C2Po2B-02 : A study of thermal performance change of cryogenic heat pipes by wick structures for wide range of working fluid filling ratio

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Introduction

Motivation: It has been successfully demonstrated the commercially available heat pipes designed for the room temperature operation could work at liquid nitrogen temperature by replacing working fluid to nitrogen for potential application to cooling of high-T superconducting magnets.

In order to make comparisons with theoretical prediction for thermal performance, data was accumulated by measuring the performance under various experimental conditions (working fluid, wick structure, filling ratio). Further detailed experiments under some interesting conditions were also conducted.

What we did

- **Experimental confirmation that heat pipe experiments to keep the condenser temperature (87.3 K) higher than 78 K by liquid nitrogen cooling can be performed: by using an additional control heater at the condenser section.**
- **Comparison of heat pipe performance at 100 % fill due to differences in wick structure (estimated in terms of the thermal resistance).**
- **Performance comparison of N_2 and Ar heat pipes for the same wick structure.**
- **Performance test under excess (over 100%) liquid fill: Consideration of an unusual thermal resistance state by regarding the liquid distribution inside heat pipe.**

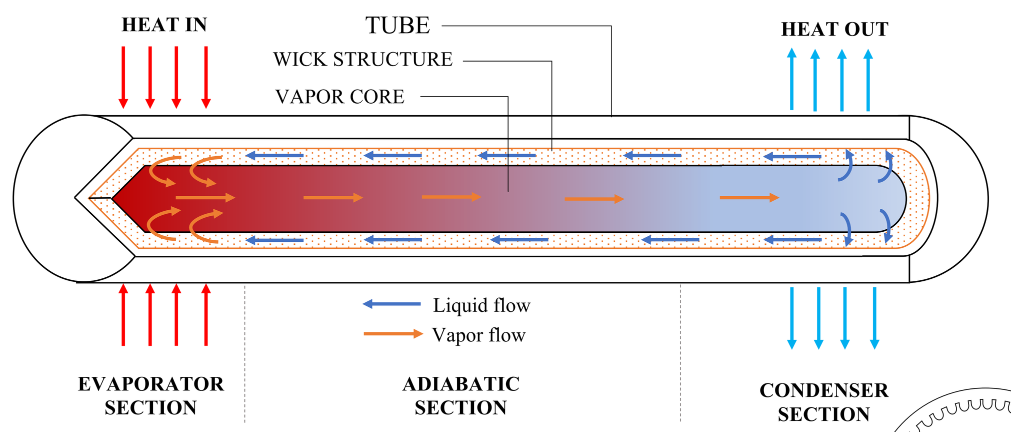
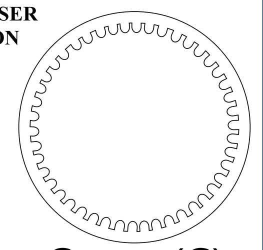


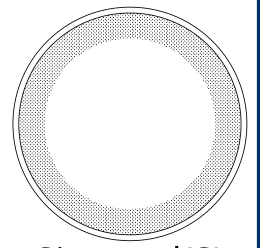
Fig.1 Working Principle of Heat pipe

Table.1 Specifications of heat pipe

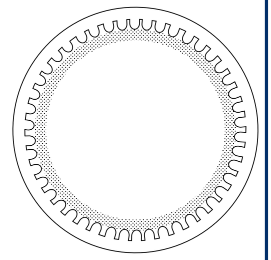
Parameter	Value
Tube wall material	Copper
Working Fluid	Nitrogen or Argon
Outer Diameter (OD)	6.0 mm
Heat pipe length	200 mm
Evap., Adia., Cond. lengths	15, 120, 65 mm
Axial groove	
Thickness of wall	0.26 mm
Groove depth	0.20 mm
Groove width	0.27 mm
Number of grooves	50
Sintered metal wick	
Thickness of wall	0.20 mm
Thickness of sintered wick	0.80 mm
Sphere radius of copper power	50 μm
Permeability (Grooved, Sintered)	3.04×10^{-9}, 6.67×10^{-11}
Porosity of wick, ϵ (Grooved, Sintered)	0.82, 0.57



Groove(G)



Sintered(S)



Sintered-Groove (SG)

