NEW DESIGN PROPOSAL FOR AN AIR-FUEL INJECTOR SWIRLER WITH VARIABLE EFFECT

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Abstract: This article presents a new model of swirl injector for air / fuel mixture that allows the control of flame stability by adjusting the turbulence number according to the conditions in the combustion chamber. Following many experiments performed in the past, was determined a influence of turbulence number on the flame, which is also reflected on the pollutant emissions resulting from the combustion processes carried out at partial loads of the system. In designing the combustion process for a combustor, nominal power, the excess air ratio, fuel type, etc. are taken into account. But in case of its use at partial load, for example in the start-up phase, or if it is not necessary to produce the nominal power, the combustion process has to suffer, its instabilities appear, facts which have a major effect on the dynamics on oxidation process of the fuel. Thus, the use at partial loads of a combustor can lead to the production of pollutant emissions generated by chemical species resulting from incomplete oxidation reactions. In present, the field of hybrid closed cycle gas turbines using solar energy are showing increasing interest so new directions of development appeared. One of these is represented by the need to optimize combustor for working on partial loads, so that the system contributes to the massive reduction of pollutants. In this article will be shown a new design of an air/fuel swirl injector, with axial flaps which offer the possibility to increase the angle from 0^0 to 20^0 and the impact of these variations upon flow velocity and turbulence.

Key words: air-fuel injector, effect swirler, variable turbulence number, pollutant emission decrease

1. INTRODUCTION

Many studies related to the analysis of burning process for various fuels are presenting the influence of turbulence number on the combustion parameters. There were many design solutions presented as solutions to achieve desired turbulence number and turbulent flows inside combustion chamber with main goals related to the combustion stability and reduction of pollutant emissions [1]. The idea of a variable swirler with active effect had appeared at the moment when we had to analyse the combustion process of gaseous fuels used in a system with closed cycle gas turbine (CCGT) assisted with solar energy. It is to mention that a solar hybrid CCGT is intended to use the solar energy to heat a working fluid, with various solutions like a concentrated solar power (CSP) tower and heat exchanger for this purpose. The hybridisation of this energy generator is realised with an attached combustor which can heat directly the working fluid in the absence of solar radiation.

A solar hybrid CCGT need a backup system related to a combustion system to cover the energy needs when the energy network is requiring more energy that the system can produce using its conventional design. During nights, or days with cloudy sky, the energy demand can be covered by transfer of required heat from a fossil fuel combustor. It is to mention that this is also necessary because of intermittent peaks in the energy demands from consumers. For this purpose, it is required to use a variable output power combustor, to cover all demands in output power. Based on these requirements it is assumed that the combustor will function using many different input flows for fuel and oxidizer and such different combustion parameters for all variables. To obtain a desired swirl number it appears the opportunity to use a variable swirler injector. This would keep the turbulent number at a desired value, increasing the combustion process burning efficiency and reducing the pollutant emissions.

As shown in previous works, swirling flows are a simple way to reach stable combustion processes [1]. Swirling flow can be obtained inducting an amount of rotation to the flow resulting a recirculating flow, known as central recirculation zone (CRZ).

Swirl flows can be considered as three types: jet swirl turbulent with low swirl, high jet swirl with internal recirculation and jet turbulence in circulation zone. All these types exist due to the difference in density between jet flowing into the combustion chamber and jet flowing out into the

atmosphere from the combustion chamber.
Using a radial vanes swirler the air is introduced into the combustion chamber tangentially, forced to change its path, fact which contributes to the formation of swirling flow [2].

