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CONFERENCE PAPER · OCTOBER 2015

DOI: 10.13140/RG.2.1.3531.6243

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Investigating the Effects of Heat Exchanger on Flame Transfer Function in a Simplified Boiler

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Abstract
The goal of the present work is to investigate the effects the heat exchanger can have on the acoustic response of the flames (flame transfer function) in a boiler. In compact condensing boilers the distance between the burner and heat exchanger is small enough to cause intense interactions. That is why we constructed a simplified CFD model of a boiler to study various cases with different distances between the burner and heat exchanger. Results show that the flame transfer function changes considerably when the flame impinges on the heat exchanger tube. The gain can acquire values above one for low frequencies due to incomplete combustion and the phase can be increased because of flame deformation and stretch. These results help analyze the acoustic behavior of the flames in such situations with more detail.

Introduction
Lean premixed combustion is widely used in industry mainly for the purpose of lowering emissions. It is well known that such systems are prone to thermoacoustic instabilities [1,2]. In thermoacoustic analysis of such systems Flame Transfer Function (FTF) approach has gained extra attention due to its simplicity and good agreement with experimental data [3,4].Most of the studies on flame transfer function treat the flames as a separate acoustic element in the chain of other elements such as ducts, area changes, cavities and boundaries, leading to a so-called Network Model for modelling the acoustic response of the whole system. However, there are situations in which important acoustic elements cannot be decoupled and treated separately. Reducing the size of high capacity condensing boilers has caused intense hydrodynamic and thermal interactions between the burner and the heat exchanger.
The goal of the present work is to investigate how the presence of the heat exchanger in the vicinity of the flames can affect the flame transfer function. A simplified CFD model was created to simulate boiler conditions with a perforated plate burner and a tube heat exchanger. The dimensions and boundary conditions of the model are shown in Figure 1.

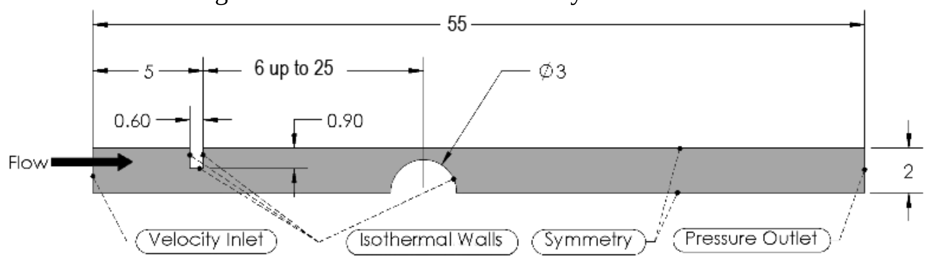
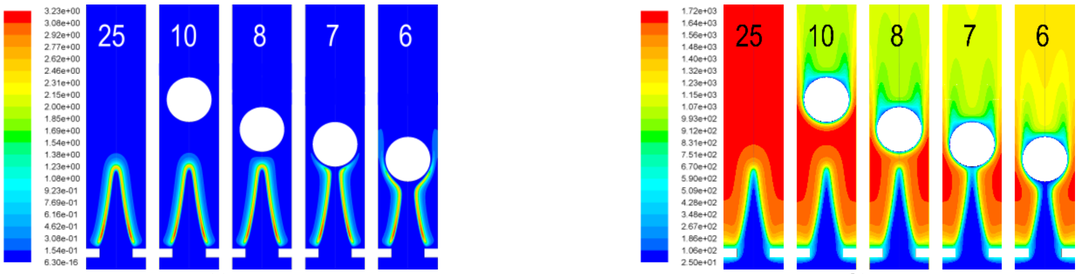


Figure 1. Numerical domain dimensions and boundary conditions.

We calculated the flame transfer function using velocity perturbations at the inlet in the form of a step profile with 5% increase (from 0.8 to 0.84m/s) as input, and heat release rate of the flames as output. We performed the simulations for different distances (6, 7, 8, 10 and 25mm) between the top surface of the burner deck and the center of the heat exchanger tube. All the walls of the burner deck are considered isothermal at 520°C which was obtained from experiments, and the heat exchanger surface temperature is 70°C to prevent condensation and boiling. The details of the meshing and numerical scheme can be found in [5].

Results and Discussion
The contours of reaction rate (kmol/m^{3}s) and temperature (°C) for different distances between the burner and heat exchanger are shown in Figures 2(a) and (b), respectively. For 25mm distance the flow and temperature around the flame are unaffected by the presence of the tube and this case would be the same as when there is no heat exchanger. This behavior continues until 10mm and based on the classification introduced by Zhang et al. [6] these two cases exhibit conical mode. However, for 8mm the flame shape starts deforming due to flow distortions and merging of flame temperature jump and heat exchanger thermal boundary layer, showing the envelope mode. Moving the heat exchanger 1mm closer will split the flame front and create cool central core mode. Further decrease of the distance

will not exhibit other modes introduced by Zhang et al. since the classification has been performed for flames impinging on flat plates. However, too close distances can cause intense flame quenching or stabilizing downstream of the tube, but these cases are not of practical importance and thus not studied here.



