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INFLUENCE OF A BLUFF-BODY FLAME HOLDER ON BLOWOUT LIMITS OF A PREMIXED FLAME INTO A STREAM OF AIR.

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ABSTRACT

Flame stabilization in a stream of air is an indispensable process in most industrial combustion devices. This is performed by means of either the recirculation zone formed in the wake of a bluff - body or step, the recirculation flow in the central region of a swirling flow or a hot body.

In this study an experimental investigation on the influence of a bluff-body flame holder on blowout limits of a premixed flame into a stream of air has been carried out. A premixed mixture of commercial butane-air is introduced co-axially through a stream of air inside a transparence cylindrical combustion duct. A cylindrical and spherical bluff - body flame holders have been determined. Measurements of critical equivalence ratios at lean and rich blowout limits have been obtained. Also, measurements of temperature and concentrations in the resulting flames are carried-out. The results show that the blowout limits are increased as flame holder size increased. Both, lean, rich and high speed blowout limits of flames are widened with increase in dimensions of flame holders. The results also demonestrated that further extended are obtained with cylindrical flame holders rather than with the spherical one.

INTRODUCTION

Combustion flames involve simultaneous processes of heat, mass and momentum transfer and chemical reaction. A flame is stabilized when a critical balance between these processes can be established. Many combustion systems of modern applications require combustors capable of stabilizing a flame at flow velocities considerably higher than the speed of flame propagation. Experience shows that the flame is blown away when the supply velocity exceeds the flame speed. The maximum supply velocity with which fresh mixture may be brought to the flame front without blowing it away is known as bolwout velocity. This velocity depends upon a host of factors which includes the nature of fuel and oxident, their ratios, mixture temperature, combustion chamber pressure, turbulence in the approach stream, burner geometry, etc.

Considering blowout as a situation arising when the time allowed by the flow is not long enough for the reactions to proceed for ignitions, one may devise various possible flame stabilizers. Three types of flame stabilizers are extensively known. These are: bluff-body flame holders, recirculation flow and the pilot flames or high temperature burnt gas stream.

A flame is stabilized behind a bluff-body primarly due to the closed recirculation zone formed in the wake, in which hot burned gas is recirculating and works as a heat and radical source.

As for the flame blowout mechanism, Zukoshi and Marble [1] assumed that a flame is blown out by the ignition mechanism. Lewis and von Elbe [2] tried to explain the blowout behaviour of flames from the critical stretching rates of the flames in the shear layer at the recirculation zone boundary. Reed [3] suggested that blowout may result from a reduction in the reaction rate caused by the enthalpy loss from the stabilization region due to shear flow, rather than from the fact that the gas velocity exceeds the local burning velocity throughout the whole flow field.

Very few reliable measurements have been made within the recirculation zone under combustion conditions with the exception of the works made by Bovina [4], Winterfeld [5] and those reported by Beer and Chigier [6]. Recently, the combustion efficiency and pollutant emissions of a confined premixed flame stabilized by a swirl-generated recirculation zone have been studied by Anand and Gouldin [7]. Also, a study of the turbulence structure in a rich premixed jet flame has been carried out by Noda et al., [8]. An experimental study and analytical description for the recirculation zone and blowout limits of flames stabilized on a bluff-body have been reported by El-Emam [9].

The objective of this work is to study the blowout merhanism and the structure of a premixed flame stabilized by a bluff-body flame holder into a stream of air. The main parameters considered in this work are the premixed air fuel ratio, the velocity of the coaxially flows air stream and the geometry of the used bluff-body flame holders. Effects of these parameters on the mechanism of the flame blowout limits and flame characteristics are investigated.

EXPERIMENTAL APPARATUS AND METHODS

The present study deals with a commercial-butane-air premixed jet flame into a coaxially stream of air. The flame was formed on a round burner set vertically and upward as shown in the schematic diagram of the experimental apparatus, Fig. 1. The air blower 1 was used to supply both the premixed air and the surrounding air stream through air line No.1 and air line No. 2, respectively. Each line was provided with a control valve 3 or 12, a calibrated metering orifice plate 4 or 13 and a manometer 5 or 14. The fuel was supplied from the fuel vessel 6 to the air-fuel mixing chamber 10 through the pressure regulator 7, the control valve 8 and the fuel flowmater 9. The air-fuel mixture was then discharged from the burner 11. The burner has an inner diameter of 10mm. The axial velocity of the discharged air-fuel mixture along the crosssection of the burner at exit was ranged from 3m/s to 6 m/s.

