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Investigating the effects of a heat exchanger on the thermoacoustics in a Rijke tube

Naseh Hosseini[1,2,*], Viktor Kornilov[1], O.J. Teerling[2], Ines Lopez Arteaga[1,3] and L. P. H. de Goey[1]

[1] Eindhoven University of Technology, Mechanical Engineering Department, Eindhoven, the Netherlands.
[2] Bekaert Combustion Technology B.V., Assen, the Netherlands.
[3] KTH Royal Institute of Technology, Department of Aeronautical and Vehicle Engineering, Stockholm, Sweden
[*] E-mail: n.hosseini@tue.nl

Abstract

The goal of the present work is to investigate the effects of a heat exchanger on the instabilities in a Rijke tube. The motivation is the experimentally observed fact that the presence of the heat exchanger in a practical boiler changes the acoustics of the system. While the interactions between acoustic waves and premixed flames have been well studied in the literature, the thermoacoustic effects of the heat exchanger as a heat sink has mainly been ignored. In this study, we strive to reveal these effects on the stability of the system. This is achieved using a Helmholtz solver for modeling thermoacoustics in a Rijke tube including a heat source and a heat sink. We perform a parametric study on the interaction indices and time delays of the elements. The chosen values are then refined based on previous CFD calculations for a more detailed analysis. The results demonstrate that the heat sink can enhance as well as suppress the instabilities. Therefore, it is of utmost importance to study the thermoacoustics of both elements together to have a correct prediction of the system stability.

Introduction

Many researchers have investigated the thermoacoustic instabilities in lean premixed systems focusing on characterizing flame transfer functions for various types of flames [1-4]. While the interactions between acoustic waves and premixed flames have been well studied in the literature, the thermoacoustic effects of the heat exchanger as a heat sink has mainly been ignored. In this study, we strive to reveal these effects on the stability of the system. This is achieved using a Helmholtz solver for modeling thermoacoustics in a Rijke tube including a heat source and a heat sink. The chosen values for thermoacoustic properties of the elements are based on previous CFD calculations of a simplified setup comprising of wedge shaped (2D) premixed flames with cylindrical heat exchanger tubes placed downstream the flames [5]. This configuration is practically relevant as it is representative for the design of a majority of boilers and is composed of relatively simple elements that have been intensively studied separately [6-8].

Rijke Tube Model

An illustration of the Rijke tube with its dimensions is shown in Figure 1. The tube length is 1m and the heat source and sink are located at X=0.25 and 0.75m, respectively.

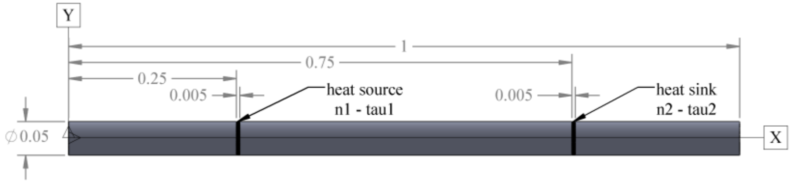

Figure 1. The Rijke tube model.

The Helmholtz solver COMSOL was used to calculate the eigenfrequencies and corresponding growth rates of the system. The heat source and sink were modeled by an interaction index, n, and a time delay, τ, using the methodology described in [9]. We use subscripts 1 and 2 for the properties of the heat source and sink, respectively. The parametric study was performed for $0 \leq n \leq 1$ and $0 \leq \tau \leq 3$ms for both elements. The effects of the mean flow and temperature variations are neglected in order to make the analysis simpler and isolate the effects of other parameters.

Results and Discussion

Figure 2 shows the eigenfrequencies and corresponding growth rates for varying τ_1 and τ_2 between 0 and 3ms when $n_1=n_2=1$. The eigenfrequency predominantly decreases with an increase in any of the time delays. For $\tau_1<2$ms, maximum growth rate occurs for $\tau_2=0.5$ms, with a large deviation from $\tau_2=0$ms. This is specifically interesting because previous CFD simulations have revealed that the interaction index and time delay of a tube heat exchanger is much smaller than that of flames [5]. It can be seen in Figure 2 that smaller values of τ_2 are even more critical than larger ones. Therefore, further analysis was made for $0 \leq \tau_2 \leq 0.5$ms and the results are plotted in Figure 3.

