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Modified theoretical model for thermoacoustic couples

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ABSTRACT

The theoretical model of thermoacoustic couples is modified to incorporate more realistic physical processes that are acoustic dissipation within the stack, and the heat exchange between the stack and its surroundings, which were not considered in the previous models. The results show good agreement between the present and previous models at high thermal conductivity of the stack. However, at low stack thermal conductivity, the previous models not only significantly overestimate stack temperature difference (ΔT_s) but at certain stack positions they predict values of ΔT_s greater than the theoretically possible values. The comparison of ΔT_s values predicted by the present and previous theoretical models with the experimental results shows a good agreement between the present model and the experiments while, the previous models significantly overpredict ΔT_s for the given range of drive ratios. It is shown that the incorporation of realistic physical processes significantly improves the accuracy of the theoretical model for the thermoacoustic couples.

1. Introduction

Heat can be transferred from a cold reservoir to a hot reservoir by utilizing sound energy. This technology is called thermoacoustic refrigeration and it has introduced a new vision towards environmentally-friendly refrigeration systems. Thermoacoustic refrigerators, which convert sound energy into heat energy use noble gases as the refrigerant and thus, eliminate the use of conventional harmful refrigerants. Furthermore, the inherent simplicity, fewer components and dimensional flexibility make thermoacoustic refrigerators more appealing as the new generation of sustainable refrigerators. Development of the thermoacoustic linear theory played a major role in the recent advancement of this technology [1,2]. However, in several cases, disagreement between the predictions of the linear theory and experimental results have been reported which could be due to the simplified assumptions made in the theory. Nevertheless, this theoretical model is the only available tool to design thermoacoustic devices.

A thermoacoustic refrigerator consists of a resonator tube, a stack, two heat exchangers and an acoustic source (e.g. a loudspeaker) to excite a standing wave inside the tube. Several different configurations of the stack (which is the heart of a thermoacoustic device) have been proposed and/or used such as parallel plates, pin array or a porous medium. The two heat exchangers are attached to either sides of the stack and maintain the desired temperature gradient along the stack by transferring heat to and from the thermal reservoirs located outside the resonator tube. The stack of a thermoacoustic refrigerator in the absence of heat exchangers is called a thermoacoustic couple.

Thermoacoustic couples are used for the study of fundamental thermoacoustic processes [3,4]. Schematic of a thermoacoustic couple inside a resonator tube is shown in Fig. 1. A half-wavelength acoustic standing wave generated by the acoustic source excites the working gas parcels within the resonator tube. Due to the interaction of the gas parcels with the solid surface of the stack, temperature gradient is established along the stack. The stack (or couple) temperature difference, herein after referred to as ΔT_s, is defined as the steady-state temperature difference between the hot-end of the stack (located close to the pressure antinode) and the cold-end of the stack (located away from the pressure antinode). The resonator tube section between the acoustic source and the cold-end of the stack is referred to as the cold-side ambient duct whereas, the resonator tube section between the hot-end of the stack and closed end is referred to as the hot-side ambient duct (see Fig. 1). Improved understanding of the fundamental thermoacoustic process occurring in thermoacoustic couples is very crucial for the design and development of efficient thermoacoustic devices which have a great potential to serve as sustainable energy sources.

Thermoacoustic couple was first introduced by Wheatley et al. [3] in 1983. By applying the thermoacoustic linear theory, they proposed a procedure and finally an equation to estimate ΔT_s. In their formulation, they neglected the change in the work flow of the stack by assuming a short stack. They also assumed that the thermal conductivity of the stack is high enough that the heat

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