Measurement of boiling heat transfer coefficients for non-flammable cryogenic mixed refrigerant in various compositions

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Introduction

- **Utilization of heat transfer coefficient – heat exchanger design**
  - Main thermal load in MR refrigeration systems : heat exchangers
  - Usage of proper heat exchangers → reduction of transient cooling time
  - Increasing operability of MR refrigeration systems
- **HTC of non-flammable mixed refrigerant (MR)**
  - Attention to utilize non-flammable MRs as working fluid of refrigerators
  - R218 & R14 : non-flammable MR with high efficiency at 140 to 270 K
  - HTC of non-flammable MR : ***insufficient information***

Objectives

- **Measurement of the boiling HTC for the non-flammable cryogenic MR sets**
  - Using R218 and R14 to compose of the experimental MR sets
  - Uncertainty analysis for the experimental boiling HTC results
- **Parametric study with various experimental conditions**
  - Effects of the molar composition, mass flux, and heat flux to the non-flammable MR's boiling HTC value

Experimental setup / Experimental results

- **Schematic diagram of experimental apparatus**
  - Compressor and throttling valve : to control an inlet pressure
  - Striling cryocooler and trim heater : to control a temperature condition

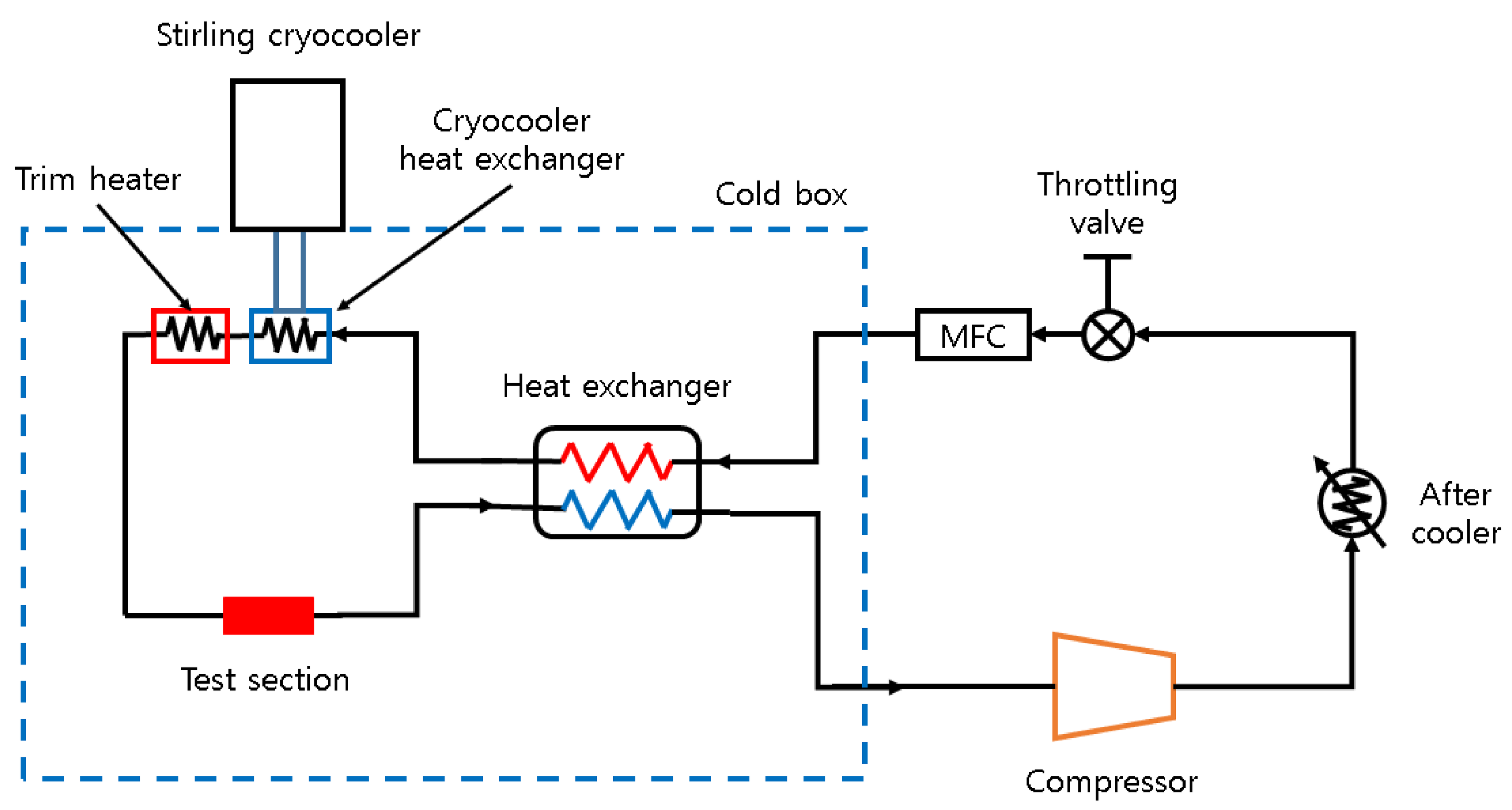

Fig. 1 Schematic diagram of whole system

- **Test section for HTC measurement**
  - Pressure and temperature measurement for using LMTD method
  - Temperature measurement point : T_{in}, T_{wall1}, T_{wall2}, and T_{out}
  - Pressure measurement point : P_{in}, and P_{out}

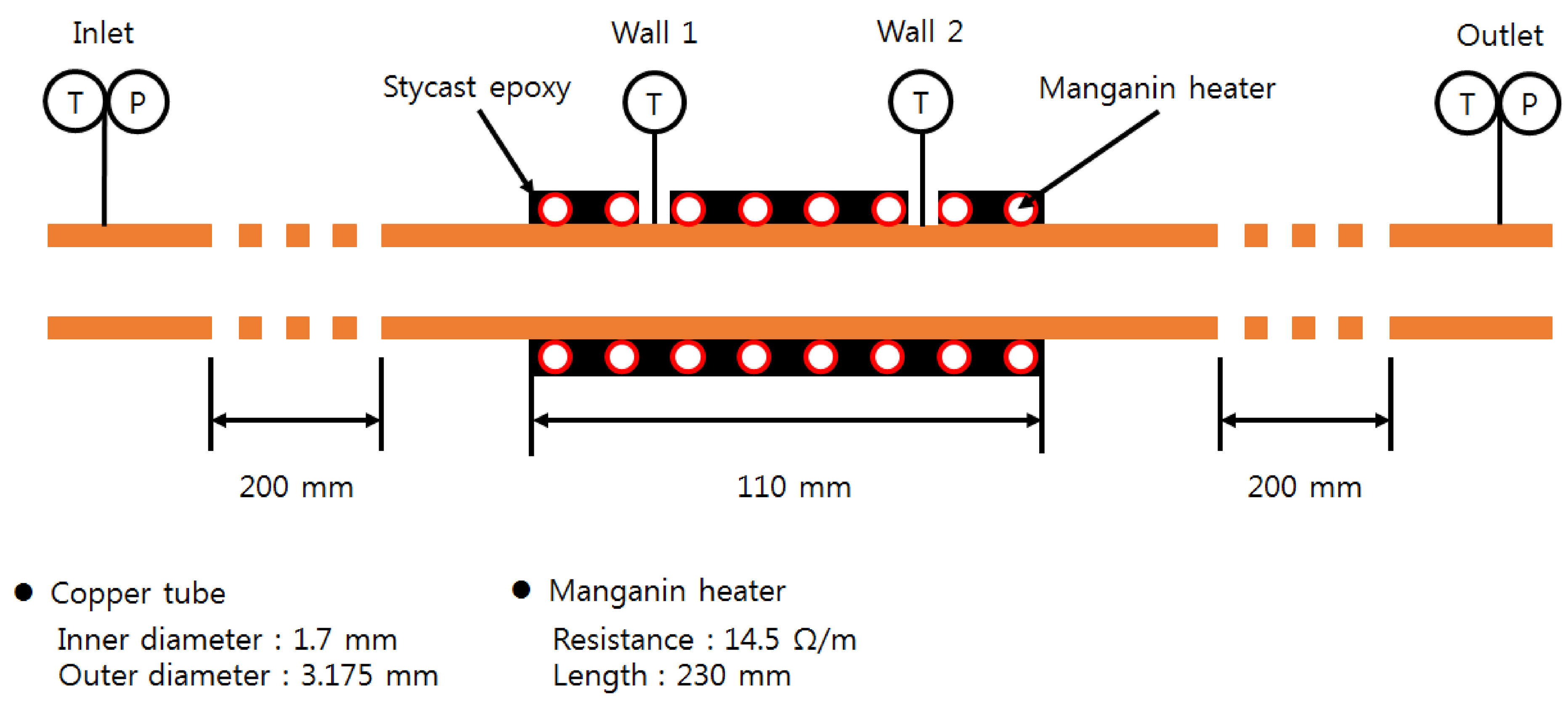

Fig. 2 Schematic diagram of test section

- **Experimental procedure**
  1. Charging the specific MR composition.
  2. Operating the compressor and cool down the whole system.
  3. Operating the test section heater when the process 2. is over.
  4. Waiting for thermal steady state and get the steady state data.
  5. Changing the temperature at the test section with trim heater.
  6. Repeating the 2 to 5 process with other conditions.

