Research Journal of Applied Sciences 2 (9): 953-957, 2007
ISSN: 1815-932X

The Mixing of Three Parallel Gas Burners

Odia O. Osadolor
Department of Mechanical Engineering, Faculty of Engineering and Technology,
Ambrose Alli University, Ekpoma, Edo State, Nigeria

Abstract: The flame of most gaseous, liquid and pulverized fuel burners assumes the characteristics of a jet. While the temperature, velocity, composition and thickness of jet flames at both the potential and fully developed zones can be determined analytically, the severally assumptions that are made often render the analysis inaccurate. Hence this research believes that experimentation is still the best solution to most engineering problems. An experimental rig was built along with three identical gas burners. The flames were made to discharge into the quiescent atmosphere. The result shows that while the flow field for the three nozzles maintained their separate identity until after x = 60mm, the supposed space between the three flames were temperature influenced at x = 20mm. The mixing of parallel identical flames is recommended for drying purposes.

Key words: Mixing, three parallel, gas burners, pulverized fuel, velocity, temperature

INTRODUCTION

A gaseous or atomized or pulverized fuel jet is burnt as it issue into air through a narrow injection nozzle at a high velocity, in numerous technological applications of combustion such as metallurgical and boiler furnaces, high temperature ovens, modern propulsion devices, etc (Turns, 1996; Bernard and Bradly, 1985). The shape and size of a jet flame and details of the composition and temperature across it are factors of importance in determining the space heating rates, efficiencies of combustion equipment and fire threat to nearby objects (Fristrom, 1995; Lewis and Von Elbe, 1987).

The jet is called plane or two-dimensional if it issues through a narrow slit of infinite length and cylindrical or more logically, circular if it issues through a fine circular hole. Most jets these days are circular as circular jets are easier to design and construct. The size of the nozzle opening (ie slit), the velocity and viscosity of the injected gas determine whether the jet will be laminar or turbulent. The high velocity jet emerging out of the port mixes with the relatively quiescent surrounding air by molecular diffusion and, if turbulent by eddy mixing(Ward-Smith, 2000; Rodi, 1993; Joel, 1972; Fox and Mc Donald, 1992; De Nevers,1970; Dohm and Dimotakis, 1987; Schlicting, 1987). However, because of the better mixing, turbulent jet flames are considerably shorter than laminar ones and in order to achieve high space heating rates, flames in most of the industrial furnaces are rendered turbulent (Spalding, 1971; Borghi, 1988; Bankal, 2000; Kataoka, 1998).

The temperature, velocity, composition and thickness of jets at both the potential and fully developed zones can be obtained by solving the appropriate conservation equations. For example, the equation of motion is

$$\frac{u\delta u}{\delta x}+\frac{v\delta u}{\delta y}=(V+\xi)\frac{\delta^2 u}{\delta y^2} \qquad (1)$$

Where, u and v, are the velocity components in the x and y directions, respectively. ξ, is the turbulent eddy diffusivity, which is zero for laminar flow, and ν is the kinematics viscosity. While the energy equation is written as

$$\frac{\delta u}{\delta x}(T-T_\infty)+\frac{\delta v}{\delta y}(T-T_\infty)=(a+\xi_t)\frac{\delta^2}{\delta y^2}(T-T_\infty) \qquad (2)$$

To solve these equations, a lot of assumptions are often considered. For example, the effects of chemical reaction, thermal radiation and pressure gradient are often neglected. Furthermore, the length of the potential zone, L and the diameter of the nozzle are considered as negligible (Lorra *et al*., 2002). These assumptions often in one way or the other affect the result of the mathematical analysis. Experimental research will therefore, remain invaluable in most engineering studies.

Also, the equations governing the jet flame phenomenon can only be reduced to forms analogous to that of inert gas equation by defining composite variables according to the Schvab-Zeldovich transformation. For a given set of conditions, including the initial, chemical and thermodynamic properties, flow situation and mixing details, the solution of a jet flame problem is often directed at yielding the flame size and shape along with the temperature and composition maps (Durao *et al*., 1992; Eckberth, 1988; Fristrom, 1976; Chigier, 1991). The results are expected to provide information for combustion's space heating rate, materials requirement and combustion efficiency (Van der Draft). For a given nozzle, the furthest distance a flame would stretch x_c is know as the flame height and for a laminar flow the relationship,

$$\frac{fY_{o\infty}}{fY_{o\infty+1}} = (1 + \frac{48x_c}{R_{ei}d_i})^{-1} - \quad (3)$$

defines the flame height for a cylindrical jet while for a turbulent cylindrical jet the relationship is

$$\frac{fY_{o\infty}}{fY_{o\infty+1}} = (1 + \frac{24cx_c}{d_i})^{-1} - \quad (4)$$

