# Experimental investigation of a cryogenic PCHE (Printed circuit heat exchanger)

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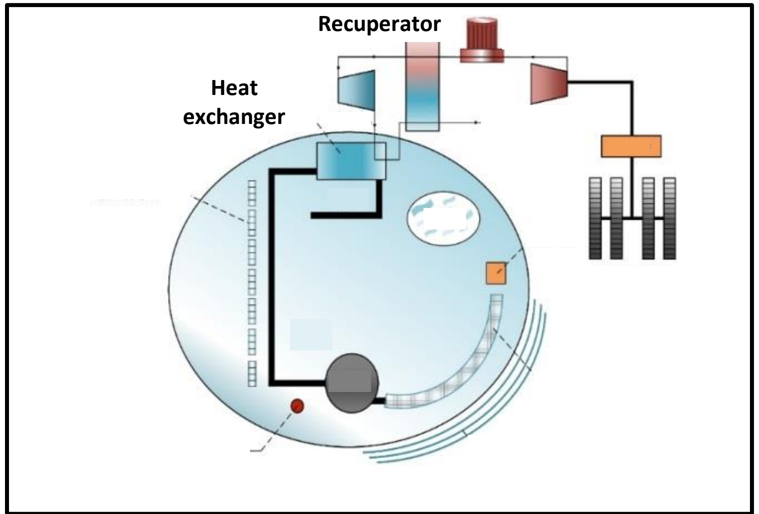
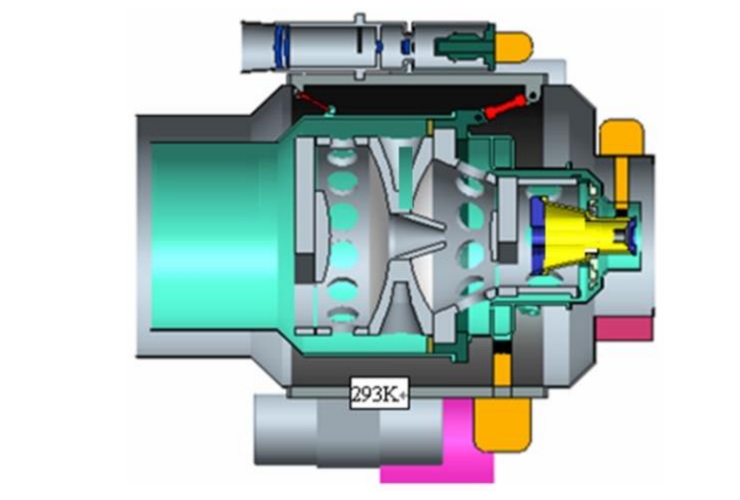
# Background & significance

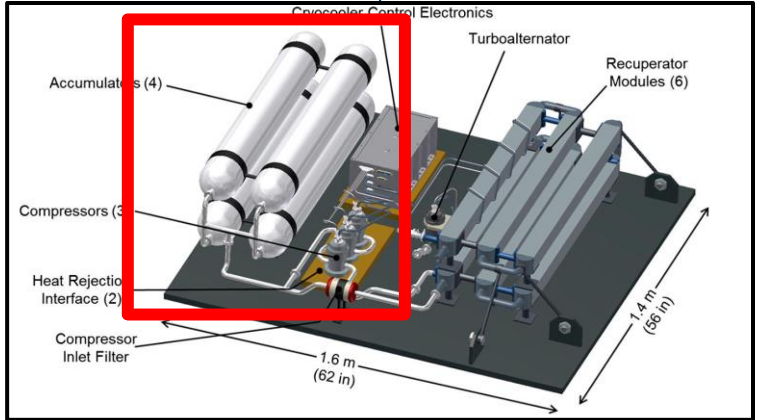
Cryogenic Storage Device in the Chinese Space Station
**193 K-277 K**




Zero-Boil-Off Storage of Cryogenic Propellants
**20 K-90 K**




Cryogenic Requirements for Space-Based Infrared Cameras
**80 K**




Reverse Brayton Refrigerator

Space cryogenic technology
a key technology for many future aerospace missions

Reverse Brayton refrigerator
the optimal approach for getting deep & large cooling capacities

Compact cryogenic heat exchangers
As the bulky and key components, need to achieve upgrades in volume and efficiency

# Research status

**Compact heat exchangers**

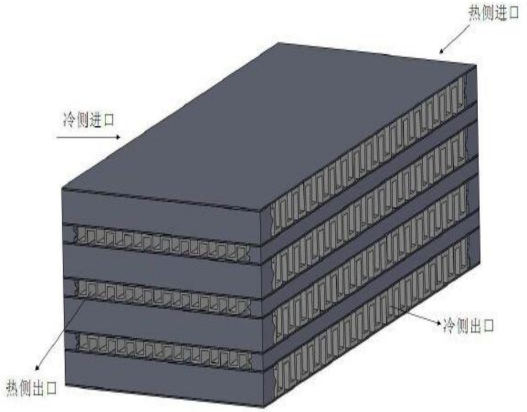
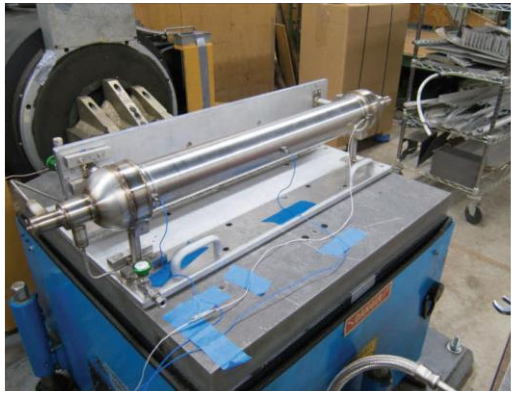
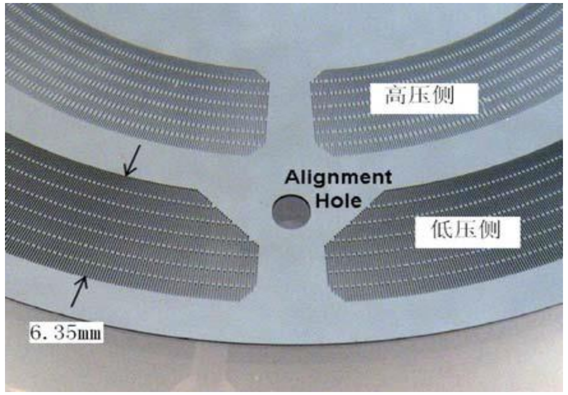



Plate-fin heat exchanger



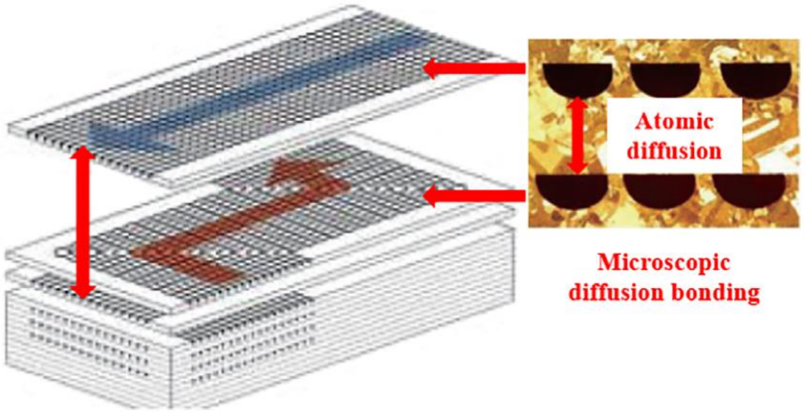
Micro-tube heat exchanger

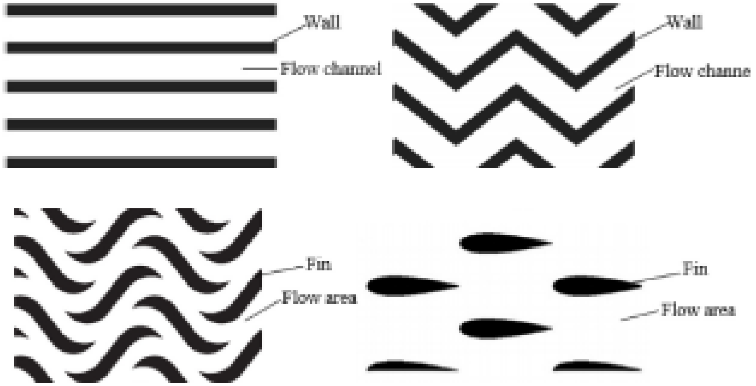



Matrix heat exchanger

performance and feasible needs improvement

**PCEH**




Channel layout

lack of cryogenic and large-temperature-span applications

lack of thermal-hydraulic performance improvement

# Research content

(1) Propose the structural design and fabrication method of an efficient PCHE with small-temperature-difference and large-temperature-span.

