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Combustion Behaviours of Different Biogases in an Existing Conventional Natural Gas Burner: An Experimental Study

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Abstract- This study discusses the combustion behaviours of biogases including different components in an existing conventional natural gas burner. Temperature and emission values have been experimentally measured and investigated on some axial and radial positions by using thermocouples and a flue gas analyzer throughout the combustion chamber. All experiments have been studied for a thermal power of 10 kW and an equivalance ratio of $\phi = 0.83$. The results show that the maximum temperature value was measured and determined to be 1386 K for the biogas flame containing methane up to 65%. This temperature value is high enough and acceptable when it is compared with the methane flame at the same combustion conditions (1467 K). The temperature values of the other biogases are less than that of this biogas temperature values due to containing amount of methane percentage. It can be concluded that the NO_X levels (under 25 ppm) of the biogases are less than that of the methane flame because of their low flame temperatures. It can also be demonstrated that the presence of CO_2 in the fuels (up to 43 % by volume) leads to a high volume of CO_2 emissions in combustion products.

Keywords Biogas; combustion; emissions; conventional gas burner.

1. Introduction

Fossil fuels are highly used in power generation systems, buildings and elsewhere. However, these fuels cause two problems. Firstly, fossil fuels are limited and are not equally distributed all over the World. Scientists estimate that coal, crude oil and natural gas will be rapidly depleted in the near future. Secondly, fossil fuels are responsible for environmental pollution such as global warming and acid rain. The scientists try to find new or renewable energy resources such as solar energy, wind energy, hydrogen energy, biomass and the others as there are some aforementioned problems.

The growing interest regarding biogas has promoted nowadays. Biogas resources are residuals, effluent, municipal solid waste, especially, gasification of biomass. These renewable energy resources are very appropriate for power generation, heating systems and elsewhere. Biogas consists mostly of methane and carbon dioxide as combustible gases depending on production or gasification methods [1]. Methane in biogas is main component and it indicates quality of biogas. However, the other components are non-combustible.

There are some studies regarding combustions of biogas or blending fuels in the literature. Adouane et al. [2] have experimentally studied reduction of NO_X emissions arising from fuel-bound nitrogen. They reveal that ammonia in the fuel drastically influences NO_X formation. Bhoi and Channiwala [3] have experimentally investigated emission characteristics and axial flame temperature distributions of producer gas including high amount of nitrogen by varying thermal inputs and equivalance ratios. The results show that the maximum temperature emerges in flame front for this gas. Hosseini et al. [4] have performed combustion characteristics of biogas under flameless combustion conditions. Hosseini et al. estimate that biogas is not appropriate for any furnaces due to its low calorific value (LCV). Huynh and Kong [5] determines NOx emissions coming from syngas combustion obtained three different biomass feedstock under different conditions. It can be concluded that highest NOx levels form under syngas combustion obtained seed corn as the seed corn has the highest nitrogen content. Leung and Wierzba [6] investigated the effect of hydrogen addition on stability limits of non-premixed biogas flames. It is demonstrated that hydrogen addition on the enhancement of biogas highly affects. İlbaş and Karyeyen [7] modelled the coal gases including high amount of hydrogen or nitrogen depending on gasification or carbonization methods. They reveal that the coke oven gas is very suitable in combustion systems in terms of combustion performances (e.g. temperature values). Sethuraman et al. [8] focuses on the effects of nitrogen content in biomass feedstock on the producer gas composition and NOx emissions in their study. They have found that there are relationships between nitrogen in biomass, ammonia in the producer gas, and NOx emissions in the flue gas. Somehsaraei et al. [9] examined the fuel flexibility and performance analysis of biogas in micro gas turbines. When minor modifications to fuel valves and compressor were taken place, They claim that these modifications are assumed to allow engine operation with the simulated biogas composition. Chen and Zheng [10] predicted hydrogen-enriched biogas MILD oxy-fuel conditions. It has been found that biogas flame can be sustained under the MILD oxy-fuel combustion. Nikpey et al. [11] investigated the combustion performance and emissions of biogas and natural gas in a micro gas turbine. The results indicate that there is almost no change in electrical efficiency comparing with the natural gas fired case. Selim et al. [12] studied effect of CO_2 and N_2 concentration during H_2S combustion. Hosseini and Wahid [13] have studied combustion characteristics of biogas under hydrogen-enriched combustion conditions. The results show that NO_X formation increases as the flame temperature increases. Lafay et al. [14] have compared stability combustion domains, flame structures and Dynamics between methane and biogas flames. They reveal that laminar flame speed strongly depends on fuel composition. Jahangirian et al. [15] examined chemical and thermal influences of biogas CO_2 content. They demonstrate that the presence of CO_2 in the fuel affects NO_X emissions considerably (reducing). Hosseini and Wahid [16] have modelled biogas under flameless combustion conditions by means of a tangential burner. The results indicate that the temperature uniformity in the tangential flameless burner is more than coaxial configurations. İlbaş and Karyeyen [17], for example, studied combustion behaviours of low calorific value coal gases by enriching hydrogen in order to improve their combustion characteristics. They conclude that hydrogen addition highly affects the flame temperature of the low calorific value coal gases. İlbaş and Karyeyen, in their another study, modelled the effect of the swirl number on combustion characteristics of the hydrogen-containing fuels [18]. The results indicate that the flame zone moves to the downstream of the burner as the swirl number is increased.

