A Compact Standing-Wave Thermoacoustic Refrigerator Driven by a Rotary Drive Mechanism

Authors : Kareem Abdelwahed, Ahmed Salama, Ahmed Rabie, Ahmed Hamdy, Waleed Abdelfattah, Ahmed Abd El-Rahman

Abstract : Conventional vapor-compression refrigeration systems rely on typical refrigerants, such as CFC, HCFC and ammonia. Despite of their suitable thermodynamic properties and their stability in the atmosphere, their corresponding global warming potential and ozone depletion potential raise concerns about their usage. Thus, the need for new refrigeration systems, which are environment-friendly, inexpensive and simple in construction, has strongly motivated the development of thermoacoustic energy conversion systems. A thermoacoustic refrigerator (TAR) is a device that is mainly consisting of a resonator, a stack and two heat exchangers. Typically, the resonator is a long circular tube, made of copper or steel and filled with Helium as a the working gas, while the stack has short and relatively low thermal conductivity ceramic parallel plates aligned with the direction of the prevailing resonant wave. Typically, the resonator of a standing-wave refrigerator has one end closed and is bounded by the acoustic driver at the other end enabling the propagation of half-wavelength acoustic excitation. The hot and cold heat exchangers are made of copper to allow for efficient heat transfer between the working gas and the external heat source and sink respectively. TARs are interesting because they have no moving parts, unlike conventional refrigerators, and almost no environmental impact exists as they rely on the conversion of acoustic and heat energies. Their fabrication process is rather simpler and sizes span wide variety of length scales. The viscous and thermal interactions between the stack plates, heat exchangers' plates and the working gas significantly affect the flow field within the plates' channels, and the energy flux density at the plates' surfaces, respectively. Here, the design, the manufacture and the testing of a compact refrigeration system that is based on the thermoacoustic energy-conversion technology is reported. A 1-D linear acoustic model is carefully and specifically developed, which is followed by building the hardware and testing procedures. The system consists of two harmonically-oscillating pistons driven by a simple 1-HP rotary drive mechanism operating at a frequency of 42Hz -hereby, replacing typical expensive linear motors and loudspeakers-, and a thermoacoustic stack within which the energy conversion of sound into heat is taken place. Air at ambient conditions is used as the working gas while the amplitude of the driver's displacement reaches 19 mm. The 30-cm-long stack is a simple porous ceramic material having 100 square channels per square inch. During operation, both oscillating-gas pressure and solid-stack temperature are recorded for further analysis. Measurements show a maximum temperature difference of about 27 degrees between the stack hot and cold ends with a Carnot coefficient of performance of 11 and estimated cooling capacity of five Watts, when operating at ambient conditions. A dynamic pressure of 7-kPa-amplitude is recorded, yielding a drive ratio of 7% approximately, and found in a good agreement with theoretical prediction. The system behavior is clearly non-linear and significant non-linear loss mechanisms are evident. This work helps understanding the operation principles of thermoacoustic refrigerators and presents a keystone towards developing commercial thermoacoustic refrigerator units.

Keywords : refrigeration system, rotary drive mechanism, standing-wave, thermoacoustic refrigerator
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