Mean longitudinal velocity:

Figure 2 and 3 shows the axial evolution of the mean velocity for two values of Rρ, heavy and light jet. For each case, we investigated seven values of velocity ratio, m. The comparison with measurements of Pagé at al. 1997, for m=0.075 presents a good agreement. The axial decrease of mean velocity is influenced significantly by Rρ and m, principally, near the nozzle exit. When Rρ increases, and for m>1, the axial velocity decreases near the exit section, passes by a minimum before starting to increase. For the helium, Rρ=7.2, this minimum is negative and the length of te potential core is reduced. This is directly related to the mixing of the shear layer of different density in the early development of the jet. In the far field, and for m>1, axial velocity becomes higher at the velocity of coflow. On the other hand, for m=1 and m<1, the Uc/Uj does not exceed the value of m.

Turbulent kinetic energy :

Figures 4a, 4b and 5 show the effects of initial density ratio and velocity ratio on the turbulent kinetic energy. For higher jet density ratios, the maximum turbulence energy shifts towards the exit section of the jet for any velocity ratio m. The value of the maximum is much more important in the case of the light jet than in the case of the heavy jet. When we plot the maximum turbulence energy according to m, we observe a minimum of the turbulence kinetic energy located at m=1 except for $R\rho$=7.2 , where the minimum is located at m=0.5 (see figure 6).

FURTER RESULTS

For the final version of the paper, we will discuss the link between the structure of turbulence in the jet and the density and velocity ratios. We will add the results of the simulation of the hydrogen jet (m=14). Finally, we will discuss the efficiency of mixing according to the ratios m and $R\rho$.

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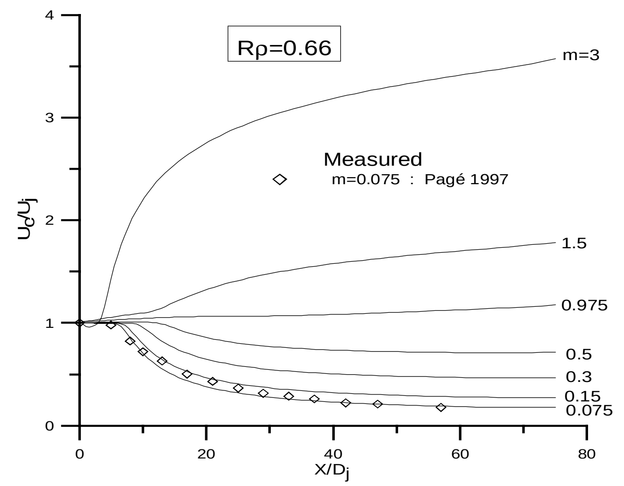

