Application of plate-fin heat exchangers with different UAs for mitigating the effects of pulsed heat load

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Background

The large scale cryogenic helium liquefiers are widely used in scientific apparatus, which suffered the periodic pulsed heat load. One of the distinct effect of the pulsed heat load is the fluctuation of the mass flow rate. It will affect the performance and stability of the compressors and turbines which are designed to operate in a narrow range of mass flow rate. In some extreme conditions, pulsed heat load will shut down the cryogenic liquefiers. Therefore, it's necessary to modify the cycle to mitigate the effects of pulsed heat load and reduce the potential risk.

Objectives

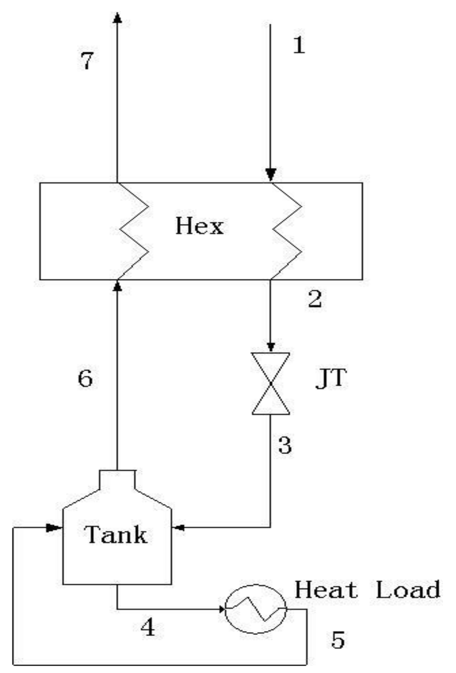
- To analyze the parameters of the usual coldest part of the refrigerator and modify the cycle configuration
- To verify the advantages of the modified cycle configuration through dynamic simulation

Conclusion

- A modified cycle configuration of the coldest part was proposed, which comprised of two different UAs heat exchangers, a JT valve, a by-pass valve and a tank together with the user heat load loop.
- The dynamic simulation of the modified cycle revealed that 81.3%, 93.98%-mitigation of mass flow rate had been achieved in modified cycle during the high and low conditions.
- In modified cold end, the liquid percent level of dewar decreased about 1.78% in one period, which was higher than the usual cold end. The time delay of re-establishing the new balance of the heat exchangers when the heat load was switched might be the main reason.

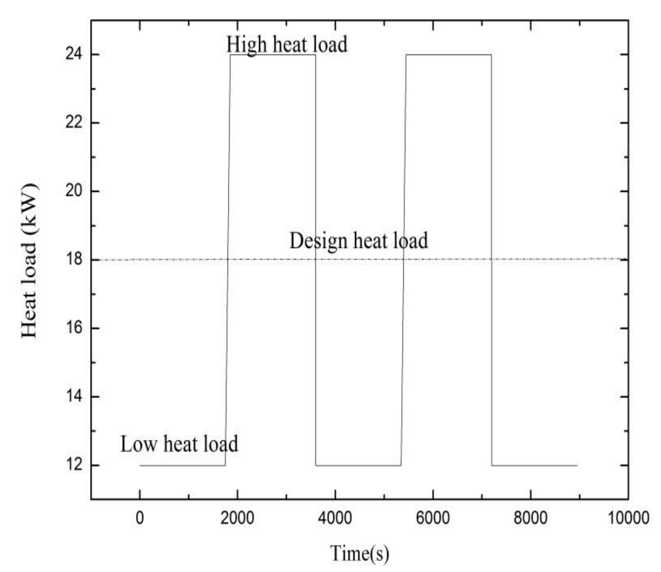
Methods

The usual configuration



- The usual cold end configuration of the refrigerators comprises of one heat exchanger, one JT valve, and a dewar together with the user heat load loop.
- Variation of the mass flow rate was as following: during the high heat load, the return mass flow rate increased owing to the increase in evaporation of liquid helium and vice versa.

