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EFFECTS OF THERMAL LOAD AND EXCESS AIR COEFFICIENT ON COMBUSTION PRODUCTS IN A NATURAL GAS-FIRED BURNER-BOILER

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ABSTRACT

Burners and boilers are used effectively in thermal systems, especially they are widely used in hot water supply. Nowadays, combustion product levels are as important as their energy efficiencies due to legal regulations. In this experimental study, combustion products investigation of natural gas has been carried out at various burner thermal loads and excess air coefficients in an industrial burner-boiler system. The findings show that although the thermal load increases, the amount of change of combustion products such as NOx, O_2 and CO_2 remains limited. On the other hand, the increase in the excess air coefficient affects these products considerably.

INTRODUCTION

Combustion phenomena, which cause the release of heat energy, are basically a process that requires a fuel, oxidizer and ignition source. The following three factors must be provided for a good combustion. These are temperature, time and turbulence. The lack of one of these either makes it impossible to burn or ceases to be a good combustion.

Most fuels contain hydrogen and carbon, hence are defined as hydrocarbons. Heat is generated from the reaction of hydrocarbon fuels with the oxidizer, commonly known as oxygen. Hydrocarbons can be present in solid, liquid and gas phases, and these three phases are widely used in industrial applications. Natural gas is the most consumed gas among others due to quantity, availability, and harmless to human health. However, after the combustion of natural gas, it emits some harmful gases such as NOx, CO, and CO_2. The NOx causes to acid rains, CO_2 triggers global warming by making a greenhouse effect in the atmosphere, and CO has a highly toxic effect and creates a greenhouse gas effect. The quantity of these gases is variable and depends mainly on combustion technique, efficiency of combustion devices, fuel quantity (thermal load) and stoichiometric conditions. Although there are many experimental and numerical studies on combustion and emissions in the literature [1-12], scientific research's are still going on due to the important effects of this issue on the lives of humans and others. In this study, the effects of thermal load and excess air levels on the combustion products, especially NOx, CO, CO_2 and O_2 are investigated experimentally.

EXPERIMENTAL TEST RIG

The test system provided by Termo Isı Sistemleri San.Ve Tic. A.S [13] used in this study consists of an ECO45 GC 3B proportional gas burner, a hot water boiler with a circular cross section made of st37 steel, gas path fittings, cooling jacket, stack and measuring devices for measure the temperature, and flue gas emissions such as O_2, CO_2, CO and NOx. The flue gas measuring device is NOVA branded. The gas path fittings, hot water boiler and burner are shown in Figs. 1-3.

The combustion test is performed with natural gas provided by CORDAS [14]. The fuel species and the volumetric ratio of the species can be shown with the aid of natural gas-air reaction as:

Combustion of Natural Gas with 20% Excess Air (λ= 1.2)

$$0{,}9505CH_4 + 0{,}0287C_2H_6 + 0{,}0094C_3H_8 + 0{,}0026C_4H_{10} + 0{,}0004C_5H_{12} + 0{,}0001C_6H_{14} + 2{,}0705 \cdot (1 + 0{,}2) \cdot (O_2 + 3{,}76N_2) \rightarrow 1{,}0497CO_2 + 2{,}0415H_2O + 9{,}3420N_2 + 0{,}4141O_2$$

The closed form of the reaction may be written as:

$$C_{1.058}H_{4.116} + 1.558O_2 \rightarrow 1.058CO + 2.058H_2O$$

$$CO + 0.5O_2 \leftrightarrow CO_2$$

where

$$C_n = \frac{\sum y_i C_i}{\sum y_{hidrokarbon}} = \frac{1.049716}{0.991853} = 1.0583 \quad (1)$$

$$H_m = \frac{\sum y_i H_i}{\sum y_{hidrokarbon}} = \frac{4.083138}{0.991853} = 4.1166 \quad (2)$$



Figure 1. Gas flow meter and regulator set where the fuel pressure is reduced to 21 mbar [13]



Figure 2. Hot water boiler and measurement devices [13]



Figure 3. Water cooled boiler and burner assembly [13]

RESULTS AND DISCUSSION

The volumetric percentage changes of CO_2 and O_2 in the combustion emissions of natural gas-air is shown in Fig. 4. It is clear that with the increase of thermal load of the burner, the volumetric ratio change of CO_2 and O_2 is limited. According to the results, it is understood that complete combustion conditions are approximately provided especially for higher levels of CO_2.

