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INFLUENCE OF AIR PREHEATING TEMPERATURE AND AIR DILUTION RATIO UPON ATMOSPHERIC COMBUSTION OF NATURAL GAS

BY

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Abstract. The paper presents the simulation of the atmospheric combustion of natural gas intended to be used in closed solar hybrid gas turbine engines. The simulation considered the following assumptions:

– air pre-heating above 800 K,
– different air primary, secondary and dilution ratios.

3D model was created using CATIA, and simulations was carried on using ANSYS. Used Mesh contains 1600000 elements, with 294000 nodes.

The simulation showed 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.

Keywords: exhaust gas composition; atmospheric combustion; high air preheating temperature; dilution ratios.

1. Introduction

Compared to fossil fuels, renewable energy resources present an inherent disadvantage: their intermittent nature. However concentrated solar

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power (CSP) is a very attractive electricity generation technology, compared to other renewable electricity generation systems, because of its ability to incorporate a gas turbine (Krieger *et al*. 2015, p. 471-481).

The project idea is to design a combustor suitable for Solar Hybrid Closed Cycle Power System, which will be able to simulate the combustion process at atmospheric pressure, using some variable parameters like: preheated air up to 600°C or above, air fuel ratio and using several combustion equivalence ratios for combustion of some typical gaseous fuels with composition prepared by a controlled mixing of natural gas with H_2, CO, CO_2, N_2.

Gas turbine combustion processes for CCS technology and other low carbon emissions technologies related studies have been realized in theoretical and experimental researches (Cameretti *et al*., 2009; Choudhuri and Love, 2008; Daniele *et al*., 2011; Fantozzi *et al*., 2009; Fujimori and Yamada, 2012; Taniguchi *et al*., 2011). With more details, Ghenai (2010) used a numerical investigation of the combustion of Syngas, fuel mixture in a gas turbine can combustor. Liu *et al*. (2012) conducted a numerical study of the thermodynamic and basic combustion characteristics of oxy-fuel combustion in gas turbine related conditions using detailed chemical kinetics and thermodynamic calculations. Xiong *et al*. (2008) performed numerical simulations of a gas turbine combustor for medium/low heating value syn-gas fuel for two design schemes. Although there is a consistent use of CFD to analyze a large range of combustion related issues, there is still a lack of published works on numerical modeling of oxy-fuel combustion. In the majority of the cases, the numerical model simulated was not validated using experimental data (Krieger *et al*. 2015, p. 471-481).

This article addresses a CFD study of a combustion process for reduced carbon emissions. The designed can-type combustor used for predictions of temperature profiles and gaseous species concentrations in various locations is the one that will be used to validate the numerical simulations in the laboratory demonstrations.

2. Design of the Combustion Chamber

The combustion chamber which is modeled and will be used in Ansys simulation was designed as part of a demonstrator, capable to recreate all the conditions for analysis of combustion process for gaseous and liquid fuels. The demonstrator has some variables to recreate with high accuracy the simulation conditions used in software modeling. That includes the variable air fuel ratio, variable temperature of preheated air, variable ratio between primary air and secondary air. The system includes an mass spectrometer, and an PLIF. In this case, the combustion chamber is cylindrical, disposed horizontal. It have 12 radial holes, to permit the secondary air to enter in the combustion process, and the cool the combustion chamber wall.

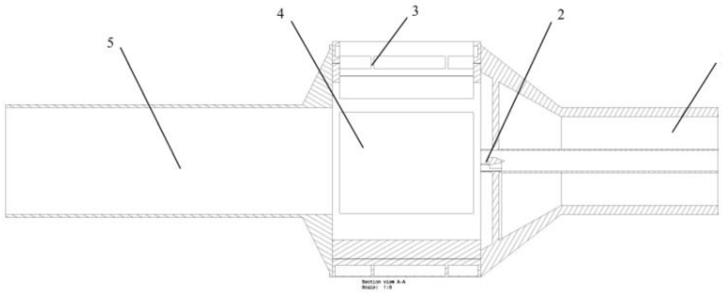


Fig. 1 – Combustor assembly.

The combustor assembly consist 5 main elements (Fig. 1): 1 – air intake, 2 – fuel nozzle (with swirl effect), 3 – secondary air hole, 4 – quartz window (for PLIF analysis), 5 – exhaust pipe (contains 7 connectors to the mass spectrometer).

