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An experimental study of emission characteristics from cylindrical furnace: Effects of using diesel-ethanol-biodiesel blends and air swirl

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ABSTRACT

In this research, experimental investigation was undertaken to find the effects of air swirling on pollutant emissions in a cylindrical combustion chamber fuelled with diesel-biodiesel-ethanol blends. At the first, a burner system with various radial air swirl generator (the vane angles were 15°, 25°, 35°, 45°, 60° and 90°) attached to the combustion chamber of 400 mm inside diameter and 2000 mm length. Fuel blends were D100, D85B10E5 (85% diesel, 10% biodiesel and 5% Ethanol on a volume basis), D80B10E10, D75B20E5, and D70B25E5. CO, HC, CO_2 and NOx as the emission characteristics were determined in this research. Moreover gas temperature in a cylindrical combustion chamber was reported. According to the results, the minimum CO and HC emissions belong to fuel blend D70B25E5 and air swirl generator with the vane angles of 15° and the maximum CO and HC emission occurs for net diesel (D100) and swirl air vane angle of 90°. Moreover, D80B10E10 has the maximum CO_2 emission. It shows that ethanol can more effective to increase in CO_2 values than that of biodiesel. Besides, the minimum CO_2 emission obtained for fuel blend D100. The minimum value of NOx emission occurs for D100 and swirl air vane angle of 45°. In addition, air swirling condition with higher vane angles of 45° leads to higher premixed combustion and temperature and causes an increase in NOx emission. Moreover, the maximum value of NOx emission will be for D70B25E5 because of higher biodiesel content as an oxygenated fuel. The results indicated that the mean temperature of combustion gas increases when biodiesel content of fuel mixture increases. On the other hand, the mean temperature of combustion gas decreases by the addition of ethanol in fuel mixture.

1. Introduction

Industrial development and social growth have caused high request of fossil fuels. On the other hand increase of pollutant emission of petroleum-based fuels and its effects on environment has led to many investigation on alternative fuels which can be derived from local feedstock within the country [25,24,31]. Biofuels as the renewable energy are a broad range of fuels which are produced from biomass material. Biodiesel as a famous liquid biofuel derived from chemistry process of vegetable oil or animal fat resources, for use in furnace burners and diesel engines [31,32]. This chemistry process is transesterification. The properties of biodiesel are similar to conventional diesel fuel. The main difference between biodiesel and diesel fuel is oxygen content which has improved its performance attributes such as increased cetane number and high fuel lubrication properties. However, the heating value of biodiesel is lower than regular diesel fuel.

Bioethanol is a biofuel that can be obtained through fermentation of sugary or starch plants or acidic hydrolysis of cellulosic sources. Vegetables such as sugar beet, sugar cane, corn, wheat and potatoes, woody plants such as stem, hay and huff, agricultural waste and remains and molasses, which are a by-product of sugar production, are among the raw materials from which bioethanol is obtained [4].

Ethanol with high oxygen content can be used in diesel and gasoline engines. Using ethanol in diesel fuel causes significant reduction in some emission characteristic such as particulate matter (PM) emissions. However, There are many limitations in the use of ethanol for diesel engines such as low cetane number of ethanol and poor solubility of ethanol in diesel fuel in cold start conditions [30].

Many researches have been carried out on biodiesel and its characteristics. The behavior of biodiesel in internal combustion engines is well documented in the literatures [1,21], but a few studies are conducted on the behavior of biodiesel in liquid burners and furnaces. Furthermore, the effects of different parameters such as air swirling flow on biodiesel combustion is not studied completely. Swirling flows are applied in a wide range of application both non-reacting and reacting system.

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Symbols and abbreviations

CO	Carbon monoxide
CO_2	Carbon dioxide
NOx	Nitrogen oxides
HC	Hydrocarbon
B	Biodiesel
E	Ethanol
D	Diesel
T	Temperature

Burners are usually used in industrial applications such as starters for boilers, district heating and cooling and also for domestic central heating system. However, bio-fuel conventional burners, operating at or above stoichiometric air/fuel ratios, produce high flame temperatures that resulted in the production of nitrogen oxides, which is then emitted to the atmosphere [6]. However, lowering NOx emission by reducing flame temperature will lead to reduced flame stability or increase in carbon monoxide (CO) emission [18]. Basically there are two techniques of controlling NOx in burner applications: those that prevent the formation of nitric oxide (NO) and those that destroy NO from the products of combustion.

Swirling flow induces a highly turbulent recirculation zone, which stabilizes the flame resulting in better mixing and combustion [13]. It has been suggested that the large torroidal recirculation zone plays a major role in the flame stabilization process by acting as a store for heat and chemically active species and, since it constitutes a well-mixed region, it serves to transport heat and mass to the fresh combustible mixture of air and fuel [16].

There exist few studies in the open literature for heavy fuel oil-fired combustors centered on pollutant emissions encompassing both NOx and particulates. Previous related studies in experimental furnaces involved staged combustion and flue-gas recirculation experiments as a means of controlling NOx emissions [29,11]. The effect of combustion staging on NOx emissions has also been studied by Beér et al. [5] who also considered particulate emissions. Another study has further addressed the effect of staged combustion on NOx formation and emission [26]. Byrnes et al. [8] have reported extensive combustion data, with emphasis in the near-burner region, but little attention was paid to pollutant emissions.

