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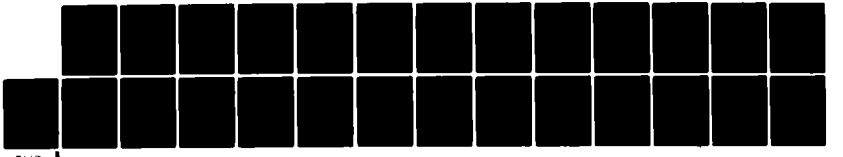

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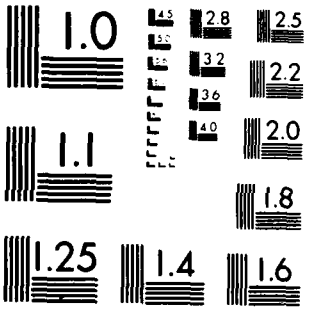

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report is comprised of two parts. In Part I a predictive model for an apparent flame length in a co-axial jet diffusion flame combustor is described. According to this model a diffusion flame is considered as thin cylindrical reactive zone composed of chemically active and dead regions. Fuel consumption by surface oxidation is assumed. Mass transport of oxygen to the reactive surface is considered to control the overall combustion process.

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Overall mass transfer coefficient, evaluated from an empirically developed correlation, is employed to predict total flame length. Comparison of the experimental and predicted data on total flame length shows a reasonable agreement within sixteen percent over the investigated air and fuel flow rate ranges of 1-2kg/s and 5-11kg/hr, respectively. In Part II a scheme to predict an apparent flame length is described for the circumstance when a recirculation region established immediately downstream of a center-body in a co-axial jet combustor is penetrated by a central fuel jet. A turbulent jet flow theory has been coupled with the theory given in Part I of the report. Total flame length has been predicted for air and fuel flow rates of 2kg/s and 16kg/hr, respectively. Comparison of calculated and experimental flame length values indicates a difference of sixteen percent.

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PREDICTION OF AN APPARENT FLAME LENGTH IN A CO-AXIAL JET DIFFUSION FLAME COMBUSTOR

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April 1983

FINAL REPORT

Prepared for

Air Force Office of Scientific Research
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FOREWORD

This report was prepared by the Department of Chemical Engineering, University of Dayton, Dayton, Ohio 45469 under Grant No. AFOSR-82-0295, Project No. 93068, Project-Task 2308/D9 with Dr. B.T. Wolfson/NA, Government Project Manager.

The report describes the mathematical developmental effort to predict an apparent flame length in a co-axial jet diffusion flame combustor of 'bluff-body' type. In Part I of the report a predictive model, based on the idea of occurrence of combustion process on imaginary cylindrical surface, is described. In Part II coupling of turbulent jet flow theory with the theory described in Part I is described. This coupling scheme was adopted to check the validity of the model developed in Part I to predict the flame length for the circumstance when a recirculation region established immediately downstream of a bluff-body in a co-axial jet combustor is penetrated by a central fuel jet.

The author is Dr. Sarwan S. Sandhu, Principal Investigator of this project. Project management is provided by Dr. Gary A. Thiele. Discussions with Drs. W.M. Roquemore, R.A. Servais and L. Krishnamurthy are acknowledged. An acknowledgement is due to Dr. E.J. Rolinski for proof-reading of the typescript. The assistance of Mrs. Mary Lu Kinzeler in the preparation of this report is greatly appreciated.

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PART I

A PREDICTIVE MODEL FOR AN APPARENT FLAME LENGTH IN A CO-AXIAL JET DIFFUSION FLAME COMBUSTOR

A PREDICTIVE MODEL FOR AN APPARENT FLAME LENGTH IN A CO-AXIAL JET DIFFUSION FLAME COMBUSTOR

ABSTRACT

Diffusion flame in a co-axial jet bluff-body combustor is modeled as thin cylindrical reactive zone composed of chemically active and dead regions. Under the consideration of mass transfer control of fuel consumption by surface oxidation a theoretical expression is developed to predict total flame length. Overall mass transfer coefficient is calculated using an empirically developed correlation. Evaluated mass transfer data are then employed to predict total flame length. Comparison of the experimental and predicted data on total flame length shows a reasonable agreement within sixteen percent over the investigated air and fuel flow rate ranges of 1-2 kg/s and 5-11 kg/hr, respectively.

INTRODUCTION

Sandhu (1981,1982,1983), Roquemore et al. (1982), Lightman and Magill (1981), Krishnamurthy (1981), and Hasen (1982) have been performing experimental and theoretical studies to understand the fluid mechanical and chemical kinetics phenomena in a bluff-body co-axial jet diffusion flame combustor. Sandhu (1981), and, Roquemore et al. (1982) have shown time variation of local combustion reaction process. This variation can be envisioned in terms of variation in local reactant specie concentrations and temperature. Under the situation of very lean concentration of a reactant specie relative to stoichiometric concentration and low gas mixture temperature, combustion reaction may not persist at a location. A local region of no-combustion reaction is termed as 'dead region' or 'hole' in luminous flame zone. One possible way for the creation of 'holes' in the diffusion flame sheet is by quenching of the combustion process due to

interaction of relatively cold air eddies with the flame sheet. In what follows thin flame reaction zone is considered to be composed of active and dead (hole) regions. Employing this reasonably valid assumption an expression to predict total flame length is developed under the consideration of mass transfer control of the combustion process. By using an empirically developed expression overall mass transfer coefficients are evaluated, and employed for the prediction of total flame length as a function of air and fuel flow rates. Finally, predicted and experimental data on total flame length are compared.