The pulsed heat load



Pulsed heat load proposed by Kuendig was chosen in this paper, and the variation of the pulsed heat load was as following:

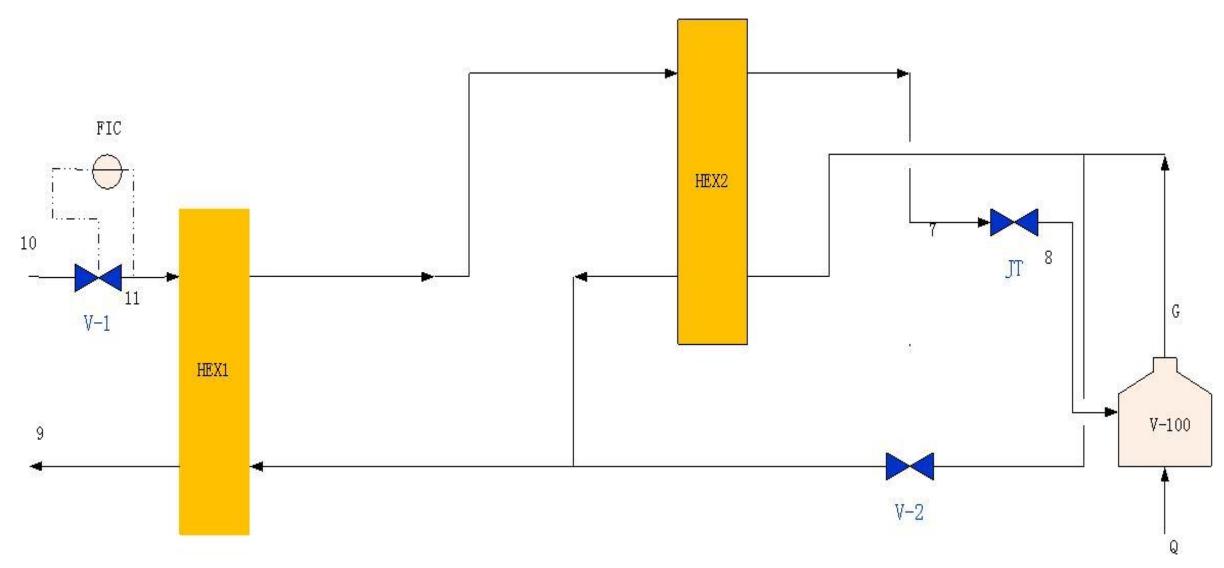
12kW: 1749s;

12-24kW ramp-up: 100s;

24kW:1750s;

24-12kW ramp-down:1s.