Hence, for a laminar flame

$$x_c = \frac{\mu i di^2}{48vfY_{o\infty}} \quad (5)$$

While for turbulent flame,

$$x_c = \frac{di}{24cfY_{o\infty}} \quad (6)$$

The temperature profile is similarly related, that is,

$$(Tc - T_\infty) = [(Ti - T_\infty) + \Delta H/C] \frac{fY_{o\infty}}{1+fY_{o\infty}} \quad (7)$$

Where

f = Stoichiometric factor.
$y_{o\infty}$ = Air purity factor.
c` = Eddy diffusion constant.
C = Flame location.

The combustion of a fuel jet is well known to be a diffusion-limited process. The fuel in the jet and the oxygen in the room are transported towards one another by convective diffusion. At all the stations where the fuel and oxygen are in stoichiometric proportion combustion takes place rapidly to also rapidly affect the surrounding zones. Hence the assumptions made during the application of these formulae will radically affect the results.

Most of this information can be determined experimentally (Taylor, 1993). That is the objective of this research, to determine the velocities of flow, the flame shapes and sizes of multiple nozzles issuing into a quiescent atmosphere.

MATERIALS AND METHODS

Three identical gas burners were designed and constructed in such a way that they will convert the flow area from 42 mm diameter to a high exit aspect ratio of 170/1.7. The burners were made such that the configurations of the flow change gradually from a round inlet of 42 mm diameter to a large divergence angle. A domestic cooking gas (methane) bottle was connected to the burner and a blower, which raised air with a flow rate of 17.533 m s^{-1}, supplied atmospheric air.

A transverse mechanism for moving the pitot static tube, which was used for measuring the mean velocities, was also devised and included. The pitot tube measured the total pressure while the static tube measures the static pressure to give rise to the dynamic pressure. The burner exit velocity was 17.533m s^{-1} for a single burner installed and 16.948m s^{-1} for the 3 burners installed. A rapid response temperature measuring devise-a Chromyl Alumel thermocouple with capacity in excess of 1000°C was also fixed on the traversing mechanism. By traversing the Pitot-static tube and the thermocouple along and across the flame and giving adequate time for instrument to stabilized, readings were taken and recorded.

RESULTS AND DISCUSSION

The temperature readings across the flame 5mm from the exit of the single nozzle were relatively low as reactionary combustion was still in progress at this point. The manometric reading at the nozzle exit was 53.5mm and the manometer was inclined at 20°, hence, $h_w mmH_20$ is 53.5 sin 20 = 18.3 mm. The three burners of the same nozzle characteristics put together had a manometric reading at nozzle exit of 50 mm, which translate, into $h_w mmH_20$ = 17.1 mm. Temperature readings were also taken across the flame at intervals of 5mm in the x-direction. The plots of $\gamma/\gamma^{1/2}$ against T show the temperature profile while the plots of $\gamma/\gamma^{1/2}$ against u/u_0 depict the velocity profile as one move away from the burner exit.

For the single burner, at distance x = 5 mm to x = 30 mm, the temperatures across the flame were relatively low (Fig. 1 and 2). This is the reaction zone. At x = 40, as shown in Fig. 3, reaction is presumed to be almost concluded so the temperature reached 410 °C. From the conditions at x = 80 mm from the burners exit as shown in

