*Heat Transfer—Asian Research*, **34** (4), 2005

# Factors Influencing the Lowest Refrigerating Temperature of the Miniature Co-Axial Pulse Tube Refrigerator

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Experimental studies of the influencing factors on the lowest refrigerating temperature of a miniature co-axial pulse tube refrigerator have been carried out in this paper. The results show that with the decrease of the mole fraction of hydrogen in the hydrogen-helium mixture, the lowest refrigerating temperature decreases, and when the mole fraction of hydrogen is below 20%, the lowest refrigerating temperature is close to that obtained using pure helium. In addition, it is also found that the optimum frequency of the compressor is about 16.7 Hz for different hydrogen-helium mixtures. When the charge pressure of the compressor increases, the lowest refrigerating temperature decreases; however, the decreasing trend gradually slows down with the increase of the charge pressure. © 2005 Wiley Periodicals, Inc. Heat Trans Asian Res, 34(4): 219–225, 2005; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/htj.20065

**Key words:** miniature co-axial pulse tube refrigerator, hydrogen-helium mixture, lowest refrigerating temperature, optimum frequency, mean pressure

## 1. Introduction

Pulse tube refrigerator (PTR) is an attractive low-temperature source device for infrared detection and superconductor devices because of its many inherent advantages, such as its simplicity of structure, no moving parts, reduced mechanical vibration of cold head, high reliability, etc [1]. However, the coefficient of performance (COP) of the PTR is much lower than that of the Stirling refrigerator. In recent years, many researchers have adopted a series of investigations to improve the COP and to decrease the lowest temperature of the PTR for practical applications. The improvements include changing the pulse tube shape, the variation of its structure parameters [2], the utilization of a new type of regenerator materials [3], the development of a high-efficiency pressure wave generator, the appropriate orientation of the pulse tube to depress the possible natural convection [4], etc.

In 1998, Indian scientists Patward and Bapt analyzed a 6–6.5 l/h Stirling refrigerator and found that the cooling capacity of the crycoolers might be improved by 10% with a helium-hydrogen mixture

Contract grant sponsors: The National Key Project of R&D in China (G2000026303) and the National Natural Science Foundation of China (Grant No. 50276046).

as a working fluid rather than with pure helium [5]. In 1999, an experimental study was carried out in a pulse tube refrigerator with mixture by the research group led by Chen in Zhejiang University. Their results show that the cooling capacity of a pulse tube refrigerator at 80 K can be increased with a hydrogen-helium mixture when other operating parameters are kept unchanged. When the mole fraction of hydrogen is 20%, the cooling capacity is 10% higher than that obtained using pure helium [6, 7]. In 2002, a numerical simulation for an orifice pulse tube refrigerator was carried out in Xi'an Jiaotong University [1]. The results show that the performance of a pulse tube refrigerator has a great relationship with the thermodynamic properties of the working fluid, and the refrigerating capacity of a PTR can be improved if an appropriate mixture is adopted.

Recently, theoretical and experimental studies have been conducted in the authors' group on the factors influencing the lowest refrigerating temperature of a miniature co-axial pulse tube refrigerator. A test rig of a miniature co-axial pulse tube refrigerator was first established and then a series of experiments were conducted. As a part of the series of experiments, the factors influencing the lowest refrigerating temperature, such as the working fluid, the frequency of the compressor, and the mean pressure of the system, have been studied. The major results are presented in this paper. The test apparatus and the experimental procedure will first be described, followed by a presentation of the results. Finally some conclusions will be drawn.

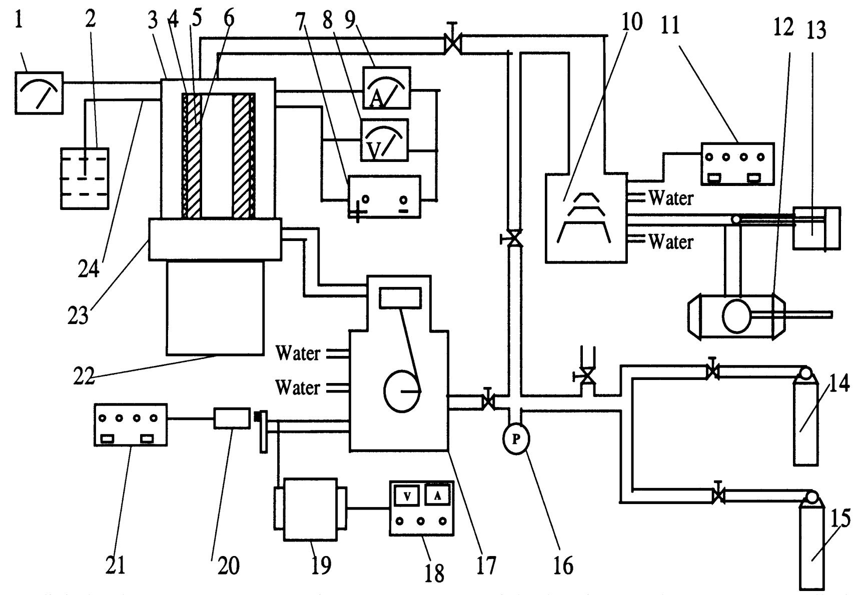
## Nomenclature

| | |
|---|---|
| COP | coefficient of performance |
| PTR | pulse tube refrigerator |
| r | circle |

## 2. Experimental Setup

The schematic diagram of the miniature co-axial pulse tube refrigerator system for the experiment is presented in Fig. 1.

