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# Plate-Fin Heat-Exchangers for a 10 kW Brayton Cryocooler and a 1 km HTS Cable


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## Abstract

Plate-fin heat exchangers (PFHX) are designed and fabricated for a cryogenic cooling system, serving for a 10 kW Brayton cryocooler and a 1 km HTS transmission cable under development in Korea. To achieve compactness and thermal efficiency at the same time, a recuperative HX for Brayton cycle and a sub-cooling HX of liquid nitrogen for HTS cable are designed as integrated parts. A key design feature is focused on the coldest part of sub-cooling HX, where the streams of liquid nitrogen and refrigerant (helium gas) are arranged as two-pass cross-flow so that the risk of freeze-out of liquid nitrogen can be reduced. Details of hardware PFHX design are presented and discussed towards its immediate application to the HTS cable system.

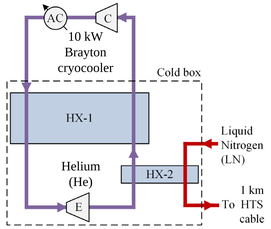

## Introduction

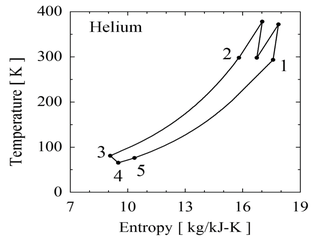
❑ **Korean HTS Power Cable Project (2011 ~ 2016)**

- Supported by Korean Government (KEPCO)
- Install & Demonstrate at **Jeju Island** (2016)
- 1~3 km HTS Cables at Transmission Class (154 kV)
- Brayton cryoooler for 10 kW Cooling

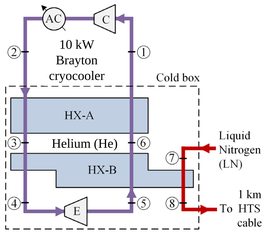

❑ **Previous Studies for Cryocooler Development**

- **Thermodynamic Design of Reverse-Brayton Cycle (Chang et al., *Adv Cryog Eng* 2012)**




- **Heat-Exchanger Detailed Design**
  **(Chang et al., *Proceedings of ICEC 24 -ICMC 2012*, 2013)**




- Plate-Fin Heat Exchanger (PFHX)
- Modify the arrangement of HX-1 & HX-2

→ **Two piece of nearly the Same Size**

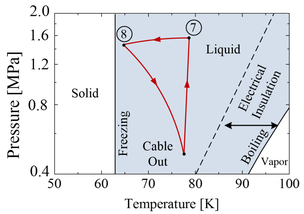
- **HX-A :** a part of HX-1
- **HX-B :** Combination of HX-2 & remaining part of HX-1
- Use commercial Software for evaluation (ASPEN MUSE)

| | Helium | | | | | | Liquid nitrogen | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| **Flow rate [kg/s]** | 0.183 | 0.183 | 0.183 | 0.183 | 0.183 | 0.183 | 0.451 | 0.451 |
| **Temperature [K]** | 293 | 298 | 150 | 80.9 | 65.5 | 145 | 78.0 | 67.0 |
| **Pressure [Mpa]** | 0.51 | 1.24 | 1.21 | 1.19 | 0.58 | 0.54 | 1.00 | 0.98 |

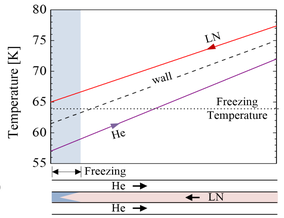
## Anti-freezing schemes of liquid nitrogen

❑ **Crucial Design Issue : Possibility of Freeze-out of LN in Long-length cable**

▪ LN Cycle on Phase diagram




▪ Example Temperature profile in HX-2

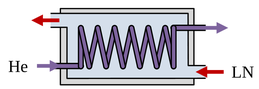



- Long-length (1 km ↑) HTS cable → Temperature of LN Supply becomes lower
- **Freeze-out of LN** @ The mean LN Temperature higher than freezing point (63.3 K)
  ✓ Become blockage of LN circulation → **DISASTER !!!**
- **Anti-freezing scheme → Preparation for unusual decrease of thermal load**

❑ **Proposed Anti-freezing Schemes**

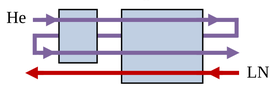
- **Yoshida et al., *Adv cryog Eng* 2012**

▪ **Tube-in-bath HX**




✓ Complete blockage of LN is avoided
✓ Size of HX could be excessively large

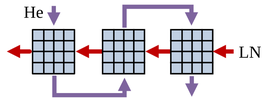
▪ **Two-stage HX**




✓ 1st stage : Cold gas is warmed-up
✓ Pressure drop of refrigerant
→ affect the thermodynamic efficiency