ASSUMPTIONS

1. Fuel is consumed by surface reaction with oxygen in thin reaction zone of cylindrical configuration.
2. Fuel transformation to product species, CO_2, $H_2O(g)$ etc. via surface reaction is controlled by the mass transport of oxygen to the reactive surface by the processes of molecular diffusion and turbulent 'eddying' dispersion.
3. Thin reactive zone is composed of chemically active and dead surface regions. A chemically dead surface region of 'hole' means a surface region where the flame combustion process does not persist.
4. Almost an entire amount of fuel disappears to its final product species, CO_2 and $H_2O(g)$.

FORMULATION (see Figure 1)

Effective area of reaction surface, where flame exothermic reaction process occurs, is composed of:

effective area of inner reaction surface nearer to the fluid recirculation zone $= \pi D_b L_a (1-S_h)$ (1)

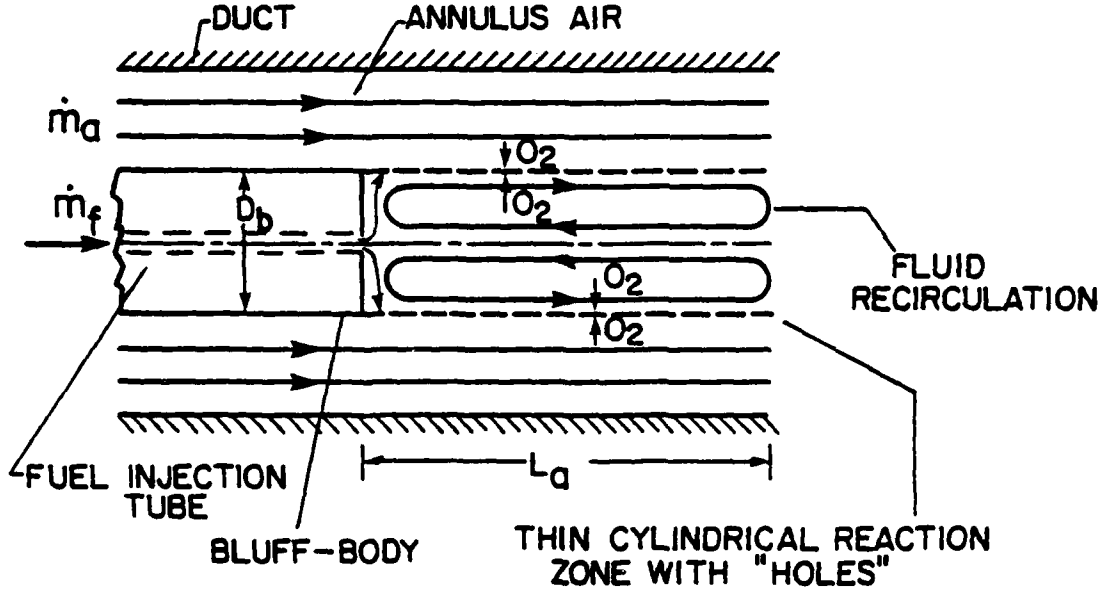

Figure 1. Schematic of the Conceptual Model of the Co-axial Jet Bluff-Body Diffusion Flame Combustor

effective area of outer reaction surface closer to the annulus air stream =

$$\pi D_b L_a (1-S_h) \tag{2}$$

(1) and (2) are approximately equal because the thickness of the flame reaction zone is relatively much smaller than the diameter, D_b of the cylindrically shaped flame. Total oxygen transport rate to the active reaction surface, $\dot{n}_{O_2}$ = oxygen transport rate to the inner surface plus the outer surface.

$$\dot{n}_{O_2} = k_{g\ O_2,r} (\bar{C}_{O_2,r} - C_{O_2,s}) \times \pi D_b L_a (1-S_h) + k_{g',O_2,a} (\bar{C}_{O_2,a} - C_{O_2,s}) x$$

$$\pi D_b L_a (1-S_h) = [k_{g,O_2,r} (\bar{C}_{O_2,r} - C_{O_2,s}) + k_{g',O_2,a} (\bar{C}_{O_2,a} - C_{O_2,s})] x$$

$$x \pi D_b L_a (1-S_h) \tag{3}$$

Because the flame reaction process proceeds at a rate which is relatively much faster than the oxygen transport rate to the surface; oxygen concentration at reaction surface, $C_{O_2,s}$ is considered to be approximately equal to zero. Therefore, Equation (3) reduces to:

$$\dot{n}_{O_2} = [k_{g,O_2,r} \bar{C}_{O_2,r} + k_{g,O_2,a} \bar{C}_{O_2,a}] \cdot x \pi D_b L_a (1-S_h) \tag{4}$$