The experimental setup consists of a refrigerating system, a vacuum system, a measuring system, and a mixture-preparing system. The vacuum system consists of an oil diffusion pump and a mechanical vacuum pump. The system pressure is measured by a pressure gauge connected to the compressor, and its measurement range is 0–4 MPa, with an accuracy of 0.25%. The exhaust volume of the compressor is 13.6 $cm^3$. The rotation speed of the compressor can be adjusted smoothly with a controllable silicon speed regulator. The compressor is cooled by water. The compressor speed is measured by a specially designed measurement system. The temperature of the cold head is measured by a thermocouple, which is pressed on the cold head of the pulse tube, and its signals are sent to a DC digital voltmeter to display the thermo-electric voltage. The inner diameter of the pulse tube studied is 6 mm, and its length is 88 mm. The hot head of the pulse tube is cooled by natural convection.




1. PZ150b DC-digital-voltmeter; 2. Ice-water mixture; 3. Vacuum (-tight) housing; 4. The regenerator wall; 5. The padding of the regenerator; 6. The pulse tube wall; 7. H1733C2 DC regulated power supply; 8. PZ114 DC-digital-voltmeter; 9. C31-mA milliammeter; 10. Oil diffusion pump; 11. Vacuometer; 12. Mechanical vacuum pump; 13. Electromagnetic valve; 14. Hydrogen tank; 15. Helium tank; 16. Manometer; 17. Compressor; 18. Rate governor; 19. DC electric machine; 20. Hall contactless switch; 21. Rotating speed display instrument; 22 Gas reservoir; 23. Copper lamella; 24. Thermocouple

Fig. 1. Schematic diagram of the miniature Co-axial Pulse Tube Refrigerator system.

## 3. Experimental Process

Before the experiment, a leak check of the system was first carried out, including such parts as the connection tube, the mixture preparing system, the compressor, and the pulse tube. The experiments were conducted in the following sequence. First, a preliminary experiment was carried out in order to get the optimal operating parameters for the miniature co-axial pulse tube refrigerator studied. Then a series of experiments with helium-hydrogen mixture were conducted under the optimal parameters, with the mole fraction of hydrogen being ranged as follows: 0, 20%, 50%, 60%, 80%, and 100%. Finally, the influences of the compressor rotation speed and the mean pressure of the system on the lowest refrigerating temperature of the system were examined. The initial pressure of the system was 1.3 MPa.

## 4. Experimental Results and Discussion

### 4.1 The effect of the working fluid on the lowest temperature

Figure 2 shows the experimental curves of temperature versus time for the pulse tube refrigerator with mixtures of helium and hydrogen.

From Fig. 2 the following features maybe noted: (1) The experimental curves of cold head temperature decreasing at a different helium/hydrogen ratio have the same pattern. The temperature

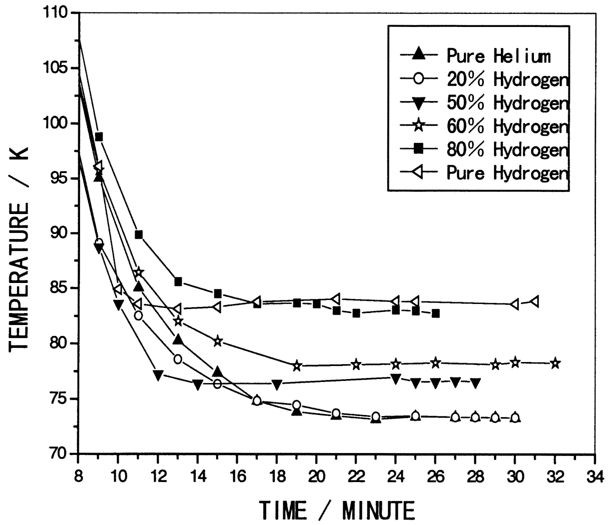



Fig. 2. The temperature versus time with helium and hydrogen mixtures.

falls rapidly in the first 12 minutes after the starting-up of the refrigerator, then its rate of decrease gradually slows down, and finally the temperature becomes stable, usually within 20 to 30 minutes after the starting process of the pulse tube refrigerator. (2) With the decrease of the hydrogen mole fraction in the hydrogen-helium mixture, the lowest refrigerating temperature decreases, and when the mole fraction of hydrogen is below 20%, the lowest refrigerating temperature is close to that using pure helium.

