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Optimization of a premixed cylindrical burner for low pollutant emission

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A B S T R A C T

A premixed cylindrical burner is numerically and experimentally investigated to realize low pollutant emission. The geometrical parameters of nozzle exit position and nozzle diameter are optimized by using a validated Computational Fluid Dynamics model. The natural gas-air mixing in the mix chamber indicates that the uniformity of methane concentration increases with the increase of distance from ejector outlet. It is found that the nozzle exit position at −3.0 mm improves the overall performance of premixed cylindrical burner, when nozzle diameter is not less than 1.6 mm. The emission characteristics of nitrogen oxides and carbon monoxide are also examined by experimental approach. It is found that load factor has a great influence on nitrogen oxides and carbon monoxide emissions, but the effect is gradually disappeared when air coefficient is not less than 1.4. When nozzle exit position is −3.0 mm, nozzle diameter is not less than 1.6 mm and air coefficient is not less than 1.4, the emissions of nitrogen oxides and carbon monoxide are less than 20 ppm and 50 ppm, respectively.

1. Introduction

In recent years, environmental problems are becoming more and more attention. Air pollution is one of the major problems of modern world. The low-pollutant emission technology has received increasing attentions. One of the main pollutants is NO_x formed by the oxidization of nitrogen during combustion process. Wei et al. [1] investigated the effects of operating parameters on the NO_x emission and found out the optimal operating conditions to reduce the NO_x emission for high-temperature air combustion furnaces. The concentration of NO_x emission reduces by 25.45% in their optimal operating condition. Gonca [2] conducted a steam injected method to supply ethanol–diesel blend fuel for a diesel engine. The results showed that the NO emission is reduced to 34% compared with conventional diesel engine (D) and steam injected diesel engine (D + S20). Kesgin [3] researched the relationship between design and operational parameters and the NO_x emission of a turbocharged natural gas engine. By reducing the charge temperature, it was found that there is an increase in the excess air ratio, which causes a significant decrease in NO emission and the concentration of emissions is decreased to a level to meet the international standards. Coelho described a numerical simulation of Eulerian particle flamelet mode in mild combustors to calculate NO emission in a post-processing stage. The combustor was characterized by relatively lower NO_x emission [4]. The further investigation [5] pointed out that N,N′-diphenyl-1, 4-phenylenediamine (DPPD) antioxidant additive can reduce NO_x emission significantly. In this case of the addition of 0.15% (m) DPPD additive in JB5, JB10, JB15 and JB20 (Jatropha methyl ester is blended with diesel at 5%, 10%, 15% and 20% by volume), the reduction in the NO_x emission is 8.03%, 3.503%, 13.56% and 16.54%, respectively, compared to biodiesel blends without the additive under the full throttle condition. Although an increase in CO emission with the addition of DPPD antioxidant to all Jatropha biodiesel blends was observed, the value is low in comparison to diesel emission. However, the low-NO_x emission approaches are based on non-premixed combustion in the above investigations, which focus mainly on engine and biodiesel fields.

Premixed combustion can notably reduce NO_x emission because it does not produce Fuel NO (F-NO) and Prompt NO (P-NO), which decrease the chance of Themal NO (T-NO) generation. Authors' research group have designed and developed a plate-type premixed burner, which have the advantages of high efficiency and low emissions. After increasing the mixing effect in mixing chamber, NO_x and CO emissions was found to be less than the conventional burners in present market [6,7]. It is characterized by high temperature, relatively short flame and excellent ductility. To improve premixed combustion behavior, some of research devoted to study the geometry parameters of burning system. Zhang et al. [8] optimized the geometry parameters of diversion plate to improve the uniformity at the outlet of gas mixing system. The

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hole diameters and the arrangement of a cylindrical multi-hole premixed burner were investigated by Lee et al. [9]. The results showed that the NO_x and CO emissions are less than 40 ppm and 30 ppm for a 0% O_2 basis, respectively. Panwar et al. [10] evaluated the performance of premixed type industrial burner with swirl vane for mixing the air and gas. However, the premixed cylindrical burner (PCB) with ejectors of mixing the air and natural gas has not been studied.

In China, it has experienced a process to establish NO_x and CO emissions standards for gas appliance. In the early 1990s, China formulated her own standards to the European standards gradually. As environmental awareness increasing, the national standards of domestic gas instantaneous water heater are established step-by-step. This makes it necessary to investigate low NO_x emission gas combustors.

