The Influence of Filling Ratio and Number of Turns on the Heat Transfer Performance of Nitrogen Pulsating Heat Pipe

Yaran Shi[1,2], Jixiang Yan[1,2], Rendong Guo[1,2], Dong Xu[1,*], Laifeng Li[1,2,*]

[1] Key Laboratory of Cryogenic Science and Technology, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing 100190, China

[2] University of Chinese Academy of Sciences, Beijing, 100049, China

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1. Introduction

- Pulsating heat pipes (PHPs) are promising high-efficiency heat transfer devices with high cost-effectiveness and flexibility.
- The heat transfer performance of PHPs with long distances, which are more valuable for practical applications, requires further investigation under different structural and operational parameters .
- In the present work, the impacts of **filling ratios (15%~95%)** and **number of turns (6 and 12)** on the heat transfer performance of nitrogen PHPs, each with a total length of 0.6 m, was experimentally tested.

2. Experiment

PHP prototype

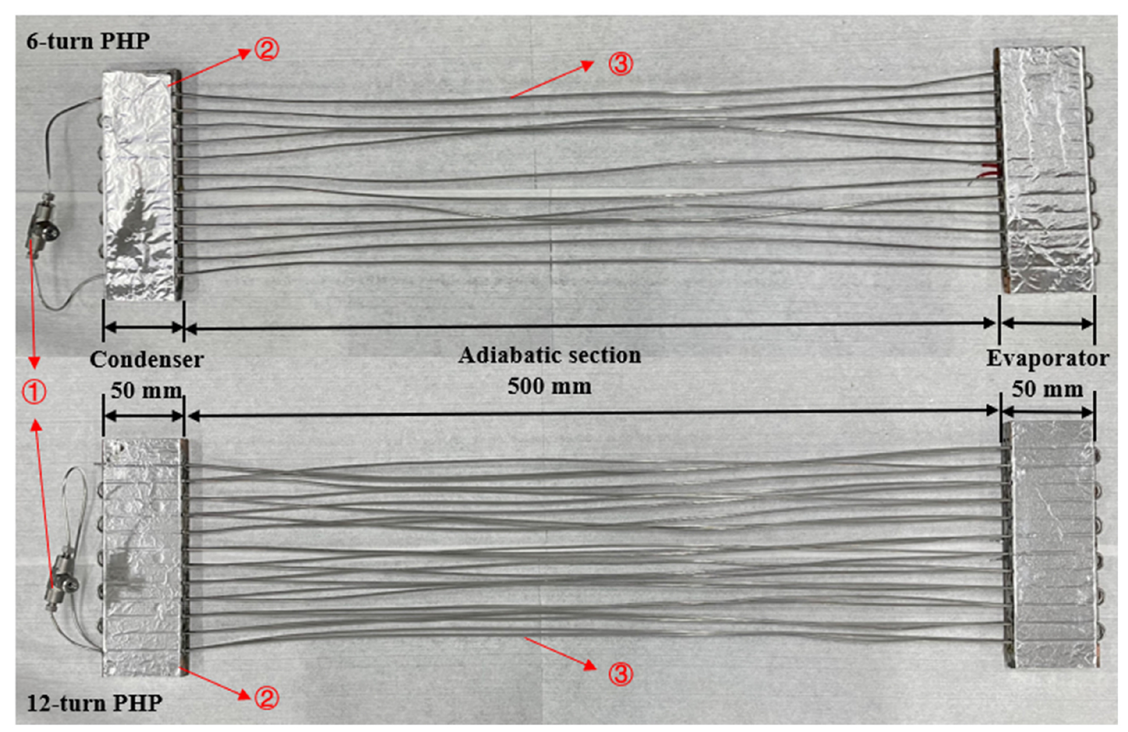

Fig. 1 Schematic diagrams and photos of PHP prototypes with 6-turn and 12-turn: (1) three-pass junction; (2) copper plate; (3) stainless-steel tube (with an inner diameter of 1 mm and an outer diameter of 1/16 inch)