In addition to the measurements of CO_2 and O_2, CO and NOx emission values were also measured at various thermal loads. Fig. 5 shows the variation of these emissions. CO emissions are indicative of incomplete combustion. Therefore, if CO is present in the pollutants, either fuel and oxygen mixing is not enough or the oxygen level in the combustion chamber is insufficient. When the figure is examined, the highest CO emission level was measured for 459 kW and CO level decreased with increasing thermal load up to 1085 kW. This may be due to the relatively low fuel-air quantities in the burner-combustion chamber, resulting in insufficient mixing. Besides, the CO levels increased at 1200 kW. This may be because there is not enough time for the entire mixture if the amount of air-fuel is high.

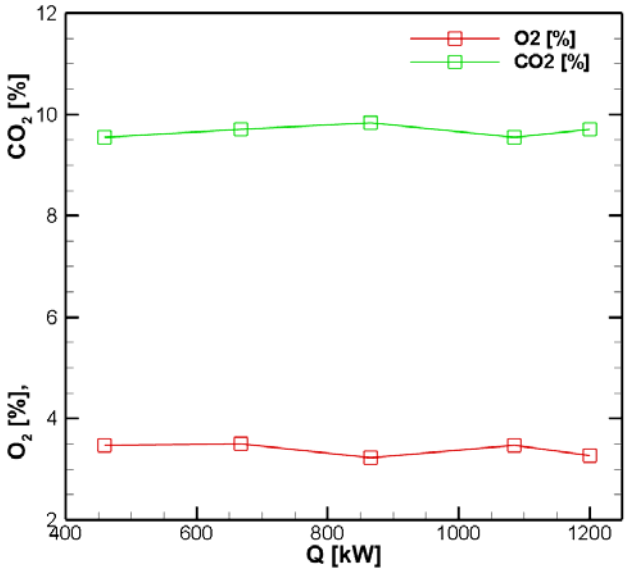


Figure 4. The variation of volumetric percentage of CO_2 and O_2 with increasing of thermal load of burner

On the other hand, increasing the burner thermal load from 459 kW to 866 kW increases the NOx level gradually. This is due to the fact that more energy enters the furnace with the increasing thermal load and the increased energy level causes the flame temperature to increase. As the flame temperature increases, the thermal NOx increases depending on the flame temperature. The increase in the thermal NOx level increases the total NOx. The increase of the burner thermal load from 866 kW to 1085 kW and 1200 kW, respectively, resulted in a slight decrease in NOx level. This can be caused by a slight cooling of the flame with increasing air velocity at the higher thermal loads or it may be due to the positive effects of the swirl burner.

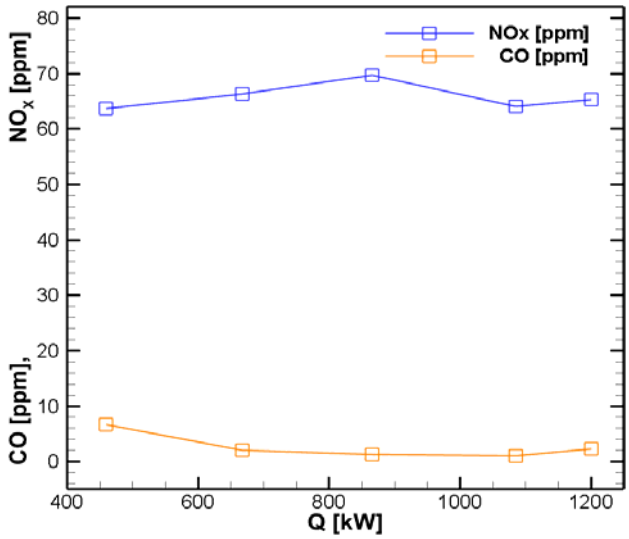


Figure 5. The variation of CO and NOx emissions with increasing of thermal load of burner