(2) Conduct a 80 K thermal-hydraulic performance testing system, demonstrate the excellent performance of the cryogenic PCHE.

(3) Analyse the effects of operation parameters on the cryogenic PCHE.

(4) Compare and analyse the difference between experimental and numerical simulation.

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# Requirement & Solution

## Design Requirement

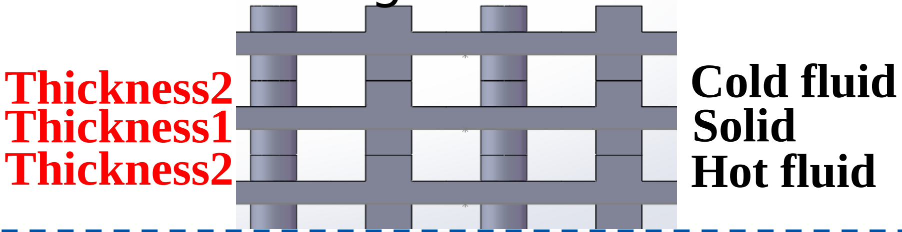
| | Fluid-hot side | Fluid-cold side |
|---|---|---|
| Working fluid | Ne | Ne |
| Mass flow rate g/s | 9 | 9 |
| Inlet temperature K | 313 | 80 |
| Inlet pressure kPa | 280 | 192 |
| Heat exchange effectiveness requirement | 97.5% | 97.5% |
| Allowable pressure drop kPa | 6 | 8 |

## Definition

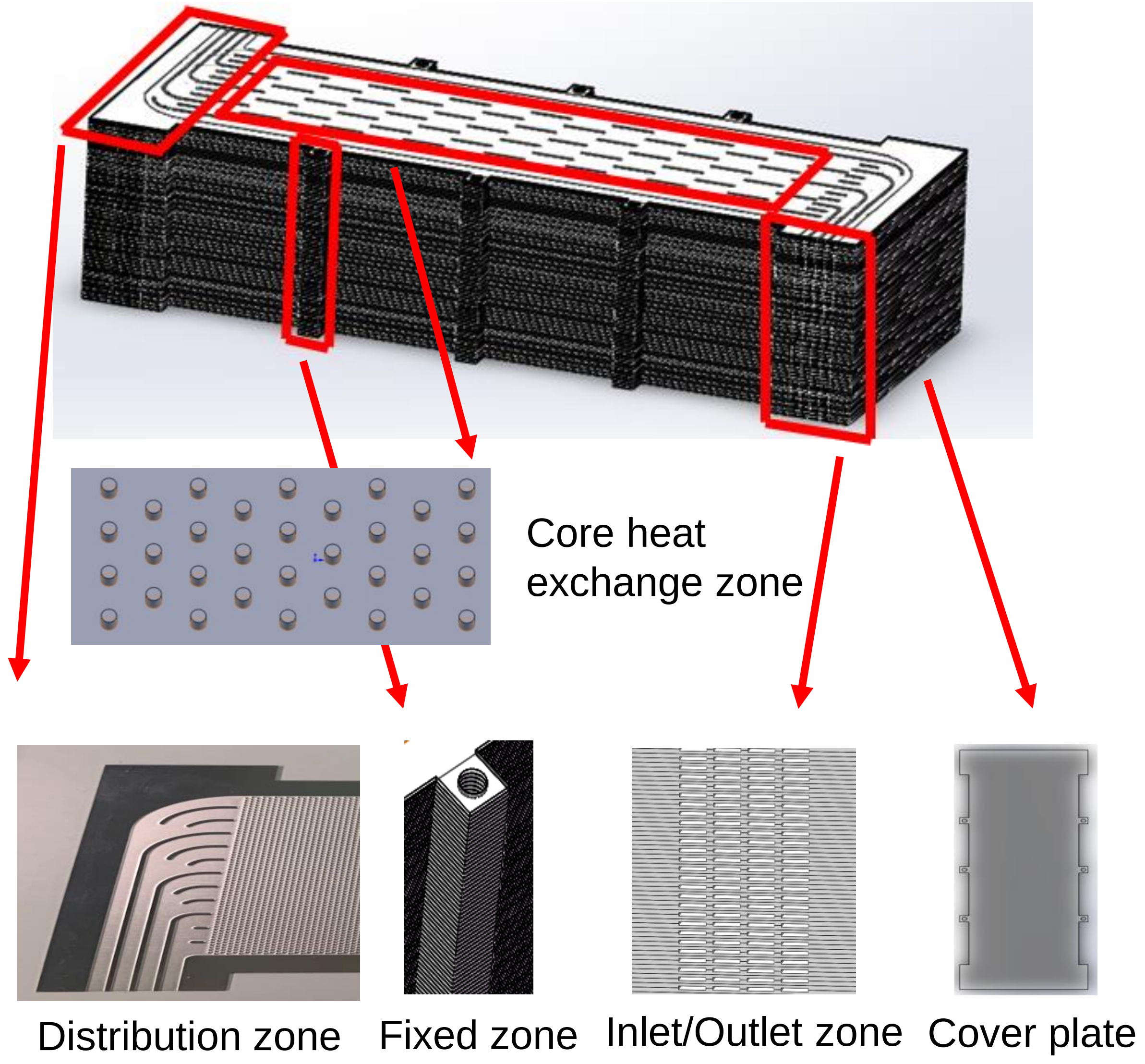
Heat exchange effectiveness $\varepsilon = \frac{Q_{actual}}{Q_{max}} = \frac{m_{fluid} c_{p,hot} \Delta T_{hot}}{m_{fluid} c_{p,min} (T_{hot,in} - T_{cold,in})}$

## Fabrication Scheme

- Metal etching
- Diffusion bonding




## Design structural



# Experimental testing platform

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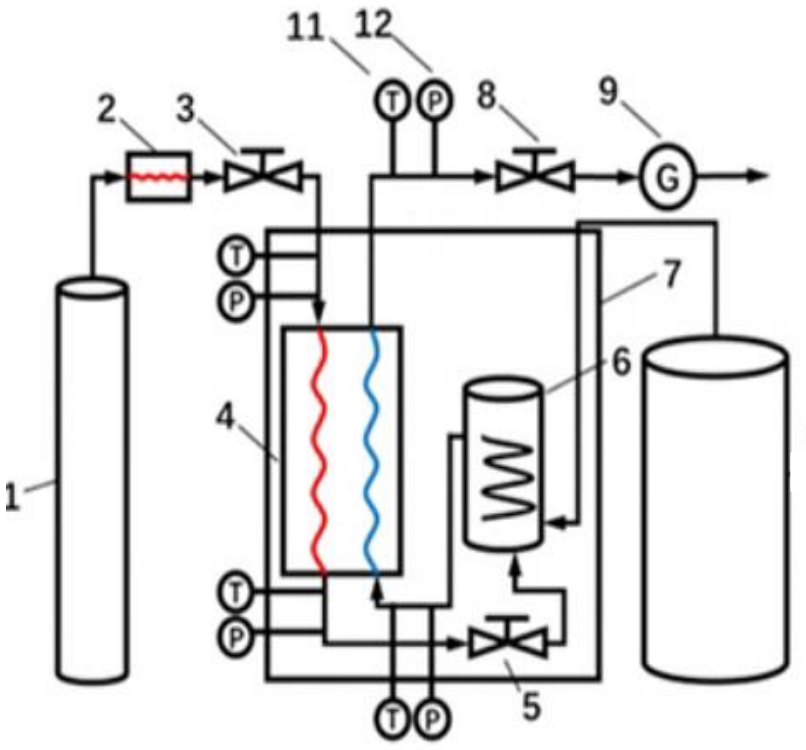
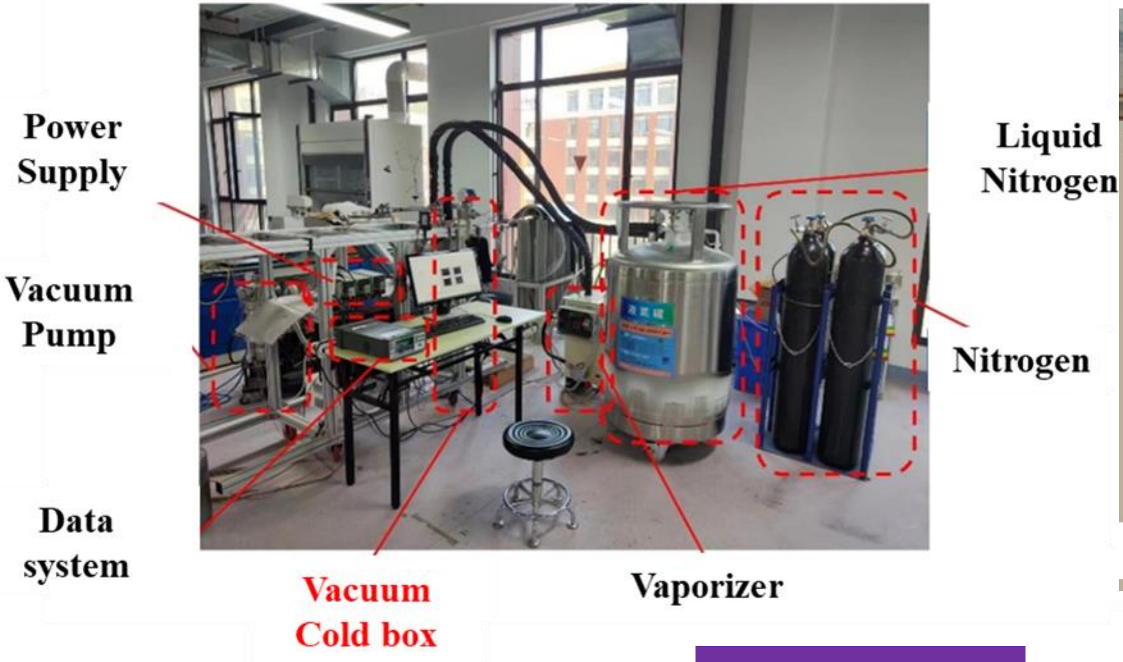
## Platform Design



