



Balanced Design and Commissioning of a 500W/4.5K Helium Refrigerator and its Liquefier



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Introduction

➤ For an equal Carnot work, an ideal helium cryogenic system can support 100W of 4.5K refrigeration or 1 g/s of 4.5K liquefaction. In fact, a designed refrigerator but used as a liquefier will not be able to provide the Carnot equivalent liquefaction capacity provided in refrigeration due to expansion limited. A designed liquefier but used as a refrigerator will not be able to provide the Carnot equivalent refrigeration capacity provided in liquefaction due to HXs limited.

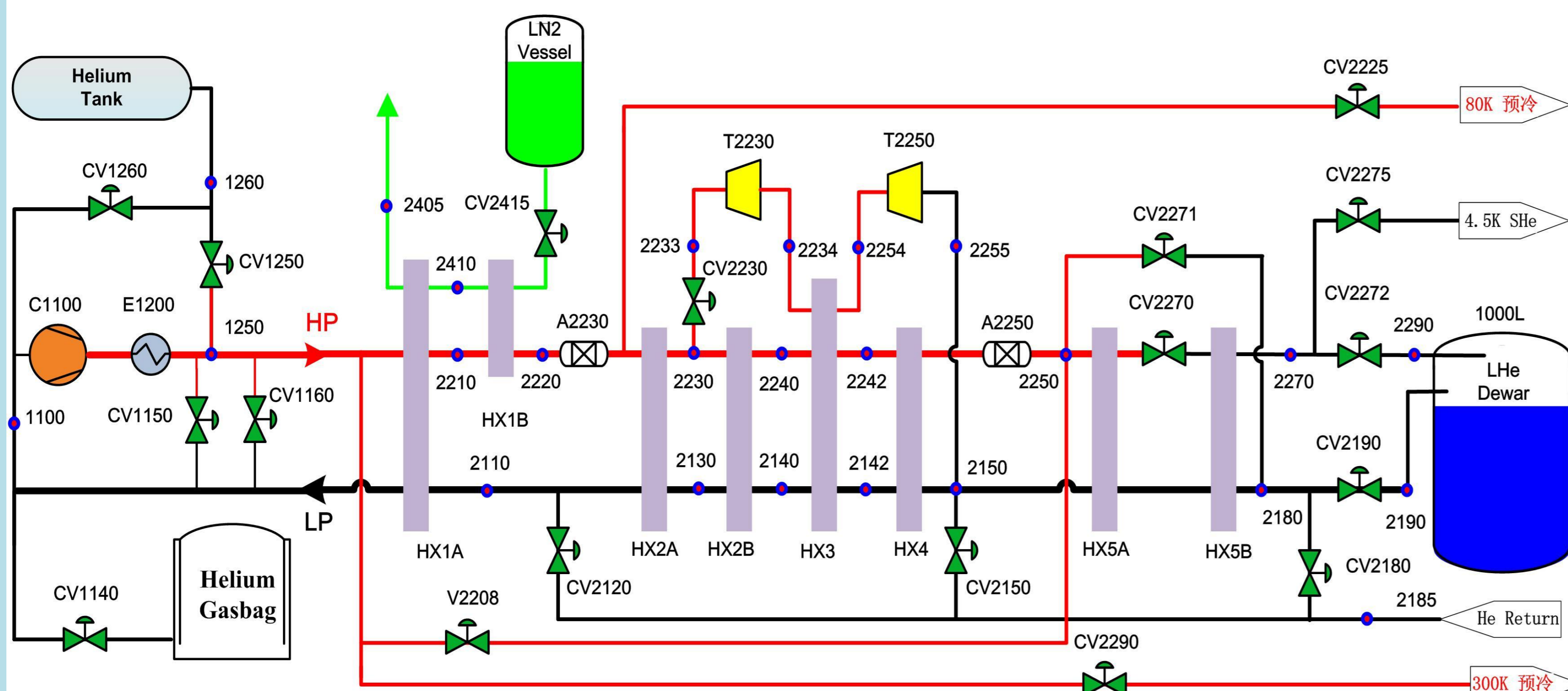
➤ In this paper, balanced design of a 500W/4.5K helium refrigerator and its liquefier for ADS (Accelerator Driven Subcritical) project of Chinese Academy of Sciences has been presented based on variable high pressure cycle for an equal Carnot work. Commissioning results indicate that this 500W/4.5K helium refrigerator can provide 5.74g/s (or 165L/h) liquid helium in liquefaction mode or 550W at 4.5K in refrigeration mode with the respective FOM (Figure of Merit) of 14% or 13.2%. Existing problems are analyzed and discussed through comparing the theory calculation and experimental data.