Although there are some aforementioned studies related to biogas or blending fuels combustion, there needs to be extremely studied combustion characteristics of biogas. In particular, the scientists need to investigate combustion characteristics of biogases experimentally as there is very limited experimental investigation of biogas combustion. For this reason, this study focuses on combustion performances and emission characteristics of biogases including different gas components by means of the existing natural gas burner under thermal power of 10 kW and excess air ratio of 1.2.

2. Experimental System

2.1. Description of the Existing Manufactured Natural Gas Burner

The existing natural gas burner used in this study is clearly illustrated in Fig. 1 and the manufactured version of this burner is depicted in Fig. 2. This burner is a diffusion flame burner and air and fuel streams are coaxial in it. There are two different types of air inlets to the combustor in the burner. The first air inlets have 15° angles to provide flame stabilization via tangential velocity while the second air inlets are comprised of annular inlets. There are 10 and 8 inlets for 15° angle air outlet and annular inlets on the burner, respectively. The fuel inlets (4 inlets) are designed to be a radial inlet to the combustor in order to achieve a better fuel/air mixture.

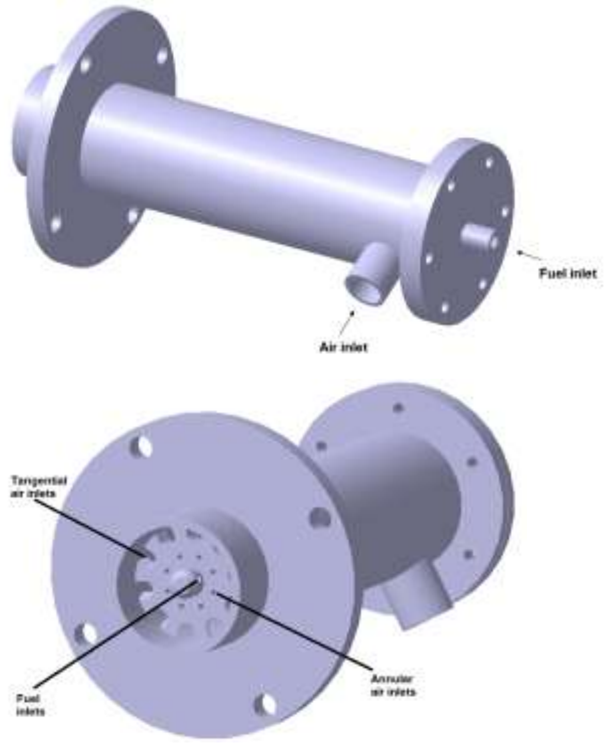

Fig. 1. The casing (top) and the outlet (bottom) of the burner

Fig. 2. The photograph of the existing natural gas burner

2.2. Layout of Experimental Rig and Description of Combustion Chamber

The schematic view of the combustion system coupled with the existing natural gas burner is illustrated in Fig. 3. The existing natural gas burner has been mounted to the combustion chamber with a flange connection from the bottom of the combustion chamber as depicted in Fig. 3. High pressure fuel cylinders, which were prepared in desired percentages of biogases as indicated in Table 1, have been integrated in order to supply the methane as baseline fuel and biogases to the system. This system is also composed of two gas lines including the fuel line and air line. These lines consist of regulators, manometers, selenoid valves and float type flowmeters. The regulators have been placed on the system to regulate gas and air pressures. Gas and air pressures have also been periodically tracked in the lines by means of the manometers in order to control fuel and air pressures during experiments. Selenoid valves have been integrated into the system to prevent gas flows when the flame at the burner front is absent. There is an air compressor to supply pressurized air in this system. Moreover, this combustion system incorporates float type flowmeters in all lines in order to achieve the desired fuel and air flow rates. Finally, this combustion system has also been equipped with a pilot ignition device (LPG: auxiliary fuel) and line to initiate first ignition because the syngases may not be auto-ignited due to their low calorific values. However, the pilot ignition device was not used during the experiments. Initial ignition of the biogases could be taken place at beginning of the experiments for each biogases.

