Report on the Short Term Scientific Mission (STSM) carried out

in the frame of the COST Action CM 1404

Scientific Report

Investigation on biogas chemistry for a possible use in semi-industrial burners

Dr. Zafer KAHRAMAN*

*Öztiryakiler Madeni Eşya San. Ve Tic. A.Ş – R&D and Technology Center, İstanbul/Turkey

Grant Period: *9th of July 2018 - 13th of July 2018*

STSM Reference Number: CM1404 - 41725

Host Institution: Chemical Process and Energy Resources Institute (CPERI) of CERTH

Home Institution: Öztiryakiler Madeni Eşya San. Ve Tic. A.Ş – R&D and Technology Center, İstanbul/Turkey

Host Supervisor: Dr. George SKEVIS, gskevis@cperi.certh.gr

1. Purpose of the STSM

The aim of this Short Term Scientific Mission (STSM) was to establish contact with the CERTH/CPERI, as well as to obtain new references on past and present research needed to further develop the theoretical and conceptual tools used in "**Investigation on biogas chemistry for a possible use in semi-industrial burners**". Furthermore, as I am doing research in biogas for commercial use (experimental and modeling approach) at home Company (ÖZTİRYAKİLER), visiting CERTH/CPERI provided me with the opportunity to network with CERTH/CPERI research team, under supervisor of Dr. George SKEVIS, as well as expose, compare, and evaluate my work in relation to current relevant work being undertaken on the same research field.

The International Energy Agency (IEA) and the World Energy Council estimates that the global energy demand will grow within the next decades. The continuously increasing energy demand, contributes to development of new technologies for utilization of renewable energy resources. Biofuels are also called as clean renewable energy. An increasing number of biofuels are being used in semi-industrial burners as one of the alternative energies. Generally, the purpose of the STSM is to investigate special semi-industrial burners designed especially for biogas and effective combustion process and knowledge in its chemistry. Another aim is presenting research activities of (ÖZTİRYAKİLER and CERTH/CPERI) in order to establish possible collaboration research work inside the SMARTCATs Cost Action.

2. Description of the work carried out during the STSM

a) Theoretical contextualisation of the international and European research

Updating the theoretical framework of the research task, collecting newest results from CERTH/CPERI research team which are published in sci journals

b) Research contextualisation in the host (CERTH/CPERI) research team

The CERTH/CPERI research team, George SKEVIS, developed an experimental setup and a model for a biogas semi-industrial burner. Dr. George gave me an opportunity to extend my research about biogas combustion modelling, by exchanging experience, knowledge and by sharing methodologies and results. In particular, I was able to learn about the analysis and explanations they found in their researches in order to improve my interpretation of the results. The discussion and comparison was undertaken considering theoretical and experimental aspects relating to biogas usage in semi-industrial burners.

3. Description of the main results obtained:

The European Union's (EU) Renewable Energy Directive [1] sets a binding target of 20% final energy consumption from renewable sources by 2020. The International Energy Agency (IEA) estimates that the global energy demand is likely to increase with 37 % by 2040 [2]. The biogas combustion process plays a great role in an industrial kitchen burner design and its performance. The biogas combustion is much more complex than the natural gas and LPG combustion due to the structure of the fuel which is a mixture of methane and carbon dioxide. There aren't systematic and comprehensive studies to investigate biogas combustion systems for cooking burner at the industrial kitchens. In this study, various biogas compositions and burner hole diameters were investigated with detailed chemistry. As a result of numerical simulations and experimental observations, the best optimum configuration was chosen for applying in semi-industrial burners.

There are several studies on biogas chemistry. Some of them are related to its detailed chemistry and calculations while others focused more on the designs to improve the devices such as semi industrial burners that utilize as a fuel in an efficient way.

The adiabatic laminar burning velocity of methane diluted with carbon dioxide, the two main components of biogas, is investigated both experimentally and numerically. The burning velocity of five mixtures with different CO_2 content (up to 50% in fuel volume) were measured using the heat flux method at atmospheric conditions. The experimental results were compared to data and correlations form literature and also to predictions from four detailed kinetic mechanisms. Results showed that CO_2 dilution reduces the burning velocity and shifts the maximum burning velocity towards leaner mixtures. The numerical model is further explored to show that the shifting of the maximum burning velocity towards leaner mixtures is determined by a combination of CO_2 dilution and reaction effects [3].