Experimental Set up

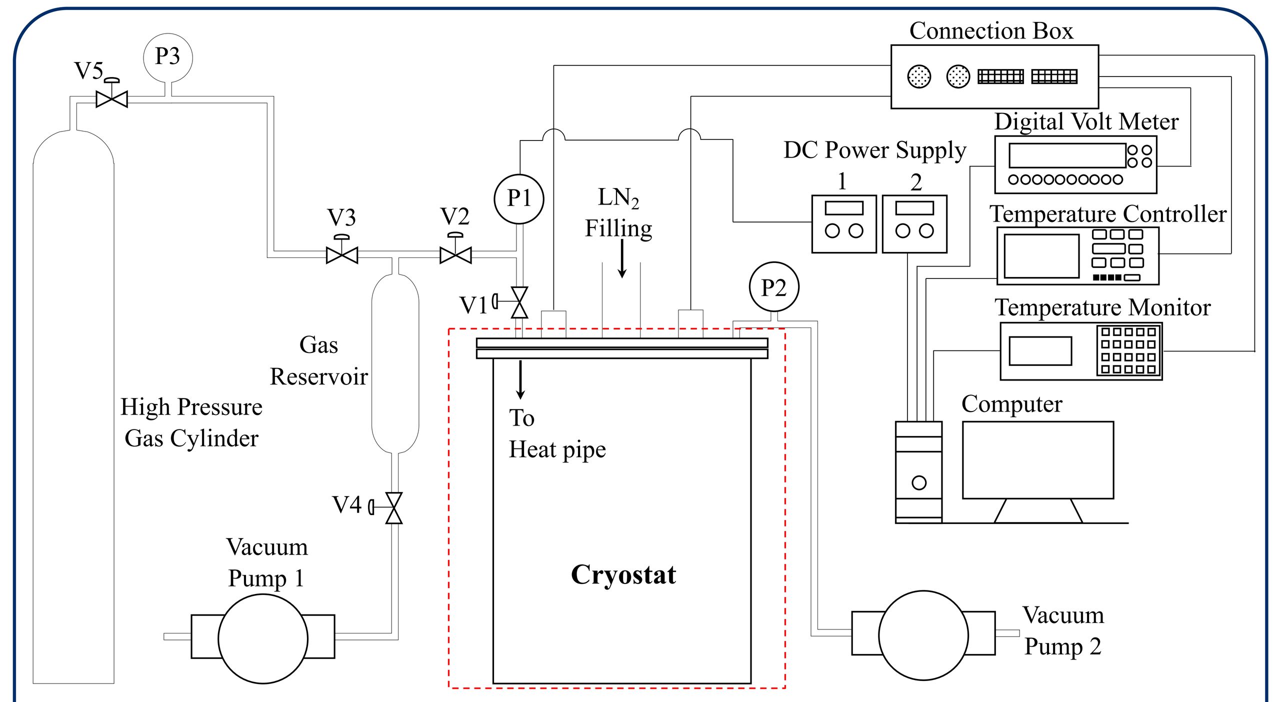


Fig.3 Experimental set up

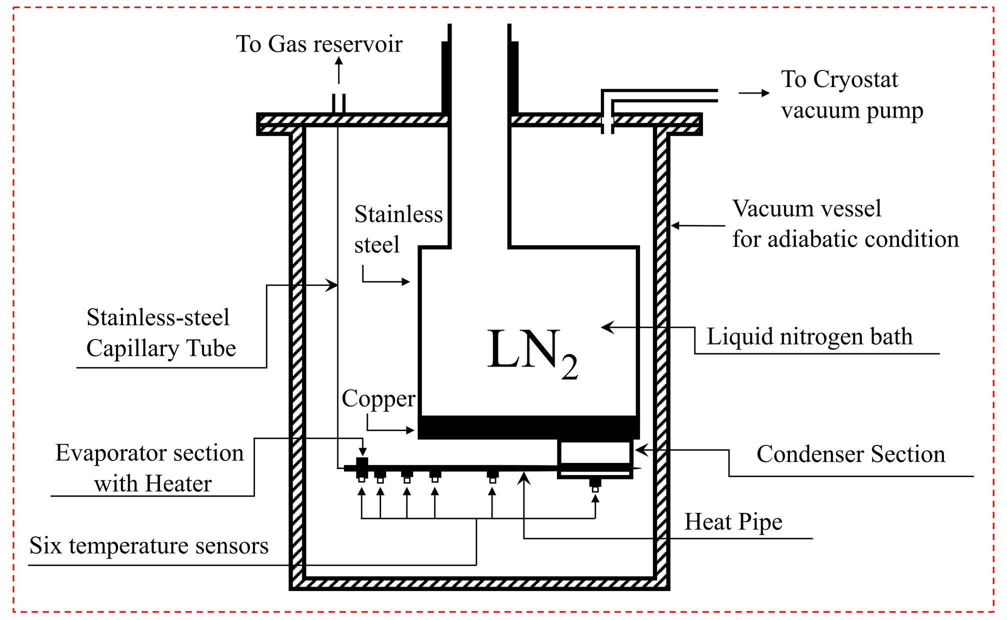


Fig.4 Cross-section of Cryostat at N_2-heat pipe

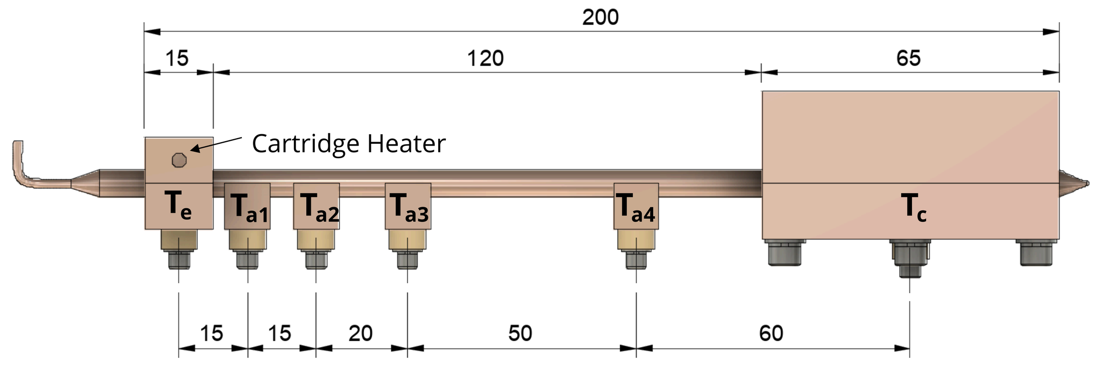


Fig.5 Heat pipe and locations of temperature sensors (in mm.)

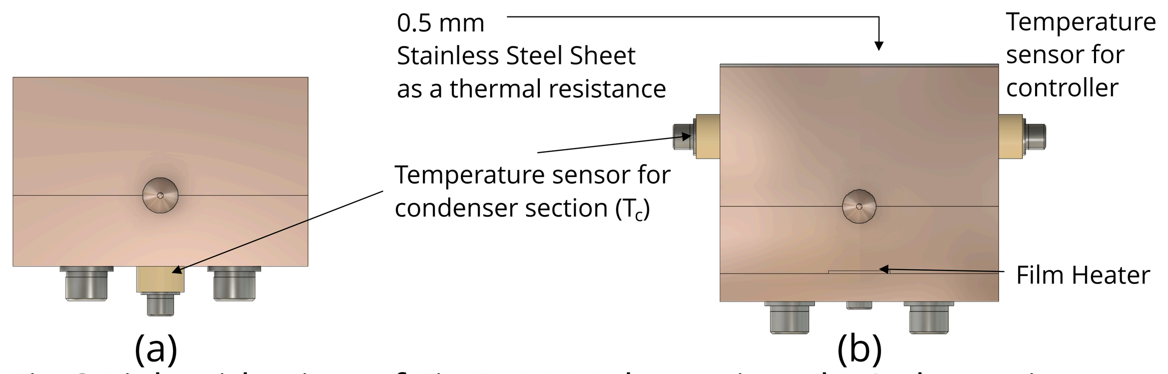


Fig.6 Right side view of Fig.5; (a) N_2-heat pipe, (b) Ar-heat pipe

Filling ratio:

- **The value of f_r is defined by the volume of condensed liquid (V_ℓ) divided by the void volume of the wick structure (ϵV_w).**

$$f_r = \frac{\frac{(P_i - P_f)\ V_r}{R_v\ T} - \rho_v A_v L}{\varepsilon \rho_l A_w L}$$