- **Experimental conditions**

Table 1 Experimental conditions for R218:R14 = 0.7:0.3 mixed refrigerant

Case	MR composition	Pressure [kPa]	Heat flux [kW/m²]	Mass flux [kg/m²s]
1	R218:R14 = 0.7:0.3	450 ± 50	1.40	22.0
2			1.40	49.6
3			1.40	82.6
4			4.90	22.0
5			4.90	49.6
6			4.90	82.6

Table 2 Experimental conditions for R218:R14 = 0.5:0.5 mixed refrigerant

Case	MR composition	Pressure [kPa]	Heat flux [kW/m²]	Mass flux [kg/m²s]
7	R218:R14 = 0.5:0.5	450 ± 50	1.40	22.0
8			1.40	49.6
9			1.40	82.6
10			4.90	22.0
11			4.90	49.6
12			4.90	82.6

- **Experimental Nusselt number**
  - LMTD method

$$\Delta T_{LMTD} = \frac{\Delta T_{wall,in} - \Delta T_{wall,out}}{\ln\left(\frac{\Delta T_{wall,in}}{\Delta T_{wall,out}}\right)} \quad \Rightarrow \quad h_{exp} = \frac{\dot{q}}{A_s \Delta T_{LMTD}}$$

$$\left[\Delta T_{wall,in} = T_{wall} - T_{in}\,,\ \Delta T_{wall,out} = T_{wall} - T_{out}\right]$$

- **Uncertainty analysis**
  - General uncertainty equation (U : uncertainty)

$$U_f^2 = \left(\frac{\partial f}{\partial x}U_x\right)^2 + \left(\frac{\partial f}{\partial y}U_y\right)^2 + \left(\frac{\partial f}{\partial z}U_z\right)^2$$

  - Uncertainty equation for HTC

$$U_h^2 = \left(\frac{\partial h}{\partial \dot{q}}U_{\dot{q}}\right)^2 + \left(\frac{\partial h}{\partial A_s}U_{A_s}\right)^2 + \left(\frac{\partial h}{\partial \Delta T_{LMTD}}U_{\Delta T_{LMTD}}\right)^2$$