Description of a 500W/4.5K helium refrigerator

Function requirements of 500W@4.5K helium refrigerator

Desired helium refrigerator can provide refrigeration of 500W at 4.5K in refrigeration mode, or liquefaction of 150 L/h in liquefaction mode.

- ✓ Providing supercritical helium gas interface at 5bar for forced-flow cooling.
- ✓ Providing 80K helium gas interface for the 300K-80K precooling using LN2.
- ✓ Providing 80K, 20K and 4.5K bypass streams respectively to utilize cold gas.
- ✓ Operated automatically in different phases, including the interlock.



Simplified process flow diagram of a 500W@4.5K refrigerator



Photograph of the 500W@4.5K refrigerator

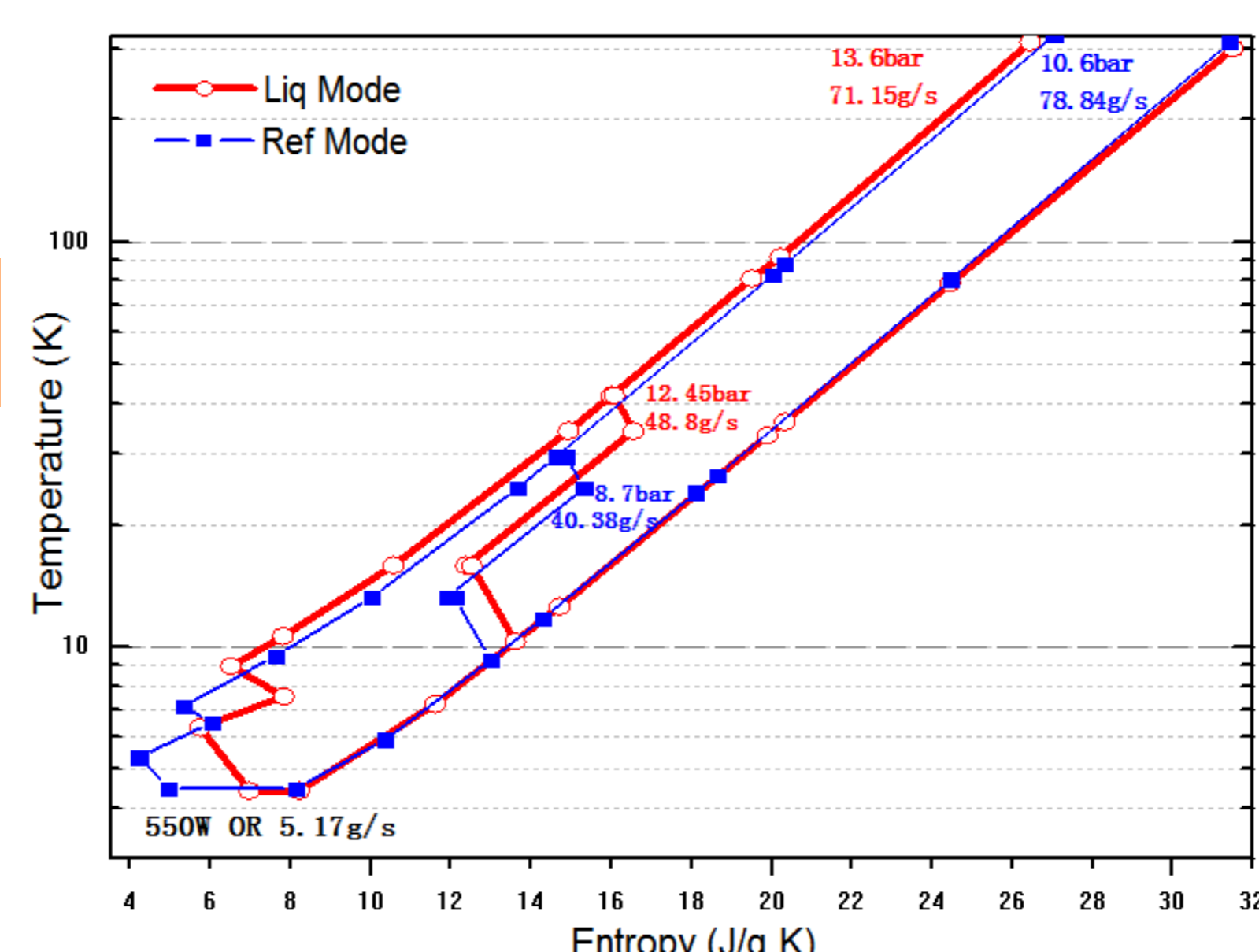
Balanced Design of thermodynamic cycle for the 500W/4.5K helium refrigerator

