Influence of He-H_2 Mixture Proportion on the Performance of Pulse Tube Refrigerator *

Huang Y.H., Chen G.B., Gan Z.H., Tang K., Bao R.

Cryogenics Laboratory, Zhejiang University, Hangzhou 310027, P.R.China

The performance of pulse tube refrigerator (PTR) can be improved by using mixtures as its working fluid. Based on an experimental work on a two-stage PTR with He-H_2 mixture whose hydrogen percentage rising from 0% to 100%, an optimal proportion of H_2 in the He-H_2 mixture for the cooling temperature around 30K was found. At this temperature region, the cooling power and COP of the PTR reach their maximum both with an increment about 30-40% against pure helium when the hydrogen percent is about 60-70%.

INTRODUCTION

Unlike the Stirling or Gifford-McMahon refrigerators, the pulse tube refrigerator has no moving parts at the cold end, which enables itself to be a promising long-life and reliable cryocooler. Improvement in its efficiency have occurred rapidly since the orifice type pulse tube was recommended in 1984 by Mikulin[1]. We embarked on the study of the influence of mixture working fluids on the pulse tube refrigeration performance[2,3] in 1995. Taking into account the thermodynamics, heat transfer and fluid flow characteristics of mixture working fluids, performance prediction[4] of pulse tube refrigeration cycle with mixtures was developed. Experimental work was repeated times to confirm the results in the last two years. Both the theoretical and experimental investigations indicate that higher cooling power and coefficient of performance (*COP*) could be achieved with He-H_2 mixtures as working fluids than those with pure He for PTRs working in the 30K and 80K cooling temperature regions. But the molar fraction of hydrogen in the He-H_2 mixture was limited in 60% in our previous work by the experimental setup. Recently, high hydrogen percentage He-H_2 mixtures were charged in the same PTR. A better result of the cooling power and COP has been obtained.

EXPERIMENTAL SETUP

The outline of the experimental two-stage PTR is presented in Figure 1. The main dimensions and regenerative materials are tabulated in Table 1.The pressure wave needed by the PTR is generated by a C100W homemade helium compressor and a rotatory valve. A pressure sensor is located at the inlet of the regenerator, as shown in Figure 1, to measure the input pressure wave. The temperatures at cold ends of the first and the second stages are measured by two Rh-Fe resistance thermometers. The electric power consumed by the compressor is measured by a powermeter. Heat balance method is used to measure the cooling power. Eight Cu-Constantan thermocouples are fixed along the first and second stage pulse tubes

* Funded by the National Natural Science Foundation (Grant No. 50376055 and 50106013) and the Special Research Fund for Doctoral Training in Universities by the National ministry of Education of China (Grant No. 20010335010).

and regenerators to show the temperature distributions. This is helpful for the adjustment of the two-stage PTR in the operation.

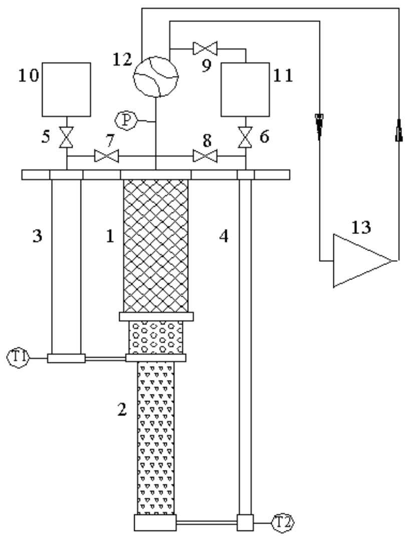


Table1 Dimensions and regenerative packing of two-stage PTR

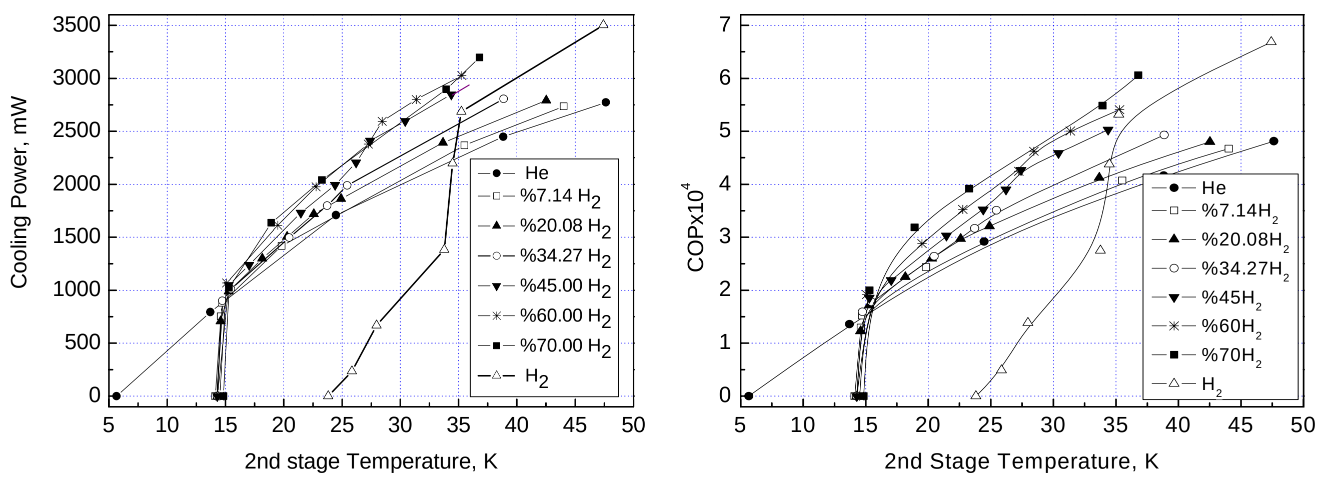
Stage	Pulse tube (mm)	Regenerator (mm)	Regenerative packing
1st	ϕ26×280	ϕ59×130 +ϕ45×60	1200 pieces of 250 mesh phosphor bronze screen +ϕ0.3mm lead 744g
2nd	ϕ12×370	ϕ19×190	Er3Ni 285g