The surrounding air stream was received in the air receiving chamber 15 and then sucked through the combustion duct 17 at uniform velocities by using the mesh plates 16. The air stream velocity at the burner tip plane cross-section of the duct was made from a pyrex glass tube with diameter of 150mm. A bluff-body flame holder 18 suspended by a fine steel wire was prepared to be placed on the axis of the combustion duct. Three cylindrical and three spherical bluff-body flame holders were used. The cylindrical flame holders were made from a three steel bars of equal lengths of 12mm and with diameters of 6mm, 10mm and 14mm. The spherical flame holders were made from a steel balls with diameters of 6mm, 10mm and 14mm.

Critical equivalence ratios at lean and rich blowout limits of flames were determined by controlling the fuel supply flow rate with the premixed air supply flow rate kept constant. Also, measurements of flame blowout limits due to air stream velocities at certain equivalence ratios have been carried out.

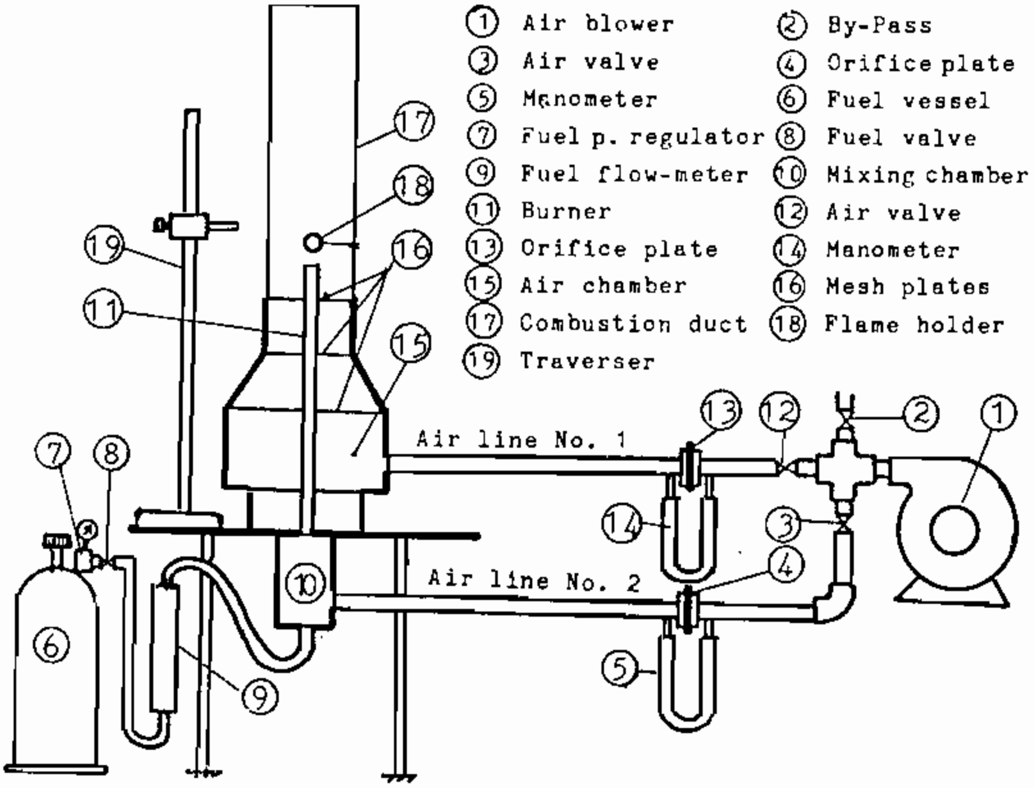
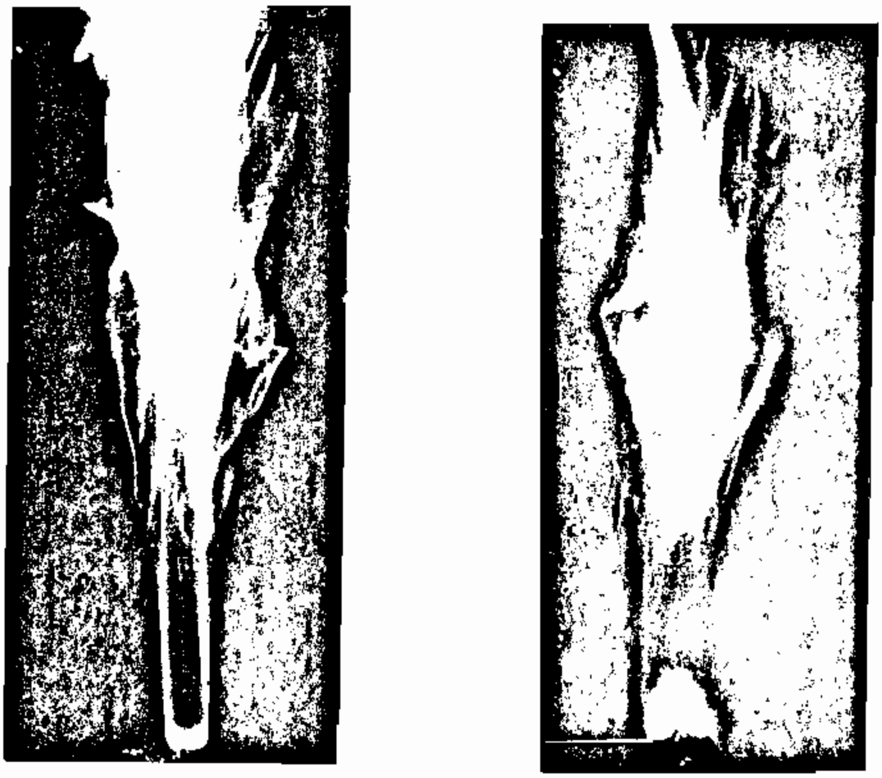