Liquefaction mode

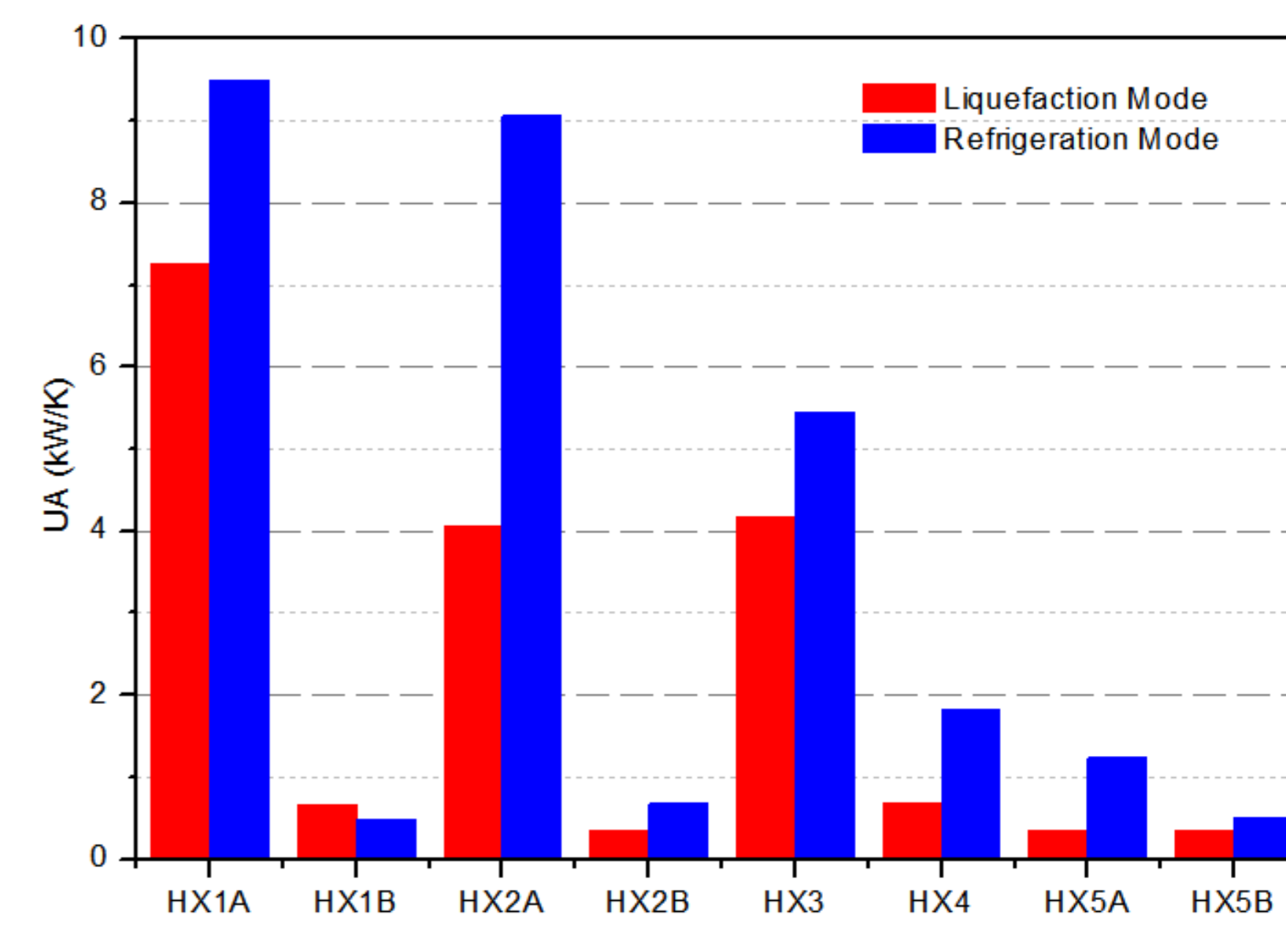
The suction pressure of compressor is 1.05 bar and the the output pressure of compressor is 13.6 bar, the mass-flow of compressor is 71.15g/s. The electric power is 250 kW and the consumption of LN2 is about 22.3 g/s. The total UA values of heat exchanges are 1.79×10^4 W/C. The FOM of 500W/4.5K refrigerator in liquefaction mode is 13.7%.