2. FUNDAMENTALS

Many applications based on a high-intensity combustion process have used various solutions to obtain a swirling flow. At the actual stage there still exist many things related to the swirling flows due to the complexity of this phenomenon. The swirling flows are used to improve the flame stability, this leading to a better combustion process with less pollutant emissions. In a combustion chamber, the aim of the swirl effect is to reduce the combustion length by creating a toroid recirculation effect where the oxidizer and fuel would reach a better mixture and also where the flue gases will continue to develop various chemical reactions reducing the pollutant emissions.
The swirl effect for a combustor can be obtained by two main solutions: either the fuel is injected in the combustion chamber using a special designed injector to induce a circular flow, either the combustion chamber can use different shapes to introduce the primary air and dilution air tangentially in a circular combustion chamber [3].
As mentioned before, the idea of a variable swirl effect injector appeared while designing a combustor with variable output power with application in solar hybrid CCGT. Combustor has a cylindrical shape, with primary air and fuel injected at one end, and dilution air injected tangentially. Since the variable output power of the designed combustor, appeared the necessity to obtain a stable functioning while adjusting the air excess ratio between 3 and 5 and while adjusting fuel flow. One of main goals was to obtain the combustion process only inside the combustor, with all chemical reactions ended inside the combustion chamber. Swirl effect increases the stability flames for many fuels and the blow-off limits can be considered infinite.
For a reactive flow, recirculation of burnt gases maintains a region of hot gases near the injector outlet which serves to anchor the flame in a high speed flow even under lean conditions. By promoting recirculation of hot gases and free radicals, this arrangement extends the blow-off limits, serves to stabilize the flames in regions where stretching rates are high, and can reduce the NOx formation by enhancing mixing of reactive components before they reach the combustion zone [1, 4]. It also has the advantage of protecting the injector with respect to the flame as a fresh stream separates the reactive region from the injector. This notably differs from other types of stabilizers like bluff-bodies which feature a flame edge in the near vicinity of the solid boundary.
Except the designed tangential flow for the dilution air, the swirl can be created with swirl generator devices, such as vanes, mechanical spinners, etc. Until now there were different solutions designed to obtain the variable swirl effect, using radial arranged vanes, actuated together, which would create the swirling flow before the mixture between oxidizer and fuel. Other solutions to create a swirling mixture of fuel and oxidizer are to implement the swirler in the case of a premixed combustion process, where the fuel and oxidizer are injected through same device, ensuring a proper mixture.
Swirling flows are characterized by a parameter known as swirl number, determined with equation (1) which is defined as the ratio of axial flux of the angular momentum, G_0 to the axial flux of the axial momentum, G_x in relation with R, which is the radius of the combustion chamber.

$$S_N=G_0/(G_x \cdot R) \tag{1}$$

Some works done unitl now describe two available solutions used to obtain a variable swirl number. One of these techniques is related to the change of the gas distribution between axial and tangential inlet points like in the case of Sydney burner, with many applications related to non-premixed combustion processes [5] or turbulent premixed flow [6]. Another possibility to continuous variation of swirl number is related to the modification of swirl device geometry. Using this solution there are some examples like [7] which uses vanes with variable angle, arranged radial on the swirl device. The project Tecflam analysed the influence of swirl number on flame stability, flame dynamics and pollutant emissions [8-10]. It is to mention that for almost all experiments related to continous variable swirler was not used the possibility to change the swirl number during the experiments and also the fact that swirl number is not determined on the testing rig but estimated through mathematical modelling.

3. PROPOSAL OF A NEW CONCEPT OF VARIABLE SWIRL INJECTOR

As presented in previous chapter, there are already some available solutions for a continuous variable swirl injector. The novelty of the proposed solution is based on the fact that the designed variable swirl injector is using a number of frontal variable vanes,

which allow the injection of fuel and oxidizer either in non-premixed or premixed setup.
In the figures it is represented the designed variable swirl injector, with its components.
The designed variable swirl injector is composed by a fuel nozzle (1), installed in a swirl body (2). Fuel nozzle contain the holes (7) used for fuel inlet, located between vanes (5). This positioning of fuel inlet ports related to the vanes ensures a proper mixture between fuel and oxidizer improving the combustion parameters.