Letting $[k_{g,O_2,r} \bar{C}_{O_2,r} + k_{g,O_2,a} \bar{C}_{O_2,a}] = 2k_{g,O_2} C_{O_2,a}$ (5)

From Equations (4) and (5):

$$\dot{n}_{O_2} = [2k_{g,O_2} C_{O_2,a}] \ [\pi D_b L_a (1-S_h)] \tag{6}$$

Propane, C_3H_8, fuel and oxygen overall reaction stoichiometric equation is:

$$C_3H_8(g) + 5O_2(g) \longrightarrow 3CO_2(g) + 4H_2O(g) \tag{7}$$

Molal rate of consumption of the propane fuel = $\frac{\dot{n}_{O_2}}{5}$

$$= \left(\frac{2\pi}{5}\right)(D_b L_a)\left[k_{g,O_2}\,(1-S_h)\right] C_{O_2,a} \qquad (8)$$

Letting $\left[k_{g,O_2}\,(1-S_h)\right] = k_{g,O_2,e}$; Equation (8) reduces to:

$$\text{Propane fuel consumption rate} = \frac{(2\pi)}{5}(D_b L_a) k_{g,O_2,e} C_{O_2,a} \qquad (9)$$

Mole flow rate of the propane fuel fed, $\dot{n}_f$ =

$$\frac{\dot{m}_f, \text{ mass flow rate of the fuel}}{\text{mol. wt.}} = \frac{\dot{m}_f}{44}$$

Under the consideration that the entire amount of the fuel fed is consumed by the surface reaction, the fuel feed rate and its consumption rate must be equal. Therefore, $\dot{n}_f = \frac{(2\pi)}{5}(D_b L_a)\, k_{g,O_2,e} C_{O_2,a}$ (11)

By the utilization of Equation (11), either apparent flame length, L_a or effective mass transfer coefficient, $k_{g,O_2,e}$ can be predicted for the known values of the system and operational parameters, $D_b, \dot{n}_f$ and $C_{O_2,a}$.

Values of the effective mass transfer coefficient, $k_{g,O_2,e}$ as function of the annulus air and fuel (C_3H_8) mass feed rates, were determined employing Equation (11) and the data on total apparent flame length by Roquemore et al. (1980). Functional form of $k_{g,O_2,e}(\dot{m}_a, \dot{m}_f)$ was determined using linear, semilog and log-log plots for the fixed geometry of the bluff-body diffusion flame reactor. The effective mass transfer coefficient, $k_{g,O_2,e}$ was then, empirically correlated with air and fuel mass flow rates

as shown below:

$$k_{g,O_2,e} = 12.18 \frac{\dot{m}_a^{2.13}}{\dot{m}_f^{1.21}} \quad (12)$$

Rearranging Equation (11) for the prediction of apparent flame length,

$$L_a = \frac{\dot{n}_f}{(2\pi/5)\, D_b k_{g,O_2,e} C_{O_2,a}} \quad (13)$$

Equations (12) and (13) can be used to predict apparent flame length, L_a for propane/air flame over the air and fuel flow rate ranges for which the correlation (12) is valid.

COMPARISON

Figure 2 shows the predicted and experimental data on apparent flame length for air and fuel mass flow rate ranges of 1-2 kg/s and 5-11 kg/hr, respectively. Experimental data taken for comparison are those reported by Roquemore et al. (1980) for duct, bluff-body and fuel tube dia. of 25.4, 14, and 0.48 cm., respectively. The predicted and experimental data are found to be within sixteen percent.

CONCLUSION

A first step simple model to predict the apparent flame length in a co-axial jet, bluff-body diffusion flame (C_3H_8/air) reactor has been developed. The model is based on the mass transfer control of the fuel consumption rate via exothermic chemical reaction occurring on the cylindrically shaped flame surface. Validity of the model is limited by the capability of the empirical correlation, Equation (12), to predict effective mass transfer coefficient.

