Analysis of the Thermo Acoustic behavior of a micro gas turbine combustor Hydrogen Methane blend

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Abstract

In recent years, more and more efforts are being made towards the use of hydrogen enriched fuel methane in micro gas turbines. This interest is due to the higher LHV and wider flammability limits with respect to other conventional fuel. On the other hand, the use of hydrogen, or hydrogen enriched fuel, leads potentially to flashback and autoignition due to the significantly higher flame speeds and shorter autoignition times. Furthermore, combustion instabilities may occur toward ultra-lean operating conditions with hydrogen. Hence, it is important to be able to predict the behavior of a burner fueled with hydrogen in order to avoid these deleterious phenomena during the design phase. For this reason, this work proposes a methodology to predict thermo acoustic behaviour involved by hydrogen. In this work thermo acoustic simulations have been performed on a typical micro gas turbine combustor, Turbec T100, fuelled with a hydrogen enrichted methane in order to analyze in what way hydrogen influences the thermo acoustic stability of the burner.

Introduction

Thermo acoustic instability is the physical phenomenon that develops inside the combustor due to the strong interation between the thermal energy released by the combustion and the acoustic wave. The interaction of the flame to the acoustic disturbances and the walls can be considered as the main causes of this phenomenon.

Figure 1 shows the mechanisms that induces the combustion instability. In this figure, the combustor consist in a combustion chamber, where the flame develops, the burner and the fuel supply. The fuel supply and the outlet of the combustion chamber are characterized by a acoustic impedance Z. The presence of turbulence at the exit of the burner leads heat release fluctuations. The non-homogeneous expansion due to the combustion process causes a pressure oscillation in combustion chamber. The resulting acoustic waves travel with the speed of sound up to the combustion chamber outlet section where they are reflected towards the flame zone. In comparison with the turbulent ”noise” generated by a flame front, the amplitude of the acoustic waves is very small. However, these waves go back to the plenum where they modify the air flow. Thus, inside the burner, velocity and equivalence ratio fluctuations appear. The velocity fluctuations, firstly promote mixing between fuel and air, but, after a time delay τ, reach the flame affecting its surface and therefore the heat production. The equivalent ratio fluctuations induce periodic temperature fluctuations and therefore density fluctuations that can interact with the acoustic field. These two mechanisms cause the feedback loop that, in absence of dissipation, promotes the combustion instability. The aim of this work is to predict the thermo-acoustic behavior of the combustion chamber of the Turbec T100 combustor fueled by methane or

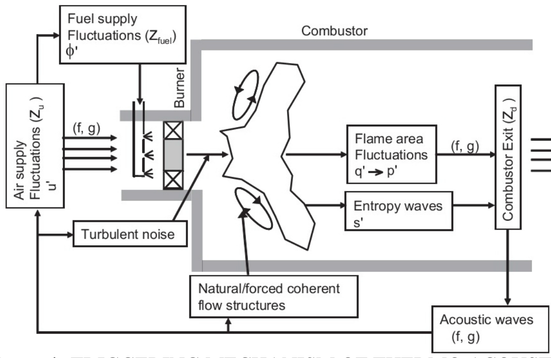

Figure 1. TRIGGERING MECHANISM OF THERMO ACOUSTIC INSTABILITY [1]

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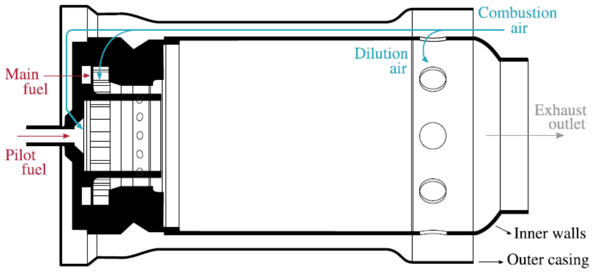

Figure 2. SECTION OF TURBEC T100 BURNER [4]

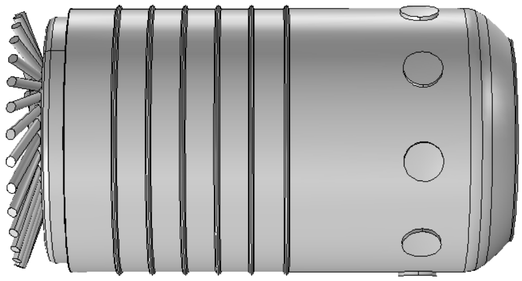
Figure 3. THE SIMULATION COMSOL Multiphysics® DOMAIN

by a blend of methane and hydrogen. Indeed, several authors found that increasing hydrogen concentration in methane-hydrogen fuel blends altered the dynamic stability characteristics of their combustor from stable to unstable [2, 3].

Numerical set up and methodology

In order to carry out an acoustic characterization of the burner, the module *Acoustic Pressure and Frequency Domain* of COMSOL Multiphysics® has been used. This software allows to detect complex self-frequencies that characterize the system and, therefore, to perform a stability study. It solve the differential equations problems, converting them into a eigenvalues problems in the frequency domain. The complete wave equation for each cell into which the 3-D acoustic domain is divided, is solved. To take into account fluid dynamics, it is necessary to transfer the results obtained from the numerical CFD simulations to the simulation in the FEM code COMSOL Multiphysics®. The monopole source that take into account the heat release is the following:

$$Q_{hr} = \frac{(\gamma - 1)}{\rho \bar{C}^2} \lambda q \frac{\hat{u}}{\bar{u}} exp(-i\omega\tau) \quad (1)$$

where γ represents the ratio between specific heat at constant pressure C_p, and that at constant volume C_v, ρ is the density, C is the speed of sound, λ represents the eigenvalue $-\omega * i$, q is the heat release fluctuation, $\hat{u}/\bar{u}$ is the velocity fluctuation and τ is the time delay between the acoustic disturbance and the flame response.

Figure 2 shows the geometry of Turbec T100 burner, according the described in [4, 5].

To also consider the thermo-dynamics characteristics of the burner, the results obtained from CFD simulation [4, 5] are interpolated on COMSOL mesh that is very coarse compared to the CFD one. By introduce these fields in COMSOL the simulation of the pilot duct and swirler vane components of geometry are unnecessary. Therfore, these parts of geometry has been eliminated in the COMSOL model (see Figure 3). The major velocity of the hydrogen leads to change the flame position, the equivalent ratio and the time delay. The greater reaction rate and smaller time delay of hydrogen methane blend stimulate a change in relationship between pressure fluctuation and unsteady heat release [2]. In this way the thermo acoustic characteristic of the burner has been altered. Also for the micro gas turbine, for the aforementioned causes, the thermo-acoustic behavior of the burner will change with the possibility of altering the stability of the burner.

Conclusion

In conclusion, in this work the preliminary analysis of the thermo-acoustic effect of hydrogen of a Turbec T100 burner is conducted. The data from CFD simulations have been used in order to develop the fields of the thermo-dynamic properties of the mixtures in the hot region, i.e., flame shape, reaction rate, density, temperature molecular weight and time delay. This fields have been interpolated by means MATLAB® code on a coarser grid used in COMSOL Multiphysics® in order to perform a thermo-acoustic analysis.

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