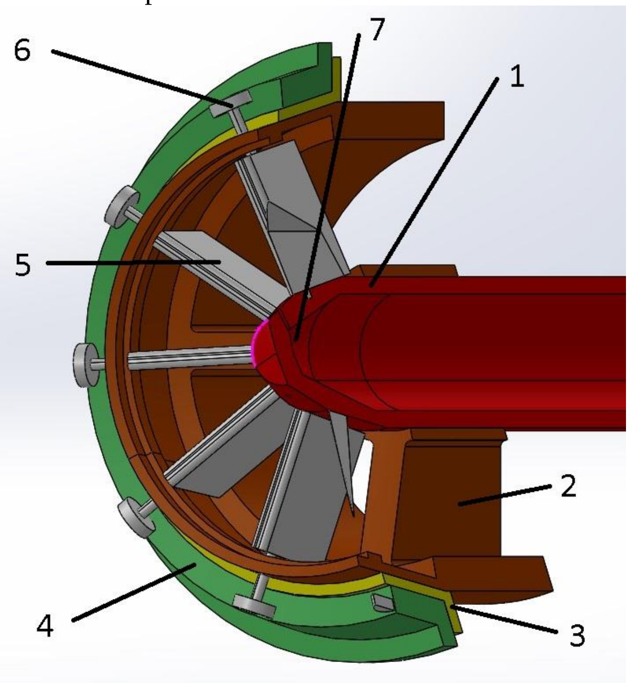

Fig. 1. Section view with vane angle 0 degrees

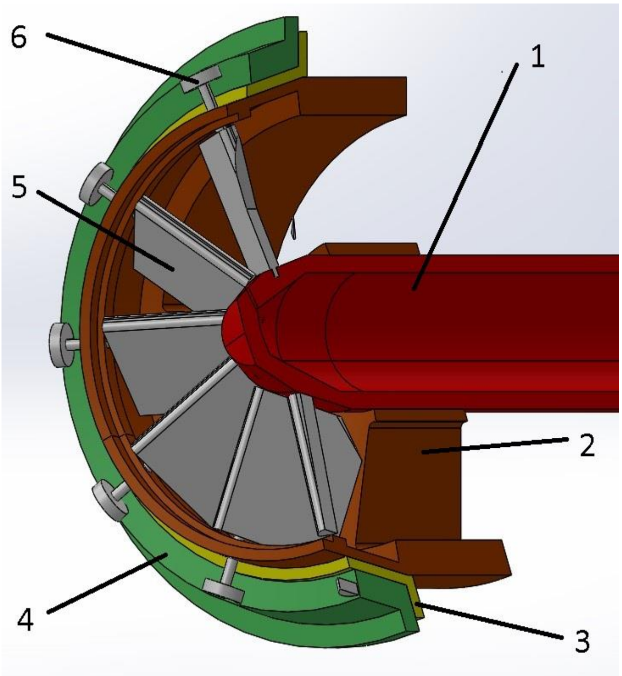

Fig. 2. Section view with vane angle 20 degrees

In figures presented above is shown a design solution based on 10 vanes, 10 inlet fuel ports between vanes, and 10 inlet fuel ports toward the combustion chamber. The vanes (5) have one end installed in fuel nozzle (1) and the other in swirl body (2). Each vane has attached at the external end one roll (6) which is in contact with main roll (4). The mechanism between rolls (6) and main roll (4) is presented as a simplified model, for precise control of each vane angle it is preferred to design them as a gear mechanism. Main roll (6) is installed on a sliding bearing (3).
Using the mechanism described it is possible to adjust the vanes angle between 0 (Figure 1) degrees and 20 degrees (Figure 2), with continuous movement, to obtain the imposed turbulence number needed for the specific combustion process. It is expected that this design of variable swirl injector with vanes arranged in the frontal plane would have less influence on the oxidizer velocity in the vecinity of inlet area, compared to the known solutions using radial vanes, which in some circumstances and for some angles are producing small unwanted turbulent flows which have a negative impact upon combustion reactions. This new design would also reduce the effect velocity reduction in the area of vanes because the change of flow directions improving overall flow in the combustion chamber with less geometrical influences on the combustion process.
Design can be modified to ensure a larger angle domain, different vanes number and also different vane shape, with the aim to improve functionality of variable swirl injector for all imposed conditions.

