3rd Asia-Pacific International Symposium on Combustion and Energy Utilization

Estimating of the Dimensions and Anchoring Conditions in a Free Jet Flame.

C. A. Vieira
Combustion and Propulsion Laboratory, National Space Research Institute, Cachoeira Paulista, SP, Brazil

H.S. Couto
Combustion and Propulsion Laboratory, National Space Research Institute, Cachoeira Paulista, SP, Brazil

D. Bastos-Netto
Combustion and Propulsion Laboratory, National Space Research Institute, Cachoeira Paulista, SP, Brazil

Abstract

The full velocity and concentration profiles for laminar and turbulent axisymmetric gaseous jets in a quiescent atmosphere are established through comparison of previous experimental results and theoretical models. The proper matching of the jet isoconcentration and isovelocity lines provides an estimate of the flame dimensions and anchoring conditions.This work shows the result of this technique applied to a propane openjet diffusive flame, to a propane/air openjet premixed flame and to a propane/air openjet partially premixed flame.

Keywords: Openjet flames, diffusive flames, premixed flames

INTRODUCTION

The existing models describing the fully developed turbulent region in axisymmetric jets are not valid in the region closer to the nozzle exit[1-3] where prevails the potential core region studied by Wall et al[2]. Between these two zones there is the transition region, usually between five and fifteen diameters long in which the velocity profile is developed. Therefore any effort to establish the full jet profile has to deal with the matching of the inner (potential core) region to the outer (fully developed, turbulent flow) region through this transition zone. Once the full jet concentration and velocity profiles are established, the isovelocity line corresponding to the flame propagation velocity can be matched with the isoconcentration lines within the flamability limits, yielding the region where the flame is probably located (as a change in the turbulence level leads to a different flame propagation velocity). This work uses the available experimental data to establish the full jet profile and the matching of the isoconcentration and isovelocity lines to estimate the flame dimensions and anchoring conditions.

PROBLEM DESCRIPTION

Consider an axisymmetric free gaseous jet in a quiescent atmosphere as sketched in Figure 1, issuing from a nozzle of radius r_0 at a constant velocity U_0 and concentration C_0, so that the fluid within the shear layer which is established between the inner region (potential core) of decreasing radius r_1 and the expanding outer edge of the jet, radius r_2, progressively mixes with the air entrained from the surroundings. This region is known as the zone of flow establishment.

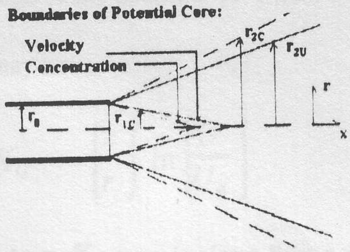

Figure 1: Open Jet Geometric Parameters (Reference 2)

The folowing equations describing r_1 and r_2 as functions of x, the axial distance from the nozzle exit were given by Wall et al[2]

$$\frac{r_1}{r_0} = 1 - J\frac{x}{r_0} \qquad (1)$$

$$\frac{r_2}{r_0} = 1 + H\frac{x}{r_0} \qquad (2)$$

where J and H are experimental constants which depend on the initial conditions and which retain different values for the calculation of either the velocity or the concentration profiles.

In particular, at the edge of the potential flow core, r_1=0, and

$$x_1 = \frac{r_0}{J} \tag{3}$$

Adopting the cosine profile for the flow velocity, U(x,r), and the concentration, C(x,r), as suggested by Wall et al [2] ,one may write:

$$r = r_1 + (r_2 - r_1)\left(\frac{1}{\pi}\right) ar\cos\left[\frac{2U}{U_0} - 1\right] \tag{4}$$

$$r = r_1 + (r_2 - r_1)\left(\frac{1}{\pi}\right) ar\cos\left[\frac{2C}{C_0} - 1\right] \tag{5}$$

In the transition region which follows the zone of flow establishment the centerline velocity decay was given by Kuhlman[3] as:

$$\frac{U_0}{U(x,0)} = 0.144\left(\frac{x}{2r_0} + 0.87\right) \tag{6}$$

The above equation can also be used for the fully developed region where the velocity profile does not change in shape anymore but in which the centerline velocity is still inversely proportional to the distance from the nozzle, according to Schlliting[4] and Wall[2]

Recalling that in the fully developed flow the velocity profile is Gaussian (Béer[1]), so that

$$\frac{U}{U_m} = \exp\left[-K_U\left(\frac{r}{x}\right)^2\right] \tag{7}$$

where U_m is the center line velocity, U(x,0), and K_U is a constant.

Assuming that this behavior can be extended to the transition zone, then, as $U_m = U_0$ at the edge of the potential core (i.e., at $r_1 = 0$), one may write:

$$K_U = -\left(\frac{x}{r}\right)^2 \ln\left[\frac{U}{U_0}\right] \tag{8}$$

where K_U now is also a fitting parameter to match the above equation with Eq.(3), so that

$$K_U = \frac{\frac{1}{J^2}\ln\frac{U(x_1,0)}{U(x_1,r)}}{\left[\frac{r_1}{r_0} + \frac{1}{\pi}\left(\frac{r_2}{r_0} - \frac{r_1}{r_0}\right) ar\cos\left[\frac{2U(x,r)}{U(x_1,0)} - 1\right]\right]^2} \tag{9}$$