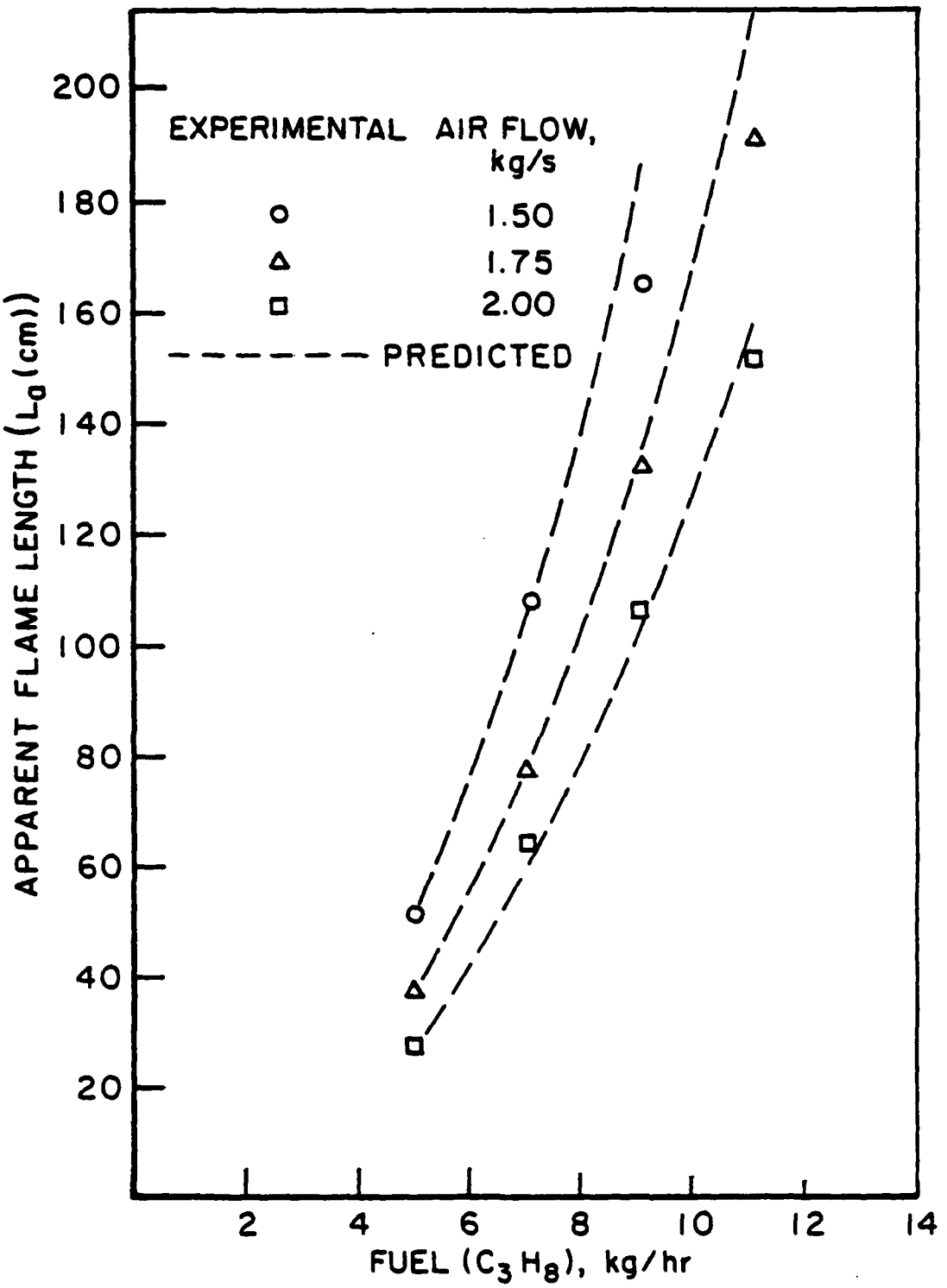

Figure 2. Plot of Apparent Flame Length as Function of Flow Rates

NOMENCLATURE

$\dot{m}_a$	air mass flow rate, k_g/s
$\dot{m}_f$	fuel (C_3H_8) mass flow rate, k_g/hr
D_b	bluff-body diameter, cm
L_a	total apparent flame length, cm
S_h	'hole' or dead-region flame surface fraction
$\dot{n}_{O_2}$	rate of transport of oxygen moles, g-moles/s
$k_{g,O_2,r}$	mass transfer co-efficient for transport of oxygen from fluid recirculation zone to reaction zone surface, cm/s
$k_{g,O_2,a}$	mass transfer coefficient for oxygen transport from annular air stream to reaction surface, cm/s
k_{g,O_2}	an oxygen mass transfer coefficient, cm/s
$k_{g,O_2,e} = k_{g,O_2}(1-S_h)$	an effective mass transfer co-efficient for oxygen transport to reaction zone surface, cm/s
$\dot{n}_f$	fuel feed rate, g-moles/s
$\bar{C}_{O_2,r}$	spatial and temporal average of bulk oxygen concentration in the recirculation zone, $\frac{\text{g-moles}}{\text{cm}^3}$
$\bar{C}_{O_2,a}$	bulk oxygen concentration in the annular air stream, $\frac{\text{g-moles}}{\text{cm}^3}$
$C_{O_2,s}$	oxygen concentration at the reaction zone surface, $\frac{\text{g-moles}}{\text{cm}^3}$
$C_{O_2,a}$	oxygen concentration in annular air stream at air stream feed pressure and temperature conditions, $\frac{\text{g-moles}}{\text{cm}^3}$

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PART II

PREDICTION OF AN APPARENT DIFFUSION FLAME LENGTH BY A MODEL INCORPORATING TURBULENT JET FLOW THEORY

ABSTRACT

A semiempirical scheme has been developed to predict total flame length in a center-body-coaxial-jet diffusion flame combustor. A central fuel jet is considered to penetrate the fluid recirculation zone established downstream of center-body. A turbulent jet flow theory is coupled with the theory given in Part I of the report, to predict total flame length. Total flame length has been calculated for air and fuel flow rates of 2kg/s and 16kg/hr, respectively. Comparison of calculated and experimental values of total flame length at these flow rate conditions indicates a difference of 16%. A suggestion has been made to test this scheme more rigorously by acquiring more experimental data.