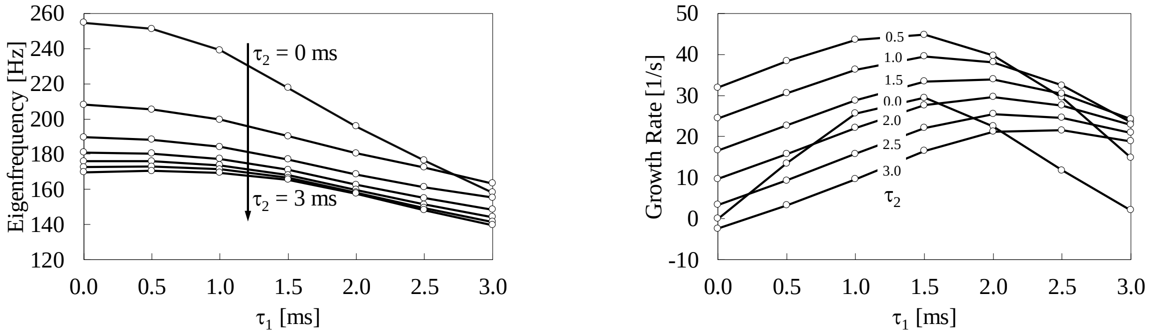

Figure 2. Eigenfrequencies and corresponding growth rates for $0 \leq \tau_1 \leq 3$ms and $0 \leq \tau_2 \leq$ms when $n_1 = n_2 = 1$.

Figure 3 illustrates the eigenfrequencies and corresponding growth rates for $0 \leq n_2 \leq 1$ and $0 \leq \tau_2 \leq 0.5$ms when $n_1=1$ and $t_1=1$ms. The results show that as long as n_2 is not zero, any increase in the time delay of the heat sink (in the specified limits), increases the system instability. The same analysis for other values of τ_1, or further increase in τ_2 will result in local maxima which should be investigated per case and are beyond the scope this short communication. However, more detailed results will be orally presented.

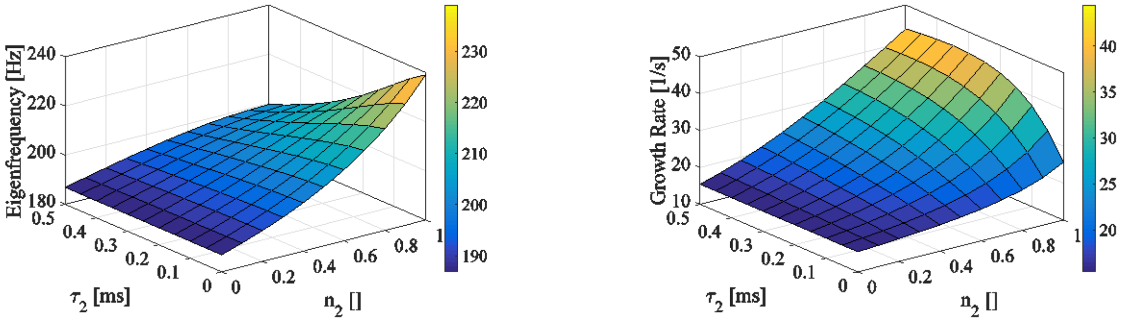

Figure 3. Eigenfrequencies and corresponding growth rates for $0 \leq n_2 \leq 1$ and $0 \leq \tau_2 \leq 0.5$ms when $n_1=1$ and $\tau_1=1$ms.

These results demonstrate that the heat sink can enhance as well as suppress the instabilities. Therefore, it is of utmost importance to study the thermoacoustics of both elements together to have a correct prediction of the system stability.

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