The influence of biogas composition upon the atmospheric combustion

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Abstract: The paper presents simulation of the atmospheric combustion of biogas. The biogas can be used in closed cycle gas turbine systems. The simulation, performed in ANSYS numerical codes, considered the following assumptions: air pre-heating above 800 K; CH$_4$ concentration between 50% - 80%; different air primary, secondary and dilution ratios. The simulation returned results regarding: the combustion temperature field, the flame OH concentration field, the exhaust gases composition fields, the gases velocity field, the gases pressure field. The simulation showed the influence of the air pre-heating temperature upon the atmospheric combustion spatial features.

1. Introduction
During last years the restrictions regarding pollution and emissions are increased and also, the level of fossil fuel is decreasing, thus a large interest appeared, regarding the closed cycle solar hybrid gas turbines, for energy generation. The idea of these power plants is to produce electrical energy at a lower price, and to supply a constant quantity of energy, even with the intermittent nature of solar radiation. For this, it is used a combustion system as a back-up for solar energy, and for start-up operations, [1]. More articles related on this subject shows that the contribution of fossil fuel over a year is less than 15%, [2]. The composition of natural gas varies from gas field to gas field. Some criteria regarding this variation are related to the nature and source. Also, another fuel suitable to be used in the closed cycle hybrid solar gas turbines is the biogas, and the bio-syngas. Biogas is produced by the anaerobic fermentation of biodegradable materials such as biomass, agriculture crop, vegetal waste, etc. Despite the possibility of biogas production, it is not widely used in this domain because of the complex chemical composition, and the variation of this. Also this is the reason for unpredictable combustion characteristics, [3, 4].

Biogas consists mainly of methane and CO$_2$ as well as some small constituents like N$_2$ and H$_2$, where the percentage of these can vary significantly depending on the procedure of gasification or production, [5].

At this moment, there are some studies regarding the biogas combustion process. In their work, Adouane et al. [6] have done some studies regarding the reduction of NO$_x$ emissions. The result was that ammonia added to the fuel will affect NO$_x$ formation. Mordaunt and Pierce [7] have designed a combustion device and investigated the effects of CO$_2$ on combustion of CH$_4$ and the emissions resulted. Chen and Zheng [8] have predicted hydrogen-enriched biogas MILD oxy-fuel conditions. They found that biogas flame can be sustained under the MILD oxy-fuel combustion. In the research
of Nikpey et. al. [9] the results indicates that there is almost no change in electrical efficiency compared to the natural gas power plant.

Related to other studies, when the combustion temperature exceeds 1800K, the NO can decrease by half, which is inversely proportional to CO emissions [7]. So, based on the flame temperature, can identify thermal efficiency, and also CO and NOx.

2. Design of combustion chamber
The idea of this work, is to analyze the influence of the air preheat temperature upon the combustion of biogas. A combustion chamber was designed for this purpose. The simulations will be carried using Ansys Fluent software. The combustion chamber is a part of a demonstrator which will be built to recreate the simulation input data to compare the results. Some features of the demonstrator include the adjustment of excess air, adjustment of primary air-secondary air ratio, and adjustment of preheat air temperature.

The system includes a mass spectrometer, and an PLIF. In this case, the combustion chamber is cylindrical, disposed horizontal. It has 12 radial holes, to permit the secondary air to enter in the combustion process, and the cool the combustion chamber wall.

![Combustor assembly.](image1)

To simulate the biogas combustion process, in Ansys is recreated the fluid area inside the combustion chamber, and then are defined the areas for fuel inlet, primary air inlet, secondary air inlet, and exhaust. The fuel inlet, primary air and secondary air are defined as mass flow inlet, using a constant flow, that allows the total pressure to vary in consistent to the reactions inside the combustion chamber. For the air inlet faces, there is utilized mass fraction 0, and the flow direction is set to normal to boundary.

![Outlet boundary.](image2)

![Inlet boundary.](image3)
Turbulence intensity is set to 5%. Outlet area is defined using pressure outlet condition. For this, must be specified a value for the static pressure in the exhaust area. The value is relative to the operational pressure, and is set to 0.

The mesh contains 1,600,000 elements with 294,000 nodes, in consistent to other simulations analyzed.

