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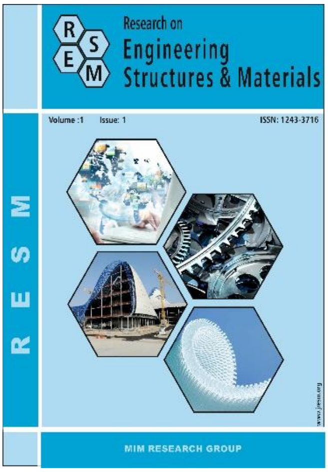

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Research Article

Experimental analysis of premixed and non-premixed methane flames by using a new combustion system

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Abstract

This paper deals with combustion of premixed and diffusion methane flames. Temperature and emission measurements of premixed and diffusion methane flames have been carried out in the present study. A new combustion system including burners and combustor has been designed and manufactured in order to determine the temperature and emission values of methane flames throughout the combustor. This combustion system includes burners, combustor, gas and air lines, regulators, manometers, flowmeters and so on. Premixed and diffusion burners with a capacity of 10 kW have been used so as to burn the methane during the experiments. Temperatures have been determined by using thermocouples throughout the combustor. Emission values have also been measured via a flue gas analyzer throughout the combustor. The results show that the maximum flame temperatures have been measured as of 1230°C under the premixed flame conditions and as of 1193°C under the diffusion flame conditions. When it comes to emission measurements, it may be said that the maximum NO_X and CO_2 emission levels form in the flame region while minimum CO formations emerge in the same region under the premixed combustion conditions due to the complete combustion conditions in the premixed burner. Therefore, it can be concluded that complete combustion has been nearly achieved by the premixed methane burner.

1. Introduction

Energy is a key parameter all over the World and is still mostly generated by fossil fuels. Fossil fuels are generally classified as solid, liquid and gaseous fuels. The most known gaseous fuel is natural gas including high amount of energy. Natural gas plays an important role ranging from power generation industries to buildings. In general, power generation or heating systems consist of a combustor and a burner to burn natural gas. Because of that, burner and combustor designs are very important to burn the natural gas efficiently.

Burners are generally separated into two groups called as premixed and diffusion (non-premixed) burners. Reactants are mixed before the reaction is initiated in premixed flames as well as fuel and oxidizers enter the combustion chamber as separate streams in diffusion flames [1]. Both of them are widely used to burn natural gas or methane that is major component of natural gas in any combustion systems. van Essen et al. [2] have investigated effects of pressure on NO formation in premixed methane flame. They have reported that NO levels increase as pressure is increased. Bidi et al. [3] have modelled a methane-air combustion taking into account the radiation effect. They have concluded that the radiation in numerical modelling can affect the temperature and species

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concentration. Brookes and Moss [4] have conducted an experimental study regarding turbulent jet diffusion flames of methane. They observed that temperature levels have increased towards outlet of the combustor. Boke et al. [5] have focused on experimental and numerical combustions of natural gas by using diffusion flame burner. The maximum temperature level of natural gas has been determined as of 1075°C in the flame. Keramida et al. [6] have studied the radiative heat transfer in natural gas-fired furnaces. The results show that thermal radiation is very important for more accurate prediction in numerical modelling. Feyz et al. [7] have explored the effect of recess length on combustion behaviours of methane in a burner. Fang et al. [8] have examined the effect of turbulence on NO formation in swirling combustion. Saqr et al. [9] have studied the effect of free stream turbulence on NO_X and soot formation in non-premixed methane flame. Khelil et al. [10] have modelled a high swirled natural gas diffusion flame using a PDF model. Fackler et al. [11] have carried out an experimental and numerical study of the emission of nitrogen oxides (NO_X) under lean premixed combustion. They have also studied the effect of diluent addition on NO_X formations under the same conditions. Lieuwen [12] have indicated the results of an investigation of the mechanisms responsible for some instabilities in lean premixed gas turbine combustors. Day et al. [13] have studied lean premixed turbulent flow experimentally and numerically. Carlsson et al. [14] have reported numerical and experimental studies of a lean premixed low swirl stabilized methane/air flame.