Fig. 1 Experimental apparatus



(a) Flame seated on the port of the burner

(b) Lifted flame stabilized on a flame holder

Fig. 2 Photographs of flame appearance

Measurements of temperature were carried out with a suction type temperature probe incorpoating a Pt-30% Rh/Pt-6% Rh bare wire thermocouple. The composition of the gases within the flame zone was measured using a water cooled sampling probe connected directly with a two gas analyzing systems. The first analyzing system was a BINOS infrared gas analyzer for caron dioxide and oxygen concentration measurements. The second analyzing system was a Beckman infrared gas analyzer for carbon monoxide and bydrocarbon concentration measurements.

A precise traverser 19 was used to move the temperature measuring probe and the gas sampling probe in vertical and horizontal directions to perform required measurements inside the flame.

RESULTS AND DISCUSSIONS

Series of experiments have been carried out with and without flame holders, at different equivalence ratios and different air stream velocities. Spherical and cylindrical flame holders with 6, 10 and 14mm diameters have been used. Measurements were made along the axis of the pyrex glass tube duct at different distances from the port of the burner. Measurements of flame appearance are made from direct photographs. It is known that for hydrocarbons the inner cone is usually sufficiently bright to enable photographs to be taken with exposures of less than a second. It is essential to use plates giving good contrast. Examples of photographs of flame appearance are shown in Fig. 2. The figure shows two types of flames, (a) flame seated on the port of the burner, and (b) a lifted flame stabilized on a cylindrical flame holder.

Results of measured blowout limits of flames at different air stream velocities with and without flame holders are shown in Figs. 3 and 4. The results with flame holders are obtained with cylindrical and spherical type bluff-body of 6 and 10 mm diameters. Three ranges of the stabilized flames are shown in each figure. These are, (1) flames seated on the port of the burner, (2) transitional range of flames seated on the port of the burner or lifted flames and (3) lifted flames. These results show that, for a flame without flame holder, at a certain equivalence ratio, as the velocity of the air stream incresed, the lifted flame is moved downstream side. Above a certain critical velocity of air stream the flame is lifted permanently and