The swirling of combustion air acts on the flow field by creating radial and axial pressure gradients. In the case of strong swirl, the adverse axial pressure gradient is sufficiently large to create an internal recirculation zone along the furnace axis and at the same time reduces the outer recirculation zone near the walls [17].

Kouremenos et al. [20] conducted an experimental study is to evaluate the use of JP-8 aviation fuel as a full substitute for diesel fuel in a Ricardo E-6 high-speed naturally-aspirated four-stroke experimental engine having a swirl combustion chamber. The study shows that the exhaust emission levels are not much different for operation with the two fuels. On the contrary, operation with JP-8 fuel increases combustion pressures, combustion intensity and irregularity.

Ti et al. [39] performed some measurements for a 600-MWe wall-fired pulverized-coal utility boiler that was retrofitted with centrally fuel rich swirl coal combustion burners. A three-component particle-dynamics anemometer was used to measure flow characteristics in the near-OFA region in the laboratory together with gas temperature and species concentrations in the OFA and burner region in the utility boiler. The results show that, with decreasing swirl air vane angle, the penetrating depth of the jet stream decreases and the divergent angle increases and Flue gas temperature increases as the OFA swirl air vane angle increases from 25° to 45°. Moreover, NOx emissions are reduced when compared with those prior to the retrofitting, with OFA swirl air vane angles of 25°, 35°, 45° and 90° providing reductions of 240, 273, 294 and 319 mg/m^3, respectively.

Wang et al. [40] studied effect of different inner secondary-air vane angles on combustion characteristics of primary combustion zone for a down-fired 300-MWe utility boiler with overfire air. Full-scale measurements (adjusting the inner secondary-air vane angle to 35°, 45°, and 55°) revealed that the influence of the high-temperature recirculating region under the arch upon the combustion and NO_x emission characteristics of the boiler is greater than that of the high-temperature flue gas entrained by the swirl burner itself. The authors found that for optimal (35°) inner secondary-air vane angle, the NO_x emissions and carbon content in the fly ash reached levels of 674 mg/m^3 (6% O_2), and 11.4%, respectively.

Li et al. [22] performed an investigation to measure the aerodynamic characteristics, flue gas temperature, and gas concentrations for various vane angles of outer secondary air in the burner nozzle region. The results show that with decreasing vane angle, the maximum axial, radial, and tangential velocities and swirl intensity of the airstream increase and the decaying rate of velocity increases and also the maximum diameter, length, and the jet divergence angle of the central reverse-flow zone increase. A decrease in vane angle increases the flue gas temperature, the rate of increase indicating a closer ignition position of the anthracite and lean coal along the airstream direction of the burner. The results also showed with decreasing vane angle, the CO concentration increases while the NO_x concentration decreases.

In another study, Thundil Karuppa Raj and Ganesan [37] have carried out The experimental and numerical investigation to study the characteristics of swirl flow are evaluated by means of size of the recirculation zone, mass trapped in the recirculation zone and also the pressure drop. It is found that no single turbulence model is able to handle both weak and strong swirl. From this study it is concluded that for weak swirl standard model is sufficient whereas for strong swirl one has to resort to Reynolds stress model. In this investigation over the range of vane angle investigated the best vane angle is found to be 45°.

Numerical simulations on coal combustion and NO*x* emissions were performed by Ti et al. [38] for a centrally fuel-rich pulverized-coal swirl burner. The new findings of this research showed the ignition performance and NO*x* reduction capacity of burner increases as primary air cone length decreases. Moreover as the inner secondary air cone length increased, ignition performance of burners becomes poor and the NO*x* reduction capacity increases. In addition, the ignition performance and NO*x* reduction capacity of burners become stronger with increases in outer secondary air cone length.

Sung and Choi [35] evaluated experimentally the influences of swirl vane angle, primary zone stoichiometric ratio, and air staging level on NO_x emission and burnout in a laboratory-scale pulverized coal fired furnace. The NO_x emission and burnout were a function of residence time in the primary combustion zone. Increasing of the residence time and decreasing of the primary zone stoichiometric ratio had a positive effect on NO_x reduction and a negative effect on burnout. From the effectiveness analysis of combustion modifications such as the primary zone stoichiometric ratio and swirl vane angle, the control of swirl vane angle was more effective than that in the control of the primary zone stoichiometric ratio.

Hodžić et al. [14] presented an experimental research on NOx emissions during co-firing of coal with woody biomass and natural gas. The aim of the research was investigation of synergetic influence of advanced and simultaneously applied different primary reduction measures on NOx emissions in a multifuel combustion system. The results showed NOx emissions reduced significantly with the increase of the staging air portion and also with an increase in the distance between the burner and OFA nozzle. Furthermore, if the reburning is performed by natural gas with OFA switched on, NOx emissions reduce below 500 mg/m_n^3 at 6% O_2 dry. The results confirmed that the design and operation of multi-fuel system using coal; biomass and gas could be optimized, such benefiting further reduction of NOx emissions.

Ashrul Ishak et al. [2] investigated a liquid bio-fuel burner system