4. NUMERICAL MODELLING OF DESIGNED VARIABLE SWIRL INJECTOR

Based on the flow nature, these can be considered reactive or non-reactive. Reactive flows will appear in combustion chambers, while the mixture flow will allow chemical reactions which will lead to new chemical products to be released with influences in the temperature and pressure fields. As first attempt to analyse the proposed variable swirl injector, this paper will present only the impact of using this new designed device in the field of non-reactive flow, presenting a influence of velocity and turbulence in a cylindrical combustion chamber for various vanes angle.
In order to analyse the flow through the variable swirl injector for different vane angles was designed a simplified model of a combustion chamber with presumption of only oxidizer inlet, thus a non-reactive flow will be analysed. Combustion chamber model have a length of 300mm and diameter 140mm.
For these simulations was used ANSYS software, in order to create the mesh and to define all the necessary input computational parameters for flow

analysis. The meshed model was developed on the inner volume of combustion chamber, and defined the inlet and outlet flow areas. The mesh has 360000 nodes and 1.5 million elements with finite element sizes of 1mm. The mesh has a refinement in the oxidizer inlet area.

Figure 3 represents an overview of mesh generated using ANSYS. For all simulations was used a simplified model based on the fluid volume described by the assembly between air-fuel injector swirler and cylindrical combustion chamber, using a different model for each vane angle setup. Using this simplified model, neglecting all other mechanical parts, assemblies, joints, fixtures, etc. the computing time is reduced without increasing the error of the modelling approach. The vane design was considered a simetrical wing design, further research related to vane profile will be required to refine the impact of using this type of swirler on fluid flow.

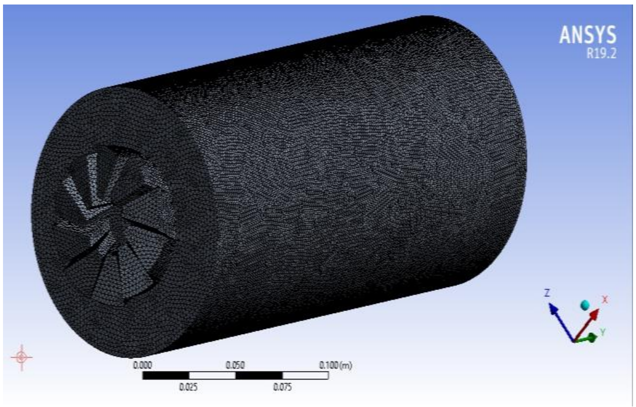

Fig. 3. Mesh generated using ANSYS

In Figure 4 is shown a detailed mesh for the air inlet area in the combustion chamber in the case of 10° angled vanes.

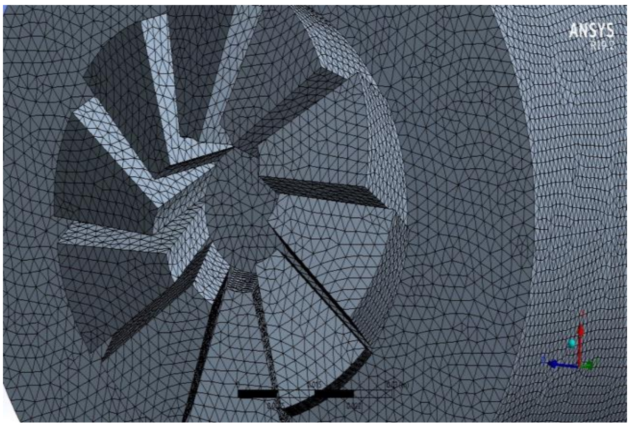

Fig. 4. Detailed mesh of swirl elements obtained using ANSYS

Mesh is containing unstructured tetrahedral elements used for difficult geometries, using a smooth transition between them. The described setup of ANSYS flow analysis would reach the solution convergence after an average of up to 500 iterations. The air inlet is defined as a normal speed inlet, with direction set normal to boundary and a velocity of 5m/s. Air inlet section measure 2910.5 mm^2. 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.

Next figures will represent the velocity field analysed in all 5 cases, with vane angle between 0° and 20°. To reduce the time and resources used for these simulations, was designed a simplified model containing only the fluid domain for all analysed cases and neglecting the combustion chamber walls and friction between fluid and variable swirler parts.

This work represents the first attempt to prove the advantage of using this type of variable injector swirler, so for first conclusion related to this design we modelled the flow behaviour considering the fluid containing only air at 25°C and imposing the velocity at the inlet boundary.