- **Experimental results**

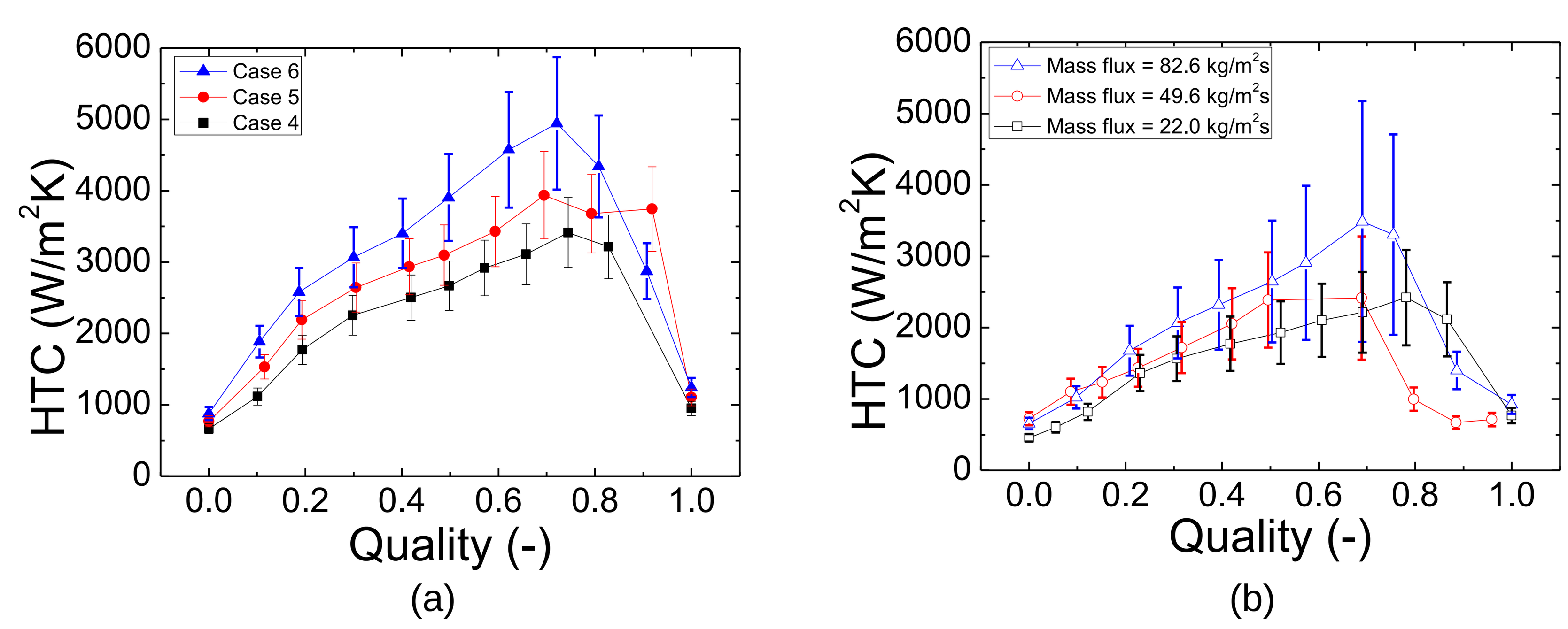

Fig. 3 Measured HTC of R218:R14 = 0.7:0.3 for (a) heat flux = 4.90 kW/m², and (b) heat flux = 1.40 kW/m²

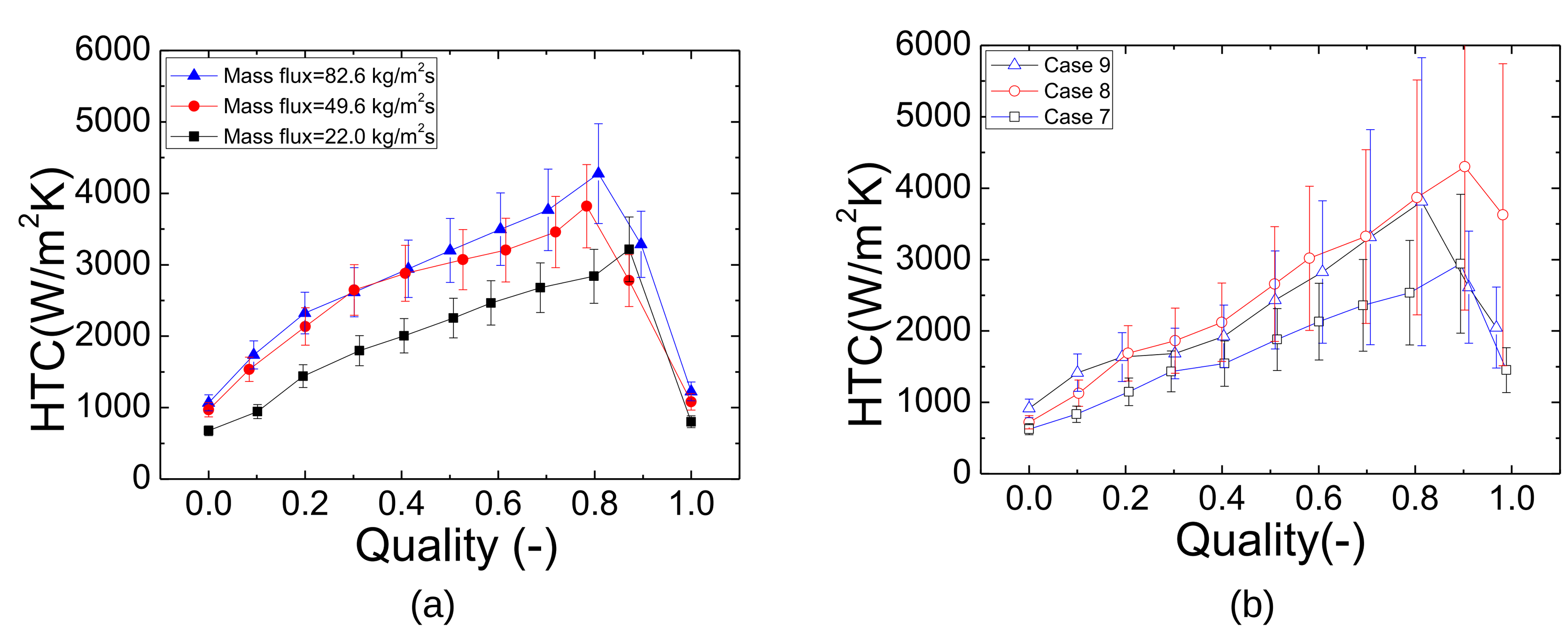

Fig. 4 Measured HTC for R218:R14 = 0.5:0.5 for (a) heat flux = 4.90 kW/m², and (b) heat flux = 1.40 kW/m²

Summary

- **The refrigerant with large composition of R218 shows large average HTC.**
- **Boiling HTC has proportional tendency to the change of the heat, and mass flux.**
- **Small heat flux and large mass flux cases have large uncertainty because of the small temperature difference at the inlet and outlet of the test section. (The temperature difference is not large enough to compared with uncertainty of the silicon diode temperature sensor)**