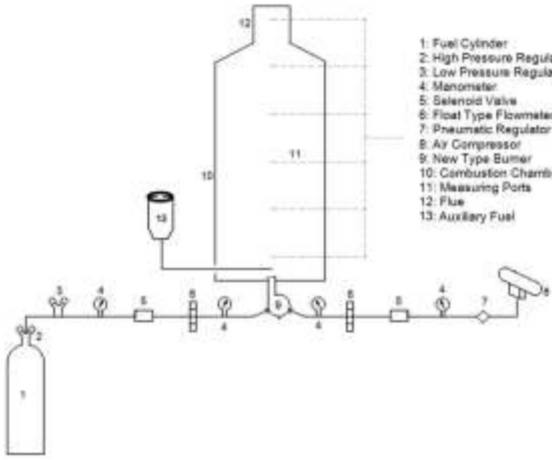

Fig. 3. The layout of the combustion system

A general view of the combustion chamber is shown in Fig. 4. The length and diameter of the combustion chamber are fixed at 100 cm and 40 cm, respectively. The combustion chamber consists of a sight glass made of tempered glass, six measuring ports and a flue. Five measuring ports are placed on the combustor wall to measure temperatures and emissions on some axial and radial positions within the combustor. The other measuring port is also located on the flue in order to determine the flue gas temperature and emissions. The first measuring port is designed to determine the flame characteristics of the biogases and location of this measuring port is 10 cm away from the combustor inlet. The other four measuring ports are placed at intervals of 20 cm from the first measuring port to the combustion chamber outlet.

Fig. 4. The combustion chamber

Ceramic coated R-type thermocouples capable of withstanding high temperatures up to 1700°C were used to measure temperature values through the combustion chamber. The diameters of these thermocouples are 5 mm. Emission values have been also been measured through the axial distance and from the flue by a flue gas analyzer.

2.3. Main Components of Biogases and Operating Conditions

Components of biogases consumed in this study and methane as baseline fuel are given in Table 1. These biogases are defined as phases 1, 2, 3 and 4 depending on contents in the present study. All experiments were performed under thermal power of 10 kW and an equivalance ratio of ϕ = 0.83 depending on the heating values of the biogases. Combustion gauge pressures of the biogases and air are fixed at 21 mbar.

Table 1. Biogas components

	Methane	*Phase 1 (%)*	*Phase 2 (%)*	*Phase 3 (%)*	*Phase 4 (%)*
CH_4	*100*	*55*	*60*	*65*	*55*
CO_2	-	*43,1*	*38*	*33*	*43,1*
N_2	-	*1,53*	*1,5*	*1,3*	*1,53*
H_2S	-	*10 ppm*	*0 ppm*	*0 ppm*	*0 ppm*
O_2	-	*0,3*	*0,5*	*0,7*	*0,37*
Calorific value (kcal/m^3)	*8040,00*	*4422,06*	*4824,00*	*5226,00*	*4422,00*

3. Results and Discussions

The existing natural gas burner integrated with the combustor has been used in order to determine the combustion performances and emission characteristics of the biogases. The flames of biogases were observed during the experiments by means of the sight glass (approximately 45 minutes for each experiments). Although any serious problem such as flame lift off or blow-off were not observed during the experiments, small partial flame stabilization problem was observed as amount of CO_2 in biogas was increased (in particular, phase 1 and 4). However, it may be consequently said that these biogases are properly consumed during the experiments.

Temperature and emission values have been measured on some axial and radial positions in the combustor by means of measuring ports on the combustor wall. At high temperatures, the radiation correction is necessary the temperature levels precisely. In particular, radiative heat transfer takes places from the flame to the combustor wall. Mean bulk velocities were calculated theoretically in the flame front taking into account fuel and air velocities. Then, it is computed to be between 2–60 K depending on the gas and wall temperatures in this study.

