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Analysis of Increasing the Optimized Parameters in Improving the Performance of a Thermoacoustic Refrigerator

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Abstract

The scarcity of energy resources and increasing concerns over the environmental degradation due to global warming and hazardous pollution has spurred extensive research into alternative clean technologies as well as more efficient energy-related systems. Most importantly, the optimization of the performance of cooling systems is crucial for best practices in energy management. Environmentally friendly thermoacoustic refrigerators that use no refrigerant or compressor are currently being considered as alternatives. The prototypes built to date, however, achieved 0.1-0.2 relative coefficient of performance (COPR) compared to that of 0.33-0.5 for the conventional vapour-compression refrigerators. This paper discussed the optimization efforts on a thermoacoustic refrigerator with multi-objective genetic algorithm (MOGA), an evolutionary optimization tool that has not been tried on the system before. Past optimization schemes, experimentally and numerically, are constrained by the discrete variations of parameters to be optimized to achieve individual objectives. The outcome would be a local minimum/maximum. In this study, simultaneous optimization of two and four parameters to obtain conflicting objectives, maximum cooling and minimum work at the stack of the thermoacoustic refrigerator is completed. The results showed that as the parameters to be optimized increases, the coefficient of performance also increases showing potential towards much improvement to be expected from thermoacoustic refrigerators.

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1. Introduction

Thermoacoustic refrigeratoris an alternative environmentally friendly system with inert gasses as the working fluid. Although several prototypes and working systems have been out, the coefficient of

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performance (COP) of these thermoacoustic refrigeration systems is relatively low compared to its conventional counter parts [1]. Optimization of a thermoacoustic refrigerator is important in the design to make it competitive for consideration by the general public. The optimization of the thermoacoustic refrigerator can be divided into two main categories; geometrical and operating parameters. The former was done byWetzel and Herman [2],Tijani et al. [3], Babaei and Kamran[4], Zink et al. [5]. Their parameters include the stack length and position, the plate spacing and the resonator length. Minner et al. [6], Emmanuel and Azrai [7], Tasnim et al. [8] were associated with the operating parameters optimization which include the frequency, working fluid, temperature, and pressure in the resonator.

The preceding brief review indicates the limited comprehensive optimization schemes that have been applied to date on thermoacoustic refrigeration systems. They are limited to the local optimum/minimum. Multi-objective Genetic algorithm (MOGA) is a relatively recent optimization scheme with a strong ability in global search for the optimized solution(s) [9]. It has not been tried on a thermoacoustic refrigerator yet. This paper reports the results of a MOGA optimization scheme applied to a thermoacoustic refrigerator; in a simultaneous two-parameter and four-paramter optimization. The system investigated follows that of Tijani et al [3] because their system was built and tested for its COP.

2. Optimization algorithm using MOGA

In a thermoacoustic refrigerator, the heat removed from the cold heat exchanger is Q_c at T_c and the net work used to accomplish this effect is W, the acoustic power used to sustain the standing wave against the thermal and viscous dissipations. The rest of the acoustic power is used in the thermoacoustic effects to transport heat from the cold heat exchanger to the hot exchanger. The expression of the heat flow and acoustic power can be rewritten in a dimensionless form[3],

$$Q_{cn} = \frac{\delta_{kn} DR^2 \sin 2x_n}{8\gamma(1+\sigma)} x\left(\frac{\Delta T_{mn} \tan x_n}{(\gamma-1)BRL_{sn}} \frac{1+\sqrt{\sigma}+\sigma}{1+\sqrt{\sigma}} - 1 + \sqrt{\sigma} - \sqrt{\sigma}\delta_{kn}\right) \tag{1}$$

$$W_n = \frac{\delta_{kn} L_{sn} DR^2}{4\gamma} (\gamma - 1) BR\cos^2 x_n x \left(\frac{\Delta T_{mn} \tan x_n}{BRL_{sn}(\gamma-1)(1+\sqrt{\sigma})} - 1\right) - \frac{\delta_{kn} L_{sn} DR^2}{4\gamma} \frac{\sqrt{\sigma}\sin^2 x_n}{BR} \tag{2}$$

In this study, the MOGA optimization scheme is applied to a system designed and tested by Tijani et al.[3] for comparison purposes. Two objective functions chosen are the minimization of the acoustic work at the stack and the maximization of the cooling load at the stack, Eqs. (1) and (2). MOGA optimization scheme in MATLAB toolbox is first used to see if the results of Tijani et al. [3]are duplicated, in the two-parameter optimization.This involved optimization of the stack center position and length. In MOGA, from an initial population, through a probabilistic technique, an intermediate population that has a higher representation of the strong species is generated. Through cross-over mating and modification with mutation, subsequent population is produced. The procedure is repeated until the termination condition isreached[10]. Then, with the same objectives, simultaneous optimization of the stack center position (x_{sn}) and stack length (L_{sn}), blockage ratio (BR), and drive ratio (DR) are done. The MOGA scheme was applied where the parameters of Tijani et al. [3] are now instead of being discretely varied, are given in the range of $0.06 \leq x_{sn} \leq 0.42$, $0 \leq L_{sn} \leq 1$, $0.67 \leq BR \leq 0.8$ and $0.02 \leq DR \leq 0.03$.

3. Results and discussions

The two parameters optimization shows that the MOGA scheme obtained what could be achieved with parametric optimization, minimum work and maximum cooling at the stack. Fig. 1 shows the outcome the two parameters optimization. Fig. 1(a) repeats what has been obtained by Tijani et al[3].