In ANSYS is recreated the fluid area inside the combustion chamber, and then is 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, which 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. 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 1600000 elements with 294000 nodes, in consistent to other simulations analyzed (Fig. 2).

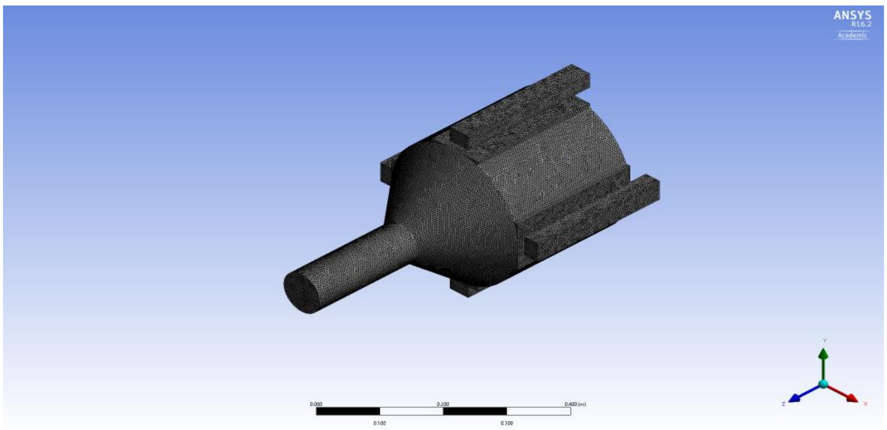


Fig. 2 – Mesh of the combustion chamber.

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, which 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.

3. Results

In Figs. 3-8 are represented the results after conducted simulations, regarding temperature field, and mass fractions for different species. The fuel air ratio is 1.05, and primary air-secondary air ratio 0.2. The temperature of the air at the inlet of the combustion chamber is 300 K.

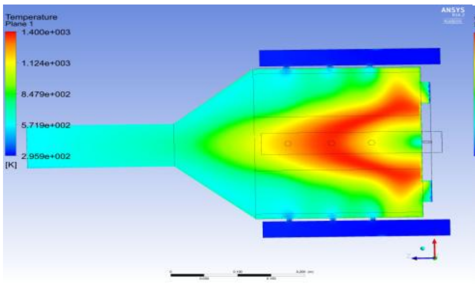


Fig. 3 – Temperature field.

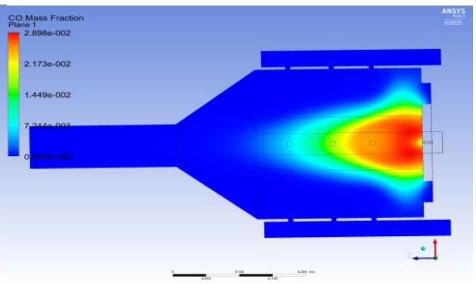


Fig. 4 – CO Mass fraction.

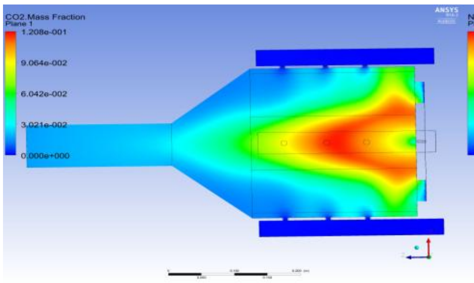


Fig. 5 – CO2 Mass fraction.

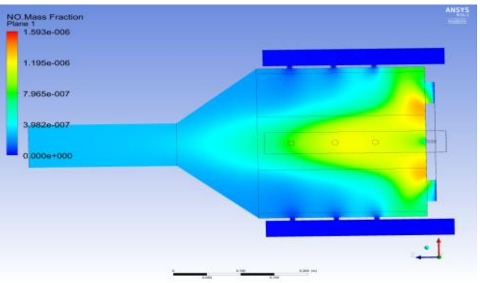


Fig. 6 – NO Mass fraction.

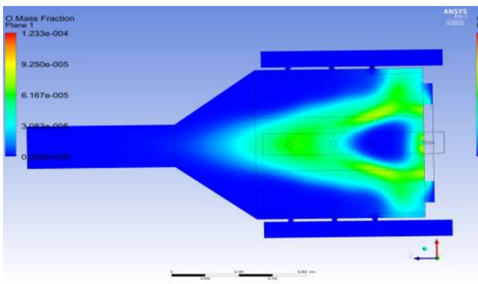


Fig. 7 – O Mass fraction.

