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Performance of solar powered thermoacoustic engine at different tilted angles

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ABSTRACT

In this study, the thermodynamic performance of a thermoacoustic engine charged with different working fluids were examined at different tilted angles ranging from −90° to 90° with 45° angular interval. The results suggest that the influence of the tilted angle on the onset temperature of the engine depends on the viscidity of the working gas. The lower the viscidity is, the more obvious the influence is. The difference between the maximum and the minimum onset temperature of the engine charged with nitrogen could be as high as 52 °C, but the difference for system charged with helium is only about 1.5 °C. The tilted angle has little or no effect on the pressure oscillation amplitude, pressure ratio, resonance frequency and the relation of the temperature versus heat power. They are mainly affected by the properties of the working gas. Furthermore, the interactions of the oscillatory motion and the natural convection of the working gas within the thermoacoustic core were also examined. The properties are of importance for the thermoacoustic engine driven by two-axis solar collector, for the tilted angle of the engine varies with the sun position.

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1. Introduction

Thermoacoustic effect is the thermodynamic interaction between acoustics and solid surfaces that possess a temperature gradient. Several useful devices including thermoacoustic engines [1–9], thermoacoustic refrigerators [2–9] and thermoacoustic electric generators [10,11] can be constructed based on thermoacoustics effects. Three of the most important advantages of thermoacoustic devices are: (1) no moving components involved except for the working gas undergoing the acoustic motion; (2) working fluid is inert, which is friendly to environment; (3) it can be directly driven by thermal energy, including solar energy, fuel gas, etc. More and more attentions have been devoted to thermoacoustic devices which can be operated by renewable energy resources.

Solar powered thermoacoustic engine is heated by thermal energy from solar radiation, and its acoustic power is then used to pump heat from external loads or to drive linear electric generators. This direct conversion between solar energy and mechanical energy or electric energy without any moving component makes the mechanism simple. Several researchers have investigated the solar powered thermoacoustic engines [3,4]. Chen [3] constructed the first solar powered thermoacoustic cooler which was heated by a parabolic dish collector. The cooler just achieved 1.5 °C temperature span due to gas leakage and thermal losses. Adeff and Hofler [4] had experimentally studied a thermoacoustic refrigerator driven by thermoacoustic engine which was powered by concentrated solar radiation with a Fresnel lens. The refrigerator produced 2.5 w of cooling power with the cold temperature reaching 5 °C and the temperature span of 18 °C.

To drive the thermoacoustic devices by solar energy, the simplest approach is positioning the hot heat exchanger of the thermoacoustic engine which circumrotates along with the solar collector near the focal spot of a concentrated solar energy collector. The tilted angle of thermoacoustic engine will vary with time continuously when the engine circumrotates along with the collector, and the magnitude of the natural convection in the acoustic power transport direction varies at different tilted angel. From a scientific standpoint, the interaction of the natural convection and the pressure wave represent very interesting research challenges. Lin et al. [12] numerically investigated the effect of the gravity on the generation and the propagation of flows induced by thermoacoustic waves in a square enclosure with side length 13 mm. They comparatively studied the temperature field within the square enclosure with normal gravity and without gravity. They also numerically investigated the effect of the rising rate of the left wall temperature on the flow filed within the square enclosure. Matveev et al. [13,14] derived a simple mathematical model to study the effect of the gravity magnitude on the Rayleigh streaming within the thermoacoustic buffer tube between the hot heat exchanger (up) and the environment heat exchanger (down). However, little research has been devoted to the effect of the tilted angle of the thermoacoustic engine on its thermodynamic performance.

The aim of this report is to investigate the effect of tilted angle of thermoacoustic engine charged with different working gas on

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the onset temperature of the thermoacoustic engine, pressure amplitude, pressure ratio, the resonance frequency and the relation of the hot heat exchanger temperature versus the heat power etc. The interactions of the oscillatory motion and the natural convection of the working gas within the thermoacoustic core were also examined. The results of the experiment are of importance for the design and the selection of working gas for the thermoacoustic engine driven by two-axis solar collector which follows the solar position.