Figure 2 : Decay of the centreline velocity along the heavy jet axis

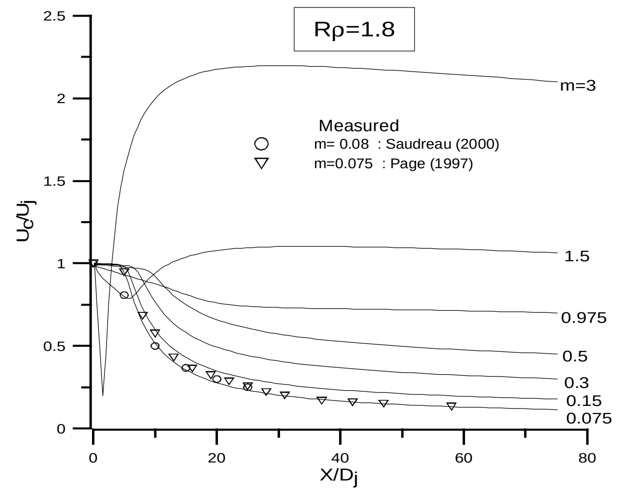

Figure 3 : Decay of the centreline velocity along the light jet axis

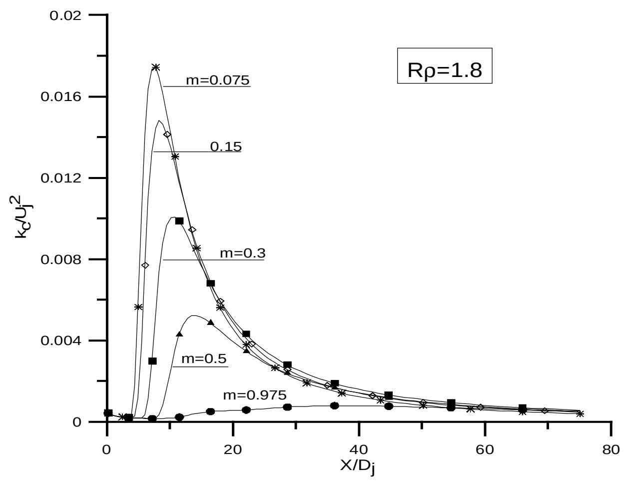

Figure 4a : Decay of the normalized turbulent kinetic energy : light jet

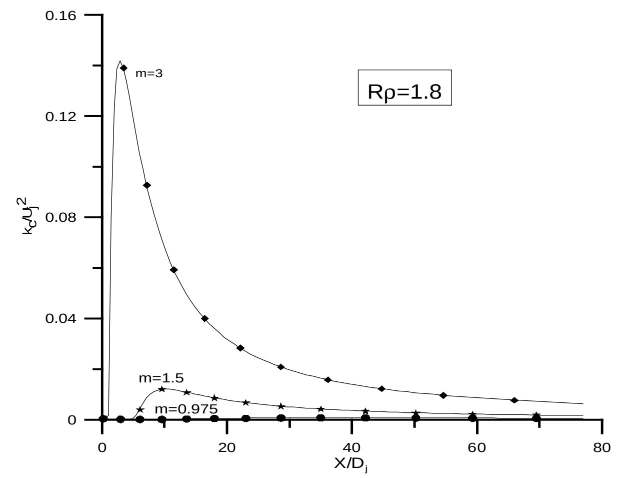

Figure 4b: Decay of the normalized turbulent kinetic energy : light jet

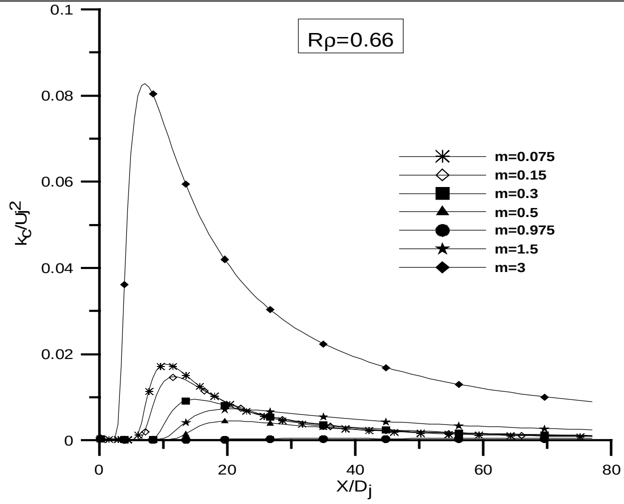

Figure 5 : Decay of the normalized turbulent kinetic energy : light jet

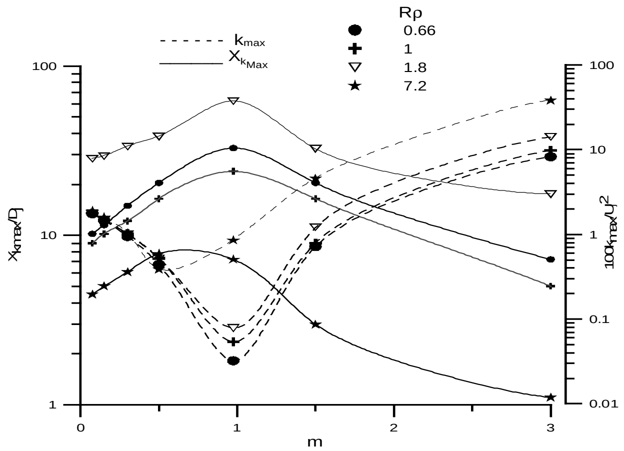

Figure 6 : Evolution of maximum of the normalized turbulent kinetic energy and position of this maximum vs velocity ratio m.