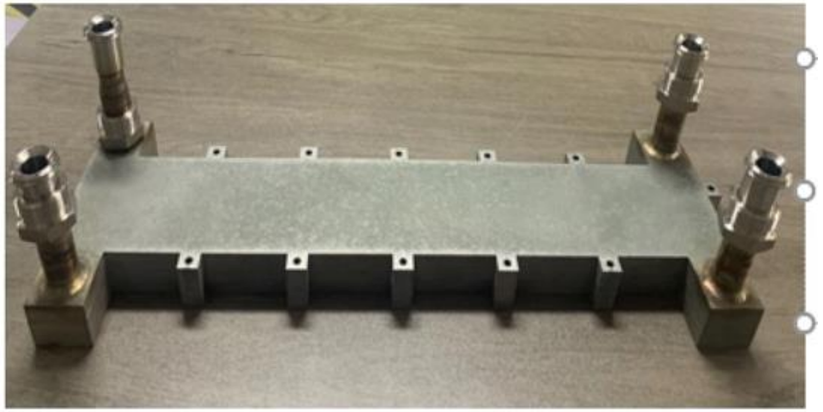

- **Temperature range：350 K-80 K**
- **Working fluid：Nitrogen**

## Experimental System Schematic





## Test PCHE



0.3 mm diameter fin
1.0 mm fin span

460 mm length
80 mm width
50 layers

# Experimental testing platform

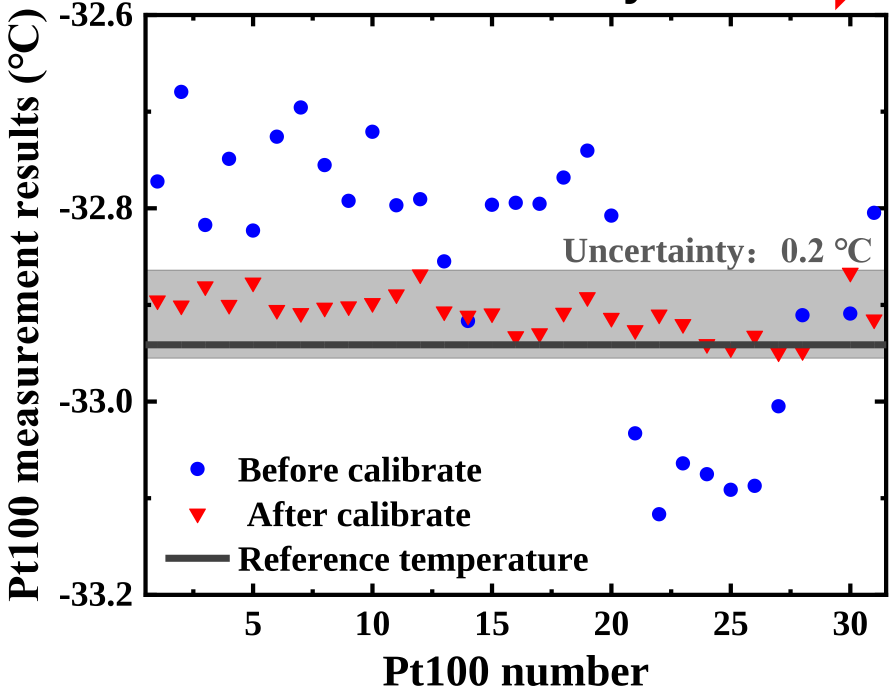
## Data measurement

**Heat exchange effectiveness** $\varepsilon = \frac{Q_{actual}}{Q_{max}} = \frac{m_{fluid} c_{p,hot} \Delta T_{hot}}{m_{fluid} c_{p,min}(T_{hot,in} - T_{cold,in})}$

**Pressure drop** $dp = P_{in} - P_{out}$

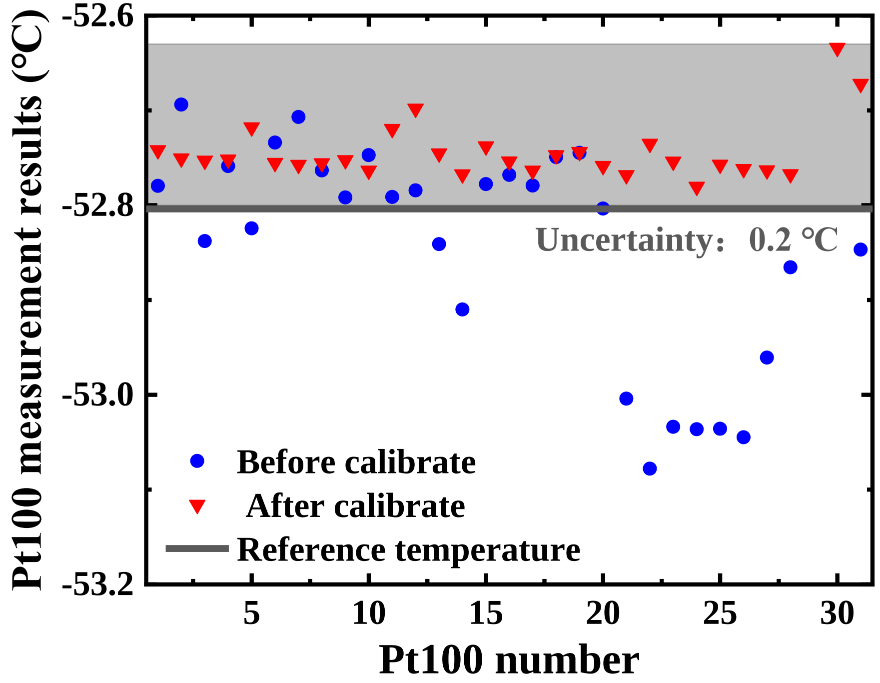
**measurement** → Mass flow, Pressure, Pressure drop
**Temperature**

**After calibration: T-uncertainty 1.0 K → 0.2 K**
**dT-uncertainty 26% → 5%**



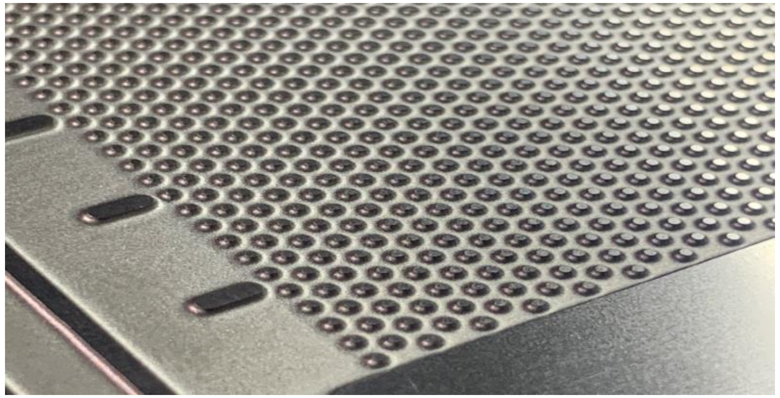

## Uncertainty

| Parameters | Unit | Uncertainty |
|---|---|---|
| Temperature | K | 0.2 |
| Pressure | MPa | 0.25% |
| **Pressure drop** | kPa | 0.25% |
| Voltage | V | 0.1% |
| **Mass flow rate** | $L\cdot min^{-1}$ | 1.5% |
| **Heat exchange temperature difference** | - | 5.2% |

