Experimental investigation on the performances of gas flow in oscillating tube

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The gas oscillating tubes are the key part of the gas wave refrigerator for heat change with environment. The flow progress of the gas in the oscillating tubes is very complex. A set of experimental apparatus has been designed and manufactured. The work medium is compressed air supplied by the oiless air compressor. The oscillating tube with shock wave damping tank and circumfluence tube have been performed with this apparatus. The experimental results show that the reflecting shock wave in the gas oscillating tubes were weaken and the temperature drops and isentropic refrigerating efficiency of the oscillating tube can be increased by coupling with shock wave damping tank or circumfluence tube.

INTRODUCTION

Gas wave refrigerator, also called pressure wave refrigerator or thermal separator, is a kind of refrigerator utilizes pressure energy of gas to achieve low temperature. The gas oscillating tubes are the key parts of the gas wave refrigerator for heat change with environment. The flow progress of the gas in the oscillating tubes is very complex.

Shock and expansion waves are two kinds of basic moving waves in the oscillating tube. Their movement and interaction between them produce the refrigerating effect. When supersonic flow from nozzle meet the immobile gas in oscillating tube, the shock wave forms in front of the interface and move to the hot end of the tube. The moving speed is supersonic contrast to the flow before shock wave, but is subsonic contrast to the flow after shock wave. The entropy increases when the gas compressed by shock wave. The shock wave stronger is, and the entropy increases larger is.

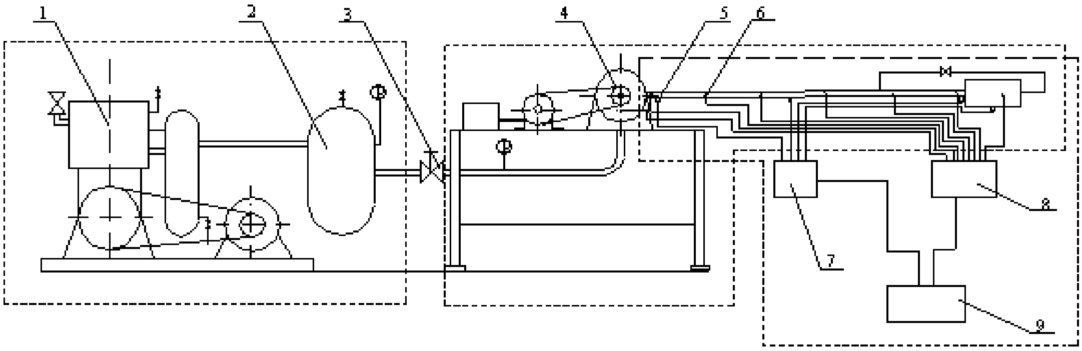
The research shows that the reflected shock wave is the main factor which influences the refrigerating effect [1]. Shock wave is reflected on rigid wall by shock wave, and expansion wave is reflected on free surface. A stronger shock wave is formed when two shock waves interaction, but the intensity weakens when it acted by expansion wave. The shock waves in oscillating tube can be eliminate or weaken by increasing friction of the wall of the tube, increasing damp in hot end, reducing the energy of the gas or acting by expansion wave.

EXPERIMENTAL APPARATUS

Considering similar to the industrial equipment and operation expediently, a set of experimental apparatus for has been designed and manufactured [2], as shown in figure 1.

The work medium is compressed air supplied by the oiless air compressor. The temperature drops and refrigerating efficiency are calculated by measuring the temperatures of the gas flow into and out the oscillating tube. The thermocouples and Agilengt 34970A data acquisition/switch unit are applied to measure the temperature. The Cy-yd-205 type pressure sensors are used to measure the pressure of the gas in oscillating tube, the signal from them are amplified by electric charge amplifier and received by an A/D card fixed in computer.

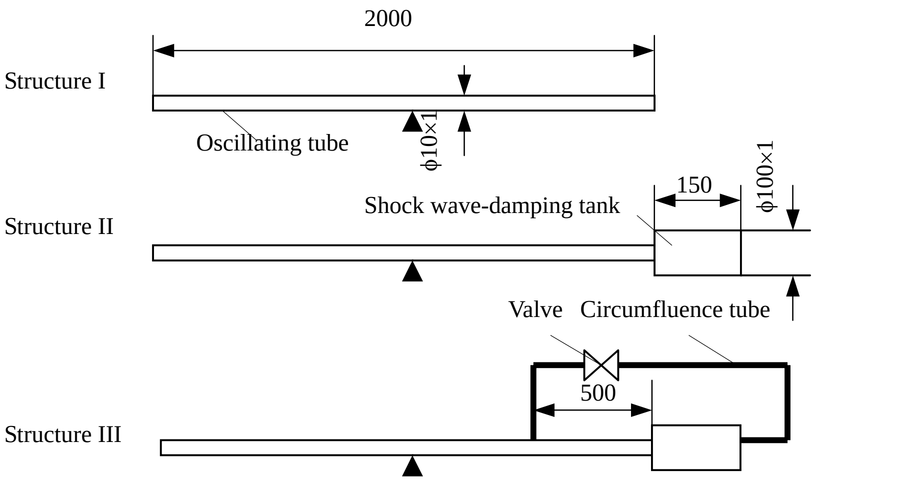
It can be know by analyzing the refrigeration mechanisms and the factors effect isentropic efficiency of gas wave refrigerator, that there are two ways to weaken the reflected shock wave and increase the isentropic efficiency: 1). To decrease the enthalpy of the gas oscillating in the tube as far as possible by enhancing heat transfer outside the oscillating tubes [3]; 2). To weaken the reflecting shock waves by changing the gas flow in the tube.