$P_i - P_f$ is pressure change in gas reservoir due to phase change
V_r is the volume of gas reservoir

Result and Discussion

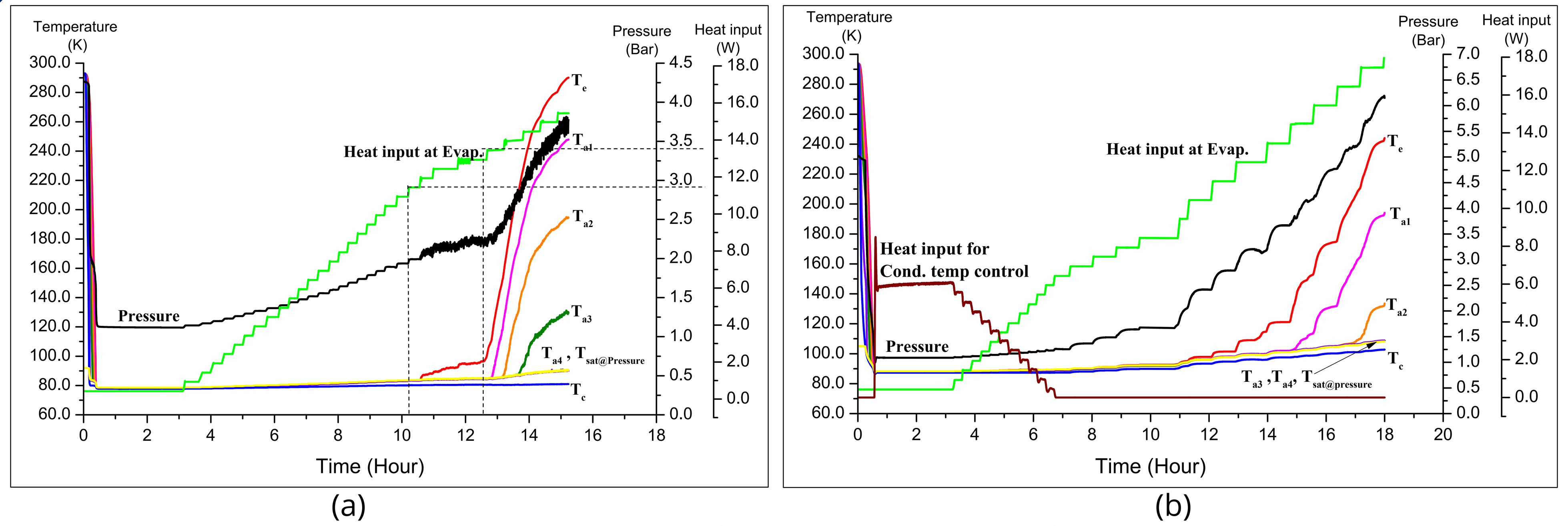
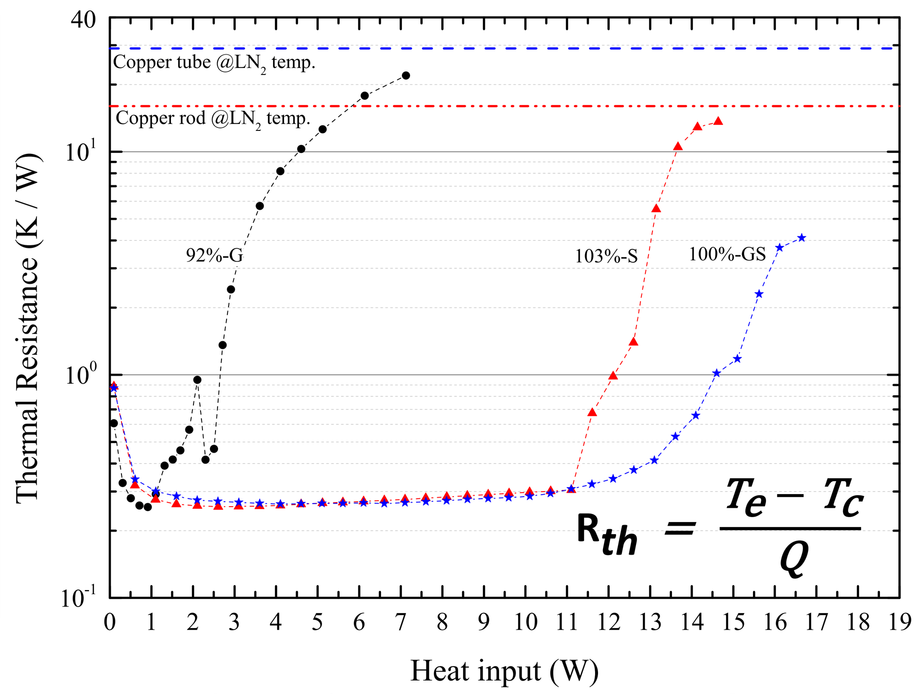