By analogy, one may take the centerline concentration decay as (Wall, [2]):

$$\frac{C_0}{C(x,0)} = 0.0692\frac{x}{r_0} + 0.2857 \tag{10}$$

and

$$\frac{C}{C_0} = \exp\left[-K_C\left(\frac{r}{x}\right)^2\right] \tag{11}$$

Assuming that this behavior can be extended to the transition zone, then, at the edge of the potential core,

$$K_C = -\left(\frac{x_1}{r}\right)^2 \ln\frac{C}{C_0} \tag{12}$$

where K_C now is also a fitting parameter to match the above equation with Eq.(4), so that

$$K_C = \frac{\dfrac{1}{J^2}\ln\dfrac{C(x_1,0)}{C(x_1,r)}}{\left[\dfrac{r_1}{r_0}+\dfrac{1}{\pi}\left[\dfrac{r_2}{r_0}-\dfrac{r_1}{r_0}\right]ar\cos\left[\dfrac{C(x_1,r)}{C(x_1,0)}-1\right]\right]^2} \tag{13}$$

These values for K_U and K_C given by Equations (9) and (13) can then be used in Equations (7) and (12), respectively, yielding the remaining velocity and concentration profiles. If there exists an open jet premixed flame, then one should bear in mind that the flame propagation velocity should be matched to its corresponding isovelocity and the proper isoconcentration line to allow the establishment of the flame anchoring position. On the other side, the isoconcentration line corresponding to the lower flammability limit yields the flame profiles of both, the open jet diffusive and premixed flames.

RESULTS/DISCUSSION

This technique applied to an open jet propane diffusion flame is shown in Figure 2 along with results obtained by using Baron[6], Kanury[5] and Spalding[7] formulations.

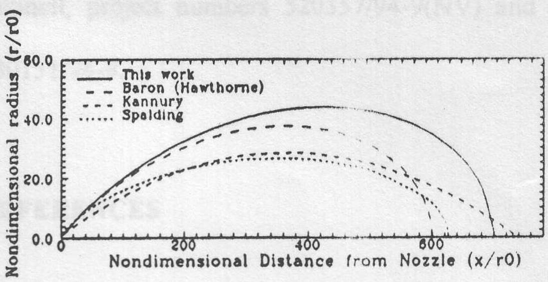

Figure 2: Diffusion Flame Profile, C_3H_8

The conditions for existence of a stable open jet premixed flame are dictated by the intersection of two envelopes: one consisting of isovelocity lines corresponding to the minimum and the maximum flame propagation velocities and the other consisting of the isoconcentration lines corresponding to the lower and the higher flammability limits.

If such intersection does not occur it means that there will be no stable flame.

The shaded areas in Figures 3 and 4 show the regions where a stable Propane/Air flame can exist for values of initial concentrations and velocities of 7% and 2 m/s and 50% and 5 m/s, respectively. Notice the latter represents a partially premixed flame as its initial concentration(50%) is greater than its higher flammability limit which is of 11.38% for this case[7].

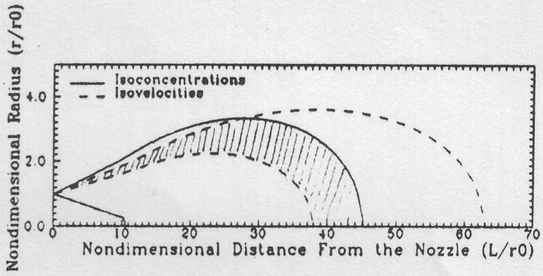

Figure 3: Premixed Flame, C_3H_8 - Air ,

$C_0 = 0.07$, $U_0 = 2$ m/s

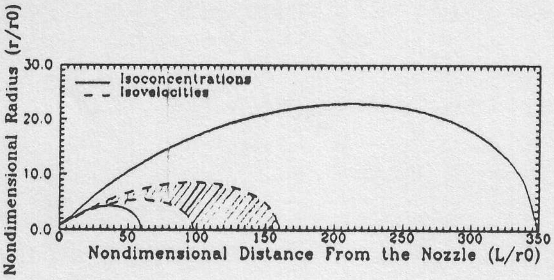

Figure 4: Propane - Air Flame,

$C_0 = 0.5$, $U_0 = 5$ m/s

AKNOWLEDGEMENT

Part of this work was done under the sponsorship of the Brazilian National Research Council, project numbers 520357/94-9(NV) and 830131/94-9.

REFERENCES

[1] Béer, J.M. and Chigier, N.A. "Combustion Aerodynamics", pp. 10- 26. Applied Science Publishers, Ltd., London, 1974.

[2] Wall, T.F., Subramanian, V. and Howley, P. "An Experimental Study of the Geometry, Mixing and Entrainment of Particle Laden Jets up to Ten Diameters from the Nozzle, pp. 231-239, Trans. I. Chem. E., Vol. 60, 1982.

[3] Kuhlman, J.M., "Variation of Entrainment in Annular Jets", pp. 373-379, AIAA J., Vol.25, No.3, Mar 1987.

[4] Schlichting, H. "Boundary Layer Theory", p. 734. MacGraw Hill Book Co., New York, N.Y., 1979.

[5] Kanury, A. M. "Introduction to Combustion Phenomena", pp. 130 - 131 and 283 - 240. Gordon and Breach Sci. Publishers, New York, N.Y., 1977.

[6] Baron,T. shown in Lewis, B., Pease, R.N. and Taylor, H.S. (Eds.), Combustion Processes , Vol. 2 in "High Speed Aerodynamics and Jet Propulsion", p. 394, Princeton U. Press., 1956

[7] Spalding, D.B.: "Combustion and Mass Transfer" Pergamon Press,