Experimental setup and procedure

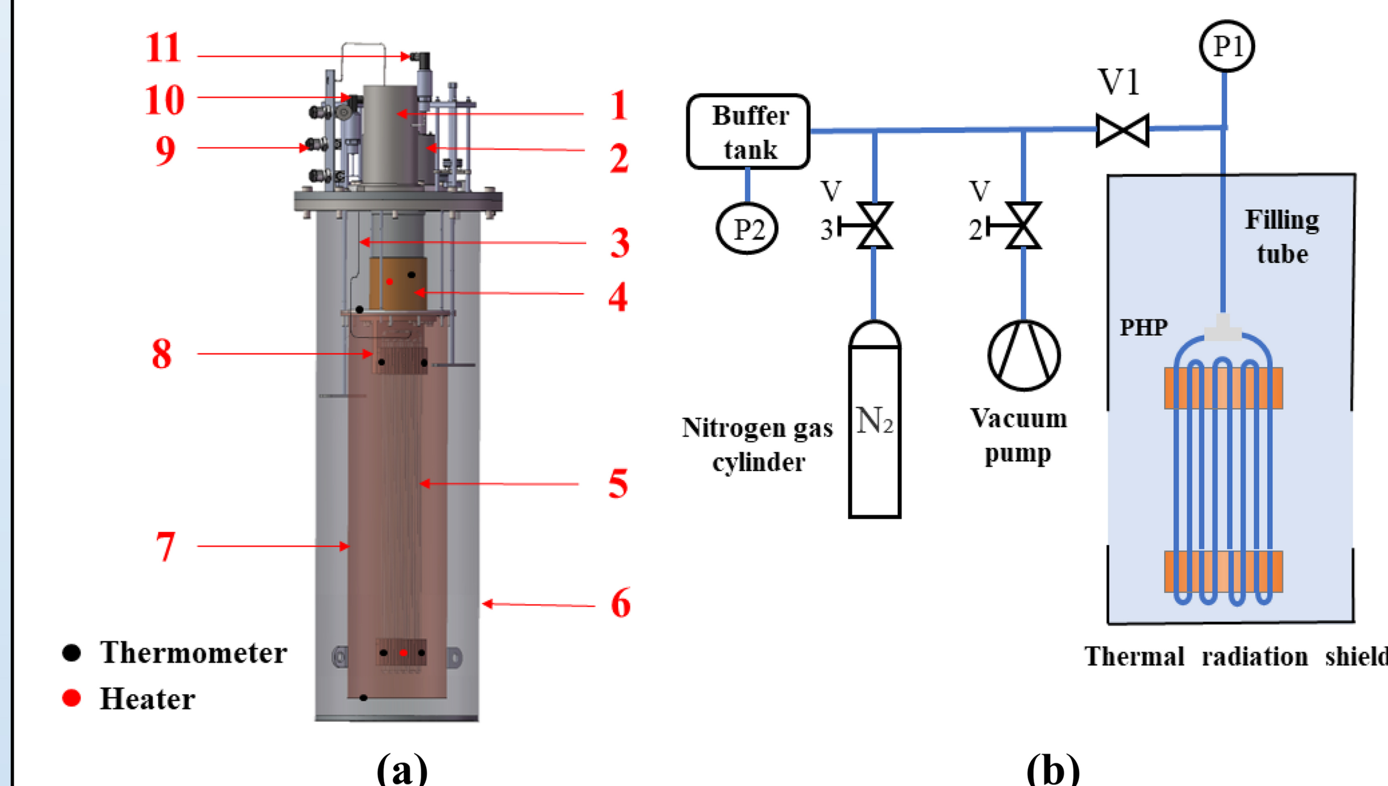

Fig. 2 Schematic diagrams of (a) the experimental setup and (b) filling system: (1) buffer tank; (2) GM cryocooler; (3) filling tube; (4) cold head; (5) nitrogen pulsating heat pipe; (6) vacuum chamber; (7) thermal radiation shield; (8) conduction cooling plate; (9) valve panel; (10) pressure transducer P1; (11) pressure transducer P2.