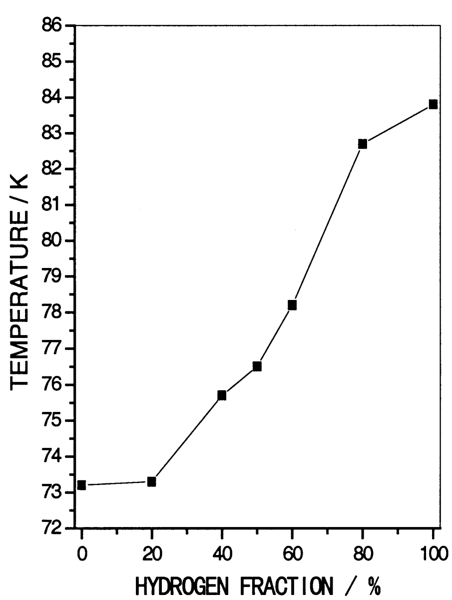
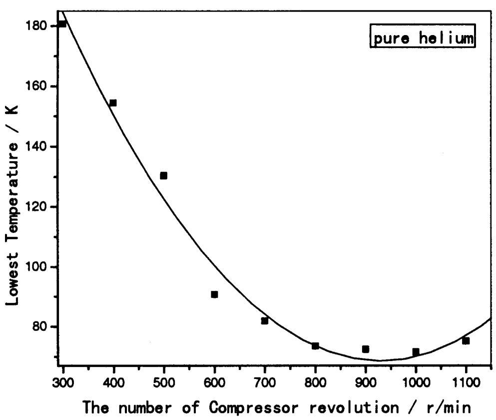
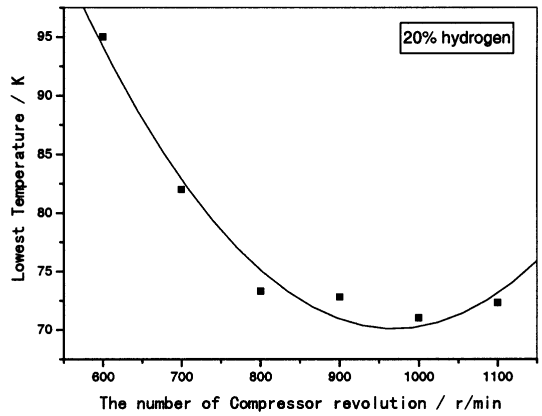


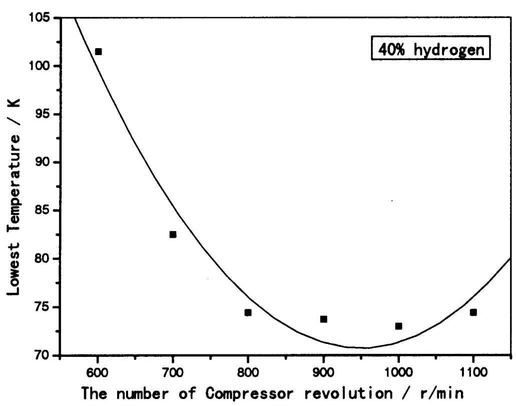

Fig. 3. The lowest temperature versus the hydrogen fraction of the mixture.