Although there are some studies related to natural gas flames, experimental studies are very restricted in the literature. Moreover, these studies cover combustion of methane flame performed by using conventional natural gas burners. However, there needs to be more studies regarding combustion behaviours of methane flames that are emerged via a new type of burner. For these aforementioned reasons, temperature and emission levels have been experimentally investigated in generated burners (premixed and diffusion) and a combustor in the present study.

2. Operating Conditions, Test Rig And Equipments

New type burners, which are premixed and diffusion flames, integrated with a combustor have been designed and manufactured to determine temperature and emission distributions of methane flames and to compare the premixed and the diffusion burners each other in terms of combustion performances and emission characteristics. Methane has been consumed as fuel in the present study. The burners that can be burned the methane fuel are shown in Figure 1.

Fig. 1. Diffusion (left) and premixed (right) methane burners

These burners are called as diffusion and premixed flame burners. Air and fuel streams are coaxial in the diffusion flame burner. The burner has two different types of air inlets to the combustor. The first air inlets have angle of 15° to provide flame stabilization via tangential velocity. The second air inlets consist of annular inlets. The fuel inlet has been also designed as radial inlet to the combustor so as to obtain better fuel/air mixture and flame stability. The premixed burner is of 8 annular inlets behind the flame region.

The schematic view of the combustion system is shown in Fig. 2. The burners have been mounted to the combustion chamber as shown in Fig. 2. High pressure methane cylinder has been integrated to supply the methane fuel into the system. The system includes two gas lines, one of which is methane fuel line and the other of which is air line. This combustion system consists of regulators, manometers, selenoid valves and float type flowmeters. The regulators have been placed to the system in order to regulate pressures of methane and air. Gas and air pressures have also been measured periodically in the lines via manometers to control the pressures of the methane and air during the experiments. Selenoid valves have been integrated into the system to prevent methane stream when absence of the flame. An air compressor has been used to supply the pressurized-air in this combustion system. Moreover, this combustion system includes float type flowmeters in both lines to reach the desired gas and air flow rates. All experiments have been conducted under the thermal power of 10 kW and equivalance ratio of ϕ = 0.83 conditions. Combustion gauge pressures of the methane and air have been fixed at 21 mbar during the experiments.

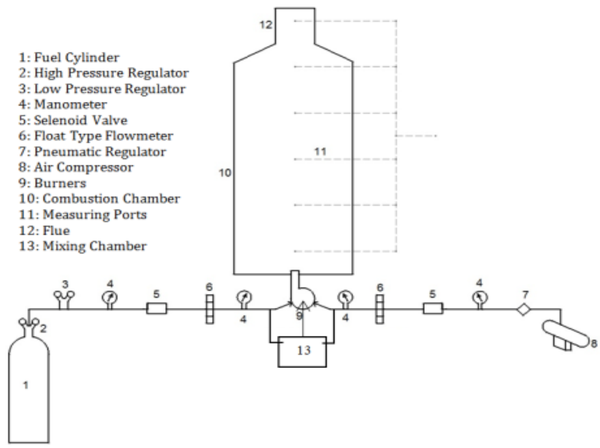

Fig. 2. The layout of the combustion system

General view of the combustion chamber is shown in Fig. 3. The length and the diameter of the combustion chamber are 100 cm and 40 cm, respectively. The combustion chamber composes of a sight glass made of tempered glass, five measuring ports and flue. Five measuring ports have been placed on the combustor wall to measure temperature and emission values within the combustor. The first measuring port has been used to determine the flame characteristics and location of the measuring port is 10 cm away from the combustor inlet. The other four measuring ports have been located in an interval of 20 cm from the first measuring port to the combustion chamber outlet.

Fig. 3. The combustion chamber

Ceramic coated R-type thermocouples that can be withstood high temperature up to 1700°C have been used to measure temperature values through the combustion chamber. Similarly, emission values have also been determined by means of a flue gas analyzer throughout the combustor.