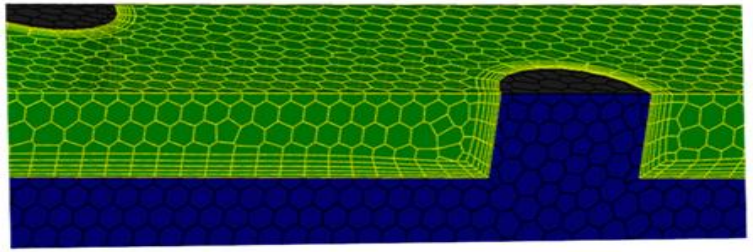


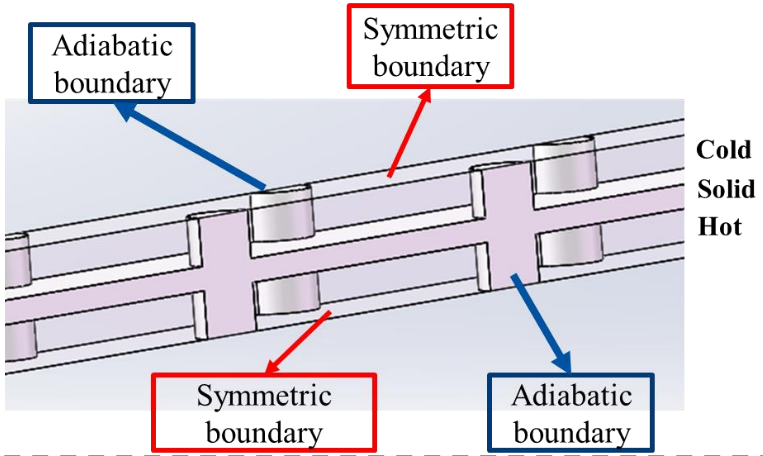
# Numerical model

## Physical model

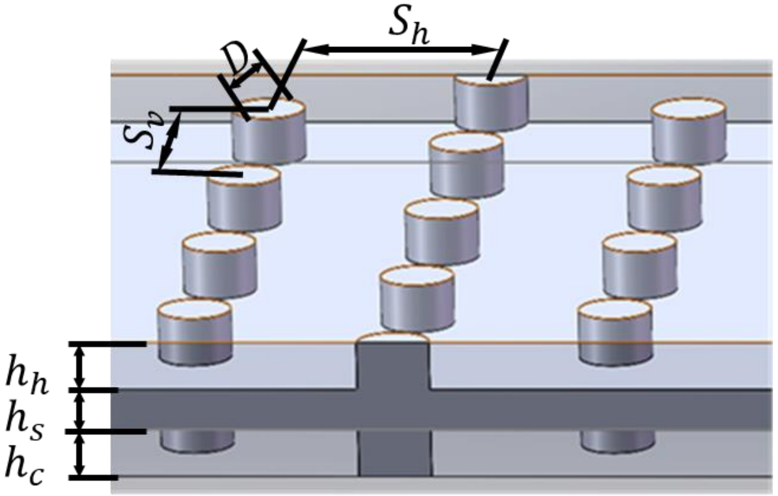


## Simulation model





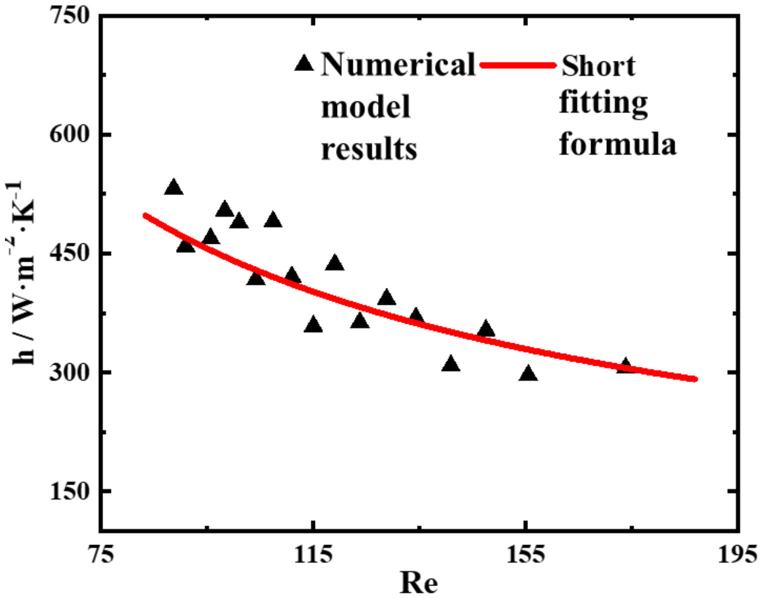

## Structural design parameters




**Five parameters**:

- d: diameter
- $S_h$: horizontal span
- $S_v$: vertical span
- $h_h$: hot fluid height
- $h_s$: soild height
- $h_c$: cold fluid height

## Simulation validation




Numerical model **accuracy**:

- Design results
- Parameter sensitivity

*Short BE, Raad PE, Price DC. Performance of pin fin cast aluminum coldwalls, part 1: Friction factor correlations[J]. Journal of Thermophysics and Heat Transfer,2002,16(3):389-396.*

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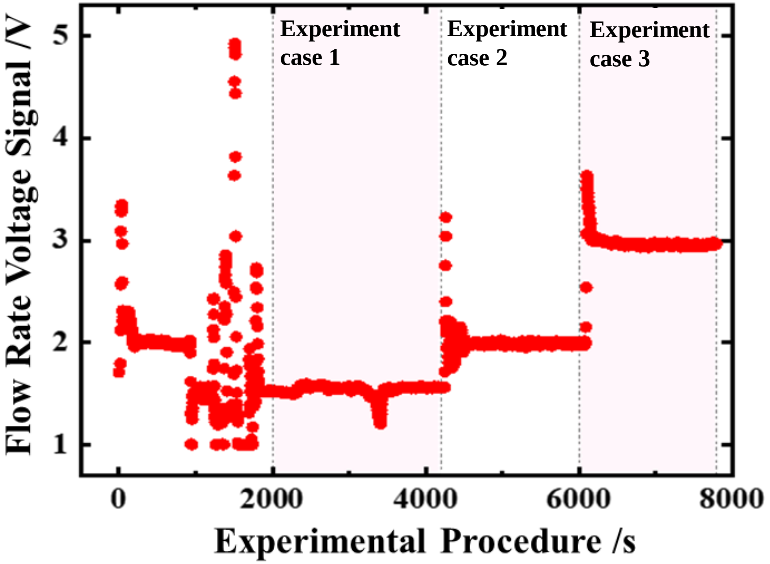
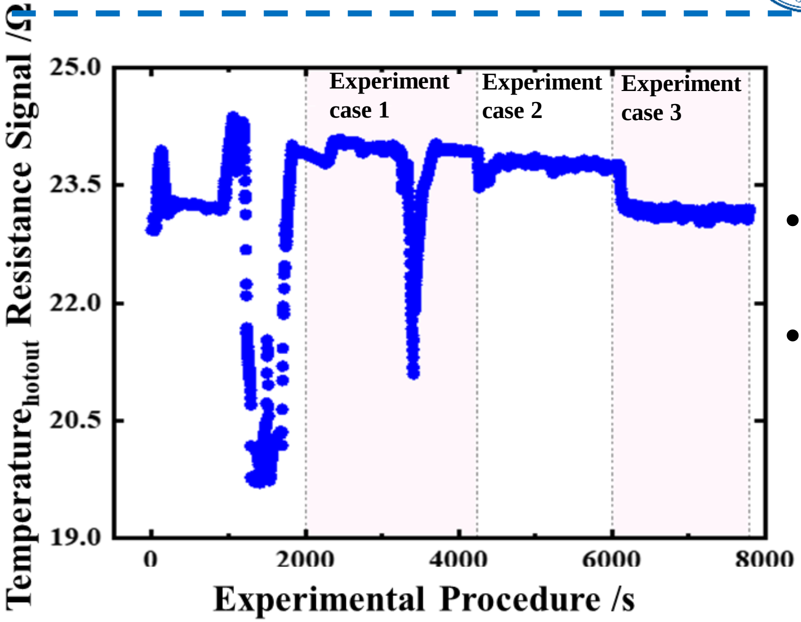
# Experimental data