Refrigeration mode

the suction pressure of compressor is 1.05 bar and the the output pressure of compressor is 10.6 bar, the mass-flow of compressor is 78.84 g/s. The electric power is 250 kW and the consumption of LN2 is about 11.4 g/s. The total UA values of heat exchanges are 2.9×10^4 W/C. The FOM of 500W/4.5K refrigerator in liquefaction mode is 13.9%.



T-S diagram Comparison in Ref & Liq mode



Comparison of UA value in Ref & Liq mode

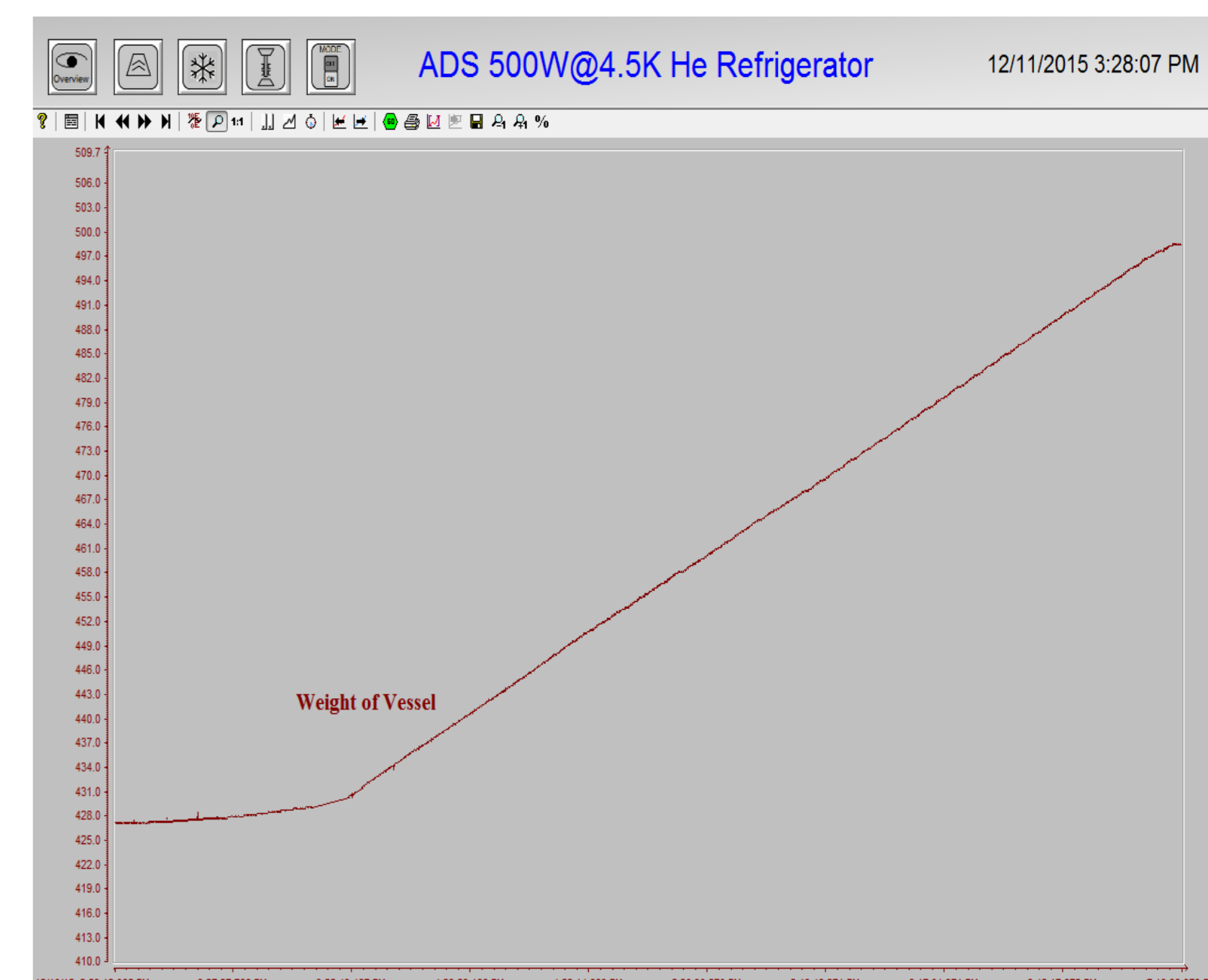
Commissioning of a 500W/4.5K helium refrigerator