Numerical modelling and simulation provide a means to understand the combustion of these renewable fuels, and more importantly, to assist the development of guidelines for their use in practical combustion systems. The study has investigated the effects of fuel composition on biogas combustion, in a laminar one-dimensional premixed flame. These results provide a basis for future development of flamelet generated manifold for turbulent combustion of biogas mixtures [4].

Although, the brief review above reveals that while there are many studies for biogas burners in the literature, the studies about the effect of many parameters all together in a single study on emissions and efficiency appear to be inadequate. Therefore, current study provides a detailed results and discussion on biogas chemistry for possible usage in energy production. In this study, biogas chemistry is investigated numerically by using commercial codes. As a result of experimental observations, an optimum chemical configuration will be chosen for local level energy production.

MODELING

In the numerical simulations, governing equations below are solved :

- Conservation of Mass:

$$\frac{\partial \rho}{\partial t} + \nabla * (\rho \vec{v}) = 0 \tag{1}$$

- Conservation of Momentum:

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla * (\rho \vec{v}\vec{v}) = -\nabla p + \nabla * (\bar{\bar{\tau}}) + \rho \vec{g} + \vec{F} \tag{2}$$

- Energy Equation:

$$\frac{\partial}{\partial t}(\rho e) - \nabla * (\rho e \vec{v}) = \frac{\partial p}{\partial t} + \nabla * (k \nabla T) + S_e + S_{rad} \tag{3}$$

Species continuity equation, given below, is used to calculate the mass fractions of species in a reacting flow:

$$\frac{\partial}{\partial t}(\rho_i) + \nabla * [\rho_i(\vec{v} + \vec{u}_i)] = \dot{\omega}_i \qquad i = 1, 2, 3, \ldots \ldots \ldots . n \tag{4}$$

where ρ_i symbolizes the density of each specie, $\vec{v}$ represents the velocity vector, $\vec{u}_i$ is the diffusion velocity of each specie, $\dot{\omega}_i$ is the production rate of each specie related to the chemical reactions.

RESULTS AND DISCUSSION

Figure 1 shows the calculated average temperatures with different fuel compositions and changing parameters of diameters and inlet pressures. All cases of propane solutions appear to be above the safety limit. Natural gas cases indicate that the burner can operate only at low pressures regions while biogas solutions with 75% methane have acceptable temperature values in all regions. Results of 65% methane cases of biogas indicate that only at higher pressure with higher diameters could be the optimal operating conditions while 50% CH_4 of biogas are below the optimal temperature range.