The combustion emission variations at different excess air coefficients are presented in Fig. 6-7. The CO_2 level gradually decreases with the increase of excess air coefficients. Whereas, the O_2 levels increases with the increase of excess air coefficients as expected. The CO emission is the maximum at the λ=1.05 as expected. Then it decreases to 1 ppm at other values. On the other hand, the NOx levels decrease gradually with the increase of excess air coefficients as expected. Because the flame temperature theoretically reaches maximum at the stoichiometric coefficient (λ=1). However, in the experimental study this value is approximately λ=1.05.

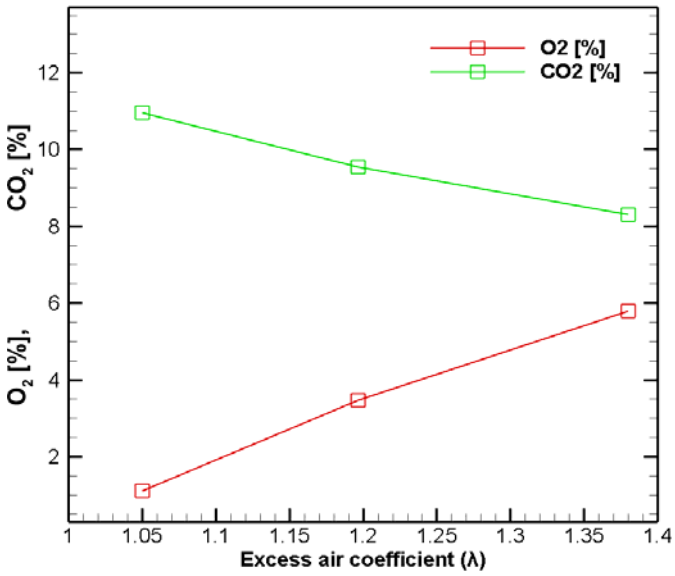


Figure 6. The variation of volumetric percentage of CO_2 and O_2 with increasing of excess air coefficient

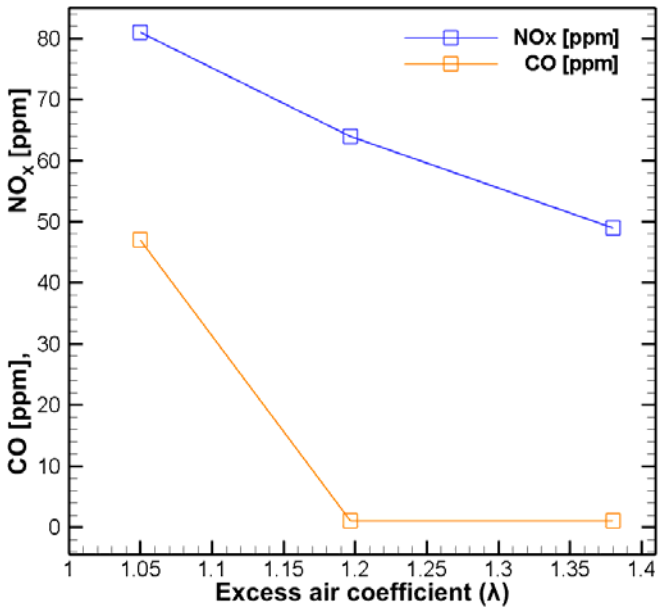


Figure 7. The variation of CO and NOx emissions with increasing of excess air coefficient

CONCLUSION

In this study, experimental tests were carried out at various burner thermal loads and excess air coefficients in a burner-boiler to investigate the combustion pollutants.
The experimental study that was carried out with different thermal loads resulted with limited variations in combustion emissions. The differences between maximum and minimum values are 6 ppm, 5.6 ppm and 2.84% of the NOx, CO and CO_2, respectively. However, the variation of them are more pronounced with the excess air coefficients. The differences between maximum and minimum values with the change of excess air coefficient are 32 ppm, 46 ppm and 24% of the NOx, CO and CO_2, respectively.

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