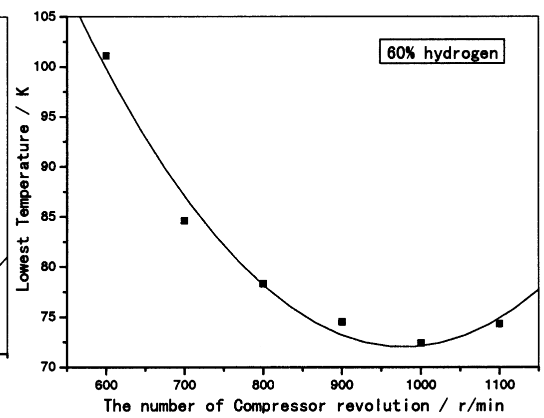

(a) Pure helium



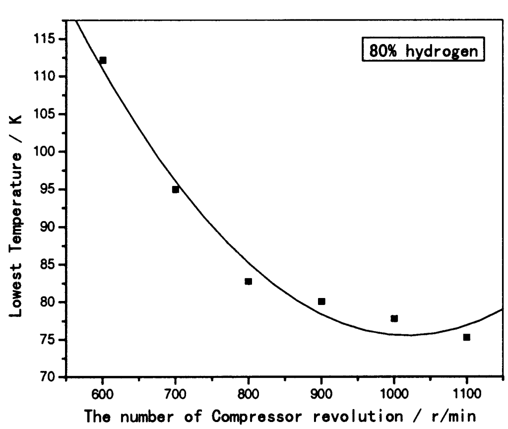

(b) 20% hydrogen



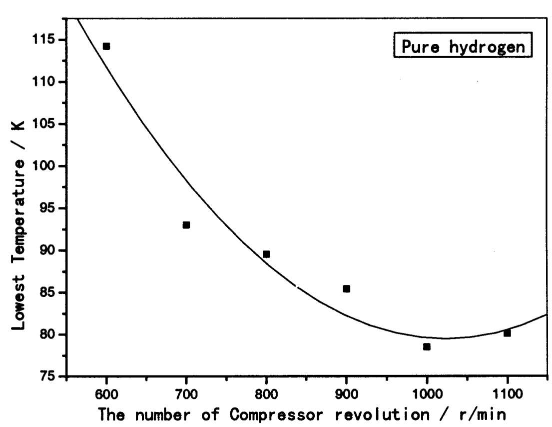

(c) 40% hydrogen




(d) 60% hydrogen




(e) 80% hydrogen




(f) Pure hydrogen

Fig. 4. The lowest temperature versus frequency.

Figure 3 shows the experimental results of the lowest temperature for the pulse tube refrigerator with mixtures of helium and hydrogen.

From Fig. 3, it can be seen that the lowest temperature is 73.2 K for pure helium, and 83.8 K for pure hydrogen. With the decrease of the mole fraction of hydrogen in the hydrogen-helium mixture, the lowest refrigerating temperature decreases, and when the mole fraction of hydrogen is 20% the lowest refrigerating temperature is 73.3 K, which is close to that obtained using pure helium.

### 4.2 The effect of the frequency on the lowest temperature

Figure 4 shows the relationship of the lowest temperature versus the frequency of the compressor.

From Fig. 4 it can be observed that the optimum frequency of the compressor is about 930–1030 r/min (15.5–17.2 Hz) with mixtures of helium and hydrogen. When the frequency is greater than the optimum frequency, the lowest temperature increases with the increasing frequency. Figures 4(a)–4(f) show that the optimum frequency slightly increases along with the increasing of the mole fraction of the hydrogen in the helium-hydrogen mixture.

### 4.3 The effect of the charge pressure on the lowest temperature

Figure 5 shows the relation of the lowest temperature versus systematic charge pressure with pure helium.

Figure 5 shows that the lowest refrigerating temperature decreases with the increase of the charge pressure of the PTR; however, the decreasing trend of the lowest temperature gradually lessens

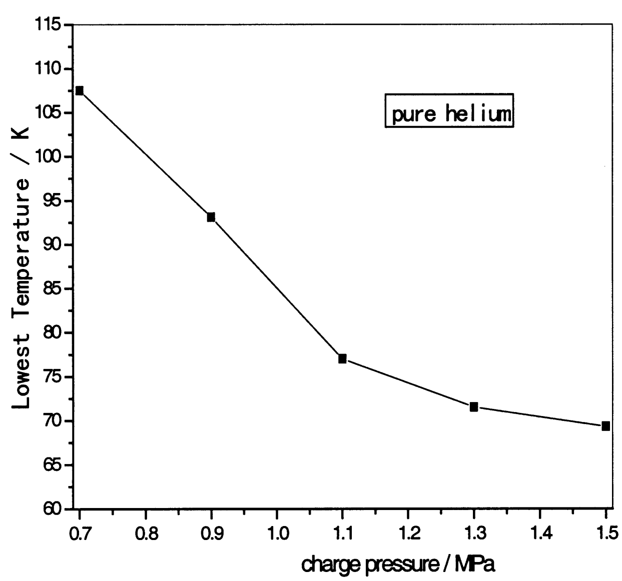



Fig. 5. The lowest temperature versus charge pressure.

with the increase in the charge pressure. Hence, within the allowed pressure limitation, the charge pressure can be adjusted to lower the lowest refrigerating temperature.

## 5. Conclusions

(1) The lowest refrigerating temperature decreases with the decrease of the mole fraction of hydrogen in the hydrogen-helium mixture, and when the mole fraction of hydrogen is below 20%, the lowest refrigerating temperature is close to that obtained using pure helium.

(2) The optimum frequency of the compressor is about 930–1030 r/min (15.5–17.2 Hz) with mixtures of helium and hydrogen.

(3) The lowest refrigerating temperature decreases with the increase of the PTR charge pressure, however, the decreasing trend of the lowest temperature gradually lessens with the increase in the charge pressure.


## Acknowledgments

The work reported here was supported by the National Key Project of R&D in China (G2000026303) and the National Natural Science Foundation of China (Grant No. 50276046).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Originally published in *J Eng Thermophys* **25**, 2004, 565–567.
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