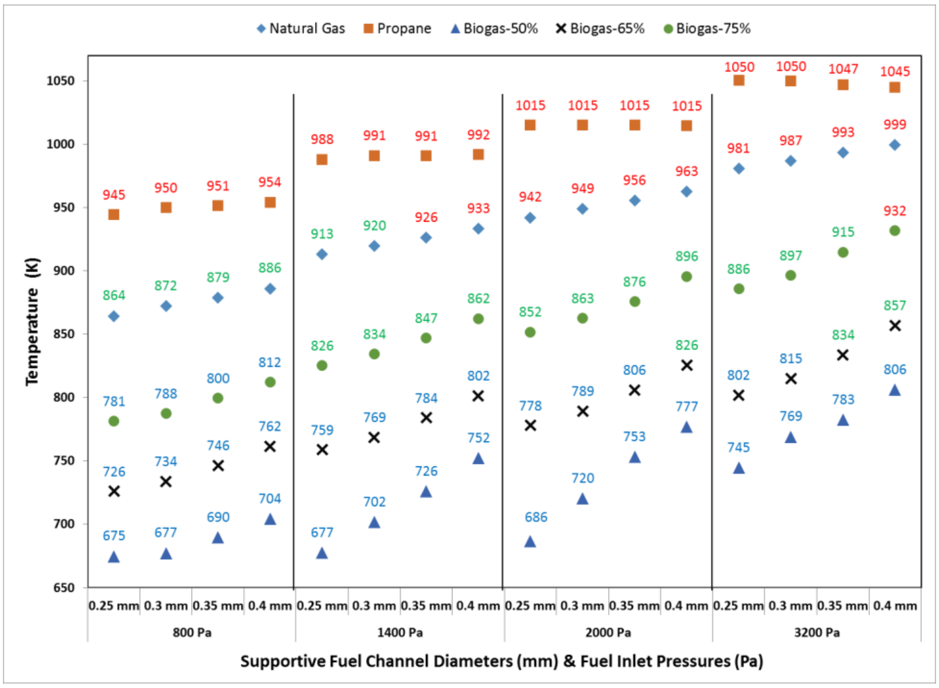

Fig. 1. Temperature variations obtained from a semi-industrial burner with several pressure inlets and diameters.

Unburnt HC emission levels of propane are increasing significantly with the increase of fuel channel diameters and fuel inlet pressure as seen in figure 2. Results showed that considerable amount of unburnt propane is escaping from the outlet surface. From the CO emission results, propane has the highest values and the natural gas is the second. CO emissions level is lower in biogas mixtures than propane for all three biogas blends.

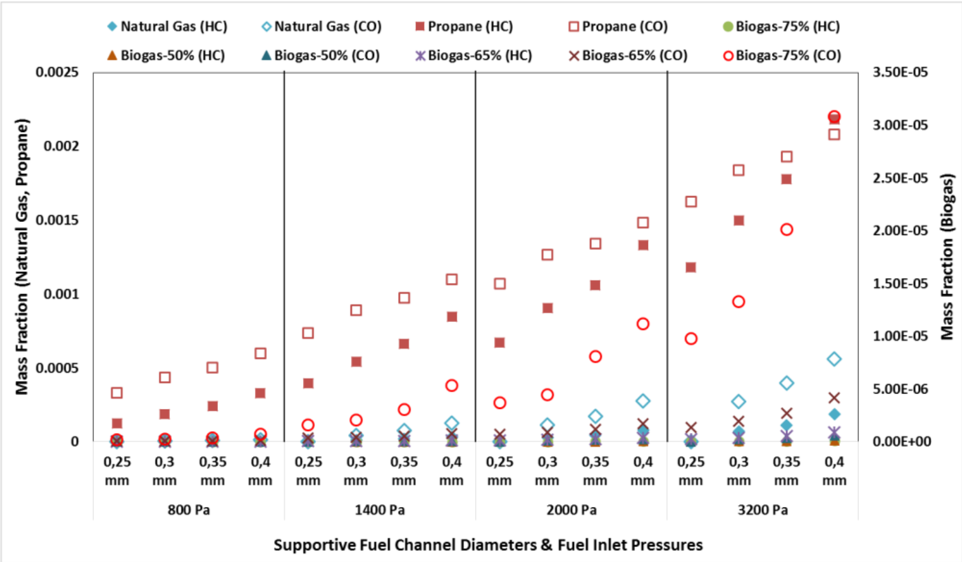

Fig. 2. UHC and CO Emissions of the semi-industrial burner for three fuels

Figure 3 shows NO levels of the burner depending on the parameters which are supportive fuel channel diameters, fuel inlet pressures, and different fuels and blends. According to the results, it is convenient to say that propane produces much higher NO emissions compared to the other fuels as it was expected. As seen here, effect of supportive fuel channel diameter on NO emissions is significant. The decrease in diameter results in a great reduction of NO emissions which is valid for natural gas and propane cases.