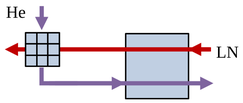
- **Chang et al., *Cryogenics* 2013**

▪ **Multi-pass cross-flow**



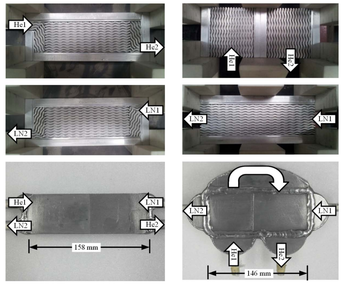

✓ Use 2-D temperature distribution
✓ Multi-pass → Increase effectiveness
✓ Pressure drop problem

▪ **Combined cross-flow and counter-flow HX**

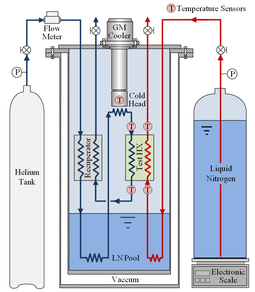



✓ Cold part → Cross flow
✓ Warm Part → Counter flow
✓ High effectiveness and Anti-freezing

❑ **Experimental Verification (Chang et al., *Cryogenics* 2013)**

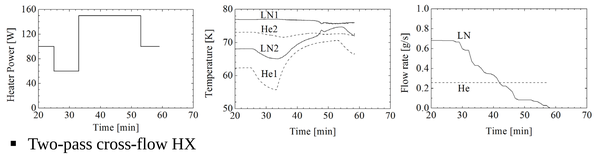



▪ Counter-flow HX ▪ Two-pass cross-flow HX

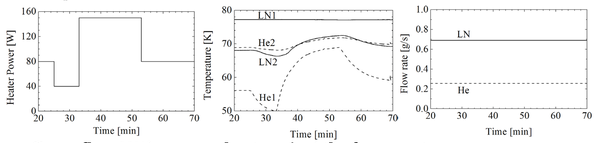



▪ Experimental Set-up

▪ Counter-flow HX




▪ Two-pass cross-flow HX



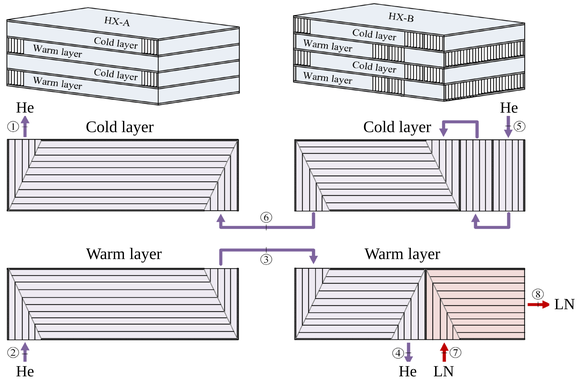

→ **Cross-flow HX's more robust against the freeze out**

## Result and discussion

❑ **Plate-fin Heat Exchanger Design Concept**

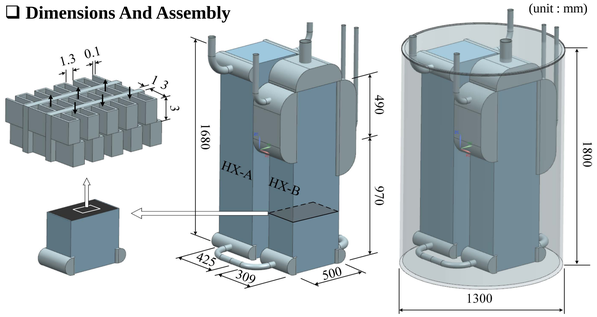
- Two PFHX'S are re-designed with incorporation the anti-freezing schemes

▪ HX-A ▪ HX-B

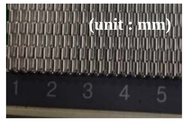



- Simple counter flow of high-pressure He & low-pressure He
- Counter flow (He-He) + Two-pass cross-flow (He-LN)
- Cryogenic expander Located between 4 and 5 → 5 is Coldest position of HX

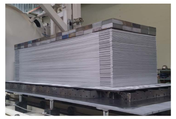
❑ **Dimensions And Assembly**



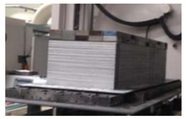

- Heat exchange rate – HX-A :141 kW, HX-B : 66 Kw (He-He) + 10 kW (He-LN)
- Basic geometry & specification : Given by the heat exchanger manufacturer (Dongwha Entec Co. Ltd.)
- Size of HX's : Use commercial software (Aspen MUSE & HTRI-XPHE)




▪ Serrated Fin



▪ Stacked HX-A



▪ Stacked HX-B

## Conclusions

❑ Korean ongoing HTS power cable project is cryogenic cooling system for a 10 kW Brayton cryocooler and 1 km HTS transmission cable
❑ Two integrated PFHX are designed for recuperation of He in Brayton cryocooler and sub-cooling of LN supplied to HTS cable
❑ HX-B is designed with incorporating the anti-freezing schemes
❑ The designed HX's are successfully fabricated and ready for practical application