Flameless combustion of propane-air mixture in a laboratory scale burner

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Abstract. In this work, the operational and emission of the laboratory scale burner under the flameless combustion regime using propane is examined. The combustor is equipped with parallel jet burner systems with controlled gas fuel and oxidizer. The combustor consists of several ports that are used to measure temperature variation and analyze gas emission. The atmospheric air was heated by flowing it inside the chamber until the air temperature increased to approximately the auto ignition temperature of the fuel. The furnace under investigation has successfully produced temperature uniformity ratios that are one order of magnitude less than such of the visible flame mode. It is observed that, flameless combustion can be achieved by using propane as a fuel. The value of NO_X emission during flameless combustion was reduced of about 70% in average compared to the conventional flame at certain range of equivalence ratio.

Introduction

The oil crisis has emerged as one of the most important topics in combustion science and technology since the 1970s. Most of the investigations have focused on increasing combustion performance by conserving energy. The preheated combustion air application was found to be the most effective method to achieve increased energy conservation and excellent combustion performance. Flameless combustion greatly affects emission reduction and combustion performance improvement. The detail of the review is available in [1]. In an experiment in 1989, fuel was observed to be completely consumed without a visible flame when the furnace temperature is 1000 °C and the preheated combustion air is at approximately 650 °C. These findings confirmed that the combustion process is stable and smooth, NO_X emissions are approximately zero, noise is low, and the CO content in the exhaust is low (<1 ppm) [2].

In 1998, Ishiguro *et al*.,[3] studied the effects of highly preheated air 1000 °C on the homogeneity and stability of a regenerative combustion burner using methane and propane as fuel. His results showed that increasingthe air combustion temperature decreased flame temperature resulting in greaterhomogeneity and stability as well as lower NO_X emissions[3-5].Also reported that preheated air effected NO_X emissionso that with high temperature preheatedair and low oxygen concentrationsresulted in lower NO_X emissions compared to higher NO_X emissions with high oxygen concentration and lower temperature air combustion[6, 7]. Guillou studied NO_X emission levels as a function of preheated at O_2 concentrations of 15%, 8% and 2% using propane and observed very low NO_X emissions at higher preheated air temperatures (constant 1150 °C) and lower oxygen concentration: 40 ppm at 2% O_2 and 2800 ppm at 21% O_2[8,7]. NO_X emissions of 10 ppm were achieved at an air equivalence ratio of 2.1 for preheated temperatures of T_{air}700 K with an inlet velocity of 160 m/s[9].Gupta reported that both color and flame size (volume) depend on oxygen concentration and the temperature of preheated air[10]. More details of this previous studied are available in.

This article summarizes the experimental work of flameless combustion that uses propane-air mixture. Stoichiometric propane was prepared with preheated air and CO_2dilution. Several important results such as visual observation, temperature distribution and NO_X formation are discussed.

Experimental Setup and Procedure

A schematic of experimental setup for the present study is shows in Figure 1. The test rig is made up of a horizontal combustion chamber of circular cross section. The combustion chamber is made of mild steel with length is 600 mm and the outer diameter of the chamber is 254 mm. The inner combustion chamber body was isolated with a 42 mm thick refractory material layer.The combustion chamber is covered with 30 mm thick glass wool. In addition, the combustion chamber is equipped with a circular quartz window diameter of 50 mm fixed on the left side of the combustion chamber in order to perform flame imaging. The combustion air is preheated by a coil placed within the furnace assembly; its temperature adjusted up to 500°C. The preheated combustion air is injected through six 5 mm diameter holes and fuel is injected through a 5 mm diameter central hole.Temperature of preheated air and the temperature of midplane along the combustion chamber are measured with K-type thermocouples. There are six holes for temperature measurements. The first hole, is placed at 60 mm from the burner, second, third, fourth, fifth and sixth at 135, 210, 325, 400 and 475 mm respectively from the burner, more details available in[11].

In an experimental run, the furnace is operated until stable conditions are reached before conducting any maneuver to activate and deactivate a new combustion mode. This is strictly followed to ensure measurement consistency. The flow within the furnace is inherently unsteady; therefore it is almost impossible to identify steady state reference conditions. However, all measurements have been conducted repeatedly to ensure that the variation of readings is negligible in comparison with the experiment reproducibility.