3.1. Temperature Measurements

Corrected axial temperature measurements of the methane (reported by İlbaş and Karyeyen [19]) and biogases are shown in Figure 5. The maximum flame temperature (1467 K) emerges during the methane combustion due to its calorific value. However, the flame temperatures of the biogases are sufficient when they are compared to that of methane. The maximum flame temperatures of the biogases (Phase 1, Phase 2, Phase 3 and Phase 4) have been measured and corrected to be 1324 K, 1352 K, 1386 K and 1313 K. It can be easily concluded that the flame temperature of any biogas as decreases CO_2 in biogases is increased. Temperature measurements decrease gradually towards the combustor outlet because of convective and in particular, radiative heat transfers. In addition to axial measurements, Figure 6 shows the corrected radial temperatures of the methane and biogases. When all measurements of the biogases are compared to that of methane and each other, temperature levels of all fuels are very closer through the combustor. Therefore, it may be said that biogases replace the natural gas in any combustors by virtue of these results without any modification of the natural gas burner.

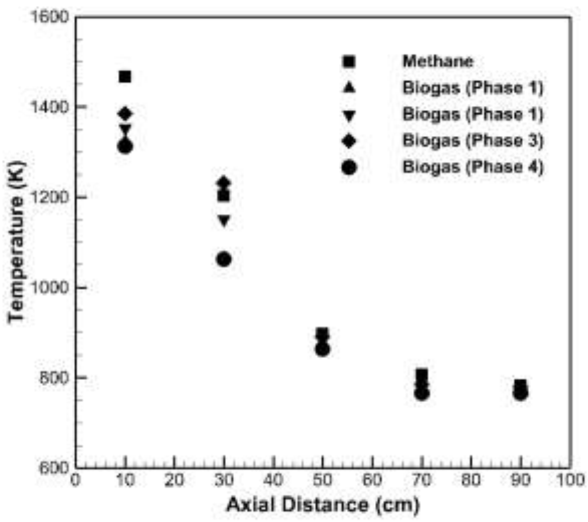

Fig. 5. Axial temperature measurements of methane and biogases

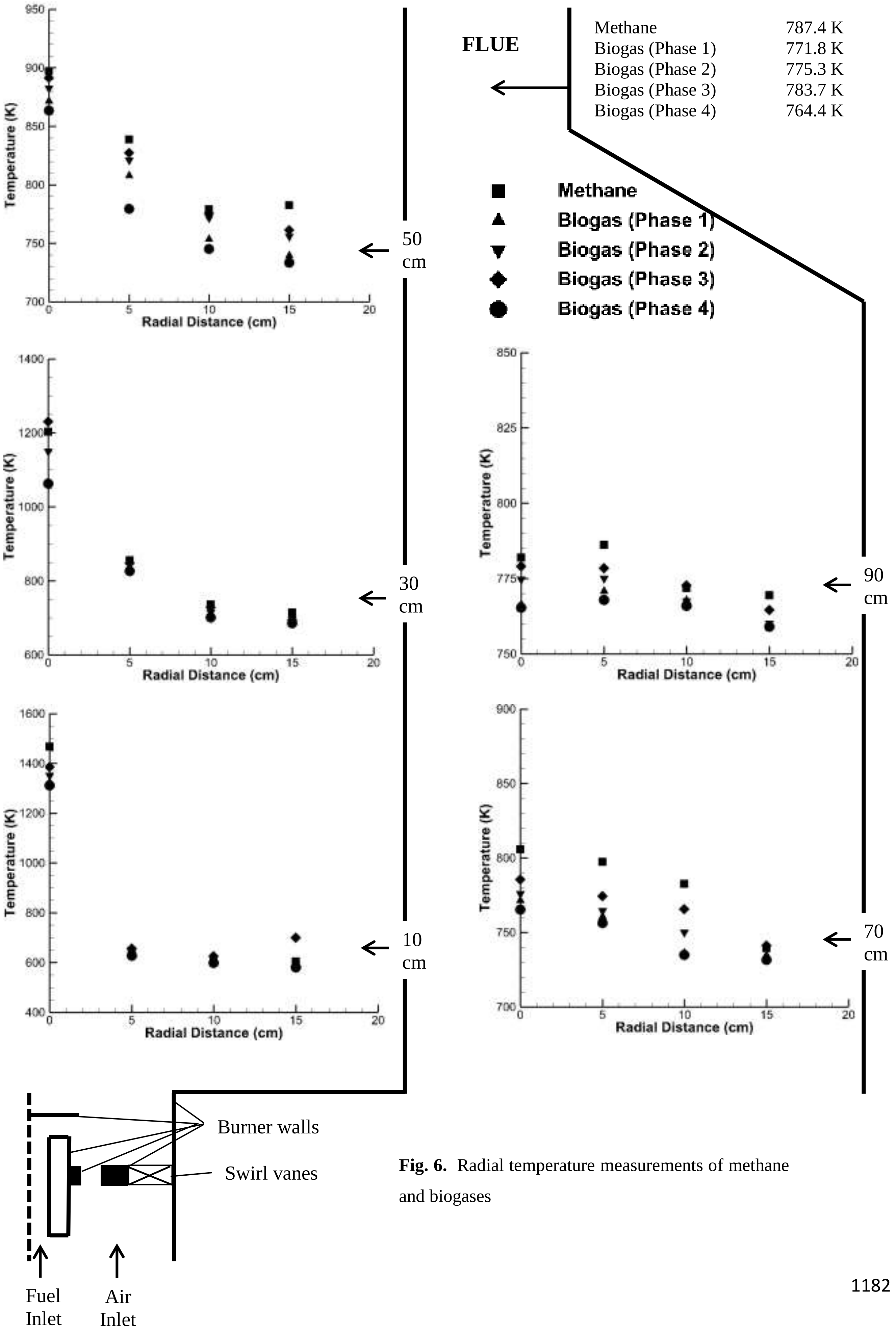

Fig. 6. Radial temperature measurements of methane and biogases

3.2. Emission Measurements

Figure 7 shows the radial NO_X measurements of the methane (reported by İlbaş and Karyeyen [20]) and the biogases through the combustor. According to the reported result, the maximum NO_X formation shows up under methane combustion conditions as 46 ppm as expected. The other NO_X levels for the biogases have been measured to be 16 ppm, 24 ppm, 15 ppm and 10 ppm in the flame front within this study, respectively. This is because of the effect of the thermal NO_X mechanism. Although the temperature measurements of the methane and the biogases are very closer as can be seen in Figure 5 and 6, NO_X levels of the biogases are quite low in comparison to that of methane. As a matter of fact, NO_X levels of the biogases are nearly under 10 ppm at the outlet of the combustor excluding biogas (Phase 3). Because the scientists try to find new and low emissions energy resources, it can be consequently that the biogases may be used as alternative fuel in combustors in terms of NO_X emissions.