PREDICTION OF AN APPARENT DIFFUSION FLAME LENGTH BY A MODEL INCORPORATING TURBULENT JET BLOW THEORY

INTRODUCTION

Cine films of flames in the co-axial jet diffusion flame combustor described in Reference 1 indicated that fuel jet penetrates the recirculation region in the wake of center-body at fuel flow rates of the order of 16kg/hr. Further, highly turbulent nature of the flow-field has been revealed in References 2,3. This leads to state that diffusion flames being investigated in the combustor of the type described in Reference 1 are of turbulent nature. Hawthorne et al. (Ref. 4) have developed semiempirical correlation to predict lengths of turbulent diffusion flames for gaseous fuel jets discharging into open atmospheric air. Development of their correlation is based on conservation of jet momentum, and, assumptions of uniform gas velocity and composition across a cross-section of the fuel jet. Wohl et al. (Ref. 5) have developed semiempirical correlations to predict lengths of turbulent flames of city gas and city gas-air mixture issuing into open air. Their development is based on the concept of eddy (or turbulent) diffusivity which is defined as the product of mixing length and intensity of turbulence. These semiempirical correlations are also given in Reference 6. Turbulent diffusion flames reported in References 1-3, 7 and 8 differ from those dealt by Hawthorne et al. and Wohl et al. in that central fuel and annular air jets discharge into a confining duct. Also, jets are widely separated at inlet plane. In addition to high fluid velocities, large separation of confined co-axial jets at the inlet plane leads to a highly complex turbulent nature of the flow field. Fuel and air mixing process, controlling the overall combustion process, is dependent upon turbulent nature of the flow-field in a complex way. It was, therefore,

decided to develop a theoretical scheme to predict lengths of turbulent diffusion flames of co-axial fuel and air jets. In what follows a turbulent flow jet theory is coupled with the theory described in Part I of the report to predict an apparent flame length of a turbulent diffusion flame in a co-axial jet combustor of the type described in Reference 1.

Theory

Figure 3 is a conceptual representation of the flow-field used as a guide to develop theoretical scheme to predict flame length in a co-axial jet diffusion flame combustor. Central fuel jet is considered to penetrate the recirculation zone. Axial location, where central jet centerline velocity equals the duct average gas velocity, is assumed to be equal to bluff-body (center-body) diameter, D_b. The amount of fluid entrained by the jet in its spreading from orifice radius, r_o to radius, $r = \frac{D_b}{2}$ is calculated using entrainment rate equation (Ref. 9) for a turbulent jet issuing into a stagnant surrounding fluid. This is clearly an approximation to reality. The entrainment rate equation is

$$\frac{dM}{dz} = 0.404\rho^{\frac{1}{2}} F^{\frac{1}{2}} \tag{1}$$

where M is jet fluid mass flow rate; ρ, surrounding fluid density and F, jet momentum. Under the consideration of conservation of jet momentum, F is given by $F = Fo$ (jet momentum at orifice exit) $= \rho_o u_o^2 (\pi r_o^2)$ (2)

where ρ_o, u_o and r_o are fluid density, velocity and radius at the orifice exit plane.

From (1) and (2):

$$\frac{dM}{dz} = 0.404\rho^{\frac{1}{2}} F_o^{\frac{1}{2}} \tag{3}$$

On integration:

