EFFECT OF N2 DILUTION ON EMISSION AND COMBUSTION INSTABILITIES FOR A BIOGAS MIXTURE USED IN INDUSTRIAL SYSTEMS

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Abstract

Biogas compositions are known as carbon free fuels for energy productions at nowadays. In this study, biogas mixture which contains %40 CO2 dilutant are tested with different N2 dilution ratios. Equivalences ratios and swirls number keep constant as 0.7 and 1, respectively. The results showed that the combustion stability of biogas mixtures diluted with nitrogen increased depending on the diluent ratio. In addition, as a result of dilution of the biogas composition with nitrogen, CO emissions decreased while NOx emissions increased.

Keywords: biogas combustion, dilution, combustion instability, emissions

1 INTRODUCTION

Today, fossil fuels used in energy production, buildings, transportation and other fields have some problems. First, fossil fuels resources are limited and researchers expect these resources will end soon. The another problem these fuels cause air pollution and global warming. This is because of the carbon dioxide they release into the air when they burn. Therefore, scientists have been working on new and alternative energy sources such as solar energy, wind energy and biomass in recent years.

Recently, interest in biogas has been increasing. Biogas, which is obtained by gasification of wastewater and solid waste, can be used in many areas, especially in power generation and heating systems. Although it contains small amounts of sulfur, nitrogen and hydrogen, the two basic components of biogas are methane and carbon dioxide [1]. Methane, which is the main component of natural gas, provdes high energy to biogas. Studies done to better understand the combustion characteristics of biogas are given here. Although biogas contains low amounts of inert gases, it consists of a high proportion of CO2. Like other low calorific gases, biogas has problems such as poor flame stability [2].

Zouagri et al. [3] in an experimental study, concluded that there is less NO production in lower CH4 compositions. In addition, the adiabatic flame temperature increased as the methane ratio increased. Liu at al. [4] performed that diluents slow down the chemical reaction rate in biogas combustion and this leads to a decrease in NOx emission. Hu and Zhang [5] analyzed the effect of fuel composition and pressure on flame shape in a study where biogas was burned with hydrogen. flame instability decreased with increasing equivalence ratio. hydrodynamic instability increases with increasing hydrogen ratio. Rowhani and Tabejamaat [6] conducted an experimental investigation of the stability limits of biogas in a vortex unmixed burner. They used 60% methane and 40% carbon dioxide composition. The flame behavior and stability limits of biogas under different vortex conditions were tested. Adding nitrogen to the air had a negative effect on the stability limits. Leung and Wierzba [7] conducted an experiment showing that instability increases as the amount of CO2 in biogas increases. It has been determined that the stability limits can be significantly increased by adding a small amount of hydrogen to the fuel. Öztürk [8] conducted a study using CO2, N2 and H2O diluents and found that the maximum NOx emission was seen at a rate of 1.39 equivalents. When N2, CO2 and H2O diluents were added to the biogas at a rate of 1.39 equivalents by 15% respectively, the NO emission decreased by 13.4%, 14.8% and 24.8%, respectively. İlbaş et al. [1] investigated the combustion properties of biogas with 3D numeric modeling. With the preheating of the combustion air, the flame temperature increased, SO2 emission increased with the increase in the amount of H2S. Şahin and İlbaş [9] examined the effect of H2O and H2S content on the combustion properties of biogas. The

composition of water vapor was varied between 0% and 10%. Yilmaz et al. [10] conducted a study examining the effect of oxygen enrichment on biogas combustion characteristics and emission behavior. While the oxygen rate increased to 28% it has been observed that a decrease in stability compared to the 24% oxygen rate. Experimental results show CO emission decreased as the oxygen ratio was increased..

2. TEST RIG

Figure-1a. A view of the experimental setup.