Fig.7 Temperature and pressure variations of the heat pipe at 100% fill with change of heat input (a) N_2-heat pipe, (b) Ar-heat pipe



$$R_{th} = \frac{T_e - T_c}{Q}$$

Fig.8 Thermal resistance variation of Nitrogen heat pipe with different wick structure

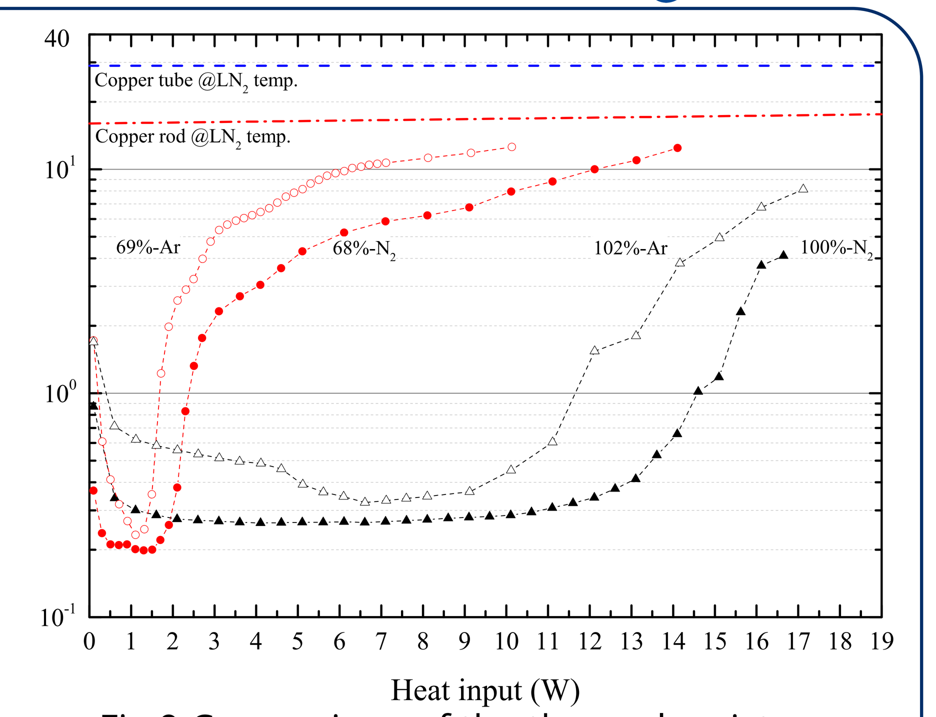


Fig.9 Comparison of the thermal resistance between Nitrogen and Argon heat pipes with the same wick structure.