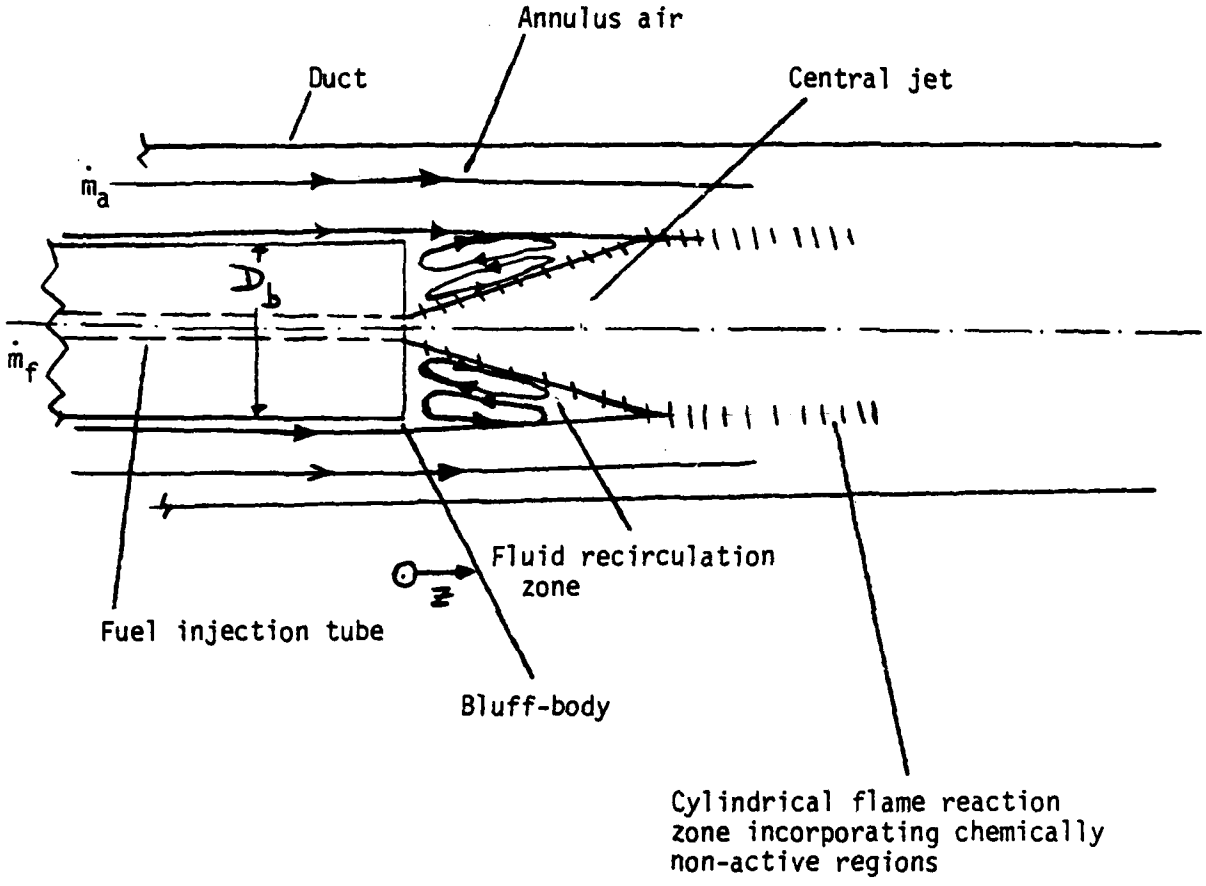


Figure 3. Conceptual representation of flow field indicating recirculation zone penetration by central jet in a co-axial jet bluff-body diffusion flame combustor.

$$\int_{M=M_o}^{M=M} dM = 0.404\ F_o^{\frac{1}{2}} \int_{z=o}^{z=D_b} \rho^{\frac{1}{2}} dz \qquad (4)$$

Taking $\rho=\bar{\rho}$, mean density of surrounding fluid, equation (4) results in (5).

$$M-M_o = 0.404\ F_o^{\frac{1}{2}}\ (\bar{\rho})^{\frac{1}{2}}\ D_b \qquad (5)$$

where M_o is orifice fluid mass flowrate. Therefore, rate of mass of surrounding fluid entrained into the jet in axial distance of $z = D_b$ is

$$M_e = M-M_o = 0.404\ F_o^{\frac{1}{2}}\ (\bar{\rho})^{\frac{1}{2}}\ D_b =$$

$$0.404\ \left[\rho_o u_o^2\ (\pi r_o^2)\ \bar{\rho}\right]^{\frac{1}{2}}\ D_b =$$

$$(\sqrt{\pi})(.404)(u_o r_o)(\sqrt{\rho_o \bar{\rho}})\ D_b \qquad (6)$$

Ideal gas law is used to relate fluid density to combustion system temperature and pressure conditions. That is, $\rho = \frac{PM}{RT}$ (7)

where P,T,R and M are system pressure and temperature, universal gas law constant and fluid molecular weight respectively. On application of equation (7) to orifice fluid and surrounding fluid,

$$(\rho_o \bar{\rho})^{\frac{1}{2}} = \left(\frac{P}{R}\right)\left(\frac{M_o \bar{M}}{T_o \bar{T}}\right)^{\frac{1}{2}} \qquad (8)$$

where T_o, M_o and $\bar{M}$ are orifice fluid temperature and molecular weight, and average surrounding fluid molecular weight, respectively. $\bar{M}$ can be safely taken to be equal to air molecular weight for the conditions used in experimental work reported in References 1,3,7. From equations (6) and (8), surrounding fluid entrainment rate is given by

$$M_e = 0.72\ \left(\frac{P}{R}\right)\left(\frac{M_o \bar{M}}{T_o \bar{T}}\right)^{\frac{1}{2}}\ (u_o r_o D_b) \qquad (9)$$

Effective (with regard to fuel combustion) air entrainment rate into the fuel jet is,

$$M_{e,e} = \alpha M_e \tag{10}$$

where α is an adjustable co-efficient.

