Cooling Characteristics of GM-type Pulse Tube Refrigerator with Neon as Working Gas

J. Ko, Y.J. Hong, H. Kim, H. Yeom, S.J. Park, D.Y. Koh

Korea Institute of Machinery & Materials
Daejeon, Korea (S), 305-343

ABSTRACT

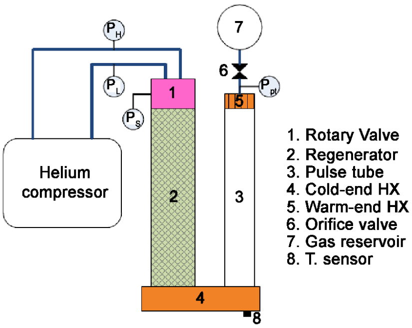
This paper describes the experimental study of a single stage Gifford McMahon (GM) type pulse tube refrigerator (PTR) with neon as the working gas. An orifice valve and a gas reservoir are adopted as phase control devices in the fabricated PTR. In experiments, both neon and helium are used as the working gas in the same compressor and pulse tube refrigerator. No-load temperature, cooling capacity, and compressor input power are measured as a function of the operating frequency and orifice valve position for each working gas. Cooling and operating characteristics for two different working gases are compared and discussed with experimental results. The fabricated PTR in this study shows improved cooling performance with neon gas.

INTRODUCTION

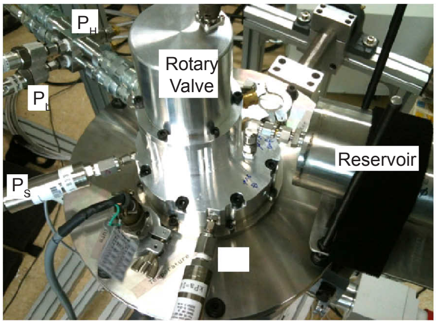
A pulse tube refrigerator (PTR) has the advantages of high reliability, simple construction and low vibration because it has no moving parts at its cold part. However, pulse tube refrigerators generally show a poorer cooling performance than Stirling cryocoolers and GM cryocoolers. Several researchers have tried to improve the cooling performance of a PTR through research and development of analysis tools, design optimization, reducing thermal losses, improvement of heat exchangers and so on. One possible improvement is the substitution of a new working gas which typically uses pure helium. Chen, et al. showed the improvement of cooling performance with mixtures of helium and other gases[1,2]. They modeled the refrigeration cycle of a PTR with the modified Brayton cycle, and predicted the specific cooling power and COP as a function of the mixture ratio. They also experimentally showed the improvement of cooling performance with helium-hydrogen mixtures. They achieved a 40% improvement in the cooling performance with a 2 stage GM-type PTR which uses Er_3Ni as the regenerator material and operates near 30 K.

In this study, we compare the cooling performance and compressor operating characteristics for two different working gases; helium and neon, with using same compressor and pulse tube refrigerator. A single stage GM-type pulse tube was fabricated and tested. The fabricated PTR adopts an orifice valve and gas reservoir as the phase shift device. In the cooling performance test, no-load temperature, compressor input power and pressure waveform are measured as a function of the orifice valve turns and operating frequency.

Cryocoolers 17, edited by S.D. Miller and R.G. Ross, Jr.



(a)



(b)

Figure 1. Schematic diagram and photo of fabricated PTR.

Table 1 Specifications of fabricated PTR.

Regenerator	• 38.1 (O.D.), 0.4 (t), 100 (L) in mm • #200 phosphorous bronze screen mesh
Pulse tube	• 31.8 (O.D.), 0.4 (t), 100 (L) in mm
Gas reservoir	• 1 liter of internal volume
Orifice valve	• Fabricated metering valve • Flow coefficient: 0 ~ 0.08 (*see* Figure 2)

EXPERIMENTAL SETUP

Figure 1 shows a schematic diagram and a photo of the fabricated pulse tube refrigerator. A commercial helium compressor (Genesis 2.1) is used. The regenerator is filled with #200 phosphor bronze screen mesh, and the fabricated metering valve has the flow coefficient of 0 ~ 0.08 as shown in Table 1.