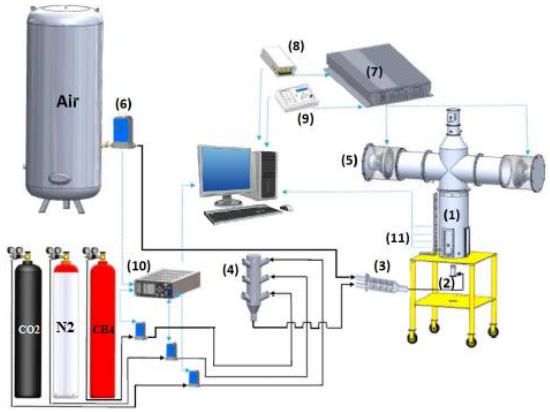


Figure- 1b. Layout of the overall combustion system. 1. Combustion chamber; 2. Burner; 3. Fuel/air pre-mixer (static); 4.Gas collector; 5. Loudspeaker; 6. Mass Flow Controller; 7. Audio amplifier; 8. Power source; 9. Function generator; 10. Vacuum system controller; 11. Thermocouples, emission analyzer probe, pressure transducers and photodiodes

The experiments are carried out in the thermo-acoustic combustion chamber shown in Figure 1. There are measuring devices around the combustion chamber where a burner with a burner capacity of 10 kW is located to take dynamic and static pressure values. In addition, thermocouples were placed around the combustion chamber to measure the flame temperature arising during the combustion of different fuel mixtures. Combustion air fed by a compressor with 1500 L storage capacity first passes through the mass flow controller that can control the flow up to 300 slm value, and the air meets the pre-mixer. Meanwhile, the gas coming from the tanks firstly passes through the mass flow controllers and after it combines in the fuel collector, the pre-mixer mixes homogeneously with the air. The resulting air-fuel mixture is ignited by entering the burner and the combustion process takes place.

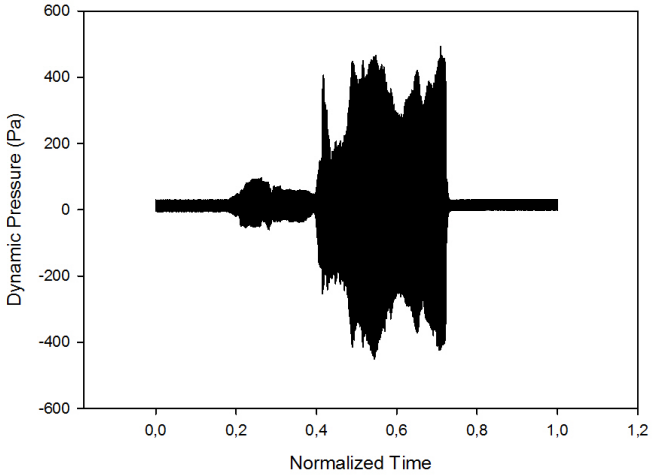
In the acoustic forcing part, which constitutes the original value of the study, two loudspeakers placed in the burner arms work by being fed by a power source and a generator. These speakers force the flame by producing sound waves at different frequencies, and thus the effect of external acoustic forcing on the burning characteristics of the flame can be examined.

3. RESULTS AND DISCUSSION

3.1. Combustion Instabilities

Firstly the biogas mixture was tested without nitrogen dilutions for the purpose of examine the effect of nitrogen addition to the biogas mixture on combustion characteristics. The dynamic pressure fluctuations, light intensity and temperature changes of the tested fuel mixes are recorded and flame instabilities are interpreted. Dynamic pressure swings that occur as a result of the combustion of a biogas mixture containing 60% CH4 / 40% CO2 are shown in Figure 2. When the dynamic pressure fluctuations are examined, it is seen that the flame is extinguished at oscillation amplitude of 944 Pa at 95 Hz, which is the first acoustic resonance value of the system.

Fig 2. Dynamic Pressure Fluctuation of %0 N2 Ratio



After the test without nitrogen dilution, the effect of dilution on flame stability and temperature was investigated by adding 10% and 20% nitrogen, respectively, into the fuel mixture. As a result of the calculation made in such a way that 10% of the total methane, carbon dioxide and nitrogen ratios sent into the combustion chamber are nitrogen, dilution was carried out with nitrogen. When the dynamic pressure fluctuations shown in Figure 3 are examined, an oscillation of 888 Pa amplitude occurred in the combustion chamber during the acoustic forcing at 95 Hz frequency and the flame continued to burn steadily against this oscillation. However, when 175 Hz forcing frequency is reached, dynamic pressure

amplitude of 814 Pa occurred in the combustion chamber and the flame was extinguished. The dynamic pressure graph is shown in Figure 4 for another dilution ratio of 20% nitrogen addition. According to this graph, while the flame was forced at 95 Hz, which is the acoustic resonance value of the system, a dynamic pressure oscillation of 648 Pa amplitude occurred and resisted this oscillation. At the second resonance value of 175 Hz acoustic frequency, 631 Pa amplitude extinction occurred.