Under the assumption of $\alpha = 1$, $M_{e,e} = M_e$ (11)

Therefore, from equations (9) and (11), air entrainment rate into jet is

$$M_{e,e} = M_e = 0.72 \left(\frac{P}{R}\right)\left(\frac{M_o M}{T_o \bar{T}}\right)^{\frac{1}{2}} (u_o r_o D_b) \tag{12}$$

Mole flow rate of air into jet is,

$$n_a = (0.72)\left(\frac{P}{R}\right)\left(\frac{M_o \bar{M}}{T_o \bar{T}}\right)^{\frac{1}{2}} \cdot \frac{1}{M_a} \cdot (u_o r_o D_b) \tag{13}$$

where M_a is air molecular weight. For $\bar{M} = M_a$, equation (13) reduces to

$$n_a = (0.72)\left(\frac{P}{R}\right)\left(\frac{M_o}{M_a}\right)^{\frac{1}{2}} \frac{1}{\sqrt{T_o \bar{T}}} u_o r_o D_b \tag{14}$$

Therefore, oxygen entrainment rate into jet is

$$n_{O_2} = 0.21\, n_a = 0.15 \left(\frac{P}{R}\right)\left(\frac{M_o}{M_a}\right)^{\frac{1}{2}} \frac{1}{\sqrt{T_o \bar{T}}} (u_o r_o D_b), \frac{\text{moles}}{\text{time}} \tag{15}$$

Taking propane fuel for combustion process, overall combustion stoichiometric equation is,

$$C_3H_8(g) + 5O_2(g) \longrightarrow 3CO_2(g) + 4H_2O(g) \tag{16}$$

If it is assumed that all entrained oxygen is consumed to combust fuel, the amount of central jet fuel consumed in axial distance, $z = D_b$ is,

$$n_{fc} = \frac{n_{O_2}}{5} = 0.03 \left(\frac{P}{R}\right)\left(\frac{M_o}{M_a}\right)^{\frac{1}{2}} \frac{1}{\sqrt{T_o \bar{T}}} (u_o r_o D_b) \tag{17}$$

If fuel combustion efficiency is η_c, then, total amount of fuel consumed per 1 time in the combustion system is,

$$n_{ft} = \eta_c\, n_f \tag{18}$$

where n_f is molar feed rate of fuel.

Rate of fuel to be consumed downstream of $z = D_b$ is,

$$n_{fd} = n_{ft} - n_{fc} = \eta_c\, n_f - n_{fc} \tag{19}$$

Under the assumption of 100% combustion efficiency, i.e., $\eta_c = 1$; fuel to be consumed downstream of $z = D_b$ is, $n'_{fd} = n_f - n_{fc}$ (20)

Fuel amount n'_{fd} (or n_{fd}) is considered to be consumed in flame reaction zone located at the cylindrical surface of diameter, D_b. Reaction zone is is considered to be composed of chemically flame active and nonactive regions. Effective mass transfer coefficient may be calculated using equation (12) of Part I of the report. It is, however, indicated that application of equation (12) to high fuel flow rates of the order of 16kg/hr is only an extrapolation. Flame length required to consume fuel amount, n'_{fd} (or n_{fd}) is determined using equation (13) of Part I. The equation in the desired form for the present case is,

$$L_d = \frac{n'_{fd}}{(2\pi/5)\, D_b k_{g,O_2,e}\, C_{O_2,a}} \tag{21}$$

Total Flame length is,

$$L_f = D_b + L_d \tag{22}$$

Predicted Flame Length and Comparison with Experimental Data

Total predicted flame length was determined as shown under 'Sample Calculations' for air and fuel flow rates of 2kg/s and 16kg/hr, respectively. Predicted flame length is 213.1 cm in comparison with the experimental value of 254.5 cm determined by linear extrapolation of the data give in reference 1. Difference based on the experimental value is approximately 16%. This disparity is reasonable in view of the following points:

(1) Entire amount of fluid entrained into the fuel jet has been assumed to be air. In fact, fluid entrained into the fuel jet is not pure air but gas mixture which is less rich in oxygen than air. This assumption leads to greater amount of calculated oxygen supply to the fuel jet, and, therefore, greater amount of fuel consumption in axial distance of $z = D_b$. Thus, this assumption should result in shorter flame as it is found so.

(2) Empirical correlation, equation (12) of Part I is valid only up to fuel flow rate of 11kg/hr. It has been used to predict mass transfer coefficient beyond its upper limit.

Suggestion

Accurate experimental data with regard to total flame length and average temperature of fluid surrounding the central fuel jet should be acquired at high fuel flow rates of 14, 16, 18kg/hr at fixed air flow rate of 2kg/s for immediate testing of the model more rigorously. In addition, expression (12) to predict effective mass transfer coefficient should be checked for fuel flow rates up to 20kg/hr.