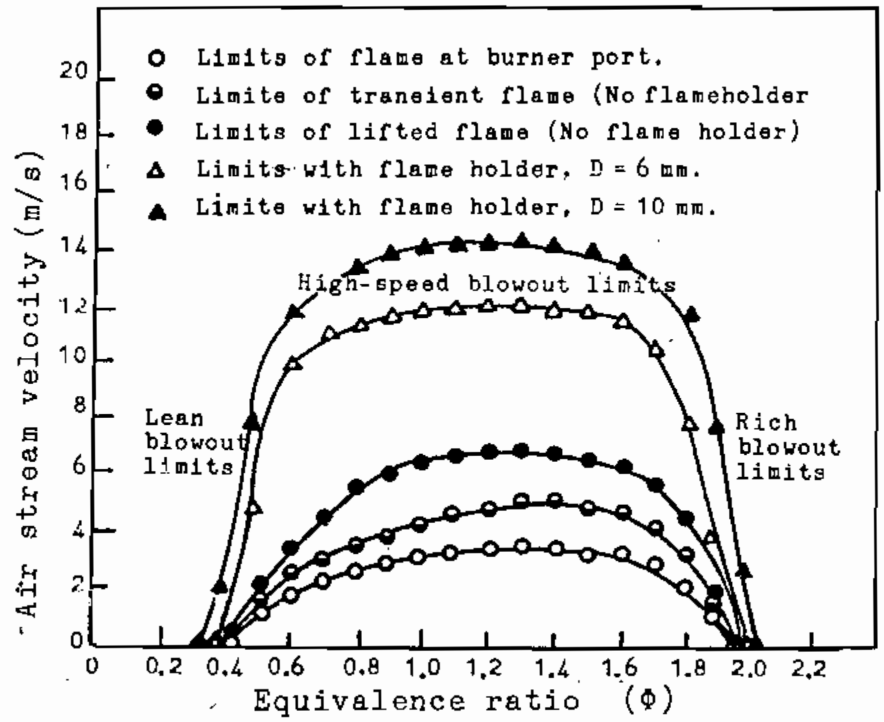


Fig. 3 Blowout limits for cylindrical flame holders.

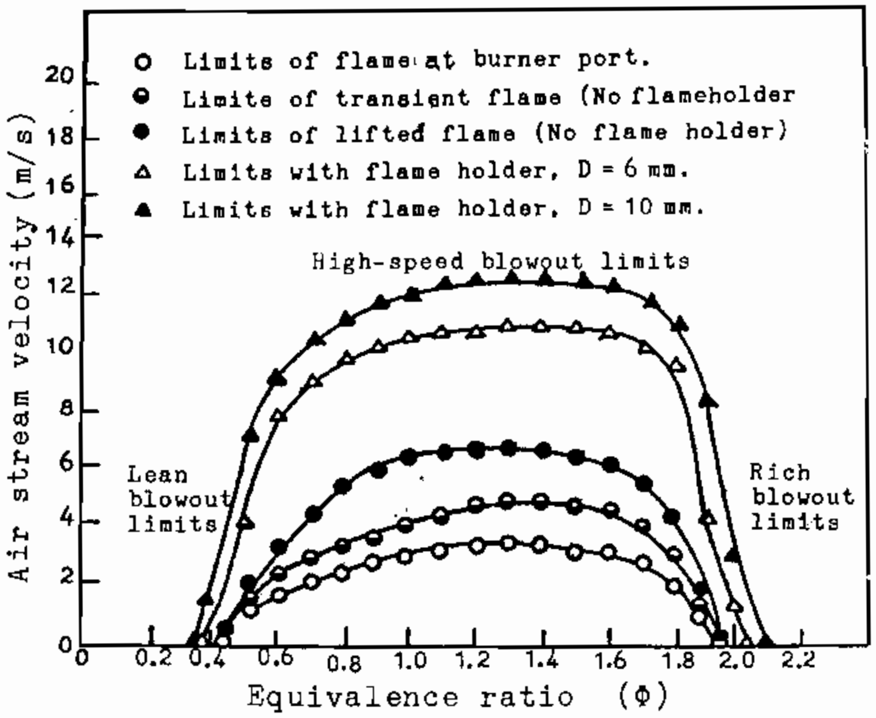


Fig. 4 Blowout limits for spherical flame holders.

blowout occurs. With the use of bluff-body, the range of the stabilized lifted flame is considerably increased.