Figure1 Outline of two-stage PTR

1.2. 1st and 2nd stage regenerators, 3.4. 1st and 2nd stage pulse tubes, 5.6. orifices, 7.8. double inlets, 9. 2nd orifice, 10.11. reservoirs, 12. rotary valve, 13. compressor, Ⓟ-pressure sensor, Ⓣ-temperature sensors

RESULTS AND ANALYSIS

Different He-H_2 mixtures with 1.4MPa gauge pressure were charged into the two-stage PTR. Meanwhile, the settings of all valves and regenerator materials were kept the same. The relationship between the cooling power or COP of the PTR and the second stage cooling temperature are shown in Figure 2. It can be seen that higher cooling power and COP are achieved with He-H_2 mixture of 7～70％ H_2 than those with pure helium in the 15~50K temperature region. The characteristics of pure hydrogen curve seem to be special. The performance of the PTR with pure hydrogen is much lower below 34K than that with mixtures whose H_2 percentage is less than 70%.

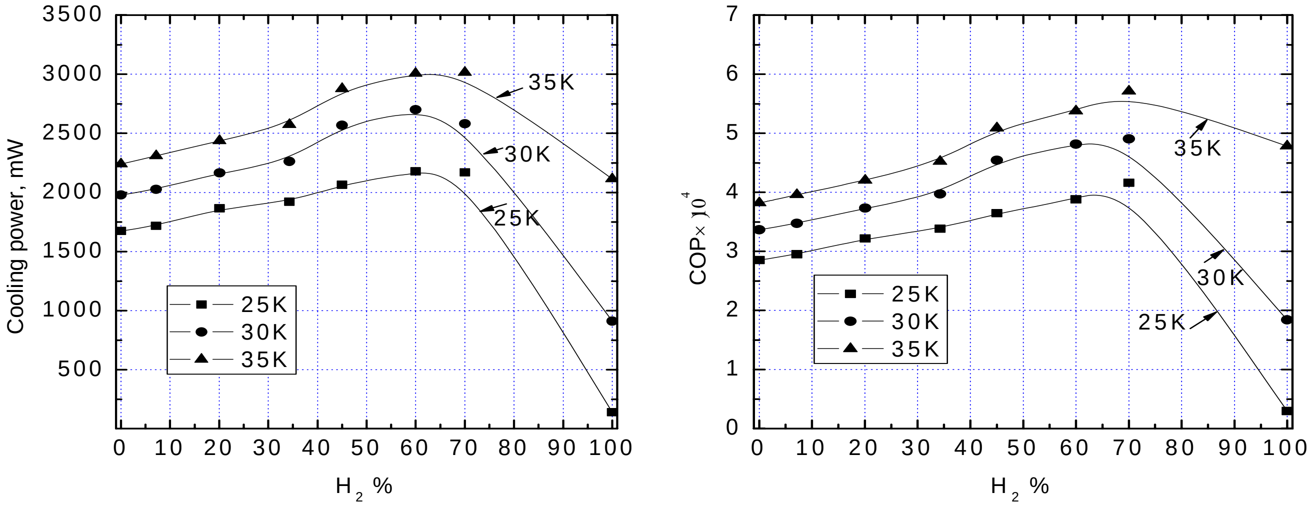


(a) Cooling Power (b) COP

Figure 2 Cooling power and COP vs. 2^{nd} stage cooling temperature

Figure 3 presents the relation between cooling power or COP and molar fraction of H_2 at the 2^{nd}