Fig 3. Dynamic Pressure Fluctuation of %10 N2 Ratio

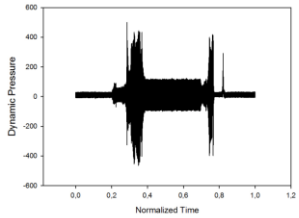
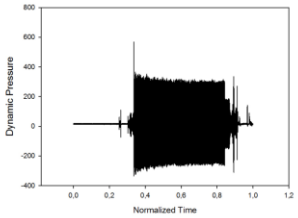


Fig 4. Dynamic Pressure Fluctuation of %20 N2 Ratio



When the dynamic pressure fluctuations of the experiments performed at different nitrogen dilution rates are compared, the following results are obtained. In case of dilution with 10% nitrogen according to the process in which the mixture of CH4 / CO2 burned without dilution, the flame resisted against acoustic enforcement at 95 Hz frequency and continued to burn steadily. Even if the flame was extinguished under 175 Hz acoustic enforcement, it was released with lower dynamic pressure amplitude than the case without dilution. The fact that the flame has been burned while maintaining its stability under force indicates that 10% nitrogen dilution by volume to be applied to the determined biogas mixture increases the stability. The main reason for the increase in stability can be seen as; The only component with calorific value in the selected mixture is methane, and dilution of methane gas with nitrogen is known to reduce the laminar combustion rate. Kozubkova et al. [11] In their study, they increased the rate of nitrogen from 79% in air to 84% by diluting pure methane gas with nitrogen. As a result of the study, while the laminar burning rate calculated according to the GRI30 model was found to be 0.347 m / s in combustion without methane dilution, it decreased to 0.160 m / s as a result of nitrogen dilution. On the other hand, when the dilution rate with nitrogen increased to 20%, the flame resisting 95 Hz, which is the first acoustic resonance value, was extinguished at a lower dynamic pressure amplitude and 175 Hz forcing frequency. This situation shows that there is a small increase in stability when the nitrogen amount is increased to 20%. The reason why the stability increasing rate decreases with the increase in nitrogen amount can be interpreted as follows; Carbon dioxide gas contained in biogas mixtures is a diluent gas with no calorific value. The molar mass of carbon dioxide gas is 44 g/mol and is heavier than any other gas entering the system. Methane, which was diluted with a heavy gas and turned into a biogas mixture under air combustion conditions, was diluted with nitrogen, which a gas that is lighter than carbon dioxide. In this case, although there was a positive effect in terms of stability at small dilution rates, the improving in stability decreased as a result of the decrease in fuel / air ratio with the heighten of dilution.

The change of luminous intensity, which is another criterion in the examination of combustion instabilities, is shown in Figure 5. In the graph without acoustic enforcement situations are taken into account, the luminous intensity of the flame in biogas combustion was measured at 3.2 mV, while the values of 3.61 mV and 3.64 mV were observed at dilution rates with 10% and 20% nitrogen, respectively. This situation shows that the flame brightness increases as a result of dilution with nitrogen similar to dynamic pressure fluctuations. In addition, in the temperature change given in Figure 6, the flame temperatures in the region closest to the burner were compared. In the Biogas combustion, 10% and 20% nitrogen dilution rates, respectively, 907 K °, 1037 K ° and 1040 K ° temperatures were measured. According to the examination of the temperature change, it has been observed that if the burner output is supported by a vortex in a premixed combustion, the flame temperatures increase as a result of dilution of a biogas containing a high proportion of carbon dioxide with nitrogen, a lighter diluent.