(a) (b)

Figure 2. Contours of (a) reaction rate [kmol/m3s] and (b) temperature [°C] for different distances between the burner deck and heat exchanger.

Figure 3 shows the gain and phase of flame transfer function for all cases. We can see that for 25 and 10mm cases the flame responses are almost identical. The gain for 8mm case has a decrease, but follows a similar behavior between 100 and 700Hz. The phase and therefore time delay for all these three cases is almost the same, except above 700Hz for which the 8mm case has a slightly larger phase. This can be attributed to the flow distortions upstream of the tube and the fact that in this case it can take longer for fluctuations to convect through the flame. The same explanation describes the overall larger phase for the 7mm case.

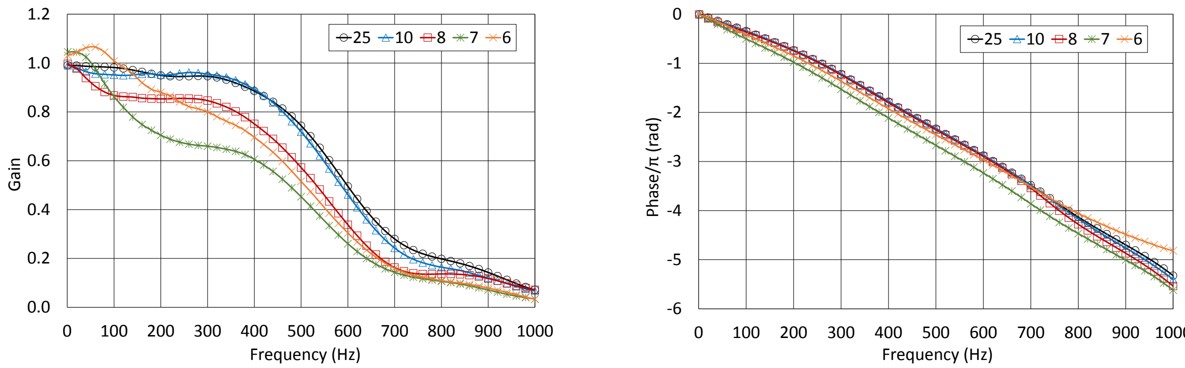


Figure 3. The gain and phase of the flame transfer function for different distances between the burner deck and heat exchanger.

For the 6mm case a part of the flame is deformed towards the high velocity region between the tubes and therefore this part of the flame has a shorter convective time. This is why the phase for this case is not as large as the 7mm case. The gain for the 6 and 7mm cases exhibits a different behavior. It starts from a value larger than one, which is not normal for flame transfer function. We need to keep in mind that unity gain at 0Hz is only when complete combustion happens, i.e. 5% increase in inlet velocity leads to 5% increase in heat release of the flame. However, when the tube penetrates the flame some amount of unburnt CH_4 leaves the flame through the thermal boundary layer around the tube. This amount decreases by increasing velocity due to shrinkage of the boundary layer. This causes more than 5% increase in the heat release of the flame and thus a gain of more than one at 0Hz. These conditions that exist for low frequencies can enhance the thermoacoustic instabilities.

This paper is a short communication of an ongoing study and more detailed results will be orally presented.

Acknowledgement

The presented work is part of the Marie Curie Initial Training Network, Thermo-acoustic and Aero-acoustic Nonlinearities in Green combustors with Orifice structures (TANGO). We gratefully acknowledge the financial support from the European Commission under call FP7-PEOPLE-ITN-2012.

References

[1] Noble, A. C., King, G. B., Laurendeau, N. M., Gord, J. R., Roy, S., *Combustion Science and Technology*, **184** (3), 293-322, 2012.
[2] Maria Luiza Bondar, *Acoustically Perturbed Bunsen Flames*, Doctor of Philosophy Thesis, Eindhoven University of Technology, 2007.
[3] Kornilov, V., Rook, R., ten Thije Boonkkamp, J. H. M., de Goey, L. P. H., *Combustion and Flame*, **156** (10), 1957-1970, 2009.
[4] Duchaine, F., Boudy, F., Durox, Daniel, Poinsot, Thierry, *Combustion and Flame*, **158** (12), 2384-2394, 2011.
[5] Hosseini, N., Kornilov, V., Teerling, O. J., Lopez Arteaga, I., de Goey, L. P. H., *ICSV21*, Beijing, China,13-17 July, 2014.
[6] Y. Zhang, K.N.C. Bray, Combustion and Flame, **116**, 671-674, 1999.