Traditional optimal ways of combustors are based on empirical models, and a large number of experiments are required. It costs not only a lot of time, but also numerous resources. With the development of computer, the numerical simulation is becoming an attractive method for its high flexibility and low cost application. The computational fluid dynamics (CFD) approach is capable of visualizing the detailed information of flow field to optimize its performance. Sharfi and Boroomand [11] validated the deviation between the numerical model and experiment data. The maximum difference between the numerical and experimental results is about 9.7% and 10.6% for the two models, respectively. Zhu et al. [12] employed the CFD technique to research the ejector geometry parameters, and showed the optimum primary nozzle position and converging angle in particular operating condition. In order to study a supersonic air ejector, Hemidi et al. [13] dealt with the comparisons between CFD and experiments. Good validation results were obtained for a wide range of operating conditions. Arghode et al. [14] numerical investigated the combustion characteristics for application to gas turbine combustors by commercial software FLUENT. It was revealed that the numerical method was able to capture the overall flow field behavior and provide insights to achieve reactions in volume distributed combustion regime to reduce NO_x and CO emissions. Sukumaran and Kong [15] used the CFD modeling to study the combustion process inside the burner, and the reduced mechanism was able to predict NO_x emission for different feedstock and operating conditions. Chui et al. [16] investigated burner design concepts of reducing NO_x formation via improved staging by CFD. It indicated that a new burner design approach can potentially reduce the NO_x compared to the existing design methods.

The present developed PCB adopts a new design principle of premixed combustor. It has the advantages on simple manufacture, convenient operation, low NO_x and CO emissions and highly combustion efficiency compared to the existing burner. The stainless steel radial heat exchanger and compact aluminum heat exchanger are used. The purpose of the present study is to optimize geometry parameters of PCB by CFD. An innovative approach of random sampling method is introduced to analyze the mixing effect in mixing chamber and the experiments are conducted to study the combustion characteristics.

2. Description of the premixed cylindrical burner and experimental rig

Fig. 1 is the schematic diagram of our designed PCB, which consists mainly of a mixer and a cylindrical burner. The mixer has 6 major components: gas distribution chamber, nozzles, air chamber, ejectors, insulating chamber and mixing chamber. For reducing gas static pressure before entering the ejectors, equal number nozzles are located at the outlet of gas distribution chamber. The ejectors described by Liu et al. [6] are arranged in circle. The distance between nozzle and ejector is defined as NXP (nozzle exit position). Mixing chamber, starting from the ejector outlets, is covered with full of distribution pores on the surface. Insulating chamber between distribution pores and fire holes plate is used to trap the flame's heat. In working conditions, the natural gas going through the nozzles of gas distribution chamber is injected into ejectors. The fan supplied air is entrained by natural gas at the nozzle outlets. After further mixing in the mixing chamber, the premixed gas through the distribution pores gets to the surface of fire holes plate to realize premixed combustion. The design heat load of PCB is 27 kW. For premixed cylindrical burner (PCB), the mixing effect of natural gas plays an important role in realizing well premixed combustion.

A schematic diagram and a photograph of the experimental rig are shown in Fig. 2a and b, respectively. The experimental rig consists of a stainless steel radial heat exchanger and three systems: a natural gas supply system, a water supply system and a fan air supply system. The natural gas supply system has a pressure regulator to maintain the required gas pressure and an Electromagnetic valve to adjust the gas flow rate of system. There are two thermometers to measure the inlet and outlet water temperature of heat exchanger in water supply system. The parameters of the fan (Model: FLW85-55H01), which is used in the fan air supply system, are the control voltage 12 V and the security voltage 36 V. The exhausted gas is evaluated by the emissions of CO, NO_x and O_2, which are measured by Testo 350 gas analyzer. The specifications of Testo 350 gas analyzer are listed in Table 1. The laboratory ambient temperature is about 20 °C with the concentration of CO and CO_2 no more than 0.002% and 0.2% respectively.

3. CFD model

In order to improve the accuracy and reduce time consumption of solution, several assumptions are made before numerical

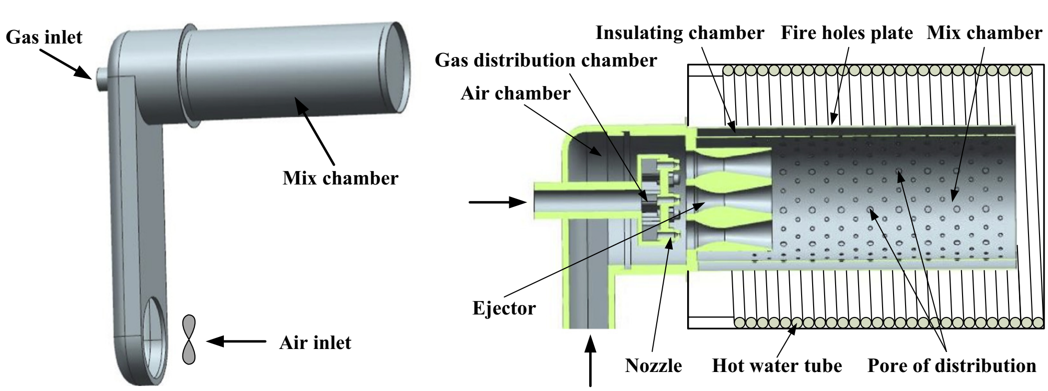

Fig. 1. Schematic diagram of PCB.