To understand the function of flame holder, consider in particular the case of a cylinder in a stream. At the upstream face of the cylinder the fluid is dammed up, so that the stream tubes enlarge in cross section, the velocity decreases and the pressure increases. At the cylinder surface in the center of the dammed-up region is the stagnation point, here the fluid comes entirely to rest, and the pressure attains a maximum. The pressure developed in the dammed-up region accelerates the flow arround the cylinder. As the fluid is accelerated, the pressure decreases. The maximum velocity and minimum pressure are attained in the region where the flow around the cylinder becomes parallel to the main flow. Under conditions of flame attachment the eddy region behind the stabilizer constitutes a zone of recirculating burned gas. Investigations by various authors have shown that the stream of explosive gas is ignited as it flows by this hot zone of recirculating burned gas, and in this manner the flame is stabilized at the downstream face of the flame holder. Because a steep velocity exists between the recirculation zone and the main stream, the flame is stretched and blows off when the critical stretch is exceeded.

The effects of flame holder size and shape on lean and rich blowout limits at different stream velocities are shown in Figs 5 and 6. These results demonestrated that, increase of flame holder size improves flame stabilization. The lean and high speed blowout limits are slightly extended with cylindrical flame holders rather than with spherical flame holders. However, in the rich region, the blowout limits are slightly extended with spherical flame holders. The lean blowout limits are remarkably increased as flame holder size increased. Rich blowout limits are slightly increased as the size of flame holder is increased. Both lean and rich blowout limits are decreased as the velocity of air stream is increased. This can be explained as, the blowout limit is determined mainly by the time which a mass element takes to sweep past the recirculation zone. This time is a function of the mixture variables. As shown from the photographs of the stabalized flame Fig. 2, the luminosity is due to the fluctuating combustion in the turbulent flame brush. The dark recirculation zone of burned gas is shown in the photograph. It is found that the length of this zone is linearly dependent on the flame holder

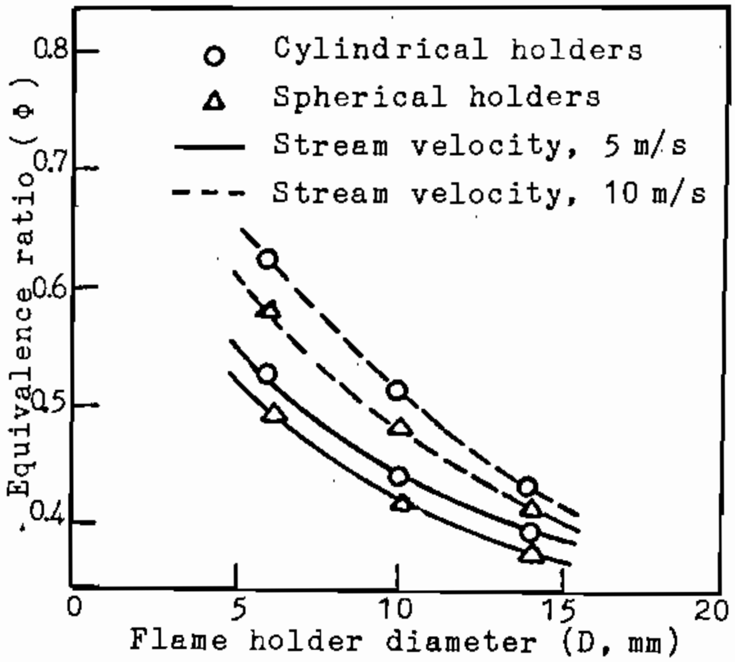


Fig. 5 Influence of flame holder geometry on lean blowout limits.