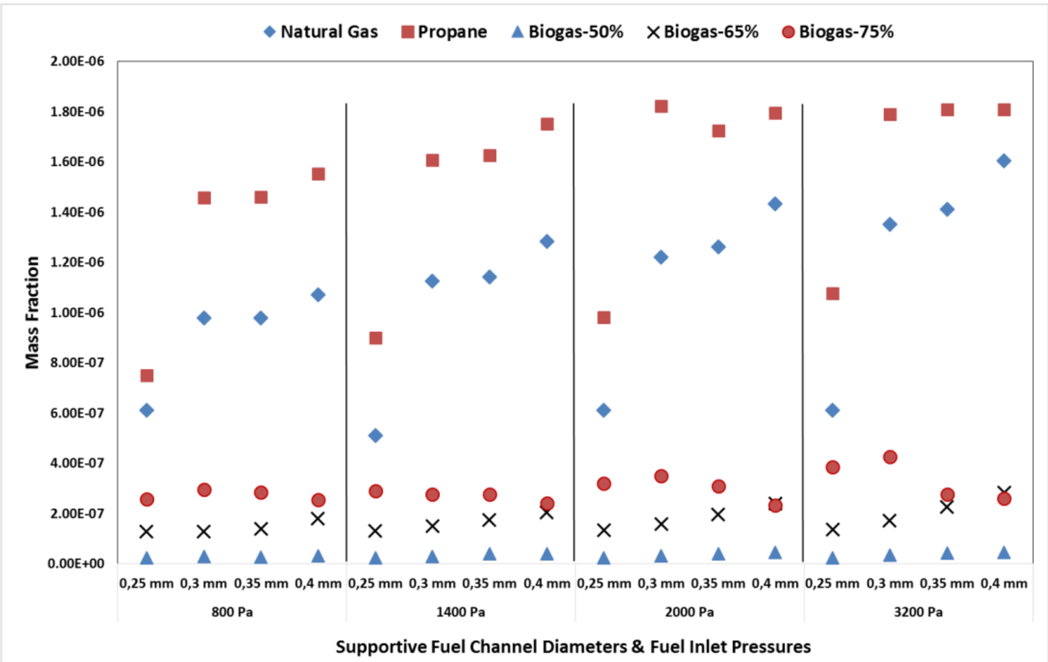

Fig. 3 NO Emissions of the semi-industrial burner for three fuels

4. How the STSM has contributed to the Action's aim
"SMARTCATs COST Action aims to set-up a Europe-wide network of leading academic and research institutions and key industries to promote the use of smart energy carriers on a large scale in order to increase fuel flexibility and carbon efficiency of energy production and to support distributed energy generation strategies", (www.smartcats.eu). Regard to mention, this STSM gave opportunity for network establishing between ÖZTİRYAKİLER and CERTH/CPERI. The plan for further collaboration work is to make an experimental and modelling work exchange in field biomass and waste to energy.

5. Future collaboration with host institution (if applicable)
This mission has passed in good spirits and understanding. In the future, I will stay in contact with Dr George SKEVIS and his research team to follow up on the experimental and modeling results in field of biogas usage in industrial equipment. Further collaboration would be beneficial hopefully for both sides. In addition, proposal preparation for H2020 calls related to local level energy production will be provided.

6. Foreseen publications/articles resulting or to result from the STSM (if applicable)
Publications resulting from STSM activities must acknowledge COST Action CM1404
If further analysis of modeling and experimental observations give valuable results, hopefully results of this analysis would be published.

7. Confirmation by the host institution of the successful execution of the STSM
The confirmation letter from the host institution (written by Dr. George SKEVIS) is attached.

8. Publications resulting from STSM activities must acknowledge COST Action CM1404
YES

I would like to express my special gratitude and appreciation to the Chair of COST Action CM1404 (SMARTCATs), Dr Mara de Joannon, for her support during my STSM. Furthermore, I would like to record my appreciation to the MC of Cost Action CM1404 (SMARTCATs) for granting the funding to allow me to carry out this STSM. I would like to thank Dr. George SKEVIS and other members of the CERTH/CPERI research team for friendly hospitality and given support.

References

[1] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

[2] OECD/IEA. (2017). *World Energy Outlook 2017.*

[3] H.O.B. Nonaka, F. M. Pereira. Experimental and numerical study of CO_2 content effects on the laminar burning velocity of biogas, Fuel, Volume 182, 15 October 2016, Pages 382-390.

[4] Angelo Greco, Daniel Mira, Xi Jiang. Effects of Fuel Composition on Biogas Combustion in Premixed Laminar Flames, Energy Procedia, Volume 105, May 2017, Pages 1058-1062.