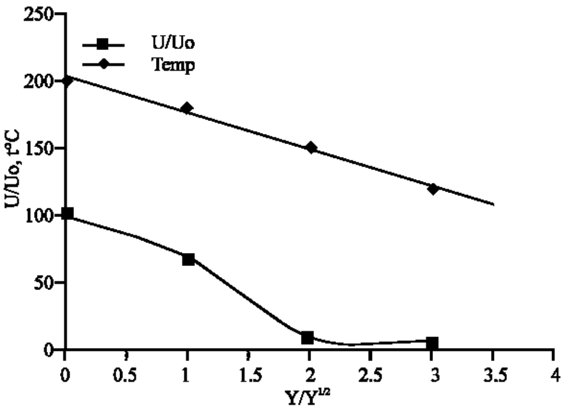

Fig. 1: Graph of U/Uo, t°C against $Y/Y^{1/2}$ at x = 5

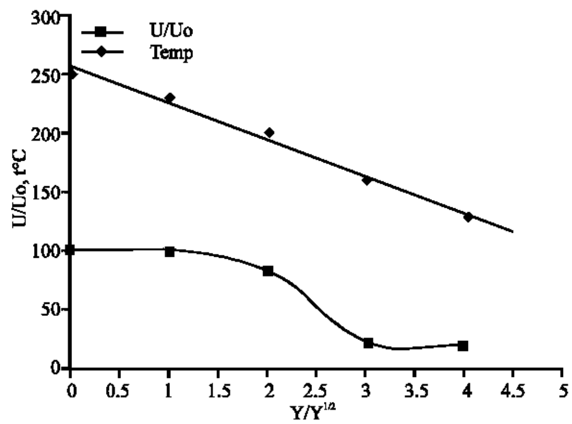

Fig. 2: Graph of U/Uo, t°C against $Y/Y^{1/2}$ at x = 10

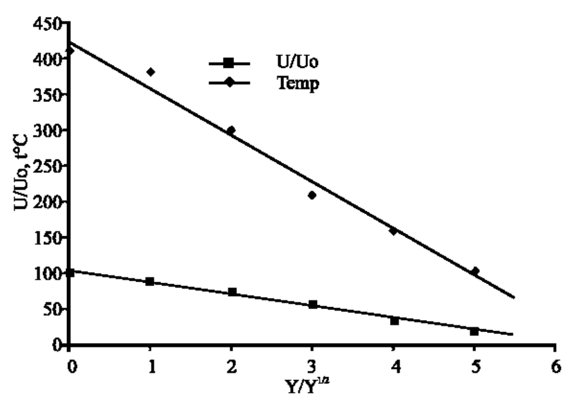

Fig. 3: Graph of t°C, U/Uo against $Y/Y^{1/2}$ at x = 40

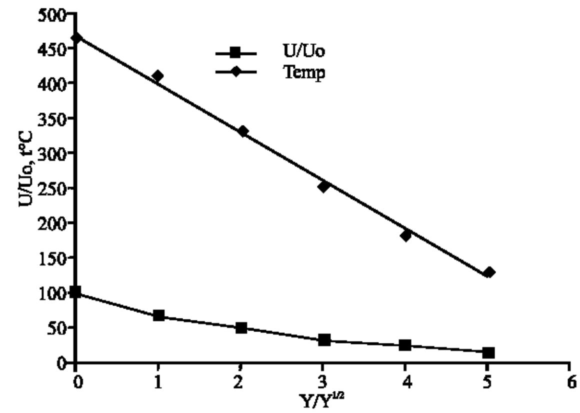

Fig. 4: Graph of U/Uo, t°Cagainst $Y/Y^{1/2}$ at x = 40

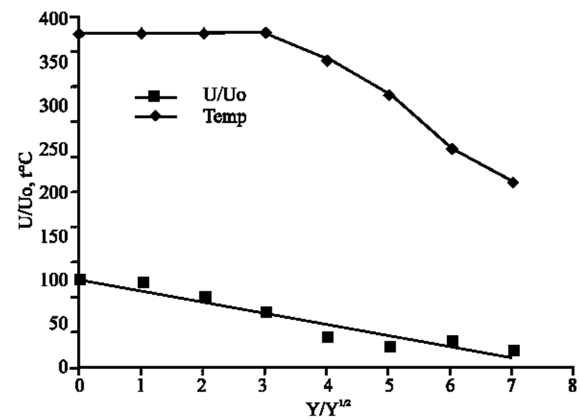

Fig. 5: Graph of U/Uo, t°Cagainst $Y/Y^{1/2}$ at x = 160

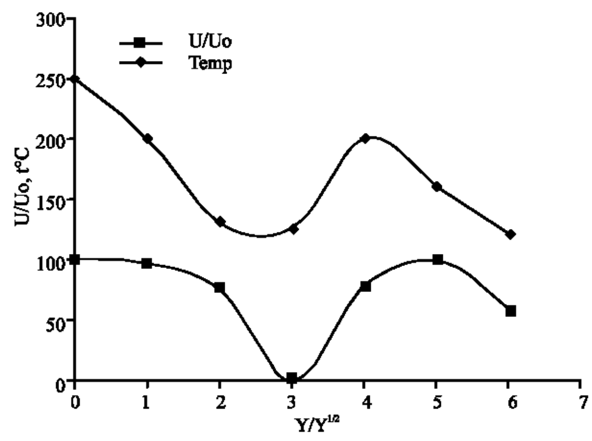

Fig. 6: Graph of U/Uo, t°Cagainst $Y/Y^{1/2}$ at x = 10 mm

Fig. 4, reaction is concluded and temperature reached 460 °C. Between x = 80 mm and x = 120 mm from the burner's exit, the temperature distribution stabilized. Beyond x =120 mm from the burner's exit, the temperature started decaying and at x =160 mm the highest temperature was 380°C, this is as shown in Fig 5.

