DESIGN OPTIMIZATION OF THE OF AN AUTOMOTIVE THERMOACOUSTIC AIR CONDITIONING SYSTEM

Hadi Babaei, Kamran Siddiqui
Dept. of Mechanical and Industrial Engineering, Concordia University, 1455 De Maisonneuve Blvd. W., Quebec, Canada, H3G 1M8 h_babaei@alcor.concordia.ca

1. INTRODUCTION

Concerns about global warming, pollution and the depletion of ozone layer due to CFC refrigerants have urged researchers to find alternatives to conventional engines and refrigerators. Some recent advancement in the field of thermoacoustics have revolutionized the way many conventional devices operate. Thermoacoustics deals with the conversion of heat into sound energy and vice versa. A heat-driven thermoacoustic refrigerator (HDTAR) can be considered as a new source of renewable energy with no moving part and no hazardous materials. A HDTAR is comprised of a thermoacoustic heat engine which converts heat into acoustic work and a thermoacoustic refrigerator which utilizes this acoustic work as an input to produce refrigeration. Thus, by applying this technology, any source of heat particularly the industrial waste heat could be utilized for cooling purposes. One of the potential applications of HDTAR is the automotive air conditioning system in which the engine waste heat could be used for air conditioning purposes. Zoontjens *et al.* [1] investigated the feasibility of using such devices as the air conditioning system of an automotive. They concluded that the thermoacoustic refrigeration is the most appealing of all the alternative refrigeration technologies considered in their studies. They used the computer program DeltaE [2] to design and propose a HDTAR for automotive air conditioning systems. In the present study, an alternative device is designed and optimized with higher overall efficiency of that of proposed by Zoontjens et *al* [1]. This device is also simulated by DeltaE to verify the results.

2. METHODOLOGY

A comprehensive algorithm has been developed by the authors (described elsewhere) to design and optimize heat-driven thermoacoustic refrigeration systems. This algorithm is applied to design and optimize a HDTAR capable of providing 30 w of cooling power at 2˚C. The four heat exchangers of the device are optimized to improve the efficiency of the system and to make them practical [3]. Finally, the computer code DeltaE is used to simulate the device. The data obtained from DeltaE simulations are used for comparison with the design of Zoontjens *et al.* [1] and discussion.

3. RESULTS

Figure 1 shows the schematic of the designed and optimized HDTAR. Helium is considered as the working gas at the mean pressure of 700 kPa. The HDTAR has the total length of 1.25 m and the cross sectional area of $0.012m^2$. A half wavelength standing acoustic wave with the resonance frequency of about 400 Hz is produced by the engine stack (the stack on the left side in Figure 1). The variation of the acoustic power along the axial coordinate of the resonator is shown in figure 2. The thermoacoustic engine can theoretically produce 25.3 W of acoustic power by utilizing 159 W of waste heat from the automobile engine. Although the temperatures of the waste heat in an automotive engine range from 200˚C to 600˚C [4], for the present case, the temperature of waste heat is considered to be 260˚C. About 7.3 W of the produced acoustic power is consumed by the refrigerator stack (the stack on the right side in Figure 1) to provide the desired cooling power of 30 W at 2˚C. Figure 2 also shows the dissipation of some acoustic power in the resonator.

Fig. 1. Schematic of the designed HDTAR. All dimensions are in millimeters.

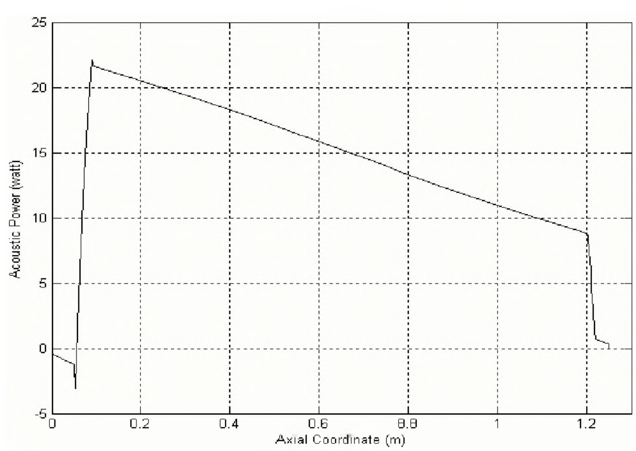

Fig. 2. Variation of acoustic power along the resonator

The device is designed to have the maximum pressure amplitude of 21 kPa. The drive ratio (DR) which is the ratio of the pressure amplitude to mean pressure is about 3% which is within the linear range of the thermoacoustic theory. Thus, the available thermoacoustic model which has been developed by linearizing the governing equations [5, 6] can be used to predict the behavior of the given thermoacoustic device with reasonable accuracy.

Figure 3 shows the schematic of the apparatus proposed by Zoontjens *et al* [1]. The parameters of the two numerically designed apparatuses are compared in Table 1.

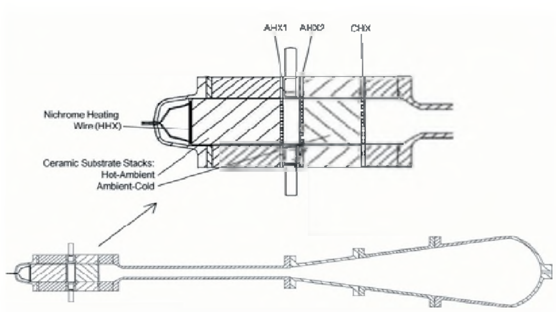

Fig. 3. Schematic of the apparatus proposed by Reference 1.

The results in Table 1 show that the device proposed in the present study is capable of providing the same cooling power (i.e. 30 W) as of that proposed by Zoontjens *et al* [1] with almost half of the heat input. Thus, the overall efficiency of the present design is 8.8% higher than that of Zoontjens *et al* [1]. The power density in a thermoacoustic device is proportional to DR^2; meanwhile, there is no theoretical model to predict the behavior and the performance of a thermoacoustic device in the nonlinear range (DR>0.03). It could be concluded that the proposed design in this study is more reliable and predictable since the apparatus of Zoontjens *et al* [1] is designed using a linear model for DR = 26.5% that correspond to highly nonlinear regime.

4. CONCULUSION

A HDTAR is theoretically designed for automotive air conditioning application. The device receives 159 W of waste heat from the automotive engine and produces 30 W of cooling power. The overall efficiency of the designed device is 8.8% higher than the previously designed thermoacoustic device by Zoontjens *et al* [1] for automotive air conditioning. The results indicate that since HDTAR devices utilize the available waste heat from the automotive engine to cool down the automotive interior, even at relatively low efficiency these devices could still reduce the amount of fuel used in the conventional automotive air conditioning systems.

By designing a thermoacoustic system operating at higher hot heat exchanger temperatures, optimizing the shape of the resonator [7] and using working gases with lower Prandtl number [8], the theoretical efficiency of the proposed system can improve to the higher values. With higher efficiencies, these devices have a very strong potential to replace the existing automotive air conditioning systems thus providing environmental as well as economical benefits to the society.

Apparatus Characteristics	Proposed in the present study	Proposed by Zoontjens *et al.*
Working gas	Helium	Helium
Mean pressure (kPa)	700	700
Drive ratio (%)	3	26.5
Frequency (Hz)	400	256
Cooling power (W)	30	30
Cooling temperature (˚C)	2	2
Ambient heat exchangers temperature (˚C)	27	27
Estimated required waste heat for engine (W)	159	300
Hot heat exchanger temperature (˚C)	260	450
Overall efficiency (%)	18.8	10

Table 1. Comparison between two numerically designed devices.

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