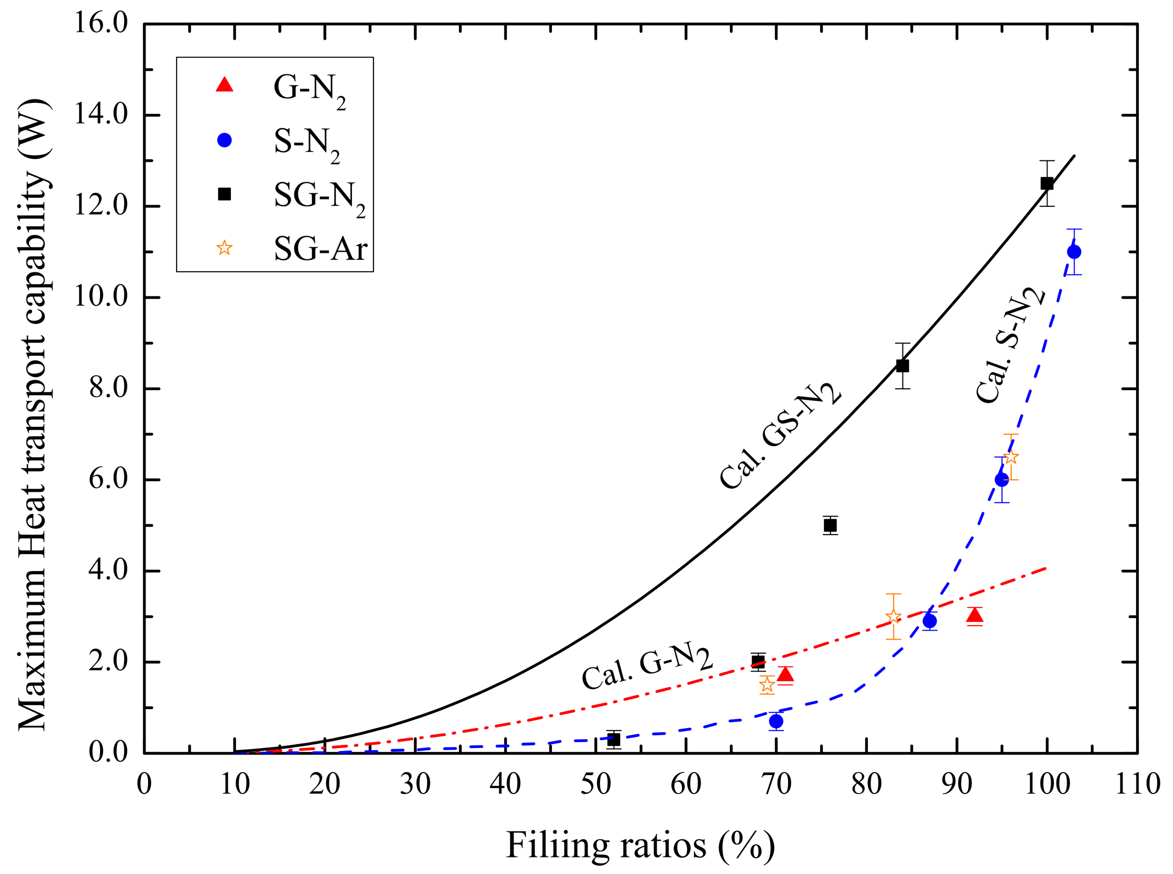


Fig.11 The experimental data and theoretical prediction of maximum heat transport capability Q_{max}