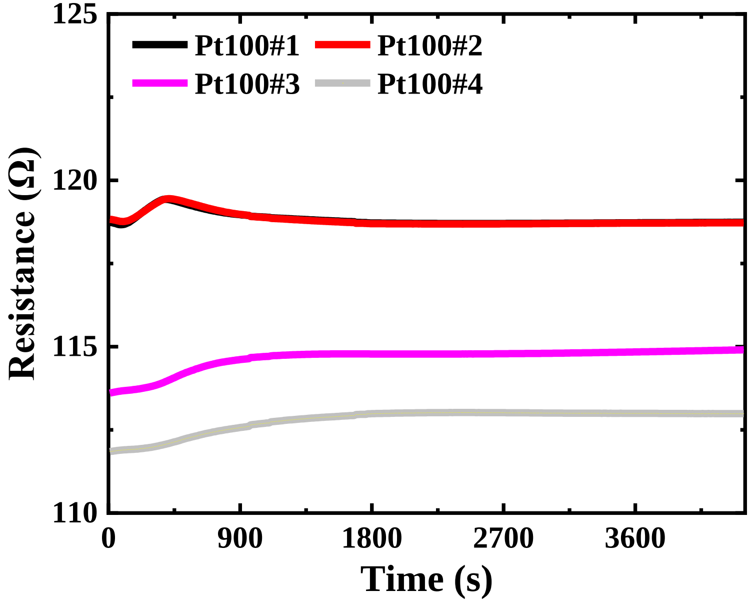
## Experimental procedure

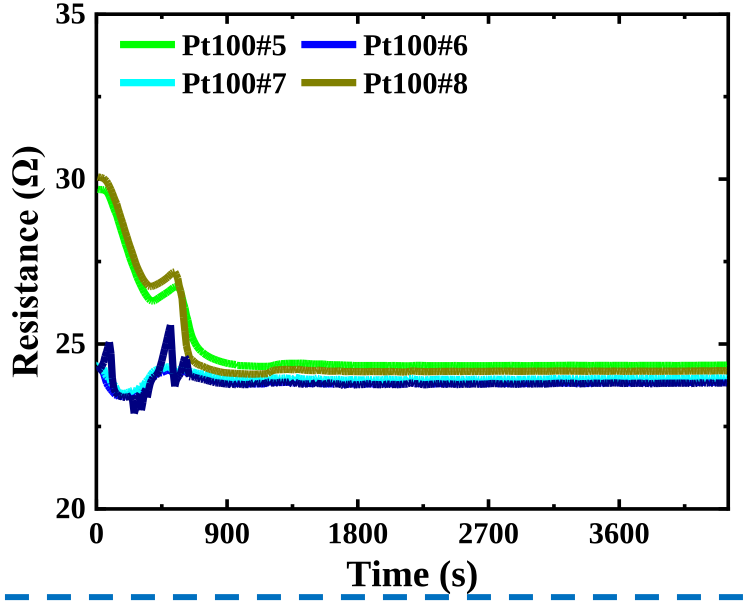


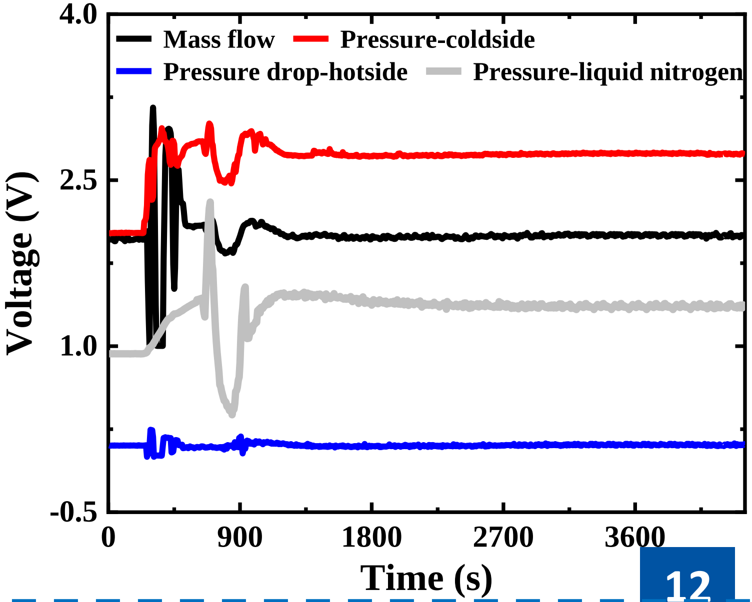




- Thermal Equilibrium Stability
- Data **Reliability**

## Stability

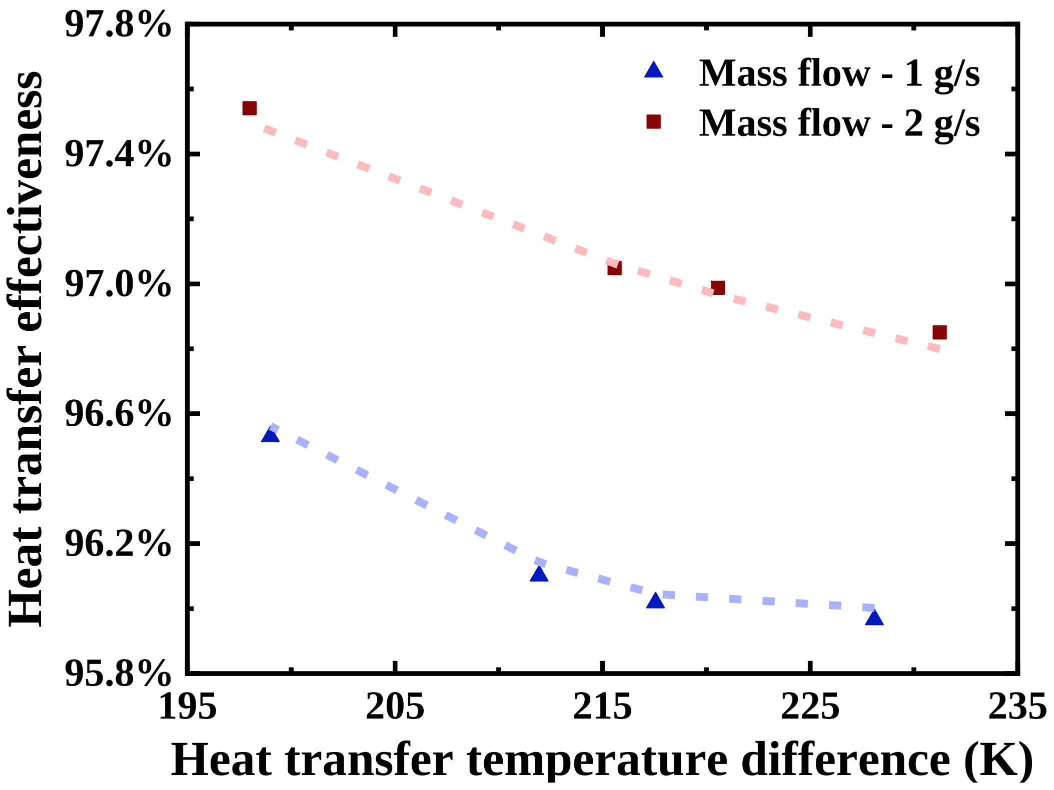


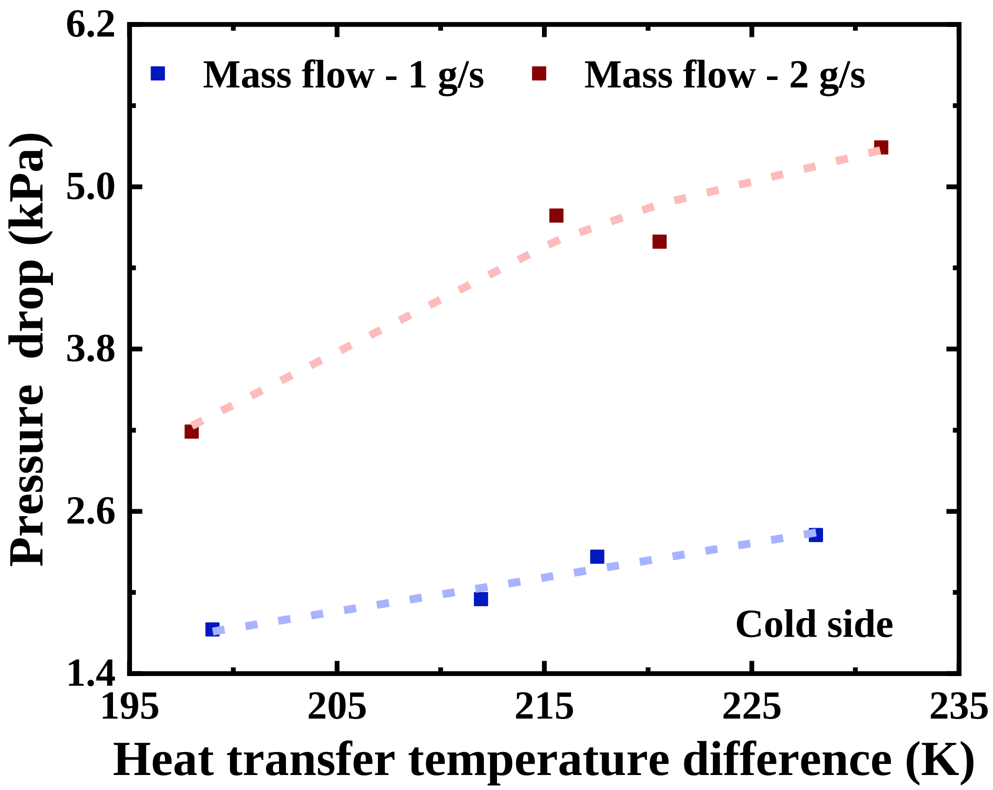



# Experimental data

## Temperature difference-Thermal characteristic



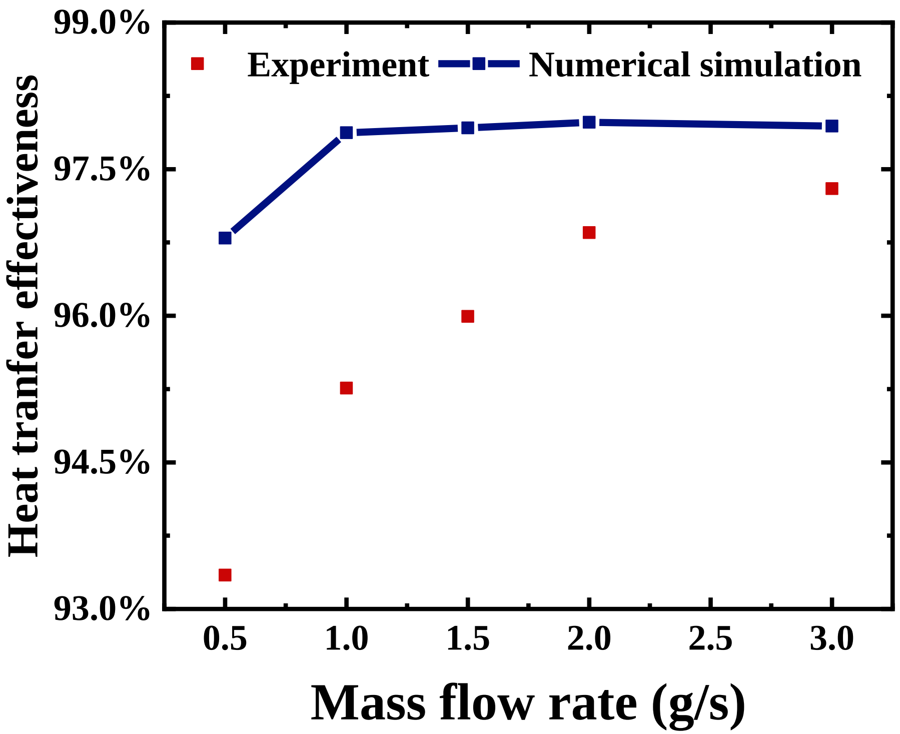