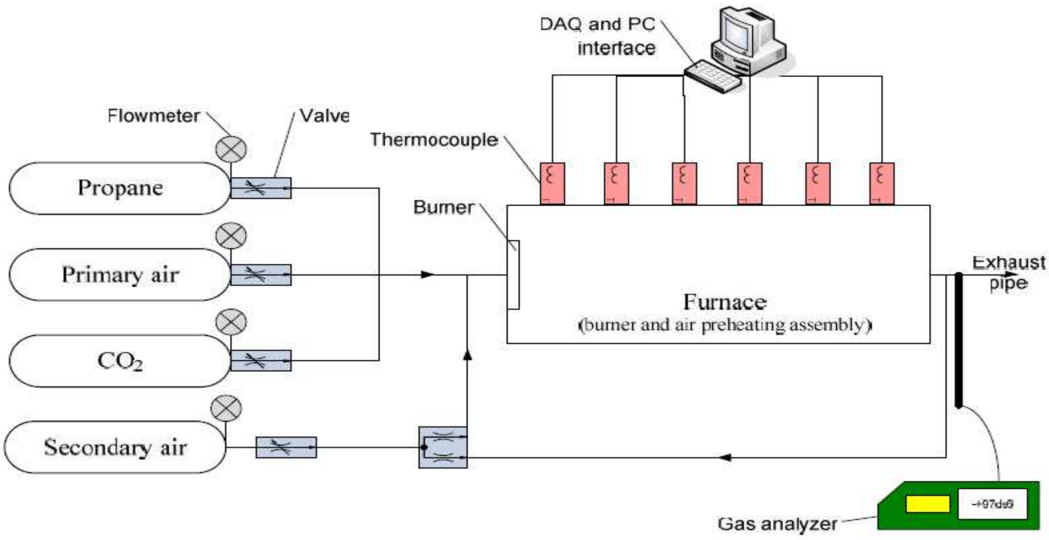

Figure 1. A Schematic of the experimental platform of the flameless combustion furnace

RESULTS AND DISCUSSION

Visual Observation

Flame color depends on oxygen concentration and temperature on reaction zone. Every flame showed a unique structure of the flame color as the temperature of air combustion and oxygen concentration changed from 20.9 to 2% on the reaction zone. Figure 2 shows the photographs of propane flames at different O2 concentrations with CO_2 as the diluent at 500°C. In this experimental, the propane flames under lean, a Stoichiometric and rich combustion showed the following four distinct colors: yellow, blue, bluish-green, and green It was shown in Figure 2 that the blue color was observed when oxygen concentration between 5-15%. The color of the flame was change when the oxygen concentration reduced to 5-2% at this case the color of the flame change to bluish green and green Fig.2. It observed colorless of the flame (flameless) under certain condition at oxygen concentration less than 2% [16]. Form this test can conclude that the oxygen concentration and temperature of air combustion in the reaction zone it is important factors of the flame colors.

O_2=5% O_2=3% O_2=2%

Figure 2. Photographs of propane-air flames at different O_2 concentrations with CO_2 as the diluent at 500 °C.

Transition from conventional to flameless combustion

Figure 3 shows the combustion chamber temperature as function of time. The data in Fig.3 represent an average of three experiments at same conditions. The difference in results between the three experiments was negligible, which proves the reproducibility ofthe experiments. The dashed vertical line represents the instant when the flameless combustion mode was activated. It was activated by closing the fuel switch for approximately one minute. The successful transition between visible flame and flameless combustion modes is evidently associated with the sudden decreased in chamber reference temperature and a strong decrease of thermal NOx emissions. After the flameless combustion mode was activated, an approximate duration of 60 minutes was required to reach steady state flameless combustion condition. The low temperature gradient throughout the chamber is an important characteristic of flameless combustion mode. The characteristics of transition from visible flame to flameless combustion in the present work agree well with the studies conducted by the other researchers [12].

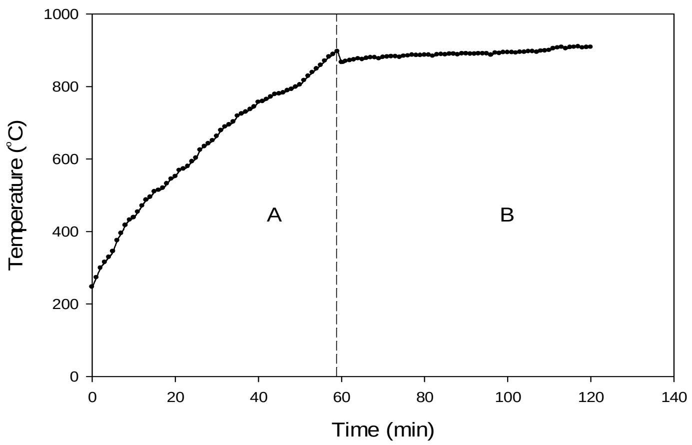

Figure 3. Variation of average temperature as a function of time from conventional (A) combustion to flameless combustion (B) for stoichiometric propane-air mixture with coaxial entry

Temperature Distribution

The axial temperature profile in visible flame, flameless, and diluted combustion modes are compared in Figure 4. This figure indicates the enhancement in temperature gradient in flameless mode over the visible flame mode. During the flameless combustion mode, the measured axial temperature profile was found to be uniform. On the other hand, in visible flame mode, a peak flame temperature was found near to the burner plane. In addition, it indicates the effect of CO_2 dilution of the flame. Slight reductions of the temperature field inside the combustion chamber have been observed due to CO_2 dilution during flameless mode; the local temperature slightly decreased. This decrease in temperature was attributed to differential heat transfer. CO_2 has higher specific heat (Cp) at high temperatures (Cp of CO_2 = 1.28 at 1200 K) and its improved radiation properties allows it to absorb more radiation from the reaction region. This situation leads to a temperature decrease of the furnace walls, which is in agreement with the studies conducted by other researchers[11, 13, 14].