Table 1 shows the properties and accuracies of the thermocouple and flue gas analyzer that have been used in the present study

Table 1. Measurement appliances and their properties

Thermocouple	**Flue Gas Analyzer**
0 – 1760 °C	MRU Type Flue Gas Analyzer
± % 0.3	O_2 (%) 0-21, ±0,2 (%)
	CO (ppm) 0-10000 ppm, ±10 ppm
	NO ve NO_2 (ppm), 0-1000 ve 0-200 ppm, ±5 ppm
	SO_2 (ppm) 0-2000 ppm, ±10 ppm
	CO_2 (%) 0-40, ±0,3 (%)
	Combustion Products' Temperature
	(°C) 0-1100°C, ±2°C

3. Results and Discussion

The measured axial temperature values of diffusion and premixed methane flames are given in Fig. 4. The maximum temperature levels of premixed and diffusion methane flames show up as of 1230,35°C and as of 1193,54°C in the flame regions, respectively. Then, it is seen that the temperature measurements decrease gradually towards the combustor outlet for both cases and the temperature values of premixed and diffusion methane flames are determined as of 571,15°C and as of 508,95°C at the outlet, respectively. When the premixed and diffusion flames are compared to each other, it is concluded that the temperature levels of premixed flame are higher than that of diffusion flame excluding measurement at 30 cm axial position considerably. Therefore, it has been demonstrated that better fuel/air mixture highly affects the temperature levels due to turbulence effect.

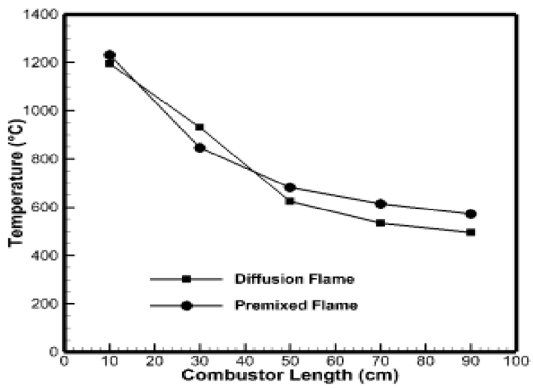

Fig. 4. Axial Temperature Measurements

Figure 5 depicts the measured radial temperature values of premixed and diffusion methane flames at 10 cm, 30 cm, 50 cm, 70 cm and 90 cm, respectively. As can be seen from the Figure 5a, temperature levels decrease rapidly towards the combustor wall as the sudden expansion combustor type has been used. Figure 45 also shows that the radial temperature measurements of premixed and diffusion methane flames are nearly the same for all measurements. When it comes to the evaluation of the temperature measurements at the other radial positions, high temperature values have been measured towards the combustor outlet as the flame has propagated to the combustor significantly. In particular, the measurement values between 0 cm and 15 cm at 70 cm and 90 cm axial position are closer to each other. This study takes into account another conclusions such as comparison of premixed and diffusion methane flames. If it is analyzed in Fig. 5d and Fig. 5e (after the flame propagates completely), the measured temperature values of premixed methane flame are higher than that of diffusion methane flame due to better fuel/air mixture.