## Temperature difference-hydraulic characteristic



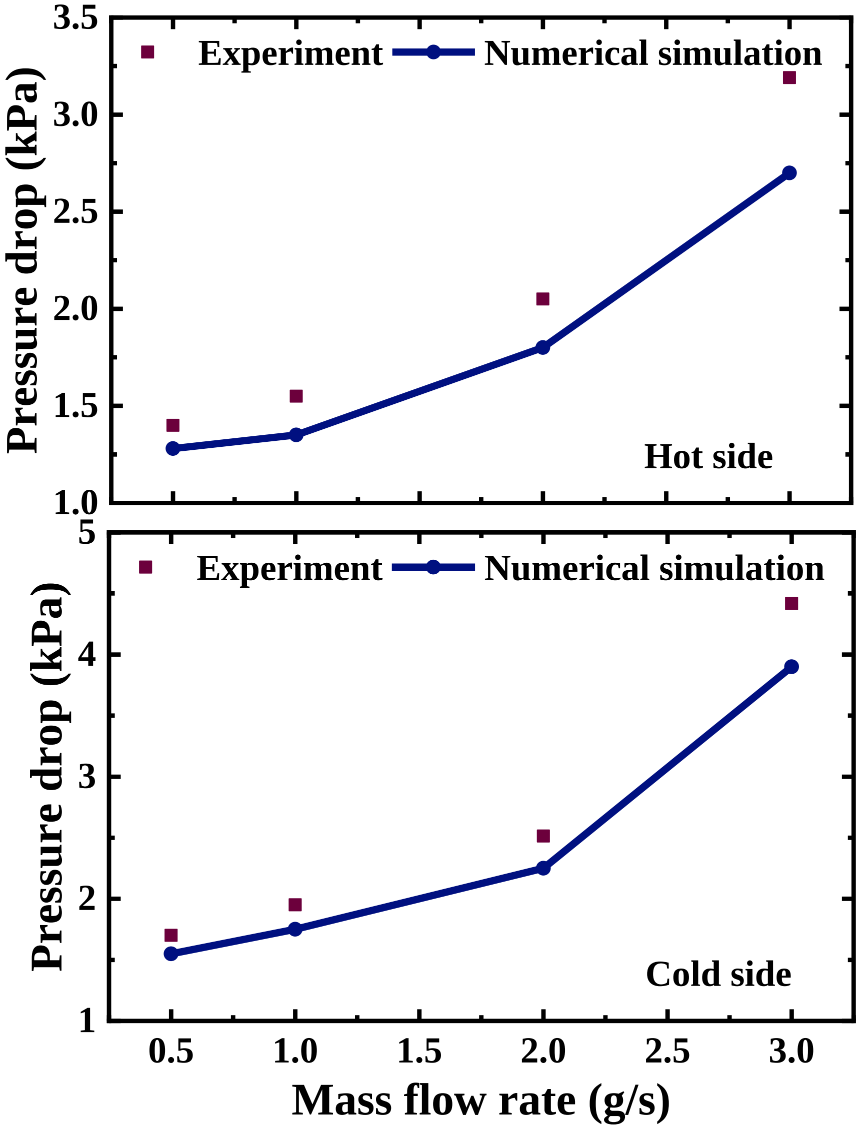
# Experimental data



## Mass flow-Thermal characteristic




## Mass flow-Hydraulic characteristic




**Mass flow increases：**

- Heat transfer effectiveness increases
- Pressure drop increase