For the three identical burner's, the flames maintained their separate identity only before x = 20 mm. At x = 20 mm from the burner's exit, the supposed spaces between the three burners were temperature influenced. This suggests that heat interaction among the three burners had commenced. On the contrary, the flow field maintained it

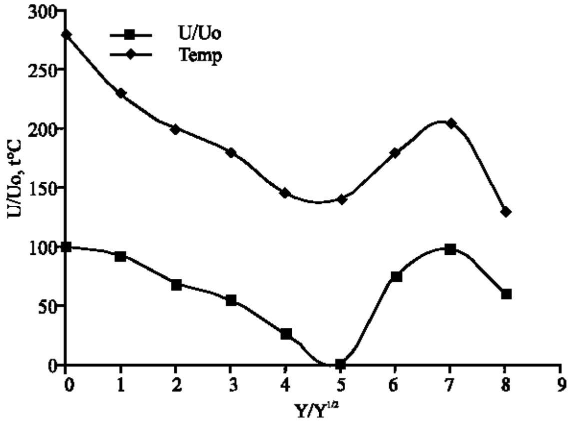

Fig. 7: Graph of U/Uo, t°Cagainst $Y/Y^{1/2}$ at x = 20 mm

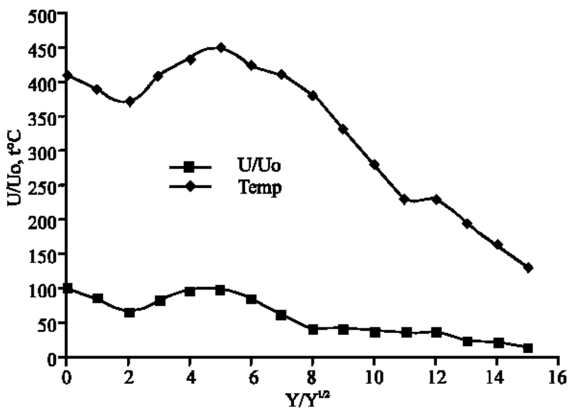

Fig. 8: Graph of U/Uo, t°Cagainst $Y/Y^{1/2}$ at x = 85 mm

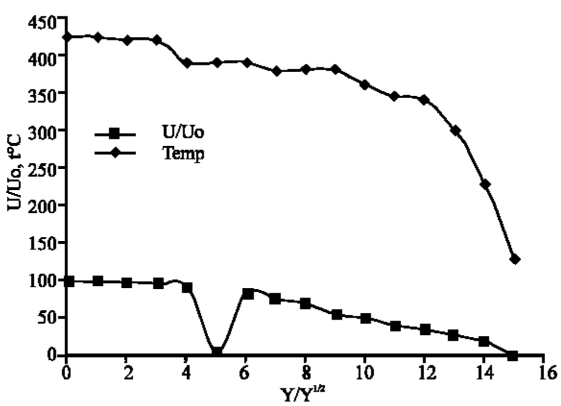

Fig. 9: Graph of U/Uo, t°Cagainst $Y/Y^{1/2}$ at x = 170

separate identity until after x = 60 mm(Fig. 6 and 7). At x = 85 mm, Fig. 8 shows that the mixing has become very pronounced and at x = 170 mm and beyond the temperature at most part across the flame was homogeneous as shown in Fig. 9. At three burner's widths away from the exit, the decaying temperature was

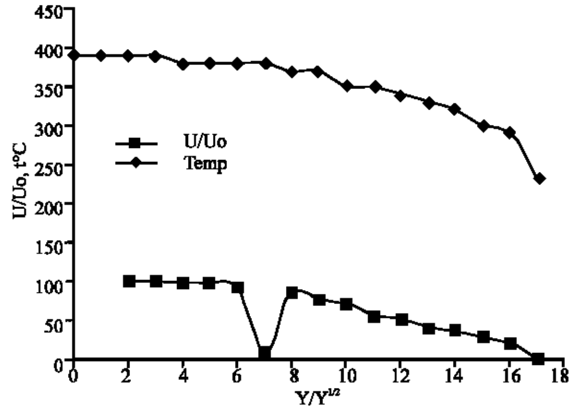

Fig. 10: Graph of U/Uo, t°Cagainst $Y/Y^{1/2}$ at x = 340

fully developed, spread out and have taken the similitude of a single burner as depicted in Fig. 10.