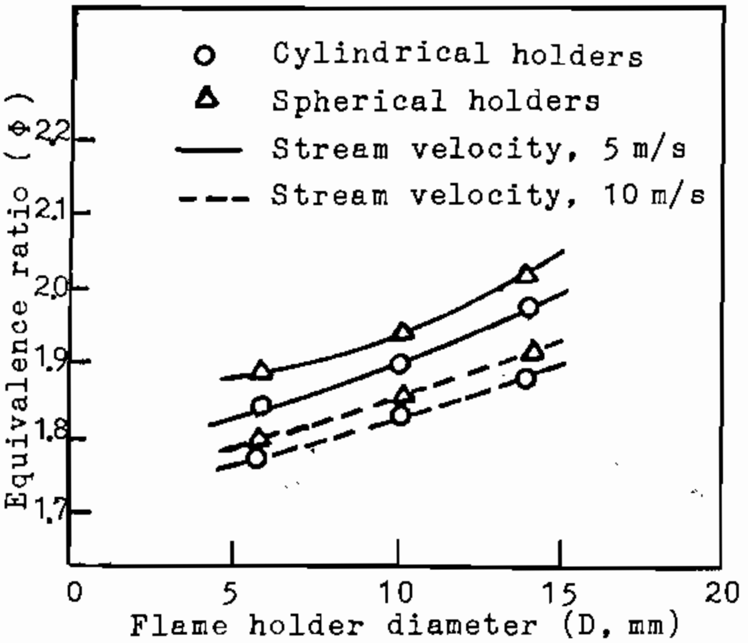


Fig. 6 Influence of flame holder geometry on rich blowout limits.

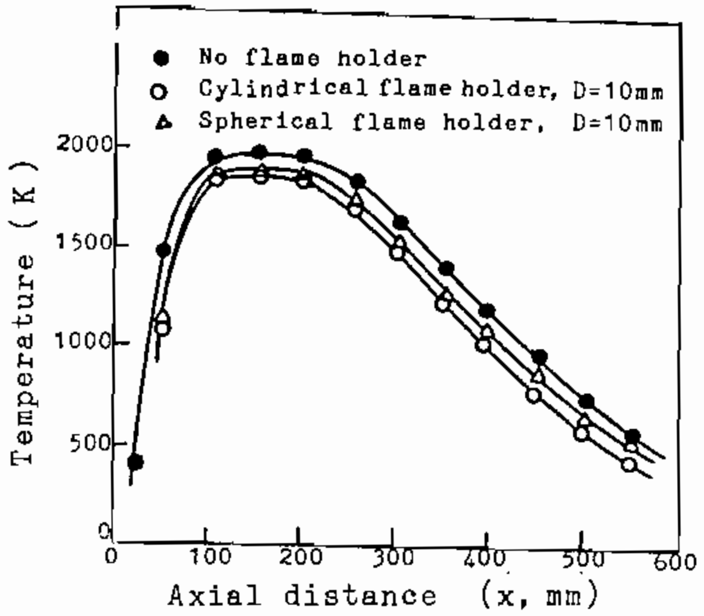


Fig. 7 Mean temperature along the axis of the flame, (Φ = 1, stream velocity = 5 m/s).

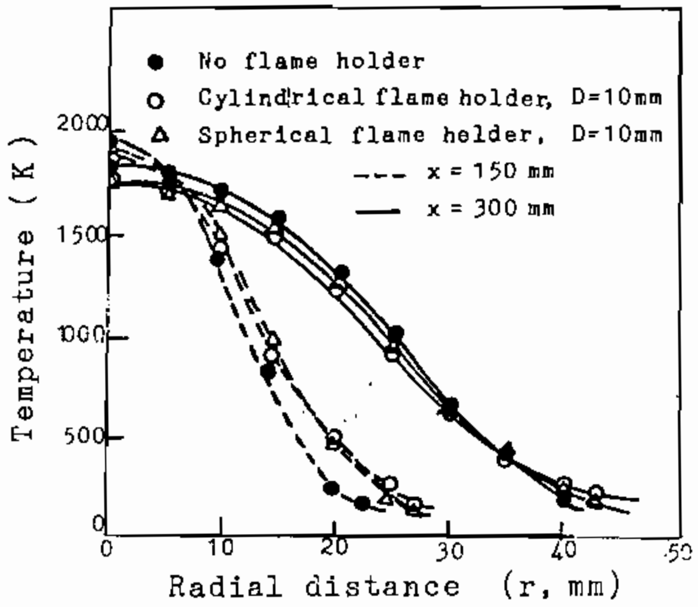


Fig. 8 Temperature radial profiles at two different axial distances, (Φ = 1, stram velocity=5m/s).

