STSM Applicant: HAKAN SERHAD SOYHAN

University of Sakarya, Faculty of Engineering, Department of Mechanical Engineering, Esentepe Kampüsü, M7 binası, Serdivan, 54187, Sakarya – TURKEY

Subject: Short Term Scientific Mission
Reference: COST Action CM1404
Host institution: CPERI/CERTH
Host Supervisor: Dr George SKEVIS, gskevis@cperi.certh.gr
Period: 2018-07-09 to 2018-07-13
COST Action: CM1404
STSM reference number: 41722

1. Purpose of the STSM

The aim of this Shortterm Scientific Mission (STSM) was to establish contact with theCPERI/CERTH , as well as to obtain new references on past and present research needed to further develop the theoretical and conceptual tools used in "investigation of the characteristics of biogas to use in industrial kitchen burners". Furthermore, as I am doing research in biogas experimentally and numerically at home University (SAÜ), visiting CPERI/CERTH provided me with the opportunity to network with CPERI/CERTH research team, under supervisor of Dr George SKEVIS in evaluating my work in relation to current relevant work being undertaken on the same research field.
In the European Union (EU), biogas production has increased by renewable energy policies. An increasing number of biofuels are being used in kitchens as one of the alternative energies. Biofuels are also called as clean renewable energy. Generally, the purpose of the STSM is to investigate special industrial kitchen burner designed especially for biogas and effective combustion process for cooking. Another aim is presenting research activities of (SAÜ and CERTH/CPERI) in order to establish possible collaboration research work beyond the SMARTCATS Action.

2. Description of the work carried out during the STSM

The work carried out during the STSM consisted of two stages. The first stage comprised close collaboration with the the research group of Dr George SKEVIS at CPERI/CERTH on modelling and simulation of biogas burners including full kinetic effects. This gave me an opportunity to extend my research about biogas combustion modelling, by exchanging experience, knowledge and by sharing methodologies and results. A comprehensive comparison of the models and methodologies used by both research groups (SAU and CPERI/CERTH) has provided the necessary background for a more accurate numerical representation of industrial kitchen burners as shown in Section 3.

The second stage involved a visit to the Burner Facility of the Heterogeneous Mixtures and Combustion Systems Laboratory of the National Technical University of Athens. There is a close collaboration between NTUA and the research group of Dr George SKEVIS at CPERI/CERTH which has led to the development and operation of a state-of-the-art swirl burner. The burner has been operated with several gaseous mixtures, including biogas, as described in recent publications [1, 2]. Discussions and comparisons were made considering the theoretical and experimental aspects of the use of biogas in burners used in industrial kithchens, on the basis of results obtained in the laboratory swirl burner.

3. Description of the main results obtained:

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 monooxide. 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 examined and the most suitable design for a biogas burner were obtained. As a result of investigations, the optimum configuration for the application in industrial kitchen appliances was chosen.

There are many studies on biogas combustion. Some of them are related to its chemistry and calculations while others focused more on the designs to improve the devices such as burners that utilize as a fuel in an efficient way. An experimental study was carried out to reveal the laminar burning velocity of different compositions of biogas [3]. Numerical simulations were also performed for the calculations on adiabatic flame temperature, structure of the flames, sensitivity analysis and concentrations of species. Simulations were conducted in a wide range of equivalence ratios and for the pressures up to 4 bar. The results have proved that formation of H-radicals increased with the equivalence ratio, where maximum values for mole fractions of OH can be observed around stoichiometric conditions. Another outcome of the study was the trend that adiabatic flame temperature followed that it had increased with the pressure and became maximum near stoichiometric ratios.

A numerical study was carried out on CH_4 and CO_2 blends to make a comparison between four diffusion flames to investigate their chemical and thermal structure. Formation of radical species as well as minor and major species were evaluated. The effect of CO_2 content in biogas on the conditions were examined thermally and chemically [4].