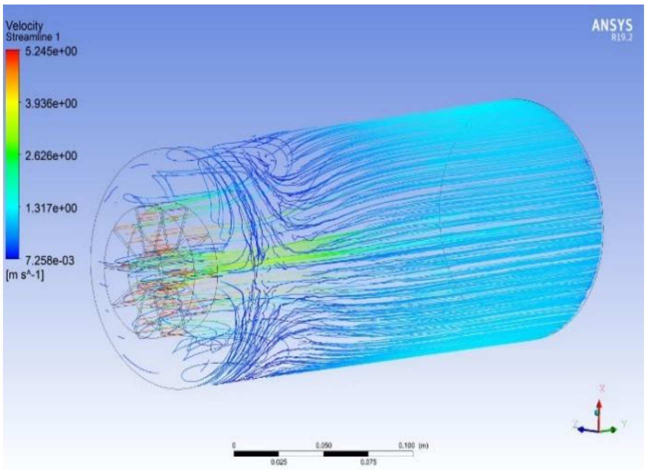

Fig. 5. Vane angle 0°

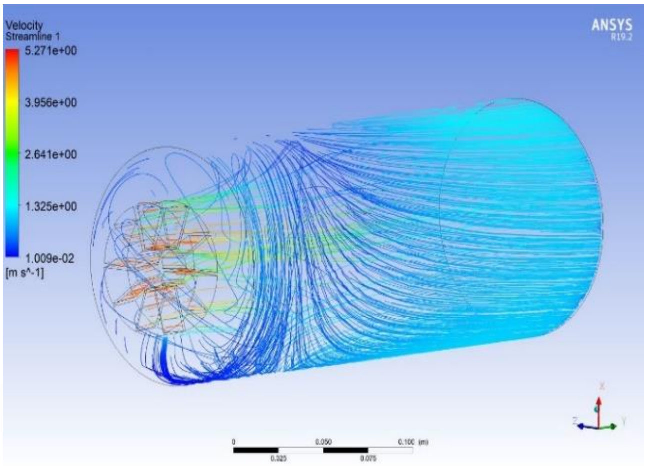

Fig. 6. Vane angle 5°

Figures 5 to 9 are representing the influence of vane angle upon the velocity field. While the minimum and maximum values for velocity will remain the same, it is to mention a variation of velocity field in the middle of combustion chamber in relation to vane angle.