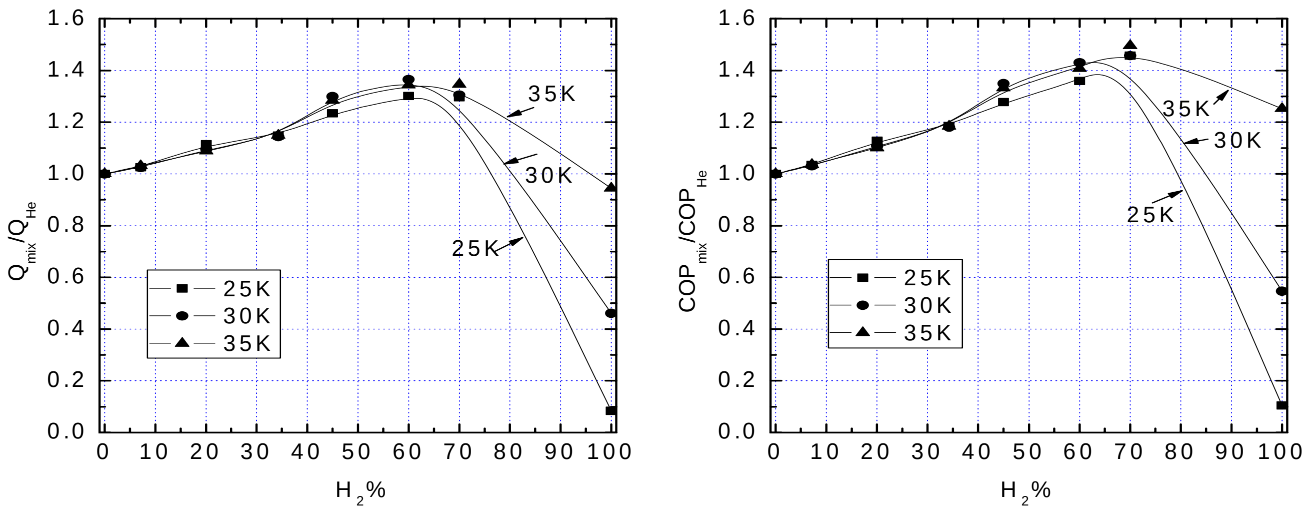
stage cooling temperatures 25, 30 and 35K. This figure says that both the cooling power and COP increase with the accretion of H_2 molar fraction and attain their maximum values with He-H_2 mixtures of 60-70% H_2.



(a) Cooling Power (b) COP

Figure 3 Cooling power and COP vs. molar fraction of H_2

Figure 4 gives the tendency of the specific cooling power and specific COP against molar fraction of H_2 in He-H_2 mixture corresponding to Figure 3. With 60-70% hydrogen, both the specific cooling power and specific COP reach their maximum and have 30-45% increment compared to pure helium.



(a) Specific Cooling Power (b) Specific COP

Figure 4 Specific cooling power and COP vs. molar fraction of H_2

In Figures 2-4, the experimental results indicate that the refrigeration performance of the PTR in the 30K temperature region is obviously enhanced by using proper He-H2 mixture as working fluid. Excellent thermodynamic performance and the reasonable heat transfer and flow properties of He-H_2 mixture contribute to the performance improvement of PTR. But we find these results are quite beyond the values predicted by the modified Brayton Cycle[4]. So far, it is found that the magnetic regenerative material Er_3Ni is able to absorb (or adsorb) H_2 and produces Er_3NiH_x. The volume specific heat of this metallic hydride is much higher than that of Er_3Ni and Pb in the temperature region of 15~50K[5], that is, Er_3NiH_x has better regenerative performance. This is an important factor of the enhancement of the PTR performance.

CONCLUSIONS

Mixtures as working fluid can improve the performance of pulse tube refrigerator. Experimental research was carried out on a two-stage PTR with He-H_2 mixture. The pulse tube refrigeration performance with He-H_2 mixtures is better than that with pure helium in 30K cooling temperature region when the hydrogen fraction is less than about 80%. A 30-45% increment of both the cooling power and COP has been obtained with 60-70% H_2 in He-H_2 mixtures. The great performance improvement of the PTR may be attributed to not only the excellent cycle thermodynamic performance and the reasonable heat transfer and flow properties of He-H_2 mixtures, but also the high volume specific heat of Er_3NiH_x regenerative materials.

ACKNOWLEDGEMENT

The project is financially supported by the National Natural Science Foundation of China (Grant No. 50106013 and 50376055) and the Special Research Fund for Doctoral Training in Universities by the National ministry of Education of China (Grant No. 20010335010).

REFERENCES

1. Mikulin, E.I., Tarasov, A.A., et al., Low temperature expansion pulse tubes, Adv. Cryo. Eng. (1984) 29 629-637
2. Yu, J.P., Chen G.B., Gan Z.H., Investigation on the regenerator performance using gas mixtures, International Conference of Cryogenics and Refrigeration Hangzhou, P.R. China (1998) 409-412
3. Chen, G.B., Yu, J.P., Gan, Z.H., et al, Experimental investigation on pulse tube refrigerator with binary mixtures. Adv. Cryo. Eng. (2000) 45 183-187
4. Chen, G.B., Gan, Z.H., Thummes, G., et al., Thermodynamic performance prediction of pulse tube refrigeration with mixture fluids, Cryogenics (2000) 40(4-5) 261-267
5. Chen, G.B., Tang, K., Huang, Y.H., et al., He-H_2 mixture and Er_3NiH_x packing for the refrigeration enhancement of pulse tube refrigerator, Chinese Science Bulletin (2004) 49(5) 527-530