CO_2 measurements of the methane (reported by [20]) and the biogases are given in Figure 8. The maximum CO_2 formations take place in the flame front. In addition to combustion-source CO_2 formation, a sum of CO_2 arises from the biogases due to CO_2 in the biogases. The authors think that combustion is nearly completed in flame region. CO_2 measurements on radial positions at 10 cm axial distance are relatively low due to sudden expansion type combustor. However, CO_2 levels increase relatively towards the combustor outlet. The maximum CO_2 levels (forming and arising from the biogas) emerge during combustions of biogas (Phase 1) and biogas (Phase 4) due to including high amount of CO_2. Moreover, the minimum CO_2 formation occurs under methane combustion. For these findings, it can be concluded that CO_2 in biogas is more dominant CO_2 formation during combustion.

CO measurements as an incomplete combustion product are shown in Figure 9. When the CO measurements are evaluated for all biogases, the maximum CO formation emerges during biogas (Phase 3) combustion through the combustor. The authors estimate that non-combustible matters in biogas cause incomplete combustion of methane in biogas. It is also seen that the CO levels decrease as the amount of CH_4 in biogases is decreased. In addition to these findings, CO measurement levels decrease gradually for all biogases towards the combustor outlet due to nearly complete combustion and CO values of the biogases have been measured to be 207 ppm, 60 ppm, 702 ppm and 195 ppm at the combustor outlet. If these results are compared with that of methane, it may be said that the existing natural gas burner needs some modifications on it. Nevertheless, it is demonstrated that the existing natural gas burner is appropriate for usage of biogases when these CO levels are taken into account.

Another important emission measurement is SO_2. This is emerged from H_2S content in biogas (Phase 1). SO_2 emissions have been measured to be 25 ppm and 8 ppm at 10 cm and 30 cm axial distances on the flame center from the downstream of the natural gas burner. This emission could not been obtained on other axial and radial positions due to its very low value.