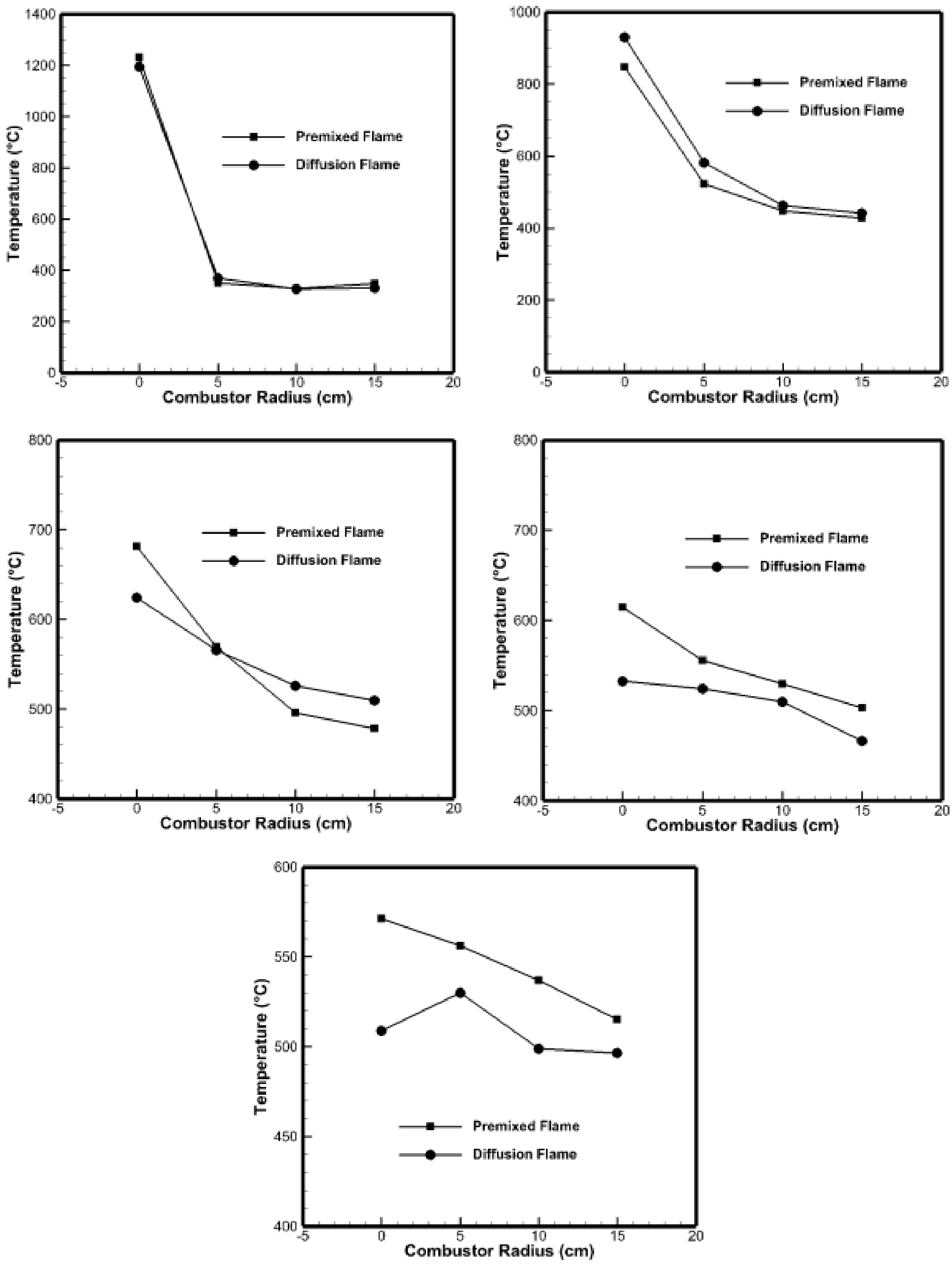

Fig. 5. Radial Temperature Measurements at 10 cm, 30 cm, 50 cm, 70 cm and 90 cm Axial Positions

Emission characteristics of diffusion and premixed methane flames have also been investigated in the present study. Emission values have been measured on axial and different radial positions in the combustor by means of same measuring ports located on the combustor wall.

Figure 6 presents the axial CO measurements of premixed and diffusion methane flames. The findings show that the maximum CO values for both conditions emerge in the flame region owing to the incomplete combustion. Furthermore, it is demonstrated that CO levels are extremely high under the diffusion flame conditions as fuel and air are mixed in the flame zone. CO levels decrease rapidly towards the combustor outlet because of the complete combustion.

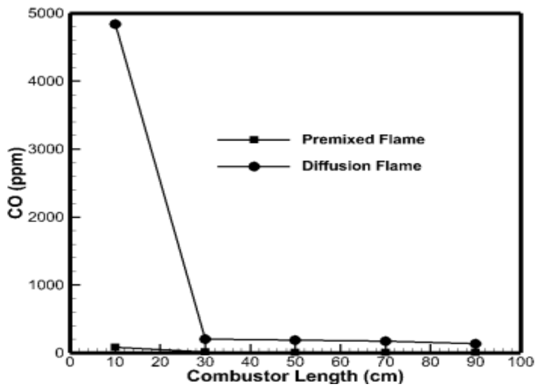

Fig. 6. Axial CO Measurements

Figure 7 also show CO levels obtained from different radial positions throughout the combustor. It can be readily said that CO values obtained under non-premixed combustion conditions are higher than that of CO values obtained under premixed combustion conditions throughout the combustor. In fact, CO levels are rather low under premixed combustion conditions because the complete combustion of methane has nearly been achieved under this conditions. Somewhat CO (almost 200 ppm) has left from the combustor as an incomplete combustion product under diffusiın flame combustion conditions

Axial CO_2 measurements of premixed and diffusion methane flames are given in Figure 8. As it can be clearly seen from the Figure 8, CO_2 levels of premixed flame are high compared to the CO_2 levels of diffusion flame. This is because of nearly the complete combustion under premixed conditions.