2. Experimental system

2.1. Experimental apparatus

Fig. 1 shows the configurations of the experimental apparatus and a picture of the solar powered system is presented in Fig. 2. Thermoacoustic core and resonator cavity were connected to both sides of the resonator tube with the inner diameter of 36 mm and the length of 1.5 m. Fig. 1b shows the local magnified view of the thermoacoustic core which consists of hot buffer, hot heat exchanger, stack, and cooling heat exchanger arranged from left to right. A silicon–carbon rod heater was used to simulate the two-axis solar collector to power the prime mover. The hot and cooling heat exchangers consist of copper fins (gas-side) which are machined by wire cutting. Fig. 3 is the appearance of the cooling heat exchanger. The fin thickness is 0.5 mm, and the fin spacing is 1 mm. The external wall (water-side) of the cooling heat exchanger has a spiral channel with water flowing. The fins within the hot heat exchanger is the same as that of the cooling heat exchanger, but the external wall of the hot heat exchanger interference fits with the internal wall of the tube of the thermoacoustic core. The parallel-plate stack is located between the hot heat exchanger and the cooling heat exchanger. The parallel-plate stack consists of parallel stainless steel plates which are spaced by stainless steel wire as shown in Fig. 1b. The dimensions of the main parts are tabulated in Table 1. To simulate the heat source from concentrated solar collector, an electrical heater consisting of 10 silicon–carbon rods was used to provide high temperature heat source, so the tilted angle can be easily set or changed. The heat power produced by the electrical heater was transferred to the stack tube by radiation, and then conducted to the hot heat exchanger. With the hot heat exchanger and the cooling heat exchanger, a temperature gradient

Fig. 2. Photo of two-axis tracking solar powered thermoacoustic engine.

Fig. 3. Photo of the cooling heat exchanger.

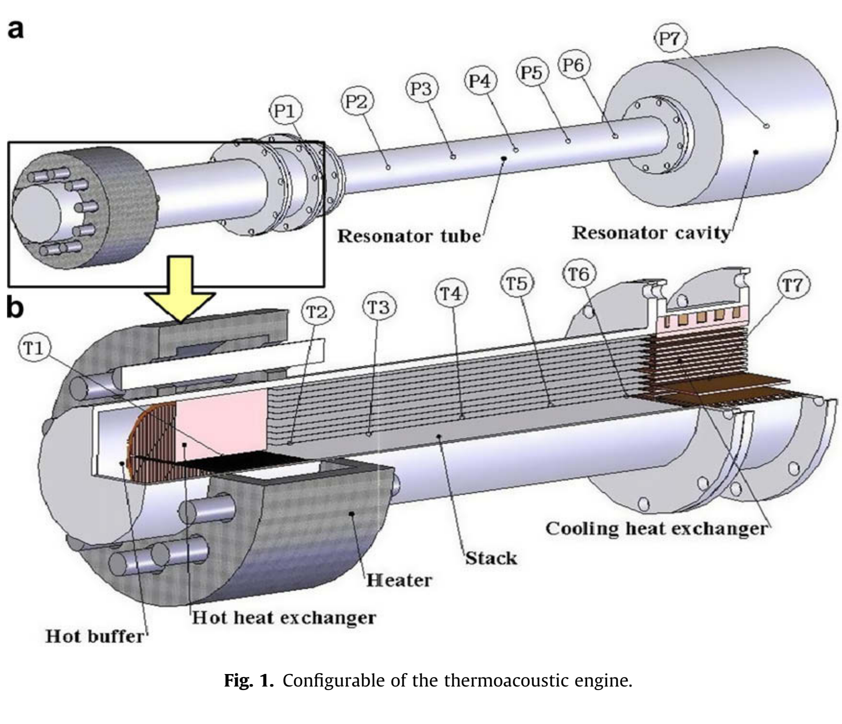

Fig. 1. Configurable of the thermoacoustic engine.

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