SAMPLE CALCULATIONS

Prediction of Total Flame Length for Air Flow Rate of 2kg/s and Fuel Flow Rate of 16kg/hr.

(1) To calculate fuel consumed in axial distance, $z=D_b$ using equation (17):

Data:

P = 1 atmosphere

T_o = 366K

$\bar{T} \simeq$ 900K

r_o = 0.24 cm (from Ref. 7)

D_b = 14 cm

u_o = 16810 cm/s

$$\frac{P}{R} = \frac{1 \text{ atm}}{82.057 \ \frac{\text{cm}^3\text{-atm}}{\text{g.mol-K}}}$$

$$\sqrt{\frac{M_o}{M_a}} = \sqrt{\frac{44}{29}} = 1.232$$

$$\frac{1}{\sqrt{T_o \bar{T}}} = \frac{1}{\sqrt{(366\text{K})(900\text{K})}} = \frac{1}{573.93} \text{ K}^{-1}$$

Fuel consumed in axial distance of $z = D_b$ is,

$$n_{fc} = 0.03 \ \frac{1 \text{ atm}}{82.057 \ \frac{\text{cm}^3\text{-atm}}{\text{g.mol-K}}} \times 1.232 \times \frac{1}{573.93\text{K}} \times$$

$$X\left(16810 \ \frac{\text{cm}}{\text{s}} \times 0.24 \text{ cm} \times 14 \text{ cm}\right)$$

$$= 0.0443 \text{ g.mol/s.}$$

Total fuel injection rate, $n_{ft} = \frac{16000\text{g}}{3600\text{s}} \times \frac{1\text{g.mol}}{44 \text{ gm}} = 0.1010$ g.mol/s.

assuming 100% combustion efficiency, fuel to be consumed downstream of $z = D_b$,

$$= n_{ft} - n_{fc} = 0.1010 - 0.0443 = 0.0567 \text{ g.mol/s}$$

This much fuel is assumed to burn according to the model presented in Part I of the report.

Effective mass transfer coefficient, $k_{g,O_2,e} = \frac{(12.18)\ (2)^{2.13}}{(16)^{1.21}} = 1.861 \frac{cm}{s}$

Flame length, L_d required to consume 0.0567 g.mol/s of fuel is calculated using equation (21):

$$L_d = \frac{0.0567 \text{ g.mol/s}}{(2\pi/5)(14\text{cm})\left(1.861 \frac{\text{cm}}{\text{s}}\right)\left(8.7\times10^{-6} \frac{\text{g.mol.}}{\text{cm}^3}\right)} \text{ at air inlet conditions}$$

$$= 199.1 \text{ cm}$$

Therefore, total flame length $= D_b + L_d = 14 + 199.1 = 213.10$ cm.

Total flame length (obtained by linear extrapolation of the data given in Ref. 1)

$$= 254.5\text{cm}$$

Percent difference in predicted and experimental value of flame length

$$= \frac{\text{Exp.} - \text{Theo.}}{\text{Exp.}} \times 100$$

$$= \frac{254.5 - 213.1}{254.5} \times 100 = 16.3$$

References

1. See Reference 4 of Part I of the report

2. See Reference 8, ibid.

3. See Reference 3, ibid.

4. Hawthorne, W.R., Weddel, D.S., and Hottel, H.C., "Third Symposium on Combustion and Flame and Explosion Phenomena", p. 266, Williams and Wilkins, Baltimore, 1949.

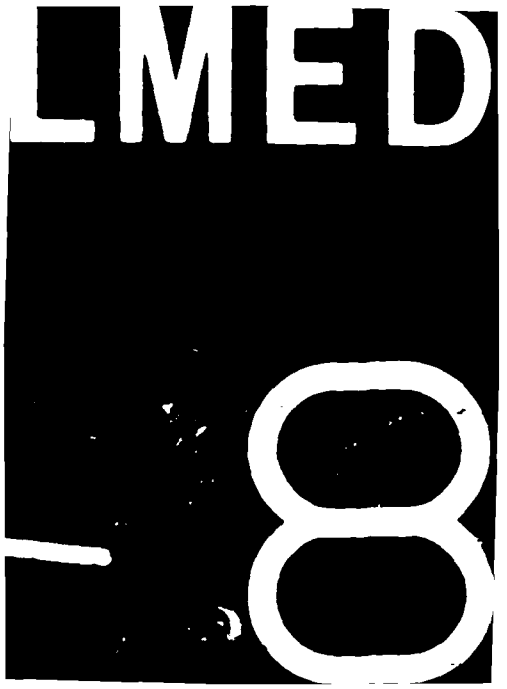
5. Wohl, K., Gazley, C., and Kapp, N., ibid, p. 288.

6. Lewis, B., and vonElbe, G., "Combustion Flames and Explosions of Gases", pp. 458-487, Academic Press, 1961.

7. See Reference 5 of Part I of the report.

8. See Reference 7, ibid.

9. Spalding, D.B., "Combustion and Mass Transfer", pp. 207, 204, Pergamon Press, 1979.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