1.ZW-1.0/8 oilless air compressor 2.gas storage tank 3.valve 4. Pulse tube-Gas wave refrigerator 5.pressure sensor 6.thermocouple 7.electric charge amplifier 8.Agilengt 34970A data acquisition/switch unit 9.computer

Figure 1 Experimental apparatus for gas wave refrigerator

The gas flow in the oscillating tubes can be changed by changing the structure of the oscillating tubes, especially the structure of the hot end of the tubes. The reflected shock waves can be weakened by designing the structure of the oscillating tubes properly or adjusting the phases of shock waves and expansion waves. Shock wave is reflected on rigid wall by shock wave, and expansion wave is reflected on free surface. So a tank was introduced on the hot end of the oscillating. When the shock waves move to the end of the oscillating tube and come into contact with the section expanding suddenly, the shock waves will weaken and expansion waves produced and move towards the cool end in the oscillating tube. A valve and a circumfluence tube were fixed to adjust the gas flow. Then, three projects for experiment were put forward, as shown in figure 2.



Structure I: straight tube Structure II: tube with shock wave damping tank
Structure III: tube with circumfluence tube ▲ location of pressure measurement

Figure 2 Schematic of different structures of oscillating tubes

FLOW IN THE OSCILLATING TUBE

In order to research the gas flow in the oscillating tubes with different structures, the pressure waves in three oscillating tubes above-mentioned were measured. At the same time, the temperatures and pressures of the entering and discharged gas were measured. The pressure of the gas entering into the tube is 0.5MPa, and the pressure of the discharged gas is 0.1MPa ($\varepsilon = 5.0$). The pressure waves in the tubes were shown in figure 3.

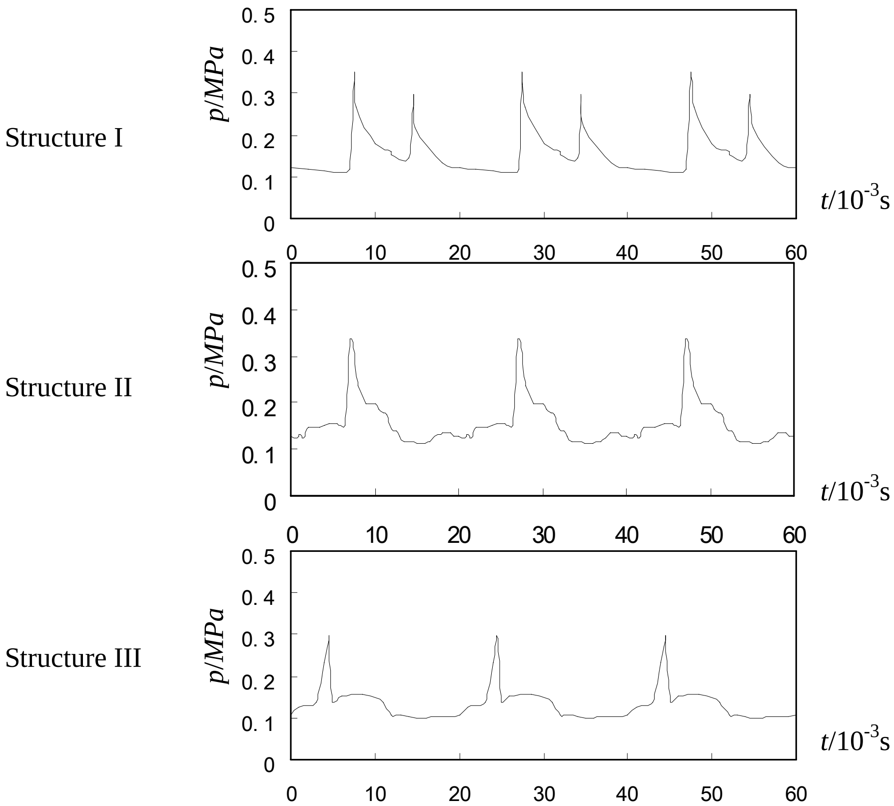


Figure 3 Pressure waves in different oscillating tubes

In the pressure waves in structure I, two peak pressures appear. The higher one is the main shock wave moving from the cool end to hot end, and the lower one is the shock wave reflected on the rigid wall of the tube. Though the peak value of the reflected shock wave is lower than the main shock wave, it is more high compared with it in structure II and structure III.