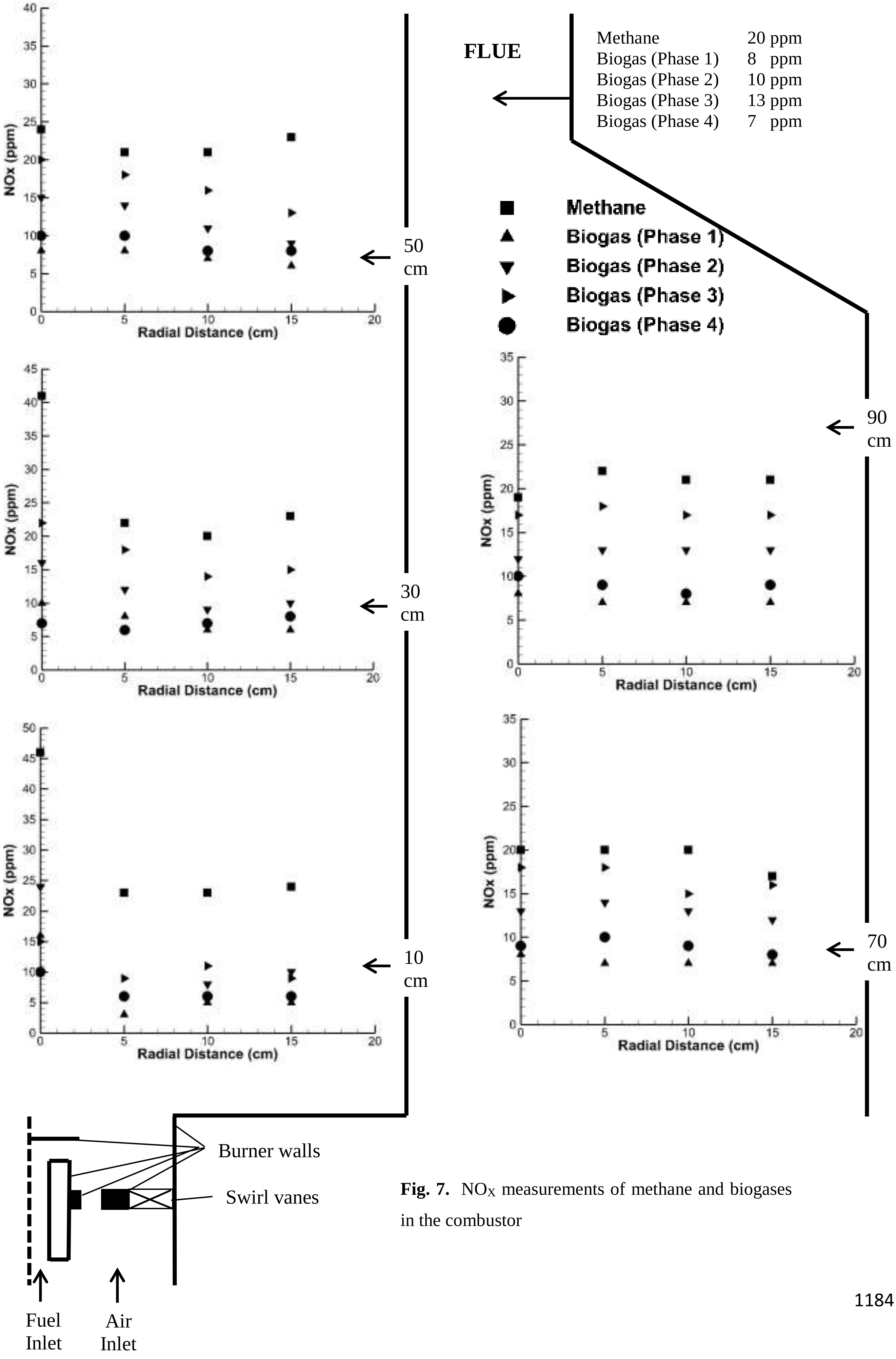

Fig. 7. NO_X measurements of methane and biogases in the combustor

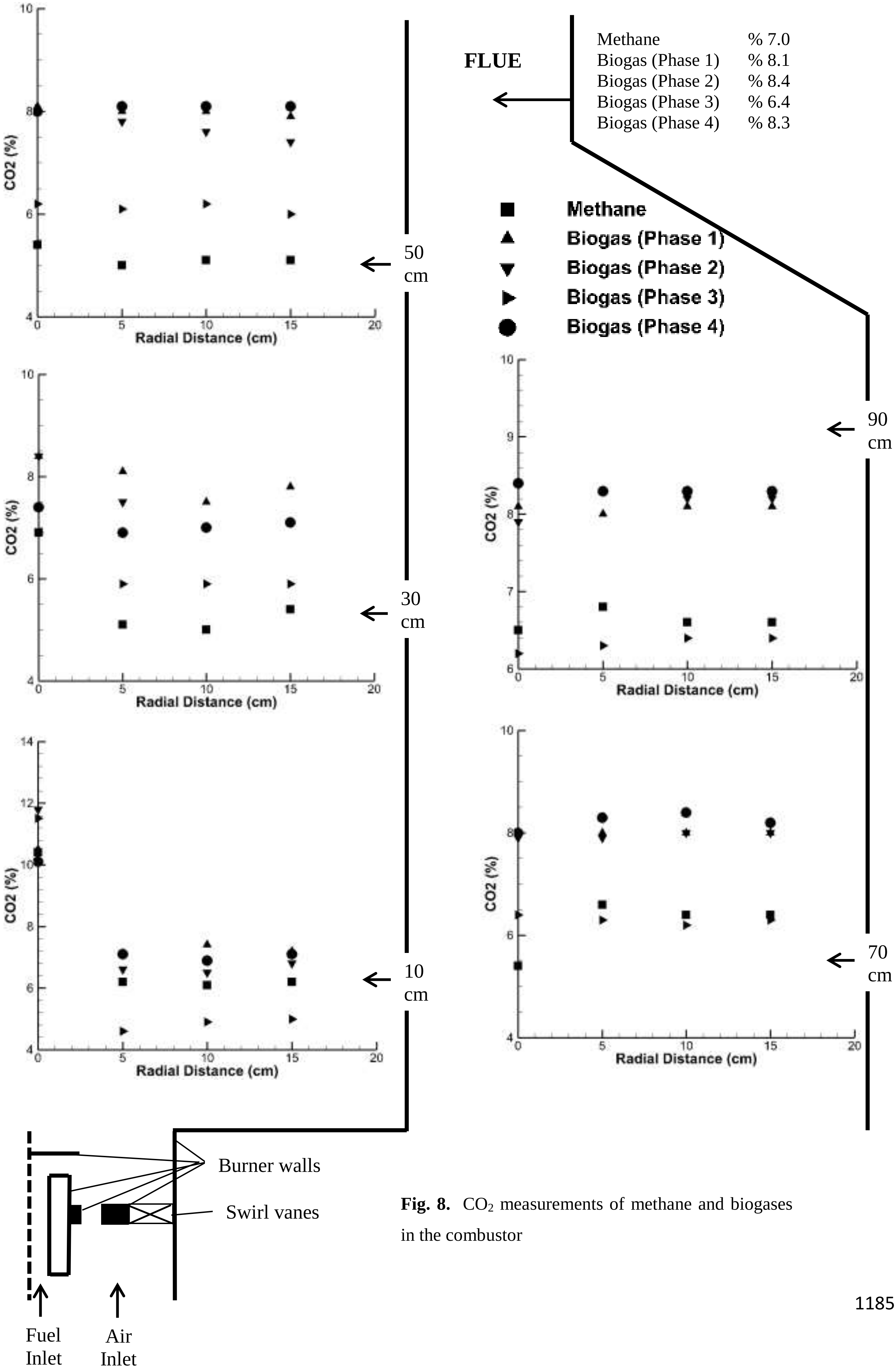

Fig. 8. CO_2 measurements of methane and biogases in the combustor

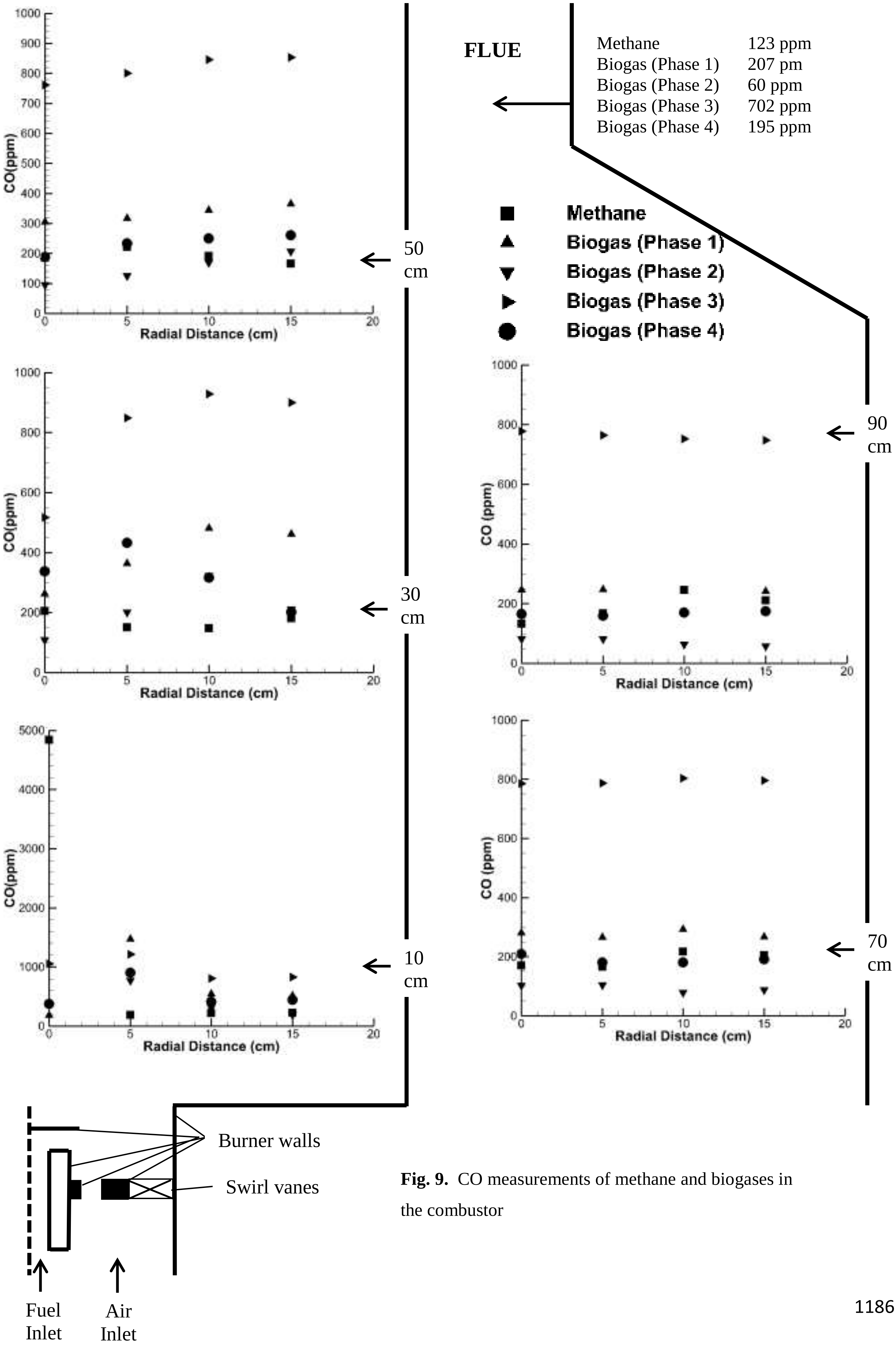

Fig. 9. CO measurements of methane and biogases in the combustor

4. Conclusions

An experimental study has been conducted to investigate the combustion behaviours of biogases including different components in the existing natural gas burner. The experimental results lead us to the following conclusions:

- Temperature levels of the biogases are very close to that of methane in the existing natural gas burner. Because of that, it can be concluded that the biogases may be used as alternative fuels in natural gas burners without any modifications.

- NO_X emission levels of the biogases are less than that of methane through the combustor and at the combustor outlet. According to these measurements, it can be easily said that these biogases are very appropriate in natural gas burners in terms of NO_X emissions.

- CO_2 emission levels of the biogas combustions have been measured higher in comparison to that of methane throughout the combustor and at the outlet. It is revealed that biogases may not be appropriate as CO_2 in biogas contributes to the CO_2 levels as well as CO_2 arising from combustion.

- CO emissions for some biogases have been measured higher when they are compared with that of methane. It can be consequently demonstrated that some biogases may not be convenient in terms of CO emissions.

- According to above findings, it may be declared that biogases may be used in natural gas burners without making any significant modifications.

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