Since, the emission rates in the world were putting the environmental sustainability at great risk, many studies stand out to be viable solutions to the problem at hand. For achieving reduced NOx emissions and increased energy efficiency, an observation on the feasibility of catalytic steam reforming of biogas was performed. By converting lower CH_4 content of biogas into a syngas that is a hydrogen-rich mixture and using it in a lean combustion systems, improved combustion stability and reduced NOx emissions were aimed. Results had proven that reformed mixture coupled with the rest of the biogas output from a waste energy recuperation process had provided a smooth operation on a test engine which can only reach 3600 rpm under the fore mentioned conditions. Using the biogas without reformation was not enough for engine to run at these speeds. Moreover, NOx reduction goal was successful with lean-fuel applications [5].

Although, the brief review above reveals that while there are many studies for gas 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 from CFD simulations on the effects of three different fuels (propane, natural gas and biogas with three different compositions) by variations of four different fuel inlet pressure and four different fuel channel diameters on thermal distributions, emissions and efficiencies.

CFD MODELING

Three dimensional (3-D) CFD simulations were performed.

3-D CAD Model and Computational Mesh for CFD Simulations: The burner simulated in the current study is vertically fired and there are 24 main fuel channels where fuel exits to ambient air, having 0.8 mm diameter each, and they are divided into 4 packs. Fluid geometry has been created according to the original drawing. Fuel enters the domain from the entrance of the venturi, goes up along with it and exits through the fuel channels. A control volume, where the fuel and air are mixed and combustion is occurred, has been defined from the bottom face of the cooker to some convenient level below the fuel channels as illustrated in the figure 1.

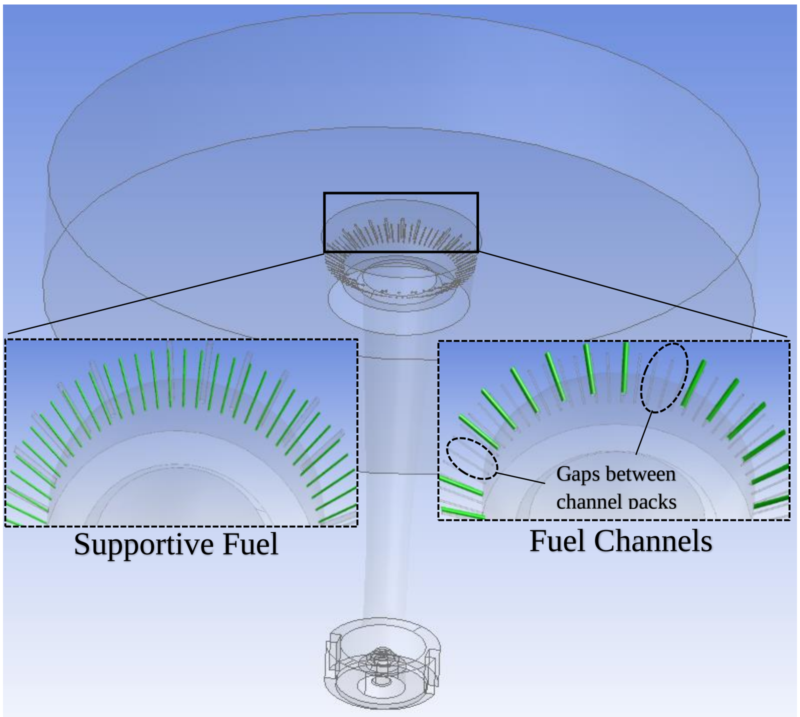

Fig. 1. 3D Model of The Burner

Boundary Conditions and Simulation Parameters

To investigate the effects of fuel properties in a domestic burner combustion, three different fuel as propane, natural gas, and biogas with three different compositions were used at CFD simulations.

Solutions have been carried out with four different fuel inlet pressures as 800, 1400, 2000 and 3200 Pa, and four different fuel channel diameters as 0.25, 0.30, 0.35 and 0.40 mm and as mentioned before, three different gas compositions: natural gas, propane and three different biogas blends. Mole fractions in each mixture can be found below:

- Natural gas – 96.5% CH4, 1.7% C2H6, 0.1% C3H8, 0.1% C4H10, 1.3 N2, 0.3% CO2
- Propane – 100% C3H8
- Biogas – 50% CH4 + %50 CO2, 65% CH4 + %35 CO2, 75% CH4 + %25 CO2

The mole fractions in the biogas blends were chosen based on the general information about the mixture contents which include the maximum (75% CH4) and minimum (50% CH4) combustible substance inside a biogas composition representing agricultural waste processing and biogas obtained from household wastes. Diameter of supportive fuel channels which they were placed right below the main ones are varied between 0.25, 0.30, 0.35, 0.40 millimetres.