In the fabricated PTR, the orifice valve is fabricated to have a wide range of flow coefficients. Its flow coefficient is measured using Eq. 1 which is suggested by the manufacturer of the commercial metering valve[3]. In the measurement, static pressures at both ends of the valve are measured for dry nitrogen flow. Flow coefficient as a function of valve turns and flow direction are measured and shown in Figure 2.

$$
\begin{aligned}
q &= N_2 C_v p_1 \left(1 - \frac{2\Delta p}{3p_1}\right)\sqrt{\frac{\Delta p}{p_1 G_g T_1}} \quad \text{for } p_2 > 1/2\, p_1 \\
&= 0.471 N_2 C_v p_1 \sqrt{\frac{1}{G_g T_1}} \quad \text{for } p_2 < 1/2\, p_1
\end{aligned}
\tag{1}
$$

where, C_v = flow coefficient
q = flow rate
p_1 = inlet pressure
p_2 = outlet pressure
Δp = pressure drop $(p_1 - p_2)$
G_g = gas specific gravity (air = 1.0)
N_2 = constant for units
T_1 = absolute upstream temperature

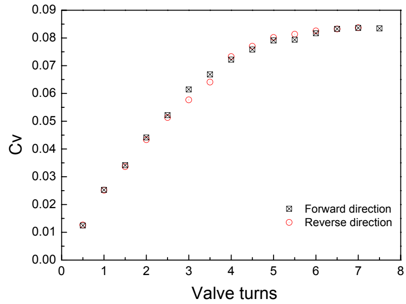


Figure 2. Measurement of flow coefficient of fabricated metering valve.

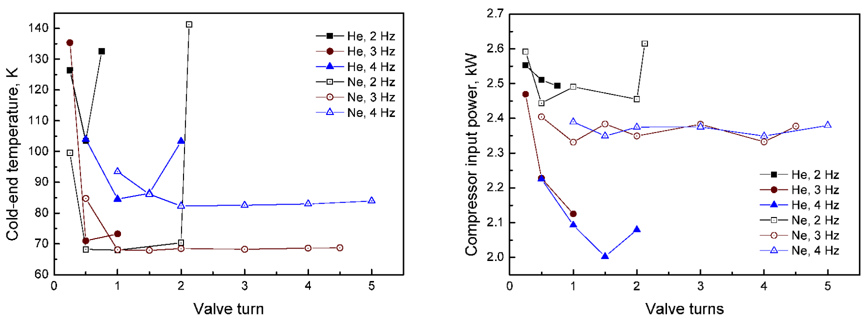


Figure 3. Results of cooling performance test: (a) No-load test, and (b) Compressor input power

The measured flow coefficient linearly increases as the number of valve turns is less than 4 turns, and shows that the valve is almost fully open after about 5 turns. A negligible change in the flow coefficient is noted as the flow direction reverses.

EXPERIMENTAL RESULTS

No-load Temperature

In experiments, the cooling performance test is performed with the same charging pressure of 1.6 MPa for both helium and neon. No-load temperature is measured for operating frequencies of 2, 3, and 4 Hz and a range of valve turns. Figure 3 shows the results of measured no-load temperature and compressor input power as a function of the number of valve turns. For the case of helium, optimum valve turn increases and compressor input power decreases as increase of operating frequency and the best cooling performance is shown at an operating frequency of 3 Hz. Compressor input power shows relatively higher dependence on operating frequency than cold-end temperature. For the case of neon, the no-load temperature is shown at the wide range of valve turns except at an operating frequency of 2 Hz. Cold-end temperature dramatically increases above 2.5 valve turns with a 2 Hz operating frequency. The dependence of compressor input power on operating frequency for neon is relatively small compared to helium. The results in Figure 3 indicate that a PTR charged with neon is less sensitive to the orifice valve position, and may give a slight performance improvement.

Pressure Measurement

In experiments, pressure waveforms are measured at four points: supply (P_H) and return line (P_L) of compressor, inlet of regenerator (P_s) and warm-end of pulse tube (P_{pt}) as shown in Figure 1.

Figure 4 shows an example of a pressure waveform during operation with each working gas. The waveform of pulsating pressure for helium shows almost rectangular shape and thus, short rising and falling time as well as no significant pressure difference between P_s and P_{pt}. For neon, the rising and falling time are relatively longer and there obviously exists a significant difference in amplitude and phase between two pressure waveforms, P_s and P_{pt}. This indicates that the regenerator has the characteristics of large pressure drop and a compliance effect for neon flow. It is thought that these characteristics result from the high viscosity and small gas constant of neon.

Pressure waveforms for each operating condition are measured and are processed to determine the average value of P_H and P_L, as well as the peak-to-peak value of P_s and P_{pt} over the period. The processed data are shown in Figure 5. From the results, neon shows a smaller dependency on the operating frequency; however, the larger pressure drop across the regenerator is observed.