Commissioning of 500W/4.5K refrigerator in Liquefaction mode

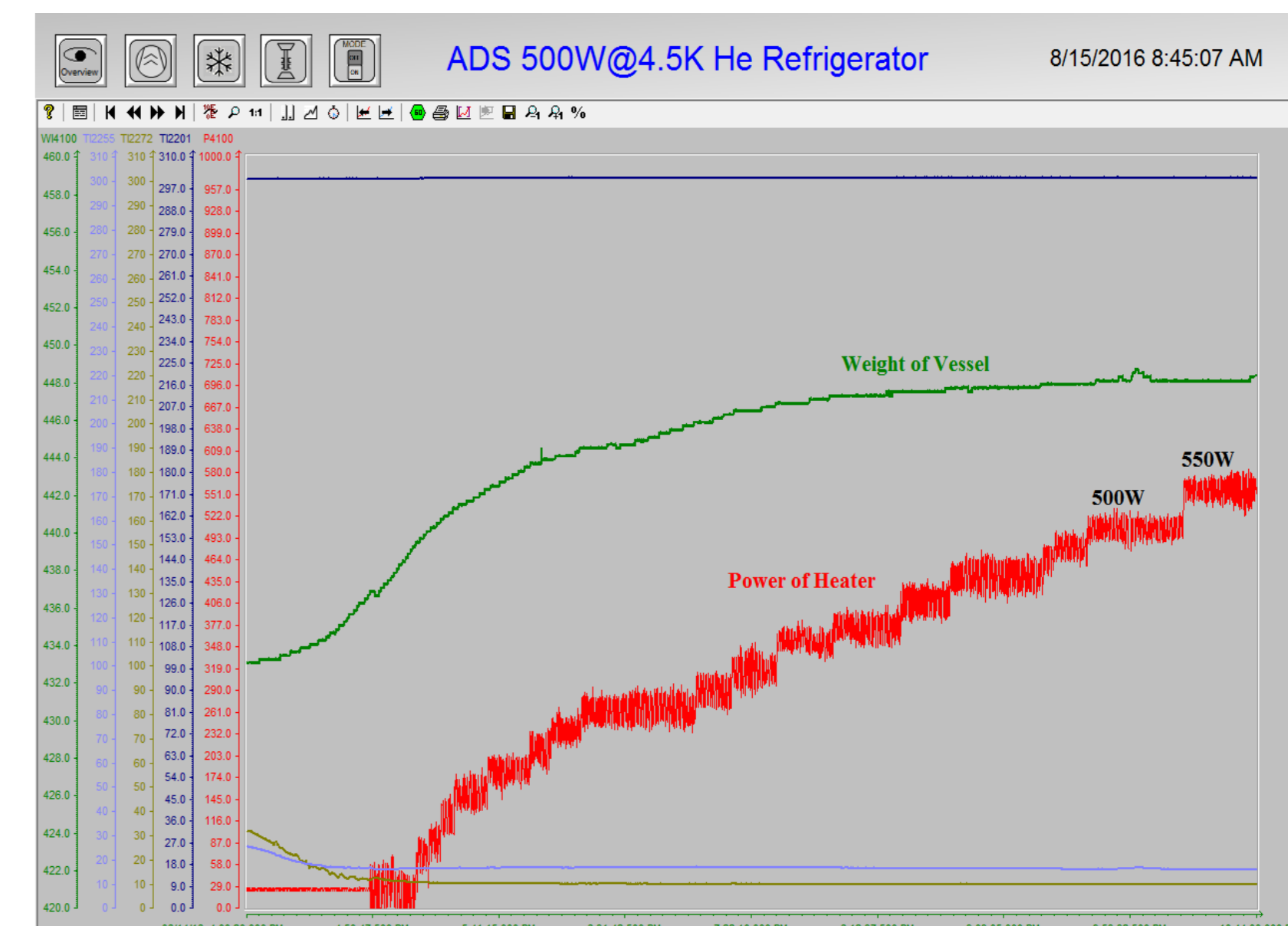
- Commissioning results indicated the liquefaction rate is 5.74g/s or 165L/h.
- Discharge pressure of compressor is 13.1 bar, mass-flow is 67.5 g/s and electric power is 253.6 kW. Consumption of LN2 is about 22.27 g/s. FOM in liquefaction mode is 14%.
- Mass flow of compressor is less than design value (71.2g/s) by 3.7g/s. Mass flow of turbine is 45.2 g/s, less than design value (48.8 g/s) by 3.6 g/s. Because the input pressure of turbine is operated at 12.2 bar, less than design value (12.45 bar).

Commissioning of 500W/4.5K refrigerator in Refrigeration mode

- Commissioning means the refrigerator can provided 500W at 4.5K.
- Discharge pressure is 11bar, mass-flow is 86.36g/s and electric power is 265.5kW. Consumption of LN2 is about 12.5/s. FOM in refrigeration mode is 13.2%.
- Mass flow of compressor is more than design value (78.84g/s) by 7.5g/s. Mass flow of turbine is 46.8g/s which was less than design value (40.4 g/s) by 6.4g/s. Because input pressure of turbine is operated at 10.2bar which was larger than design value (8.7 bar) by 1.5bar.



Weight curve of vessel in liquefaction mode



Power curve of heater in refrigeration mode

- Actual temperatures of HX4, HX5 are higher than design parameters. This means actual NTUs of HX4 and HX5 were smaller than design values. This resulted that actual efficiency of 500W/4.5K was a little less than design value.

Conclusion

- Commissioning in liquefaction mode indicate that it can provide 5.74g/s (or 165L/h) LHe with FOM of 14%. Both of the liquefaction rate and FOM are larger than design parameters which are 5.17g/s (or 150L/h) and 13.7%.
- Commissioning in refrigeration mode indicate that it can provide 550W at 4.5K with FOM of 13.2%. But the FOM is less than design parameters which is 13.9% due to the limits of terminal two heat exchanges.