**Two differences：**

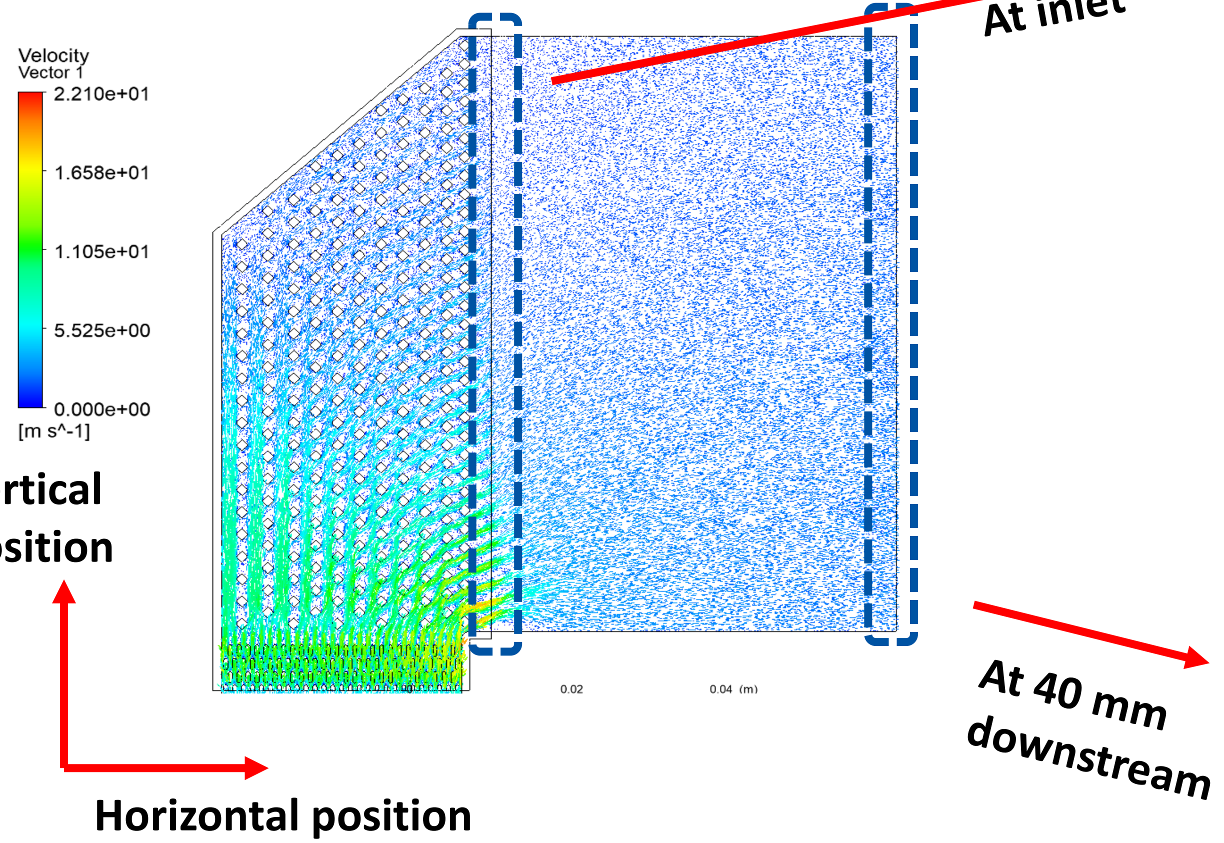
- Experiment & Numerical simulation
- Pressure drop： hotside & coldside

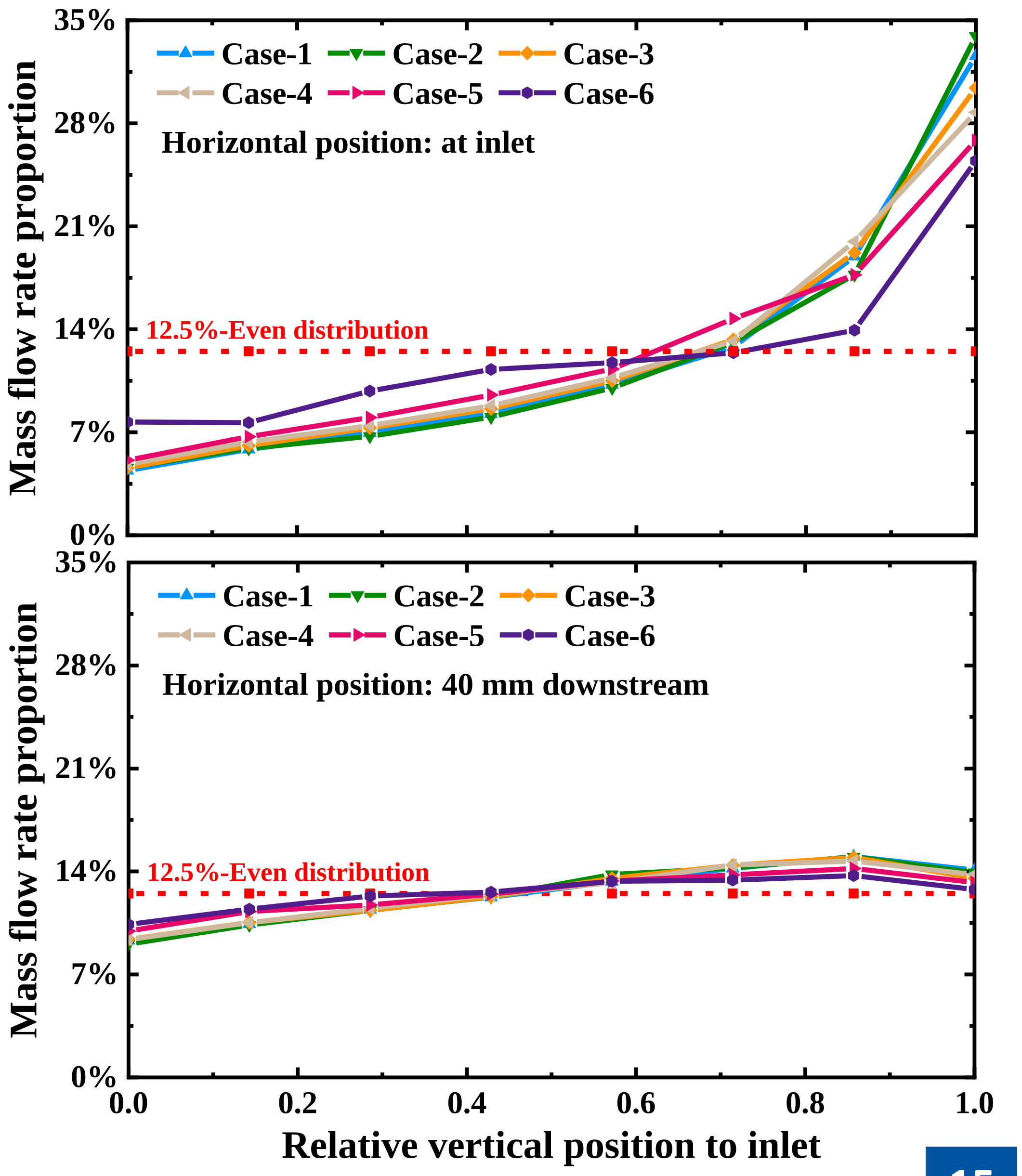
# Experimental data

## Possible reasons

### 1. Simulation simplified

- **Axial conduction**
  cryogenic heat exchanger with large temperature difference
- **Uneven Distribution**
  Symmetric flow distribution region