- The **filling ratio (FR)** was calculated by

$$\frac{P_0 V_{Buffer\ tank}}{R_g T_{amb}} = \frac{P_f V_{Buffer\ tank}}{R_g T_{amb}} + \frac{P_f V_{filling\ tube}}{R_g T_{filling\ tube}} + m_t$$

$$m_t = \rho_l V_l + \rho_v (V_{PHP} - V_l)$$

$$FR = \frac{V_l}{V_{PHP}} \times 100\%$$

- The heat transfer performance was evaluated using the heat transfer limit Q_{max} (the maximum heat input that the PHP can load) and the effective thermal conductivity K_{eff}.
- The K_{eff} was calculated by

$$K_{eff} = \frac{4QL_a}{n\pi d_i^2 (T_e - T_c)}$$

3. Results and discussion

Temperature and pressure response under different head loads

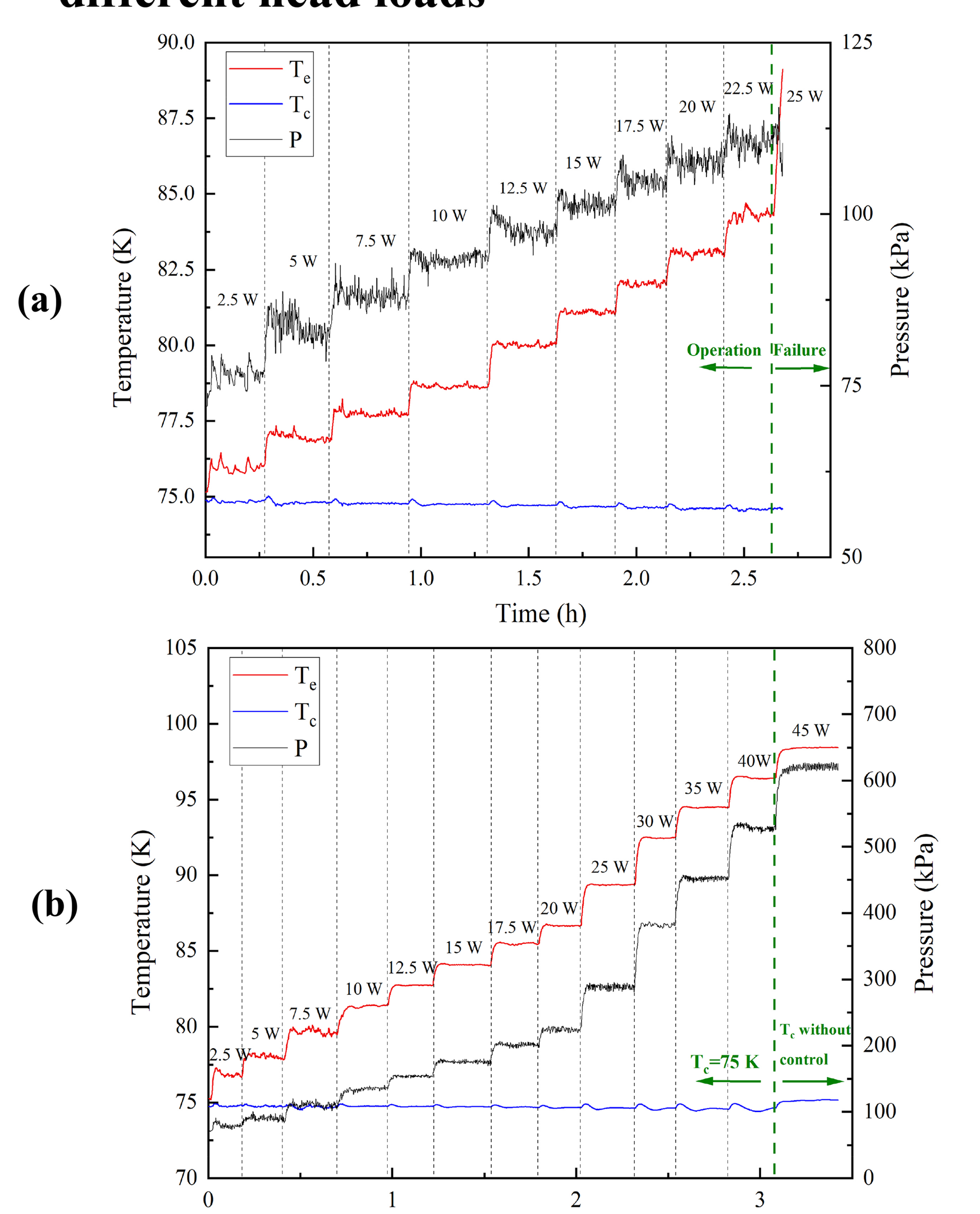

Fig. 3 The temperature and pressure variations of the 6-turn PHP: (a) FR=31.8% and (b) FR=48.8%.