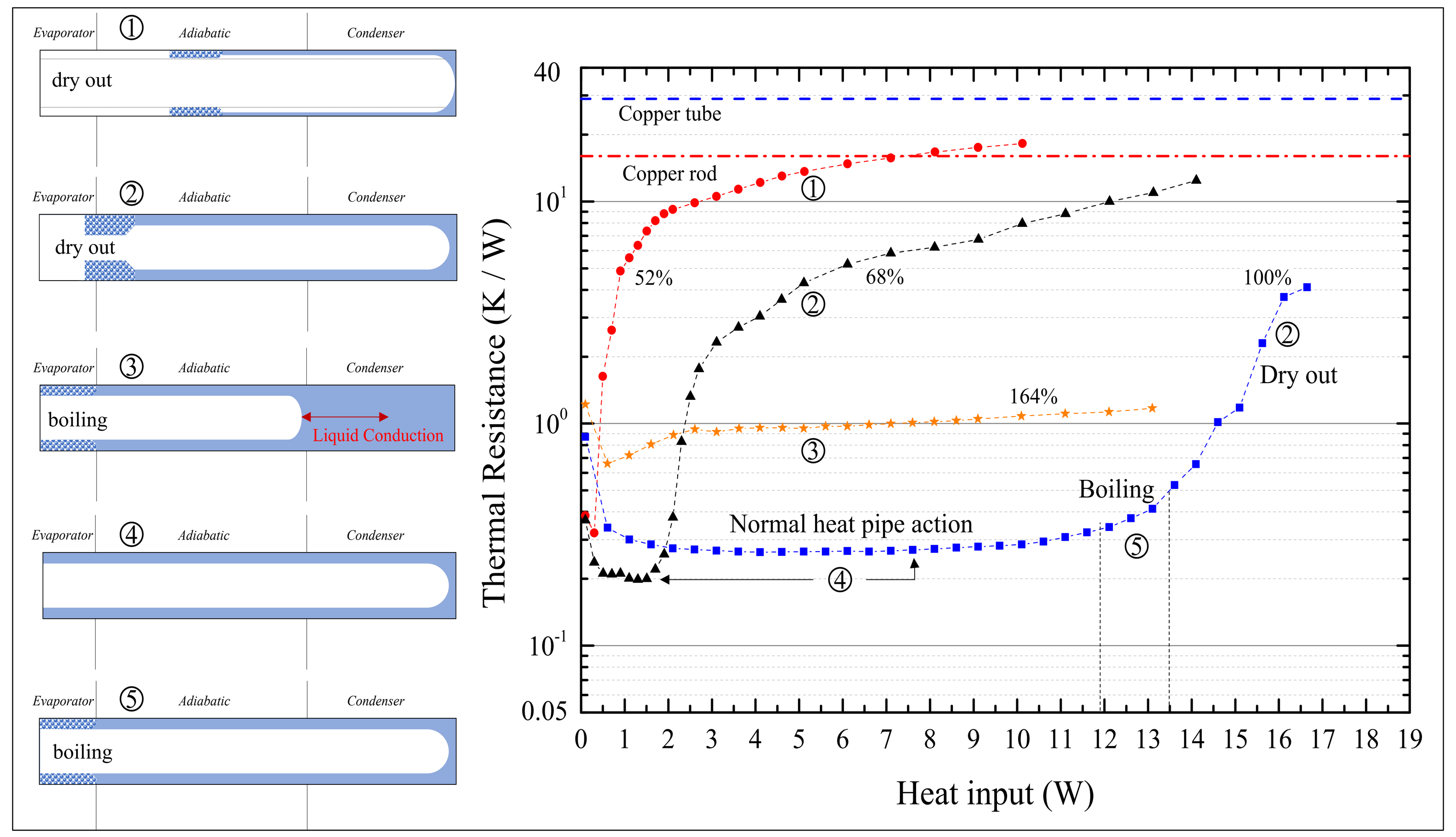


Fig.10 schematic illustration of working fluid distribution in the heat pipe of Nitrogen heat pipe with SG wick

- **For low filling ratio, dry-out occurred even at low heat input because liquid was insufficient to the evaporator section; ①, ②.**
- **For proper filling (100%), The minimum value of R_{th} is achieved during the normal heat pipe operation phase; ④, boiling start increasing when heat input was applied between 12.0-13.5 W; ⑤, local dry-out occurred after 13.5 W of heat input that causes temperature in the evaporator section rapidly rise and R_{th} also starts increasing; ②.**
- **For excess filling, R_{th} is larger than in case of normal heat pipe operation, because in condenser portion heat is transferred by conduction through the existence of excess liquid column in the heat pipe; ③.**

Conclusions

- ❖ **The performance rank by the wick structures is as follows in descending order; SG, S and G.**
- ❖ **The result of thermal performance test with the same wick structure (SG) indicates that both N_2 and Ar heat pipe have nearly identical R_{th} but significantly different in Q_{max}.**
- ❖ **In order to normally operate the heat pipe, liquid should be filled at least 50%.**
- ❖ **Q_{max} can be extend to 12W in case of the heat pipe with S or SG wick structure at sufficient liquid fill.**
- ❖ **It is interesting to note in the case of high liquid fill, R_{th} is constant without dry-out even at high heat input although R_{th} is higher than in case of normal heat pipe operation.**
- ❖ **The satisfactory agreement of the experimental results with the theoretical prediction for the case of composite wick structure, SG wick, seems to confirm our hypothesis for the wick function.**

Future work

- ➢ **Develop a theoretical mathematics model of heat pipes with Sintered-Groove composite wick structure and confirm with the experimental result.**
- ➢ **The new experimental set up by using the new variable temperature cryostat with a cryocooler is in designing process. The heat pipe experiment will be continued to test with a few working fluids, such as nitrogen or argon or neon.**

Reference

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