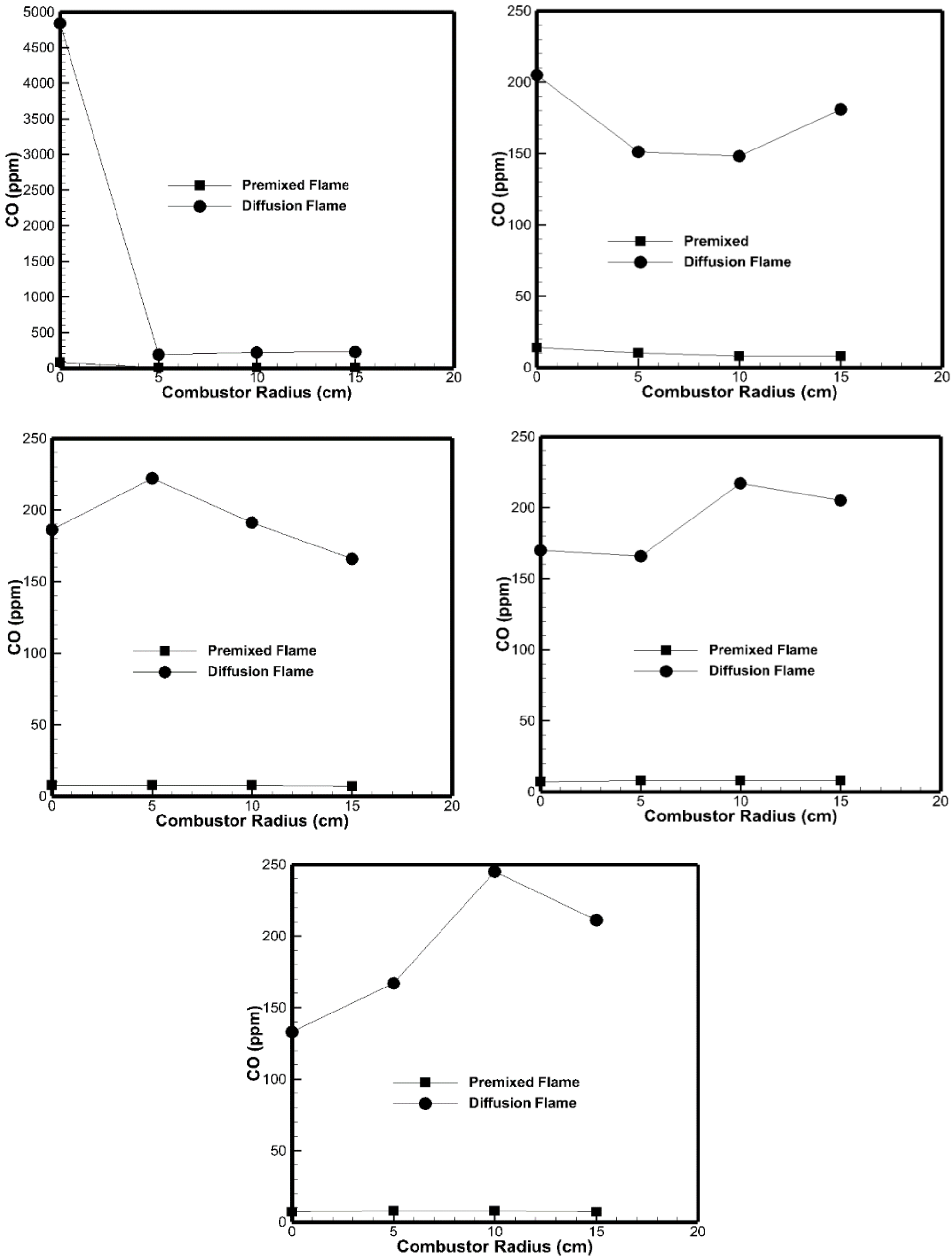

Fig. 7. Radial CO Measurements at 10 cm, 30 cm, 50 cm, 70 cm and 90 cm Axial Positions