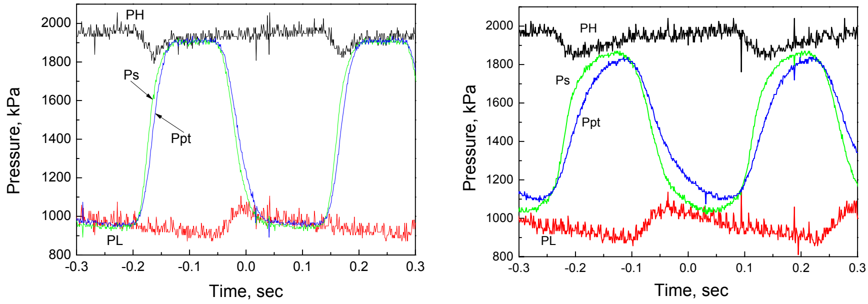


Figure 4. Example of measured pressure waveform; (a) helium, 3Hz, 1/2 turns, and (b) neon, 3Hz, 2 turns

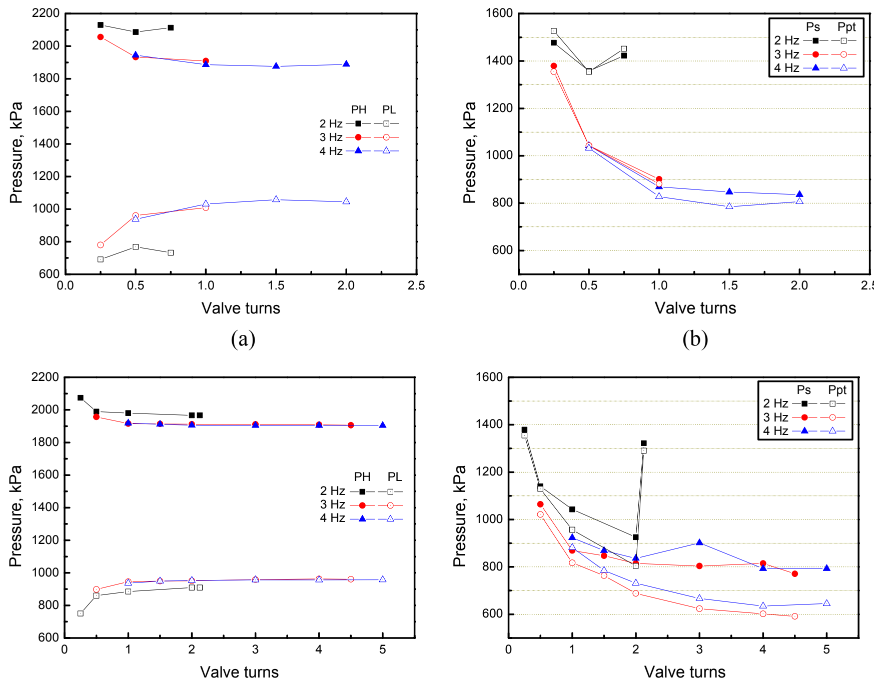


Figure 5. Results of pressure measurement as a function of valve turns and operating frequency: (a) Helium/average of P_H & P_L, (b) Helium/peak-to-peak of P_s & P_{pt}, (c) Neon/average of P_H & P_L, and (d) Neon/peak-to-peak of P_s & P_{pt}.

SUMMARY

In this study, we fabricated a single stage GM-type pulse tube refrigerator and tested with both helium and neon gases. From the measurement of the no-load temperature, the PTR operation with neon shows a slight improvement in cooling performance and the optimum performance over a wide range of valve opening positions. For the compressor, input power and pressure have less of a dependency on operating frequency when neon is used. From the measurement of the pressure waveform, the regenerator shows characteristics of a larger compliance effect and pressure drop for neon. The use of neon as the working gas may yield decreased sensitivity to orifice valve position, resulting in more stable operation of the GM-type PTR.

ACKNOWLEDGMENT

This work is supported by the Korea Institute of Machinery & Materials and The Ministry of Knowledge Economy.

REFERENCES

1. Chen, G., Gan, Z., Thummes, G., Heiden, C., "Thermodynamic performance prediction of pulse tube refrigeration with mixture fluids," *Cryogenics*, Vol. 40, Issue: 4-5 (April-May 2000), pp. 261-267.
2. Chen, G.B., Tang, K., Huang, Y.H., Gan, Z.H., Bao, R., "Refrigeration performance enhancement of pulse tube refrigerators with He-H_2 mixtures and Er_3NiH_x regenerative material," *Cryogenics*, Vol. 44, Issue: 11 (November 2004), pp. 833-837.
3. "Valve Sizing: Technical Bulletin," http://www.swagelok.com,