RESULTS AND DISCUSSION

The temperature contours on bottom surface of the cooker in general show the expected distribution with increasing diameters and fuel inlet pressure. The impact of gaps between channel packs on the temperature distribution can easily be spotted from figure 2, which creates a cooler regions between the hotter areas on the surface. As it was expected, temperature rises with both diameter and fuel inlet pressure. Another observation is the temperature distribution along the venturi. At lower pressure zone the combustion at the top heats the unburnt fuel coming through the venturi greater than in higher pressure condition, which can be explained by the slow motion of the fuel in low pressures and thus, increased contact time with the heated area. According to the experiences of the industry and the experts, optimum cooking temperature at the bottom surface of the cooker is in the range of 823-923 K and 923 K is given as the approximate limit that heat and moderate corrosion resistance starts to occur 25. Figure 3 shows the calculated average temperatures with different fuel compositions and changing parameters of diameters and inlet pressures. The graph also reveals both the safe, optimum, and unsafe operating zones for cooking process. Values in the safe zone were marked with blue, values in the optimum zone were marked green, and values in the unsafe zone were marked red. And as it can be seen that propane is not suitable for this cooking process with the mentioned burner. 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 with staying in the optimal zone. Biogas solutions with 75% methane have temperature values in all three regions, most of them remain in the optimal zone which makes it the most suitable choice among the other fuels/blends. Results of 65% methane cases of biogas indicate that only at higher pressure with higher diameters could be the optimal operating conditions in this application. All the design points for the remaining blend (50% CH_4) are in the safe zone which is below the optimal temperature range.