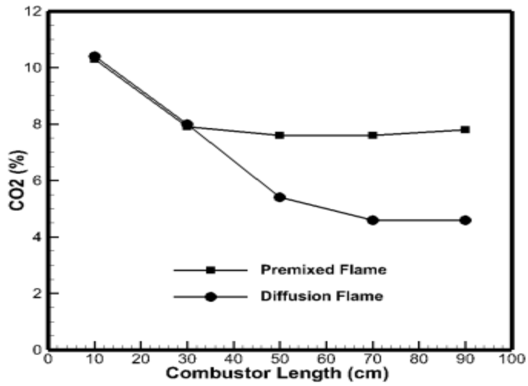

Fig. 8. Axial CO_2 Measurements

Radial CO_2 measurements of premixed and diffusion methane flames are presented in Figure 9. It may be firstly said that the maximum CO_2 levels emerge for both combustion conditions in the flame region. Radial CO_2 levels decrease rapidly towards the combustor wall at the axial distance of 10 cm as the combustor is sudden expansion type. Then, CO_2 levels measured from further radial positions increase slighlty to the combustor outlet. Because, it is thought that combustion is nearly completed. When CO_2 levels of premixed and diffusion flames are compared each other throughout the combustor, CO_2 levels of premixed flame are generally higher than that of diffusion flame due to better air-fuel mixture.

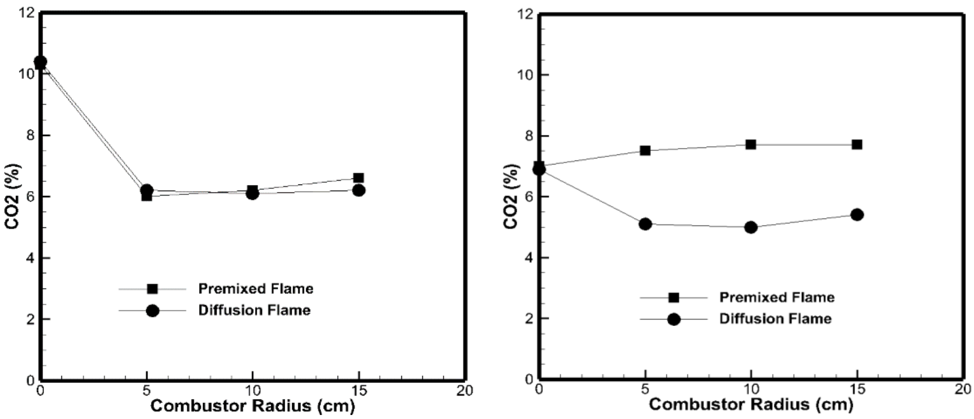

Fig. 9. Radial CO_2 Measurements at 10 cm, 30 cm, 50 cm, 70 cm and 90 cm Axial Positions