Effect of the filling ratios

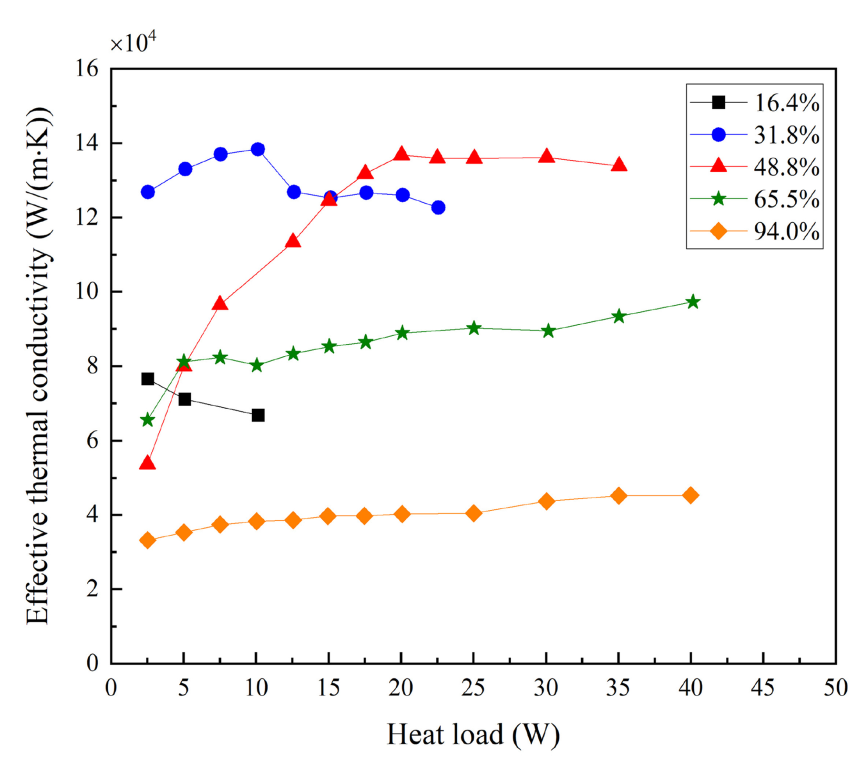

Table 1 The heat transfer limit of 6-turn PHP.

FR (%)	Q_{max} (W)
16.4	10
31.8	22.5
48.8	35
65.5	> 40
94.0	> 40

Fig. 4 Effect of the filling ratio on the effective thermal conductivity of 6-turn PHP.

- The Q_{max} **increased** with the increasing filling ratio.
- The high FR led to a **sharp decrease** in K_{eff}.
- The **optimal FR** range was between **30% ~50%**.
- Different heat load ranges corresponded to **different optimum FRs** within 30%~50%.