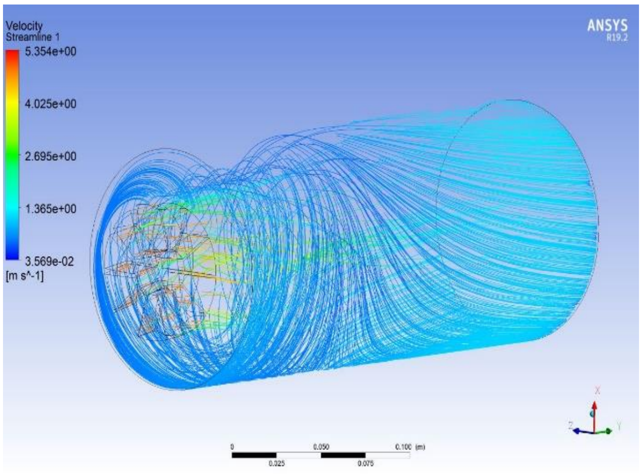

Fig. 7. Vane angle 10°

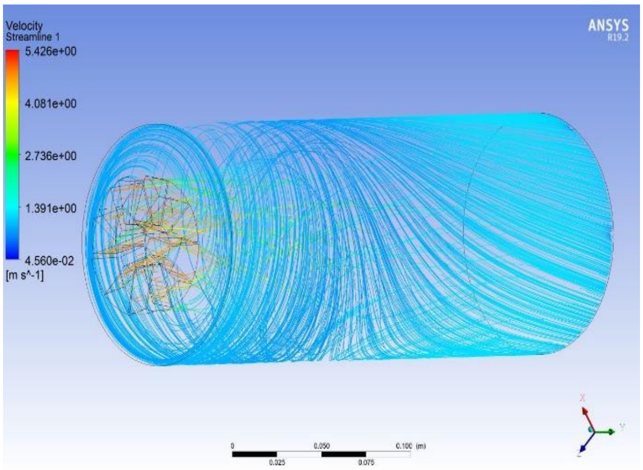

Fig. 8. Vane angle 15°

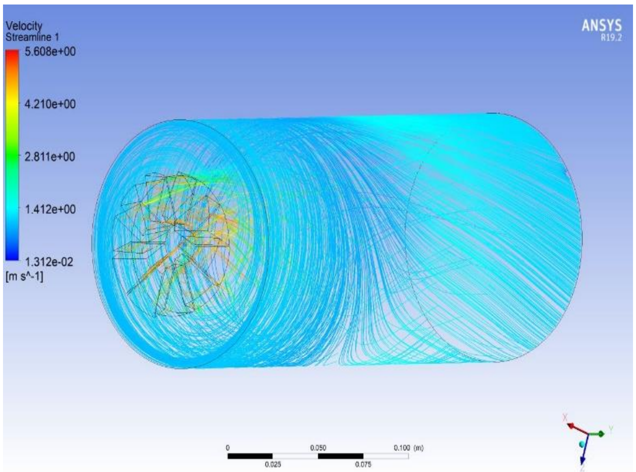

Fig. 9. Vane angle 20°

In case of vane angle 0°, Figure 5, the maximum velocity is achieved in vane area, with value 5m/s, while in the core of combustion area the velocity will be between 1.7-2.7 m/s.

While increasing the vane angle, as shown in Figures 6 – 9, the flow velocity will be reduced more in the first part of combustion chamber, reaching the value of 4m/s for 5° and less than 2.7m/s for 20°. Together with the increase of vane angle it is also noticed that the flow becomes more turbulent, without reversing flows like in the case of radial vanes variable swirler. For these imposed criteria, the velocity at the combustion chamber outlet has approximately the same value.

5. CONCLUSIONS

As already mentioned in previous section, this design solution for a variable swirler comes with many advantages, most important is the possibility to adjust the turbulence number without altering the flow behaviour. Using this variable swirler can be achieved the best mixture between oxidizer and fuel before burning process begins and also the best flow of combustion products, leading to a complete burning process for the entire operating range of a variable combustor, reducing in this way the pollutant emissions for all output power values.

It is to mention that to reduce the pollutant emissions, for different values of oxidizer and fuel flows it is necessary to have a turbulent flow in the combustion chamber, which will lead to a complete burning process without chemical reactions involved in flow of chemical mixtures through exhaust collector. For a reactive flow, like in the case of a combustion process, the chemical reaction mechanism and chemical reaction dynamics will also be influenced by the turbulent flow which could improve or alter the chemical reactions, and at the same time influencing the pollutant emission

As stated in the first chapter, this air-fuel injector with variable swirler is intended to be used for applications related to CCGT, fact which require special attention related to the impact of this new design proposal toward burning process and pollutant emissions. This research will be completed with laboratory scale combustion testing rig, which will include a variable swirler manufactured based on previously described design. The aim is to continue the work from actual stage of this research by experiments to achieve the estimated results for various mixtures for air and gaseous fuel using the variable vane angle swirler for different flow values for fuel and oxidizer, taking into account the excess air ratio in order to achieve a less pollutant burning process. The desired solution is based on a technical solution which would mean an active control of vanes angle using a stepper motor which will actuate the vanes

based on predefined software with feedback loop from a gas analyser system.
Further investigations will include the analysis of a reactive flow including premixed and non-premixed cases.
While actual work is an introduction to proove the possibile positive impact of using the solution of air-fuel injector swirler with variable effect towards pollutant emissions reduction, it is also important to continue our work in the direction of assembly design, with further analysis focused to obtain the suitable design to meet all required specifications and at the same time regarding the manufacturing processes and materials used for all components to achieve a reliable solution.
This new design proposal for a variable air-fuel injector swirler is registered to OSIM for Patent Pending with deposit number a/2020/00425 from 21.07.2020.

6. ACKNOWLEDGEMENT

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