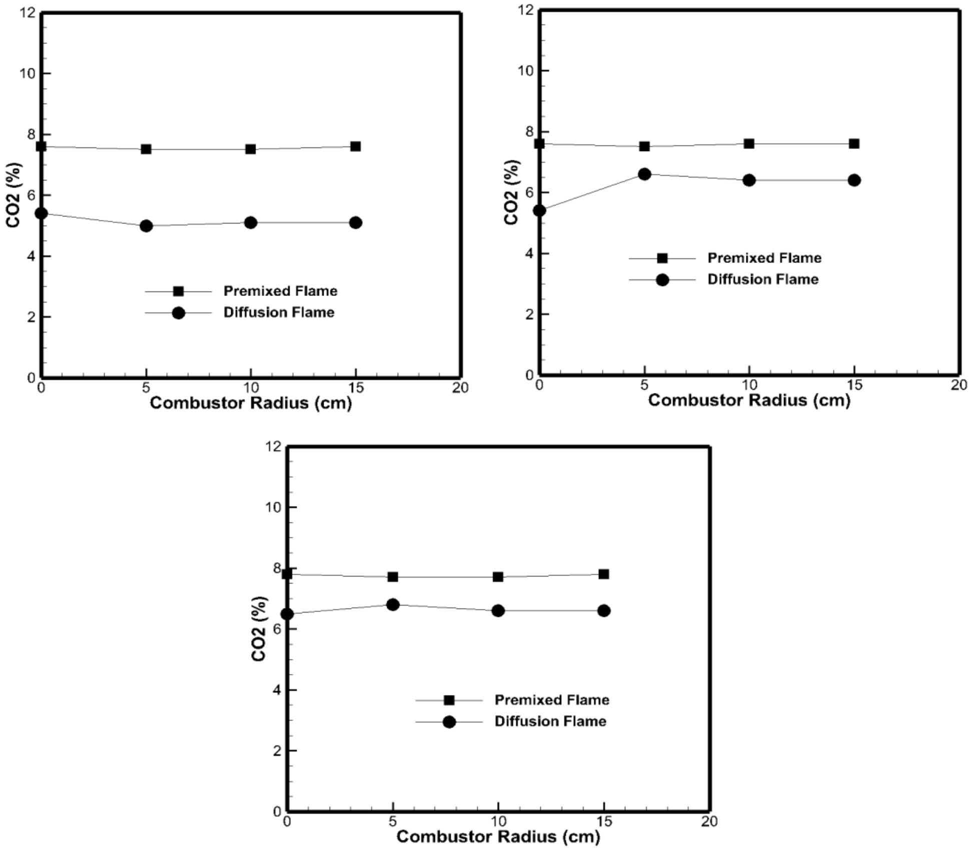

Fig. 9. Radial CO_2 Measurements at 10 cm, 30 cm, 50 cm, 70 cm and 90 cm Axial Positions (Continued)

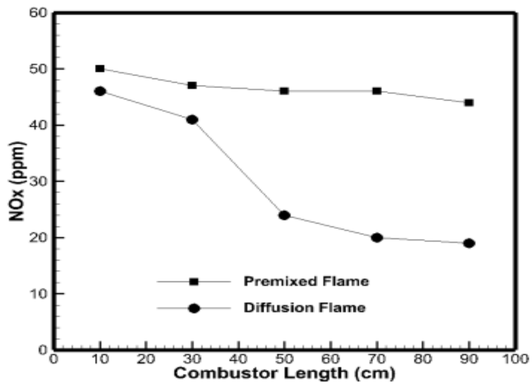

Fig. 10. Axial NO_X Measurements

Axial NO_X measurements of premixed and diffusion methane flames are shown in Figure 10. It can be readily said that the maximum NO_X formations are taken place under premixed combustion conditions due to effect of thermal NO_X mechanism. It may also be specified that NO_X levels decrease slowly towards the combustor outlet under the premixed combustion conditions as well as the NO_X levels decrease rapidly towards the combustor outlet under diffusion flame conditions. If Figure 4 and Figure 10 are examined carefully, it can be readily seen that there is a strong correlation between Figure 4 and Figure 10 as high NO_X levels are seen in the high temperature zone because of effect of thermal NO_X. Radial NO_X values of premixed and diffusion flames are also shown in Figure 11. As it can be seen from Figure 11, NO_X levels obtained under premixed flame conditions are rather higher than that of diffusion flame conditions throughout the combustor. It may be also mentioned that there is a similar correlation between the measured radial temperature and NO_X values.