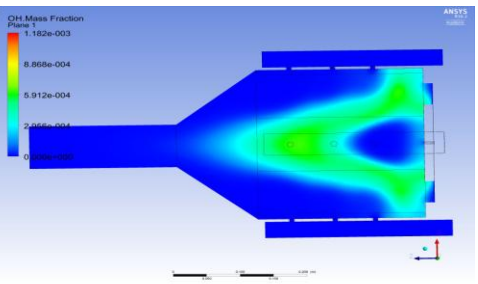


Fig. 8 – OH Mass fraction.

In Figs. 9-14 are represented the results after conducted simulations, regarding temperature field, and mass fractions for different species. The fuel air ratio is 3, and primary air-secondary air ratio 0.2. The temperature of the air at the inlet of the combustion chamber is 300 K.

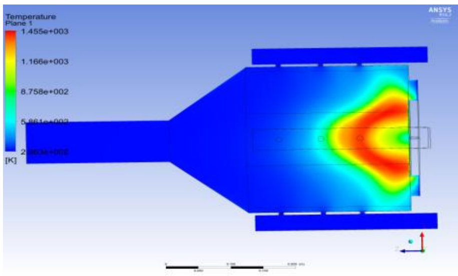


Fig. 9 – Temperature field.

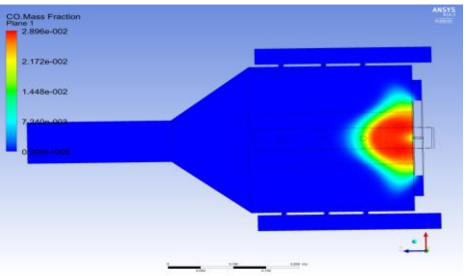


Fig. 10 – CO Mass fraction.

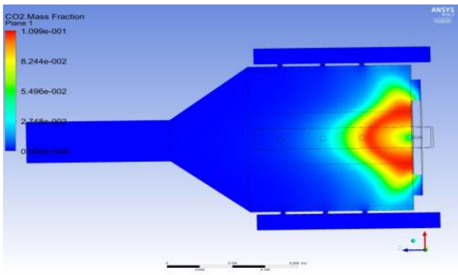


Fig. 11 – CO2 Mass fraction.

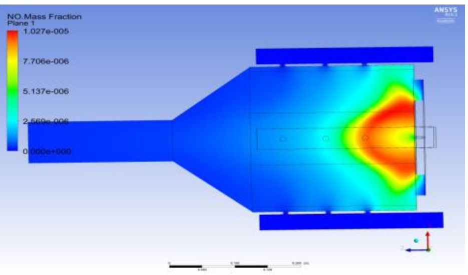


Fig. 12 – NO Mass fraction.

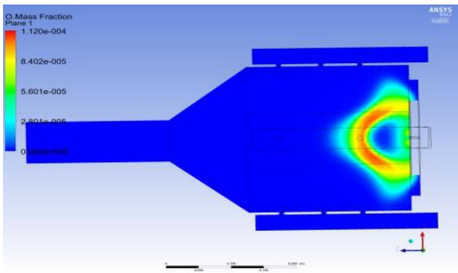


Fig. 13 – O Mass fraction.

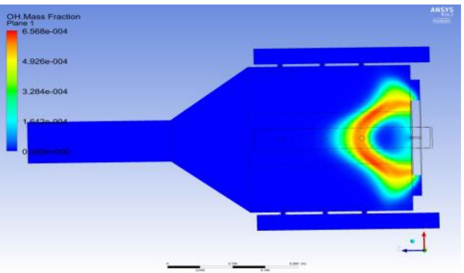
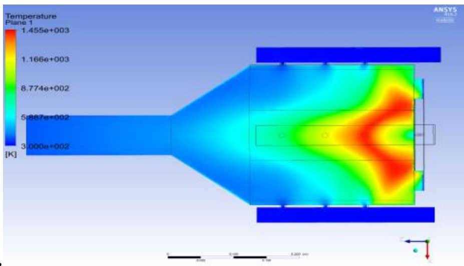


Fig. 14 – OH Mass fraction.