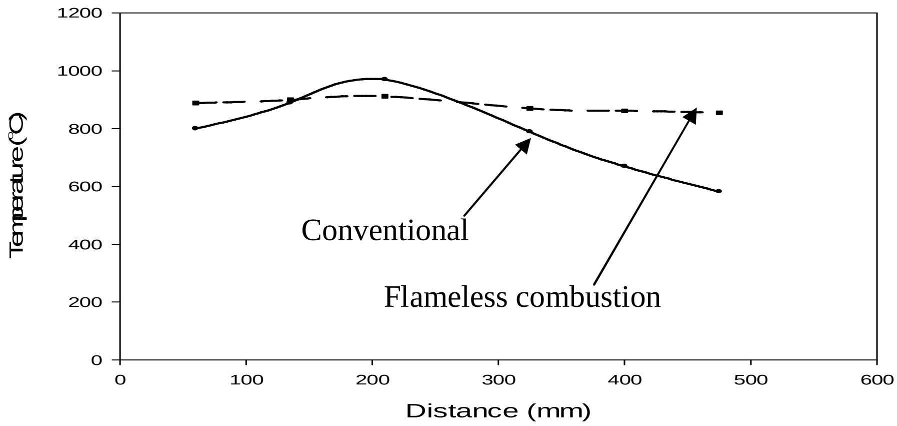

Figure 4. Temperature distribution along the central axis for stoichiometric propane-air mixture with coaxial entry for conventional and flameless combustion

NO_X Emissions from the Combustion of Propane

The most prominent feature of flameless combustion is low NO_X emission. To emphases on this fact, series of experiments have been conducted for the conventional flame that later transit into flameless combustion of for stoichiometric propane-air mixture with coaxial entry with CO_2 as gas diluted.

Figure 5 shows Temperature and NO_X emissions for stoichiometric propane-air mixture with coaxial entry at preheated air 500° C. From this Fig. 5 the NO_X emissions from flameless combustion were about 70% less than conventional combustion due to temperature uniformity within the combustion chamber.Table 1 gives a brief overview of several studiesin comparison to the present studies. The recorded lowNO_X emissionswere in good agreement with those previously reported combustion experiments flameless.

Table 1:Summary and comparison of NO_Xemissions for propane (ppm)

Reference	Equivalence ratio (Φ)	Configuration of air entry	Fuel	NO_X(ppm)	T_{air} (°C)
Kim et al [15]	0.80	Coaxial	Propane	27	27
Dally et al [14]	0.83	Coaxial	Propane	25	1151
Gupta [16, 17]	0.83	Coaxial	Propane	40	1000
Present work	1.0	Coaxial	Propane	6	500

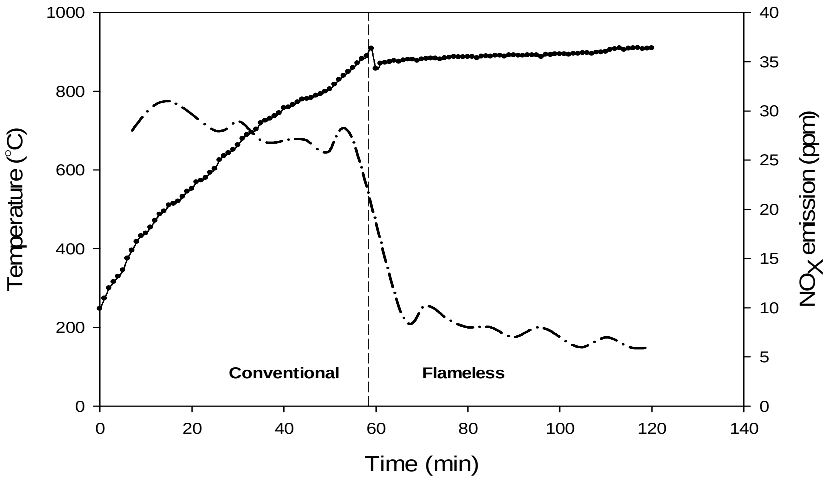

Figure 5. Temperature and NO_X emissions for stoichiometric propane-air mixture with coaxial entry at preheated air 500° C

Conclusion

This study presented characteristics of flameless combustion in a laboratory-scale burner. The transition from conventional to flameless combustion was achieved for stoichiometric propane-air mixture with coaxial entry at preheated air 500° C. The temperature uniformity for propane was studied. The higher temperature uniformity for propane gas was recorded under internal preheated flameless compared to conventional combustion. These results show that temperature uniformity within the combustion chamber is characteristic of flameless combustion.A NO_X emission was reduced two folds in internal preheated flameless combustion and in comparison with conventional combustion.

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