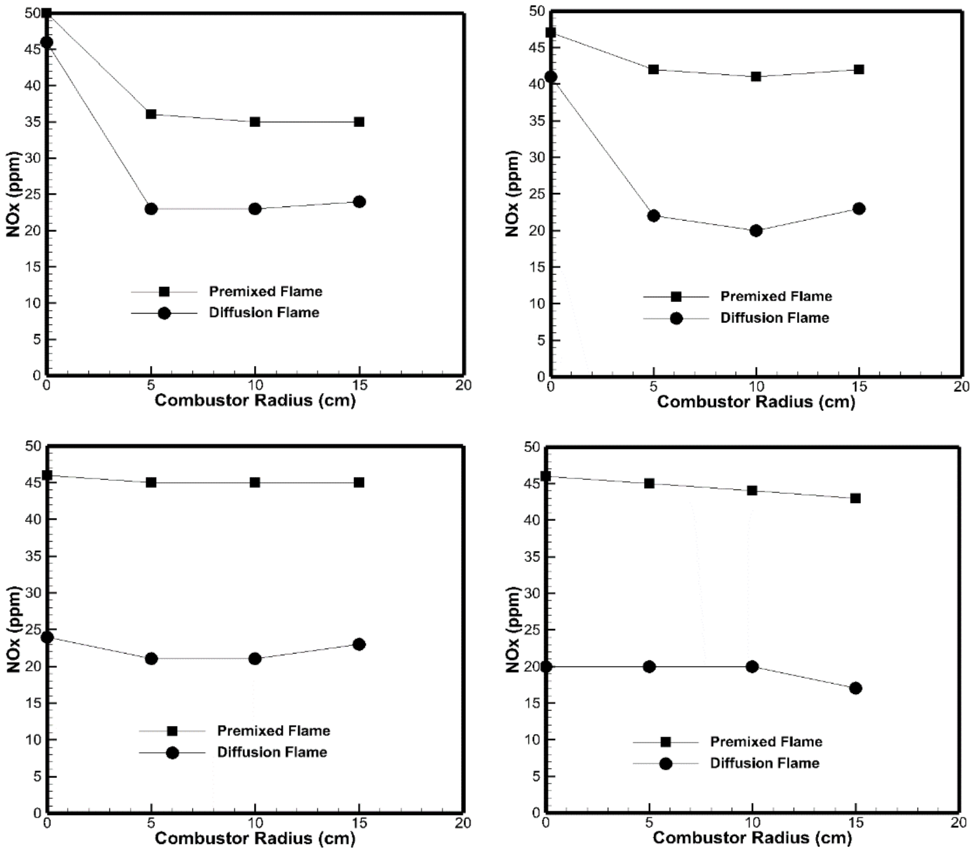

Fig. 11. Radial NO_X Measurements at 10 cm, 30 cm, 50 cm, 70 cm and 90 cm Axial Positions

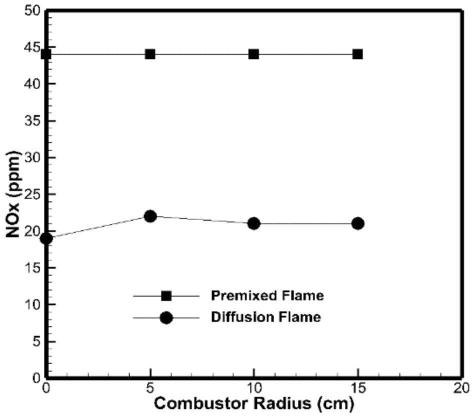

Fig. 11. Radial NO_X Measurements at 10 cm, 30 cm, 50 cm, 70 cm and 90 cm Axial Positions (Continued)

4. Conclusions

A new combustion system including burners and a combustor has been designed and manufactured so as to determine the temperature and emission values of methane flames throughout the combustor. Some conclusions that can be drawn from this study are presented below:

- The new type of burners have been developed and manufactured to burn the methane flames more efficiently and these burners have been used to consume the methane fuel under premixed and diffusion flame combustion conditions.
- The axial temperature distributions have been exhibited under premixed and diffusion flame conditions. It has been concluded that the temperature levels are high throughout the combustor under premixed condition excluding the temperature value at 30 cm axial position. When the radial temperature values are evaluated, it can be said that the flames propagate to the combustor in time due to combustor type (sudden expansion).
- It has been revealed that the temperature values of premixed flames are generally high over the temperature values of diffusion flames due to better fuel/air mixture.
- It has been demonstrated that CO and CO_2 emissions of premixed methane flame are low and high compared to that of diffusion methane flame due to better fuel/air mixture, respectively.

It can be concluded that NO_X emissions of premixed methane flames are high in comparison to that of diffusion methane flame due to effect of thermal NO_X mechanism.

5. Acknowledgement

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