Effect of the number of turns

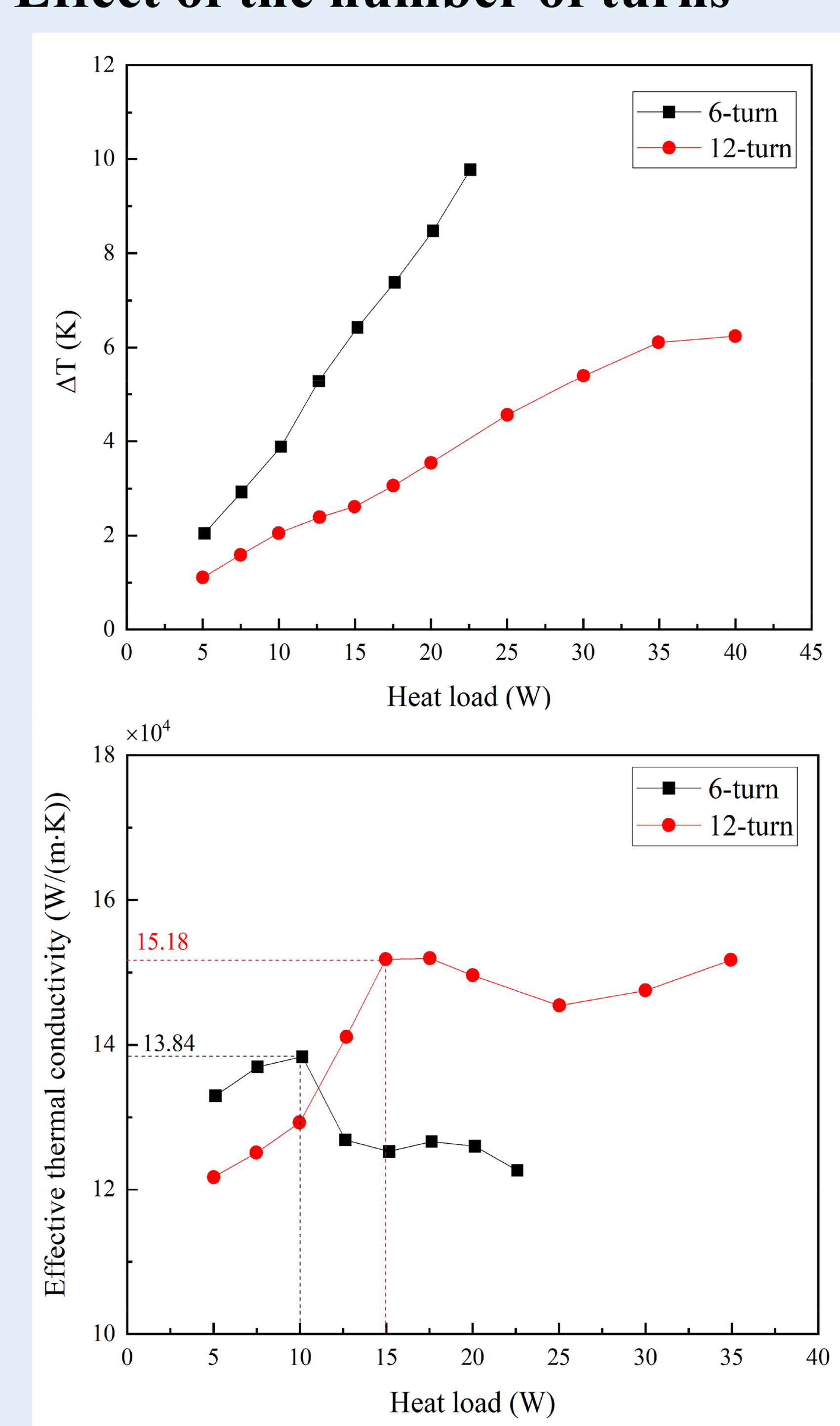

Fig. 5 Effect of the number of turns on (a) the ΔT and (b) K_{eff}.

- The ΔT was **reduced** proportionally by doubling the number of turns.
- At Q < 10 W, the **6-turn PHP** performeded **better**.
- As Q increased, **degradation** occurred **earlier** in **6-turn PHP**.

4. Conclusion

- The heat transfer performance of the nitrogen PHP was significantly affected by the FR. The Q_{max} could be **enhanced** by increasing the FR. However, the high FR led to a **sharp decrease** in K_{eff}. The recommended FR was between **30% and 50%.**
- For the 6-turn PHP, the best heat transfer performance was achieved at a FR of 31.8% at a heat load less than 15 W whereas the optimal FR was 48.8% at a heat load exceeding 15 W. The maximum K_{eff} of **138.4 kW/(m·K)** and **136 kW/(m·K)** were achieved at FRs of 31.8% and 48.8%, respectively.
- The ΔT between the evaporator and condenser was significantly **reduced** and the **maximum** K_{eff} was **increased** by increasing the number of turns from 6 to 12. Notably, at higher heat loads, the **12-turn PHP** exhibited better heat transfer performance compared to the 6-turn PHP, achieving a maximum effective thermal conductivity of **151.8 kW/(m·K)** at a heat load of 15 W.