In Figs. 15-20 are represented the results after conducted simulations, regarding temperature field, and mass fractions for different species. The fuel air ratio is 5, and primary air-secondary air ratio 0.2. The temperature of the air at the inlet of the combustion chamber is 300 K.



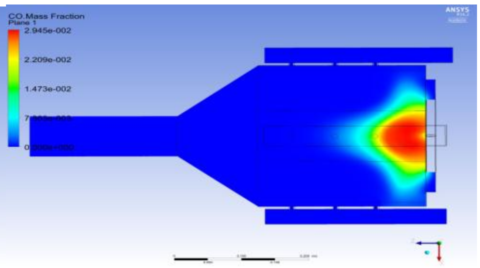
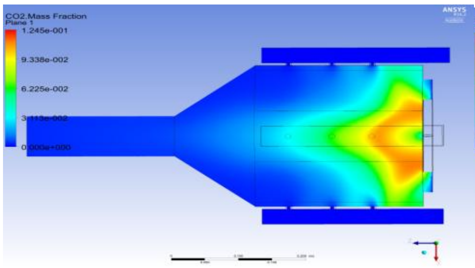


Fig. 15 – Temperature field. Fig. 16 – CO Mass fraction.



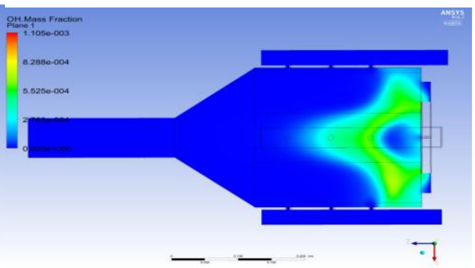
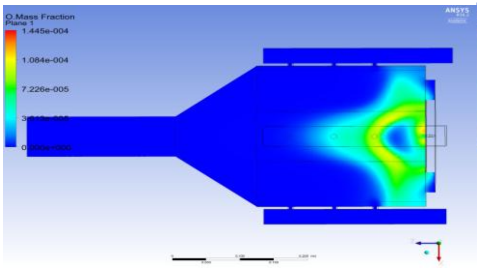


Fig. 17 – CO2 Mass fraction. Fig. 18 – NO Mass fraction.



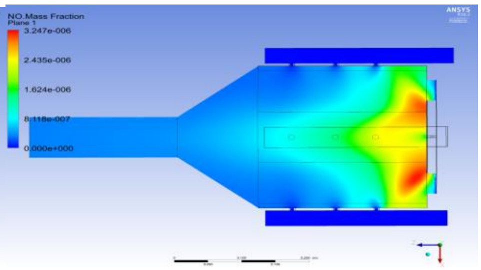


Fig. 19 – O Mass fraction. Fig. 20 – OH Mass fraction.

4. Conclusions

After conducted simulations, it is visible that mass fractions for CO, CO_2, OH and O are increasingly proportional to the air fuel excess factor, while the lowest value for NO mass fraction is achieved at air fuel ratio 4. Also, for same air fuel ratio, the mass fractions are more concentrated in the flame area, while on the other values for air fuel ratio the mass fractions are disposed more to the direction of exhaust gases. In addition to this work, all simulations will be recreated and evaluated using combustion demonstrator.

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INFLUENŢA TEMPERATURII DE PREÎNCĂLZIRE A AERULUI ŞI A RAPORTULUI DE DILUȚIE ÎN ARDEREA ATMOSFERICĂ A GAZULUI NATURAL

(Rezumat)

Lucrarea prezintă simularea procesului de ardere atmosferică a gazului natural destinat utilizării în cadrul motoarelor cu turbine cu gaze cu ciclu închis.

Simulările au avut în vedere următoarele considerente:

– temperatura de preîncălzire a aerului de până la 800 K,

– diferite rapoarte între aerul primar şi aerul secundar.

Modelul 3D a fost realizat în CATIA, iar simulările au fost realizate în ANSYS. Reţeaua de discretizare conţine 1600000 elemente, cu 294000 noduri. Rezultatele simulărilor arată câmpul de temperaturi, câmpul de concentraţii OH, compoziţia gazelor de ardere, câmpul de viteze al gazelor de ardere, cât și câmpul de presiuni. Simulările arată influenţa temperaturii de preîncălzire a aerului asupra caracteristicilor combustiei atmosferice.