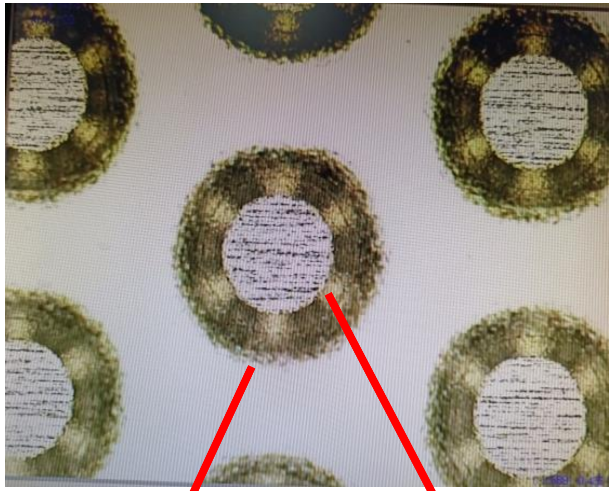



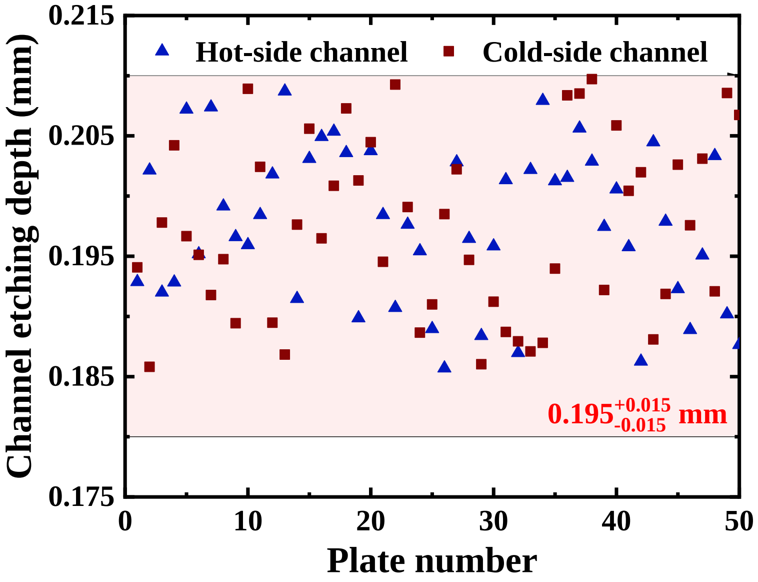
# Experimental data

## Possible reasons

### 2. Manufacturing deformation

- Metal etching






**Subtractive manufacturing**

**Bottom diameter & Top diameter**

**Within the tolerance range**

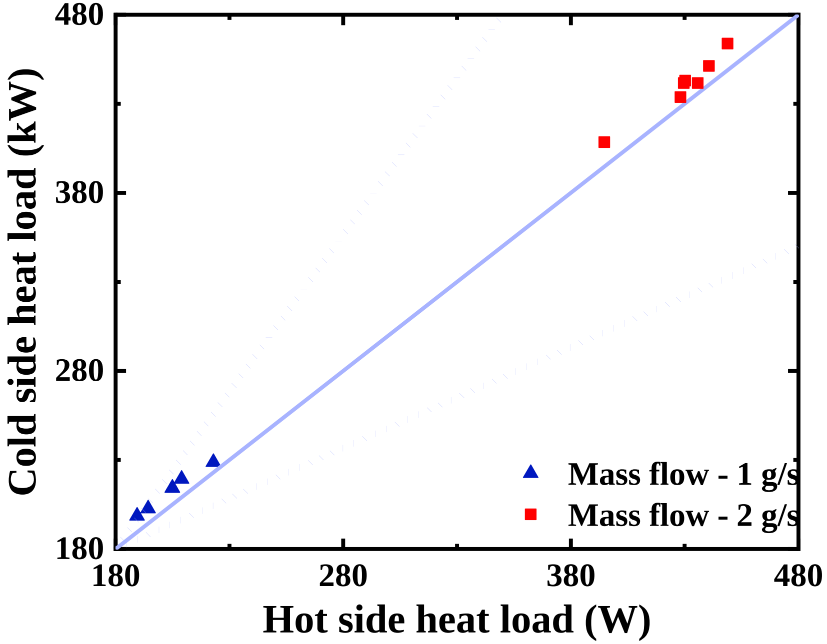
**Etching depth: Random & Uneven**

- Diffusion bonding

**High temperature & pressure**

**Deformation rate: 3%-10%**

### 3. Thermal Insulation

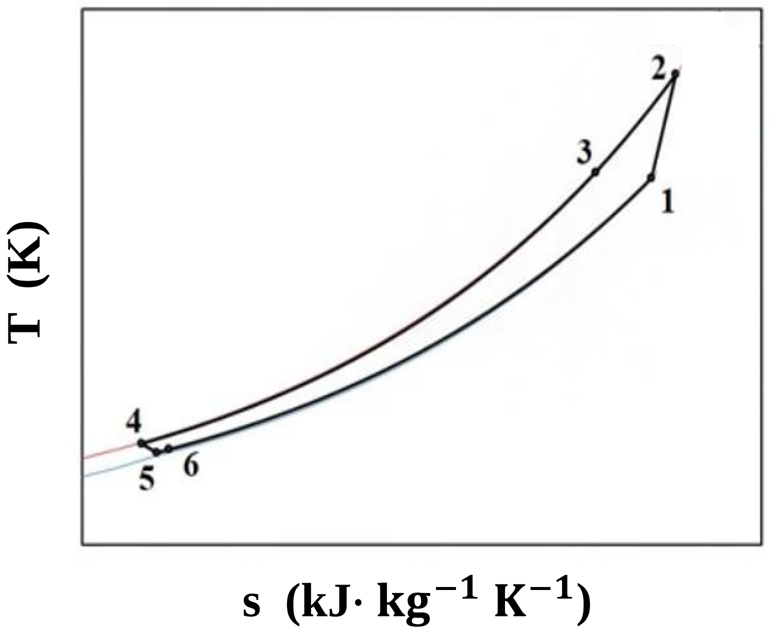


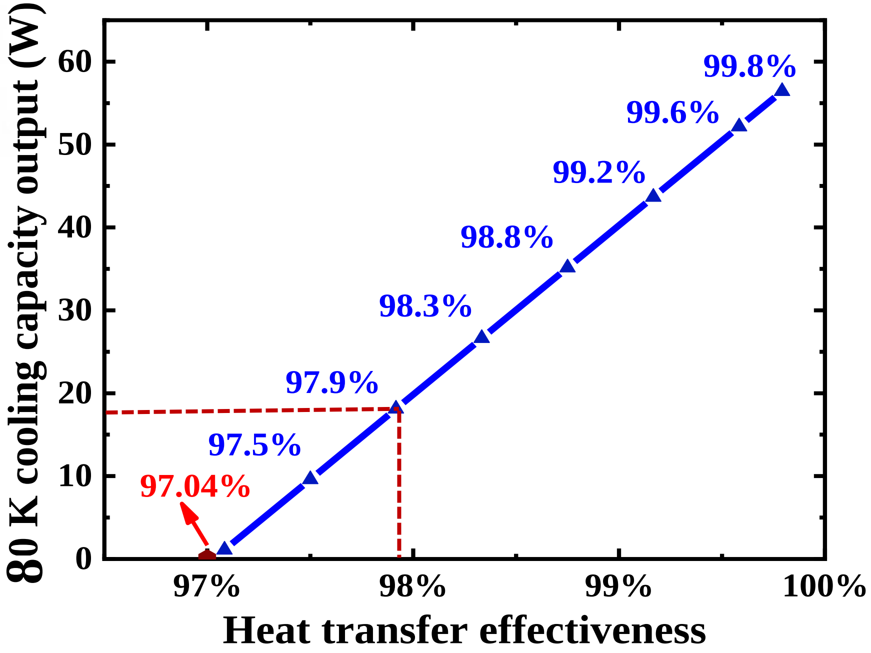

**Cold side > Hot side**

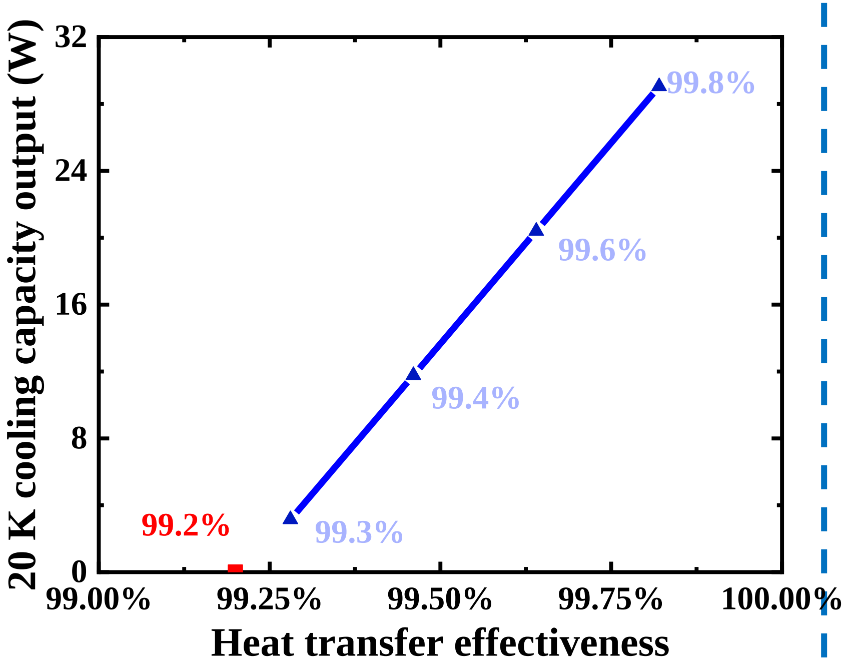
- Improve vaccum degree
- Improve insulation materials

# Outlook

## Effect of the effectiveness on system performance




- Heat transfer effectiveness **directly impact** the 80 K cooling capacity of reverse Brayton refrigerator.
- The refrigerator with proposed PCHE holding 97.9% heat transfer effectiveness can achieve **18 W @ 80 K** cooling capacity output.
- For futher higher cooling capacity refrigerator, must **upgrad the heat exchanger**.

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# Conclusion

(1) For a high-efficiency, lightweight 80 K @ 20 W reverse Brayton refrigerator, we design a cryogenic PCHE with the **compact structure, large temperature span, small temperature difference**. Conduct **80 K cryogenic experiment** to verify the high-efficiency performance of the proposed PCHE. The heat exchange effectiveness and pressure drop at design point are 97.9 %, 3.2 kPa, 4.4 kPa.

(2) Analysis the thermal-hydraulic performance **sensitivity** of cryogenic PCHE. The mass flow rate and temperature difference are discussed.

(3) **Differences between experiment and numerical simulation** are developed, verifying the importance of experiment on cryogenic heat exchanger design and potential way to improve the experiment.

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# Thank you


**Reporter：Zixin Zhang**

**Advisor： Professor Liang Chen**



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