In the structure II, the reflected wave is weaker than it in structure I. It indicates that the tank on the hot end of the oscillating tube can weaken the shock wave effectively.

In the structure III, the reflected wave is weaker tan it in structure I and II. The pressure wave becomes smoother after the main shock wave. Also, the time of the shock wave acting in the tube become shot.

TEMPERATURE DISTRIBUTION ALONG THE OSCILLATING TUBE

Figure 4 shows the temperature distribution on the outer surface of the oscillating tube. In structure I, the temperature is most high in the three structures. The temperature climbs from the open end to the hot end. The highest temperature appears on the end of the oscillating tube. A small peak appears near the end of tube as a result of the reflected shock wave influencing in the tube. In structure III, the highest temperature appears near the middle of the oscillating tube. The temperature becomes stable after the peak point. It indicates that the gas flow stably in the tail part of the oscillating tube.

REFRIGERATING EFFECT IN DIFFERENT OSCILLATING TUBES

Figure 5 and 6 show the temperature drops and the isentropic refrigerating efficiency with different structures of the oscillating tubes (under different pressures of the entering gas).

The experimental results show temperature drops and isentropic refrigerating efficiency of the oscillating tube can be increased by coupling with shock wave damping tank or circumfluence tube. Especially by coupling with the circumfluence tube, the temperature drops and isentropic refrigerating efficiency increase by 7.6K and 5.0% ($\varepsilon = 8.0$) respectively contrast to the shock damping tank structure.

Therefore, the max temperature drop of the experimental oscillating tube is 48.2K and the max refrigerating efficiency is 49.3%.

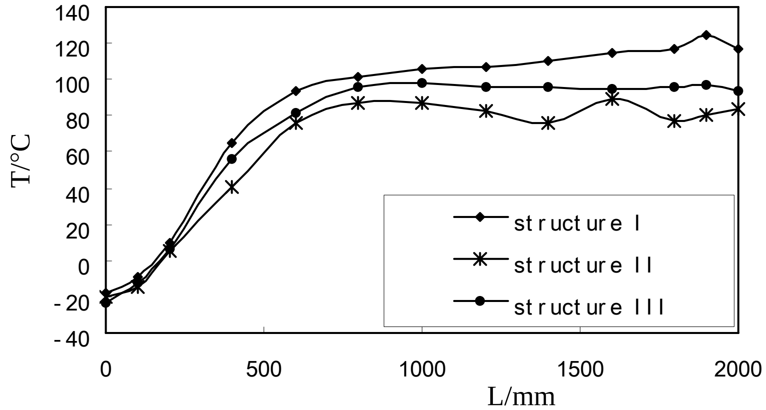


Figure 4 Temperature distributions along oscillating tube with different structures

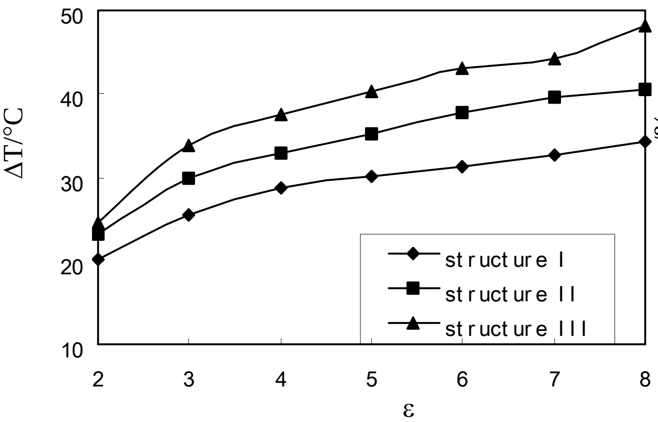


Figure 5 Temperature drops with different structures

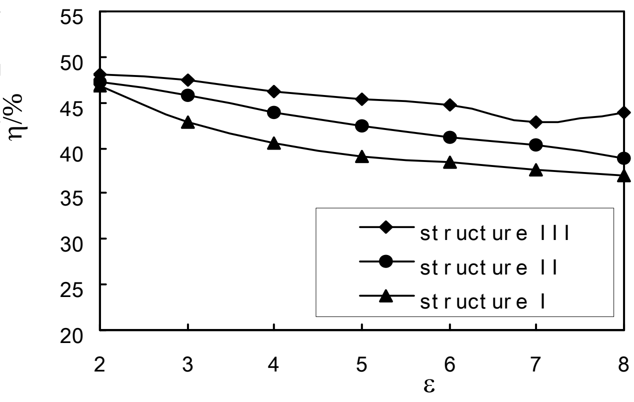


Figure 6 Refrigerating efficiency with different structures

CONCLUSIONS

Shock wave damping tank and circumfluence tube can weaken the influence of reflecting shock wave and adjust the gas flow. In the oscillating tube. The temperature drops and isentropic refrigerating efficiency of the oscillating tube can be increased by coupling with shock wave damping tank or circumfluence tube.

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