This arrangement will be useful in areas were uniform temperature is required over a wide area. It will be very useful in the drying industries where uniformly distributed temperature is very necessary for uniform heating rates.

CONCLUSION

Maximizing the use of energy is very important in our domestic and industrial lives, particularly now that energy sources are very expensive. In some industries point concentration is to be avoided in favour of uniformly spread out heating. This research has shown that identical burners adjacently arranged can be used to achieve uniformly distributed temperature over a wide area. The study revealed that at three burners widths way from the exit the process was fully developed and the temperature homogenous across the flame. The arrangement is therefore, recommended for drying industries where load may come in contact with the flame.

REFERENCES

Bankal, C.E., 2000. Heat Transfer in Industrial Combustion CRC Press, Boca Raton, FL.

Bernard, J.A. and J.N. Bradly, Flame and Combustion, 1988. 2nd Edn. Chapman and Hall, London.

Borghi, R., Turbulent Combustion Modeling, Prog. Energy Combust. Sci., 14: 245-292.

Chigier, N., 1991. Combustion Measurements, Hemisphere Publishing, New York.

Dohm, W.J.A. and P.E. Dimotakis, 1987. Measurements of entrainment and mixing in turbulent jets, AIAA J., 25: 1216-1223.

Durao, D.F.G, M.V. Heitor, J.H. Whitelaw and P.O. Witze, 1992. Combusting flow diagnostics, Kluwer Acadamic Publishers, Dardrecht.

De Nevers, N., 1970. Fluid Mechanics, Addison-Wesley, Reading MA.

Eckberth, A.C., 1988. Laser Diagnostic for Combustion Temperature and Species, Abacus Press, Cambridge, MA.

Fox, R.W. and A.T. McDonald, 1992. Introduction to Fluid Mechanics, 4rth Edn. John Wiley and Sons, New York.

Fristrom, R.M., 1995. Flame Structure and processes Oxford University Press, New York.

Fristrom, R.M., 1976. Probe Measurements In Laminar Combustion Systems, in Combustion, Measurements-Modern Techniques and Instrumentation, R. Goulard, (Ed.). Academic Press, New York.

Joel, O. Hougen, 19725. Measurement and Control Applications for practicing Engineers, CAHNERS Books, Barnes ands Noble Series for professional Development.

Kataoka, A., 1998. New Type of High Temperature Surface Combustion Burner, Proc. of the 1998 International Gas Research Cont. Industrial Utilization, D.A. Dolenc, (Ed.). Gas Research Institute, Chicago.,Vol. V

Lewis, B. and G. Von Elbe, 1987. Combustion, Flames and Explosion of Gases, 3rd Edn. Academic Press, New York.

Lorra, M., Schnepper, Ca and S. Stephen., 2002. Investigation of a duct Burner Design using CFD Capacities in Conjunction with-Scale Experiments, Proc. 6th Eur. Cont. on Industrial furnaces and Boilers, Estoril, Portugal.

Rodi, W., 1993. Turbulence Models and their Application in hydraulic-A State of the Art Review, Association for hydraulic Research, 3rd Edn. Delft.

Schlicting, H., 1987. Boundary Layer Theory, 7th Edn. McGraw-Hill, New York.

Spalding, D.B., 1971. Mixing and Chemical Reaction in Steady Confined Turbulent flames, 13th symp. (Int) on Combustion, pp: 649- 657.

Van der Draft, A., N.B.K. Rasmuslem and K. Jorgendsen, 1997. improved efficiency drying using selective emittance radiant burners, Applied Ther-Eng., 17: 91 -920.

Taylor, A.M.K.P., 1993. Instrumentation for flows with Combustion, Academic Press, London.

Turns, S.R., 1996. An Introduction to Combustion, McGraw-Hill, New York.

Ward-Smith, A.J., 2000. Critical flow metering, the characteristics of Cylindrical Nozzles with sharp upstream edges, Int. J. Heat and Fluid Flow, Vol 3.