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Experimental investigation of ceramic substrates in standing wave thermoacoustic refrigerator

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Abstract

This work experimentally investigates the performance of ceramic substrates used as stacks in standing wave thermoacoustic coolers. Thermoacoustic technology is proposed in this study as an alternative sustainable solution to current issues with vapour compression refrigerators because of its environmentally friendlier attributes. However, the main hindrance to the expansion of this technology is its current lack of efficiency. Hence, an experimental investigation was conducted in this study. The influence of the geometrical configuration of the stack, described as the heart of the device, is investigated. The device was equipped with different selected low-cost porous materials (ceramic substrates) for performance testing and studies. Porosity, length and position of the ceramic substrates are variables that are considered in order to investigate the performance of the cooler. Eight cordierite honeycomb ceramic substrates with square cross sections and of four different lengths (26 mm, 48 mm, 70 mm and 100 mm) were considered. Five different stack positions, measured from the hot ends of the stack to the pressure antinode in increments of 100 mm, were investigated. Measurement of temperature difference at steady state was used to determine the performance of a particular configuration. Guidance on the design of this sustainable solution for refrigeration and selection of the best geometrical configuration of ceramic substrates are provided. In addition, clarity on the relation between the geometrical configurations and the frequencies of the sound wave is highlighted.

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Nomenclature

f	Resonant frequency	(Hz)	Tm	Mean temperature	(^oC)
δk	Thermal penetration	(mm)	T_{hot}	Temperature at hot side of stack	(^oC)
v	Speed of sound	(m/s)	T_{cold}	Temperature at cold side of stack	(^oC)
L	Length of resonator tube (mm)	(mm)	ΔT	Temperature difference	(^oC)
CPSR	Cells per square inch		Xs	Stack position from closed end	(mm)
Ks	Thermal conductivity of stack	(W/mK)	L_s	Length of stack	(mm)

1. Introduction

Thermoacoustics is a study that focuses on the interaction of thermodynamics and acoustics. Acoustic waves contain coupled pressure and displacement oscillations. These sound waves drive parcels of gas and interact with boundaries that cause a thermal change [1]. Thermoacoustic effect is the energy transformation of acoustic work absorbed to transport heat (thermoacoustic refrigerator TAR) or the energy conversion of the heat supplied to produce acoustic work (Thermoacoustic engine TAE) [2]. The thermoacoustic cooler converts acoustic standing waves into a temperature gradient. They consist of a resonator tube connected to loudspeaker filled with a gas medium. Inside the resonator tube, a stack and two heat exchangers can be found (see Fig. 1). The loudspeaker produces an acoustic standing wave at the fundamental frequency which interacts with a porous medium known as the stack [3]. The incentive for these systems to compete with commercial refrigerators is lack of moving parts. Furthermore, unlike the vapour compression cycle, the thermoacoustic refrigerator uses gas mediums which are environmentally friendlier than commercial refrigerants. Although these systems are simple to design, the main hindrance of the development of this technology is the efficiency and performance [4]. Therefore, further research is required.

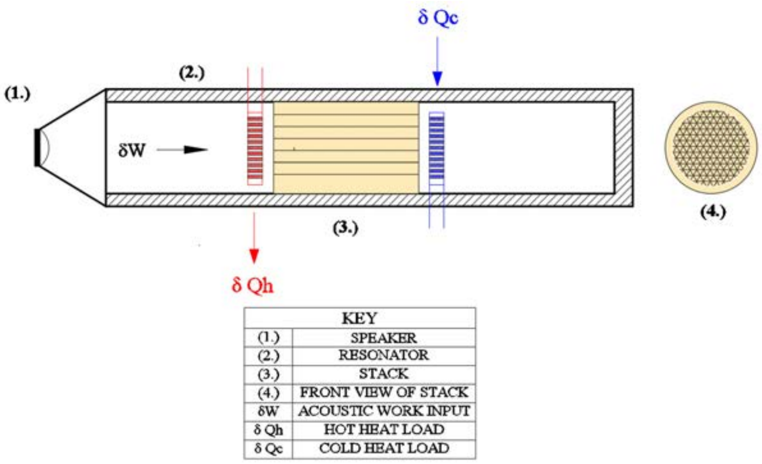

Fig 1. Thermoacoustic Refrigerator

The 'heart' of a thermoacoustic system is known as the stack. This porous medium experiences maximum losses due to viscous resistance and thermal losses [5]. The stack acts as a boundary for the compression and expansion of gas. The gas follows an approximate Brayton cycle [6]. The stack material is of vital importance as the thermal conductivity and specific heat capacity influence the heat transfer performance in the system [7].