Fig 5. Luminous Intensity of Different N2 Ratios

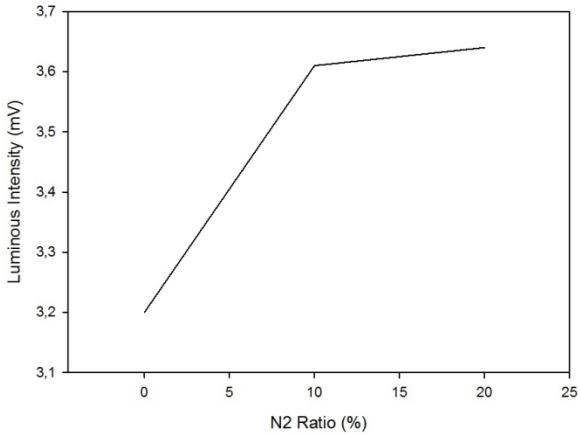


Fig 6. Flame Temperatures of Different N2 Ratios

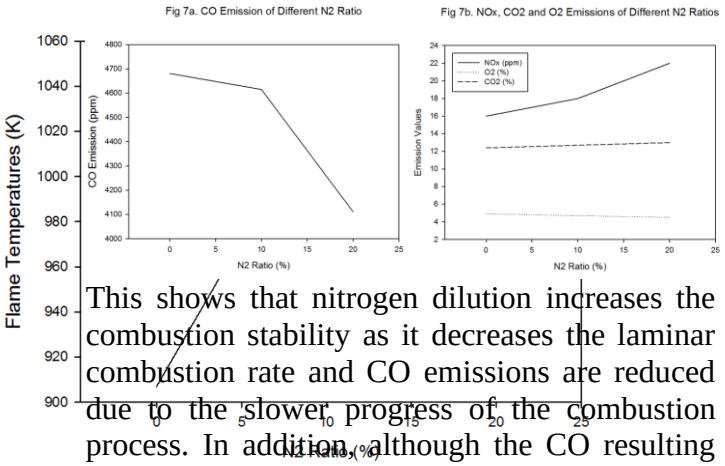


Fig 7a. CO Emission of Different N2 Ratio

Fig 7b. NOx, CO2 and O2 Emissions of Different N2 Ratios

3.2. Emission Measurements

Another important result of the combustion tests is the flue emissions. There are three pollutant emissions arising from the combustion of hydrocarbon-containing fuels. These; They are called CO2, CO and NOx emissions. Since carbon dioxide emission is an end-of-combustion product that carbon atom combines with oxygen, it is expected that carbon dioxide emission will occur naturally as a result of all combustion processes [12]. The reduction of other pollutant emissions is very important in preventing environmental pollution, which is one of the most important problems of today.

Figure 7 shows the emission rates after combustion of the biogas mixture at 0%, 10% and 20% nitrogen ratios, respectively. When the graph is examined, it is observed that NOx formation increases as the rate of nitrogen entering the burner increases. Fuel-NOx, one of the NOx formation mechanisms, can be shown as the reason for the increase [13]. Another pollutant emission, CO, decreases as the dilution rate with nitrogen increases. The CO emission, which was 4681 ppm at 0% nitrogen, decreased slightly during the 10% nitrogen addition and reached 4615 ppm. When the nitrogen ratio was increased to 20%, 4111 ppm was measured. In order to better understand the change in CO emissions, it is necessary to examine the CO2 and O2 emissions. As nitrogen is added according to the CO2 emissions shown in Figure 7, the CO2 emission rates in the flue gas are respectively 4.9%, 4.7% and 4.5%. On the other hand, there is an increase in O2 emissions as follows. O2, which has a ratio of 12.4% in the flue gas in biogas combustion, is 12.7% in 10% nitrogen dilution, while it is 13% when it is increased to 20% nitrogen.

This shows that nitrogen dilution increases the combustion stability as it decreases the laminar combustion rate and CO emissions are reduced due to the slower progress of the combustion process. In addition, although the CO resulting from the incomplete combustion of the carbon atom as a result of the nitrogen addition has decreased, the total combustion product CO2 has decreased. Accordingly, O2 emission has increased. As a result, although nitrogen dilution reduced CO emissions, it delayed the combustion of the fuel by meeting with oxygen and increased the rate of unreacted oxygen and decreased the CO2 rate that must occur in an efficient combustion.

4. CONCLUSION

In this study, the instability and emission behavior of a biogas containing 60% CH4 / 40% CO2 at different N2 dilution rates were investigated. The results of the study are as follows;

- Considering the dynamic pressure fluctuations used in the investigation of combustion instabilities and the resistance of the flame to these fluctuations, nitrogen dilution applied to the biogas mixture had a positive effect in reducing the combustion instabilities.
- When nitrogen dilution is made at the level of 10%, it significantly increases the flame stability due to the decrease in the laminar burning rate, and when the dilution rate is increased to 20%, no great increase in stability has been observed.
- When flue gas emissions are analyzed, nitrogen dilution caused a decrease in CO level and an increase in NOx emissions. In addition, the increase in the dilution rate caused an increase in O2 emissions, which was interpreted as the decrease in combustion efficiency.

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