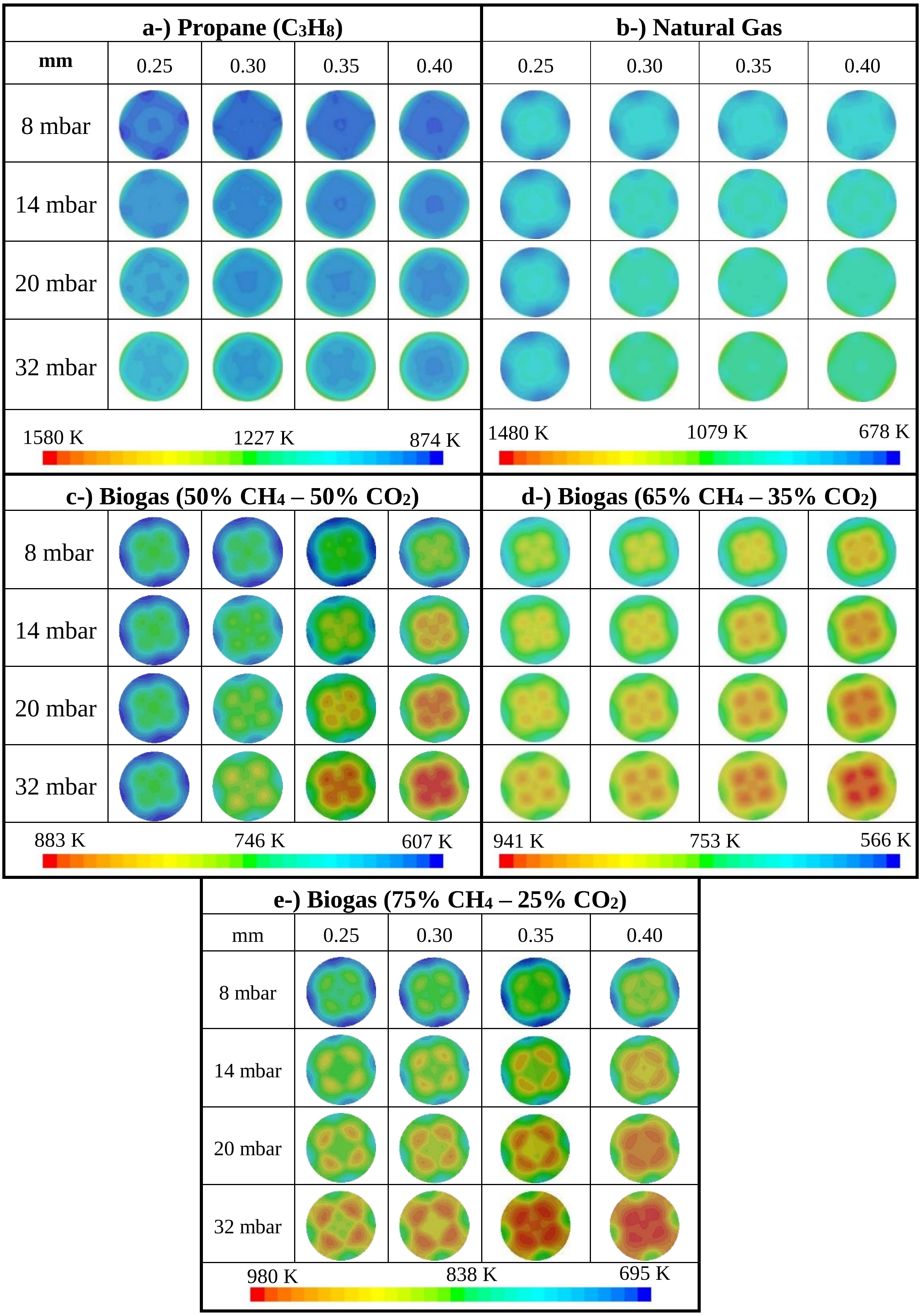

Fig. 2. Temperature Distribution on Bottom Surface of the Cooker

As can be seen in figure 3, propane cases show an almost independent behaviour with respect to the change in diameters whereas all the other fuels are affected by it in different scales. Possible reason could be the diameter of the cooker which is too small for propane cases. Due to high flame lengths, it barely touches the sides of the cooker. Biogas and natural gas cases have wider range than other applications in terms of optimum operating conditions.

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 SAÜ and CERTH/CPERI. The plan for further collaboration work was made (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 equipments. Further collaboration would be beneficial hopefully for both sides.

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 (attached the original document)

Kindly ask you, please see the pdf document written by the host, Dr George SKEVIS, attached to the email.

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 CPERI/CERTH research team for friendly hospitality and given support.

References

[1] Colin Banyon, Jose J. Rodriguez-Henriquez, George Paterakis, Zisis Malliotakis, Konstantinos Souflas, Christos Keramiotis, George Vourliotakis, Fabian Mauss, Henry J. Curran, George Skevis, Panagiotis Koutmos, Maria Founti (2018) A comparative study of the effect of varied reaction environments on a swirl stabilized flame geometry via optical measurements, Fuel, 216:826-834.

[2] Doss, T.P., Keramiotis, C., Vourliotakis, G., Zannis, G., Skevis, G., Founti, M.A. (2016) Experimental investigation on the influence of simulated EGR addition on swirl-stabilized CH4 flames. Journal of Energy Engineering, 142, art. no. E4015008.

[3] Askari, M. H.; Ashjaee, M.; Karaminejad, S. Experimental and Numerical Investigation of the Laminar Burning Velocity and Combustion Characteristics of Biogas at High Pressures. Energy and Fuels 2017, 31 (12).

[4] Vrbová, V.; Ciahotný, K. Upgrading Biogas to Biomethane Using Membrane Separation. *Energy & Fuels* **2017**, *31* (9), 9393–9401.

[5] Dabir, S.; Cao, M.; Prosser, R.; Tsotsis, T. Feasibility Study of Biogas Reforming To Improve Energy Efficiency and To Reduce Nitrogen Oxide Emissions. *Ind. Eng. Chem. Res.* **2017**, *56* (5), 1186–1200.