3. Results
Simulations carried on ANSYS covers a variety of parameters, like CO₂ concentration, air preheat temperature, primary air - secondary air ratio. In this paper are represented the results for 3 values of air preheat temperature: 300K, 500K and 700K, primary air - secondary air 0.2, excess air factor 1.15, and CO₂ concentration 20%, 35%, 50% as most concluding results.

3.1. Preheat air temperature 300K, CO₂ concentration 20%
In the following figures, are represented mass fractions for some chemical species like: CO₂, CO, NO, O, OH, and also the temperature field.
3.2. Preheat air temperature 500K, CO₂ concentration 20%
In next figures, are represented the results for preheat air temperature 500K, and CO₂ concentration of 20%.
3.3. Preheat air temperature 700K, CO₂ concentration 20%
In this case, the OH mass fraction have the lowest value, for concentration 20% CO₂ concentration 20%. Temperature field and other chemical species have similar values as for air preheat temperature 300K and 500K
Figure 20. CO mass fraction.

Figure 21. NO Mass fraction.

Figure 22. O mass fraction.

Figure 23. OH mass fraction.

3.4. Preheat air temperature 300K, CO$_2$ concentration 35%

In the next figures, are represented mass fractions for some chemical species like: CO$_2$, CO, NO, O, OH, and also the temperature field. In this case, O and OH mass fraction have lower values compared to the air preheat temperature 300K and CO$_2$ concentration 35%.

Figure 24. Temperature field.

Figure 25. CO$_2$ Mass fraction.
3.5. Preheat air temperature 500K, CO\textsubscript{2} concentration 35%  
In this case, O and OH mass fraction have lower values compared to the air preheat temperature 500K and CO\textsubscript{2} concentration 35%.
3.6. Preheat air temperature 700K, CO₂ concentration 35%
In this case, mass fraction values are similar as in the case of preheat air temperature 700K, and CO₂ concentration 20%.
3.7. Preheat air temperature 300K, CO$_2$ concentration 50%
Values for CO, NO, and O mass fractions are lower compared to same preheat air temperature and 35% CO$_2$ concentration.
3.8. Preheat air temperature 500K, CO\textsubscript{2} concentration 50%
In this case, CO mass fraction are more concentrated in the fuel injection area, OH and O mass fraction are lower compared to same preheat air temperature and CO\textsubscript{2} concentration 35% and 20%.
3.9. Preheat air temperature 700K, $CO_2$ concentration 50%
In this case, values for mass fraction for CO, NO, O and OH are maximum compared to other cases previous analyzed.

Figure 50. $CO_2$ Mass fraction.

Figure 51. NO mass fraction.

Figure 52. O mass fraction.

Figure 53. OH mass fraction.

Figure 54. Temperature field.

Figure 55. $CO_2$ mass fraction.
4. Conclusions
After all, conducted simulations, the results show the lowest value of NO mass fraction and CO mass fraction at a value of preheated air at 500K, and a CO₂ concentration of 20%. For NO mass fraction, a lower value is obtained again in the case of preheat air at 700K, and a CO₂ concentration of 50%. Also, at the lower concentration of CO₂, the combustion temperature is lower. It is noticeable that mass fractions for CO, CO₂, OH, O are increasingly proportional to the air-fuel ratio. These simulations will be recreated in the combustion demonstrator, in order to verify the accuracy of the results.

In this article are presented only some results with higher impact, in the background of this work, there are completed simulations for a variety of air preheat temperatures, from 300 K up to 1100 K. In conclusion, after all these simulations, there are some issues to be mentioned like:
- for air-fuel ratio 4 and 5, the high temperature area and the flame path, are more concentrated to the area of fuel injection;
- related to the primary air/secondary air ratio, it is noticeable a lower temperature near the combustion chamber wall, for the value 0.4;
- for same value of primary air/secondary air ratio, mass fraction CO is more concentrated in the burning area, for all temperature domains, and mass fraction NO have lowest values;
- as preheat temperature is increased, the values for O and OH mass fraction are higher.

As in other researches, the mass fraction NO have lower values for a preheating temperature lower than 600 K, after this value, the mass fraction NO have higher values.
Considering the results, the primary/secondary air ratio in value of 0.2 is optimal because ensures \( \lambda = 1.05 \) in the burning area, which is in character with other researches in this domain.

5. References

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