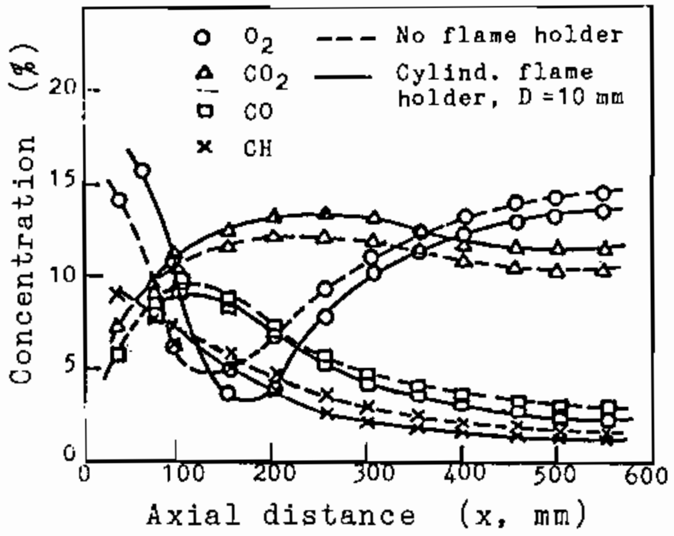


Fig. 9 Concentration distributions along the axis of the flame, (Φ = 1, stream velocity= 5 m/s).

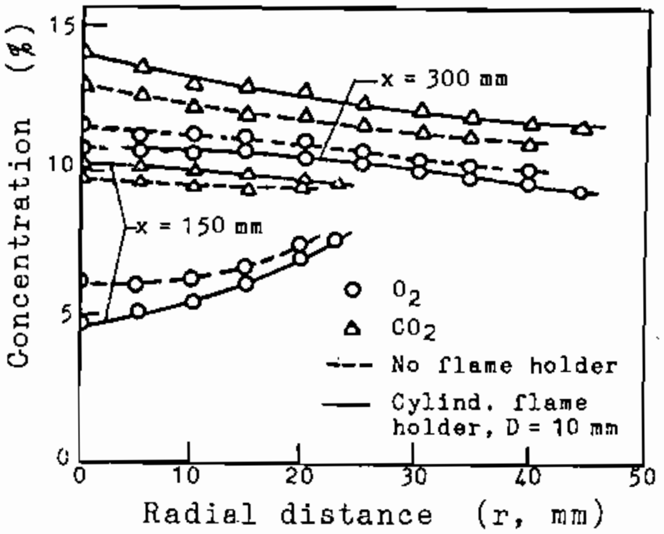


Fig. 10 Radial profiles of oxygen and carbon dioxide at two different axial distances in the flame, (Φ = 1, stream velocity = 5 m/s).

diameter. This increases the residence time of the reactants in the recirculation zone and improves the blowout limits.

An example of the time average temperature distribution along the axis of the flame is shown in Fig. 7. In this work, correction for radiation losses were not made. The temperature shows its maximum values on a distance from X=80mm until X=300mm, then gradually decreases along the axis of the flame. Fig. 8 shows an example of temperature radial profiles at two different axial distances in the flame. Around the axis of the flame, the temperature shows a lower values with flame holder rather than without flame holder. This is, may be, due to flame stretch occured when flame holder is inserted in the flame.

Examples of O_2, CO, CO_2 and CH concentration profiles along the axis of the flame are shown in Fig. 9. It can be noted that, the decay rate of concentration along the center-line of the flame has the same trend for both cases with or oithout flame holder. The O_2 concentration has a steep decay until a distance of X=120mm then it gradually increased along the axis of the flame. The CO_2 concentration is gradually increased until a distance of X=300mm, then it has a small change along the axis of the flame. The figure also shows that the decay rate of CO and CH concentrations is so fast along a distance from X=100mm until X=300mm, then the decay rate is decreased along the axis of the flame. Examples of radial profils of O_2 and CO_2 concentrations at two different axial distances are shown in Fig. 10.

CONCLUSIONS

An experimental investigation on the influence of a bluff-body flame holder on the blowout limits of a premixed flame into a stream of air has been carried out. From the results obtained, the following conclusions have been reached:

1- Introducing a bluff-body flame holder for flames in a stream of air is extending the flame blowout limits.
2- Each of lean, rich and high speed blowout limits of flames are widened with increase in dimensions of flame holders.
3- Cylindrical flame holder has higher influence on lean and high speed blowout limits rather than spherical flame holder.

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