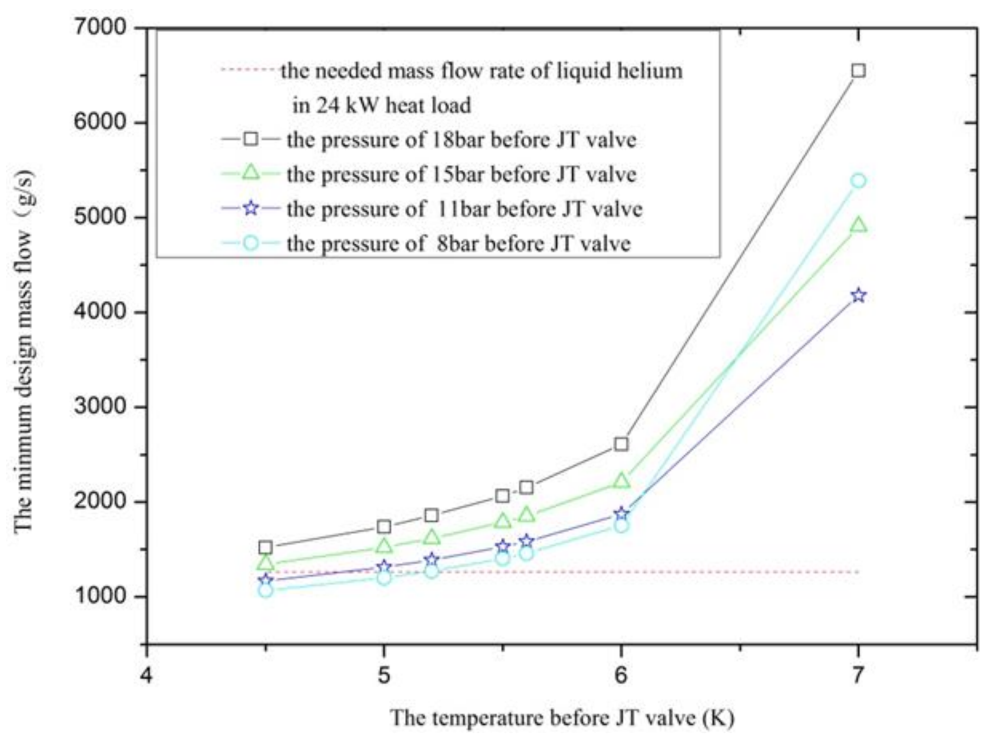
The modified cold end configuration



- In the proposed cycle, the coldest part was modified by incorporating the two different UAs heat exchangers.
- The main principle of this configuration was to adjust the UA of the heat exchanger to change the temperature before the JT valve.
- The UA of the heat exchanger can be achieved by distributing the mass flow rate between the two heat exchangers.
- The valve operation of the modified cycle during high and low heat load conditions was as following:
  - during high heat load, the valve v-2 was closed;
  - during the low heat load, the valve v-2 was controlled to adjust the temperature before JT valve.

Results

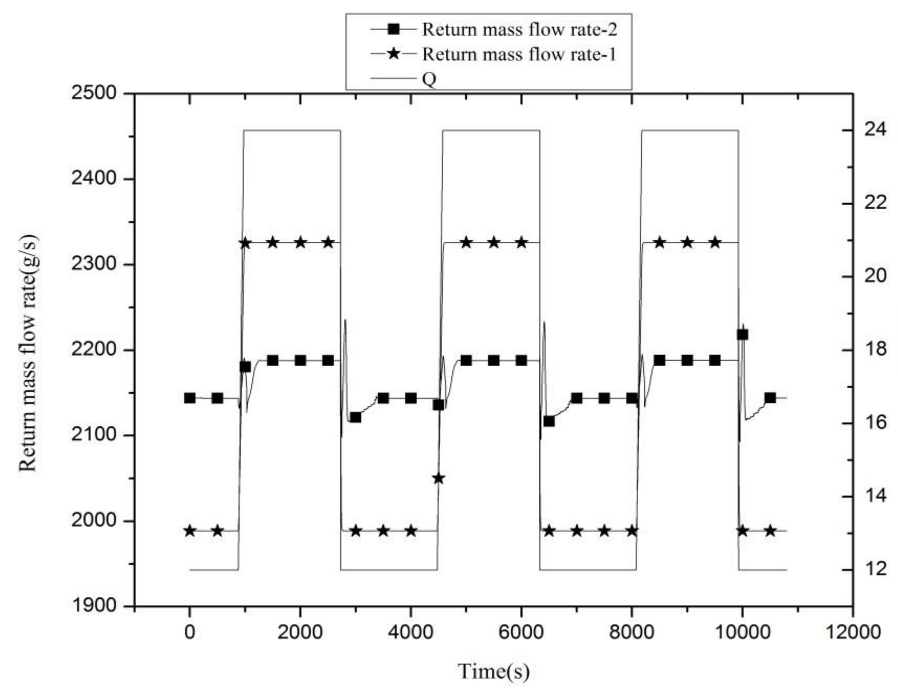
The relationship between the state before JT valve and the design mass flow rate



- when the design mass flow of the refrigerator ($\dot{m}_{design}$) is less than the evaporation of liquid helium by high heat load ($\frac{\dot{Q}_{high}}{h_l}$), it's not possible to completely mitigate the flow rate fluctuation by changing the vapor fraction after JT valve, as shown under the red dotted line.
- When $\dot{m}_{design}$ is more than $\frac{\dot{Q}_{high}}{h_l}$, changing the state before the JT valve is one useful method, which is shown above the red dotted line.

In steady state, the return mass flow rate is equal to the design mass flow rate. The return mass flow rate of the refrigerator included two parts: the vapor generated after expansion in JT valve and vapor generated by the heat load:

The fluctuation of return stream mass flow rate

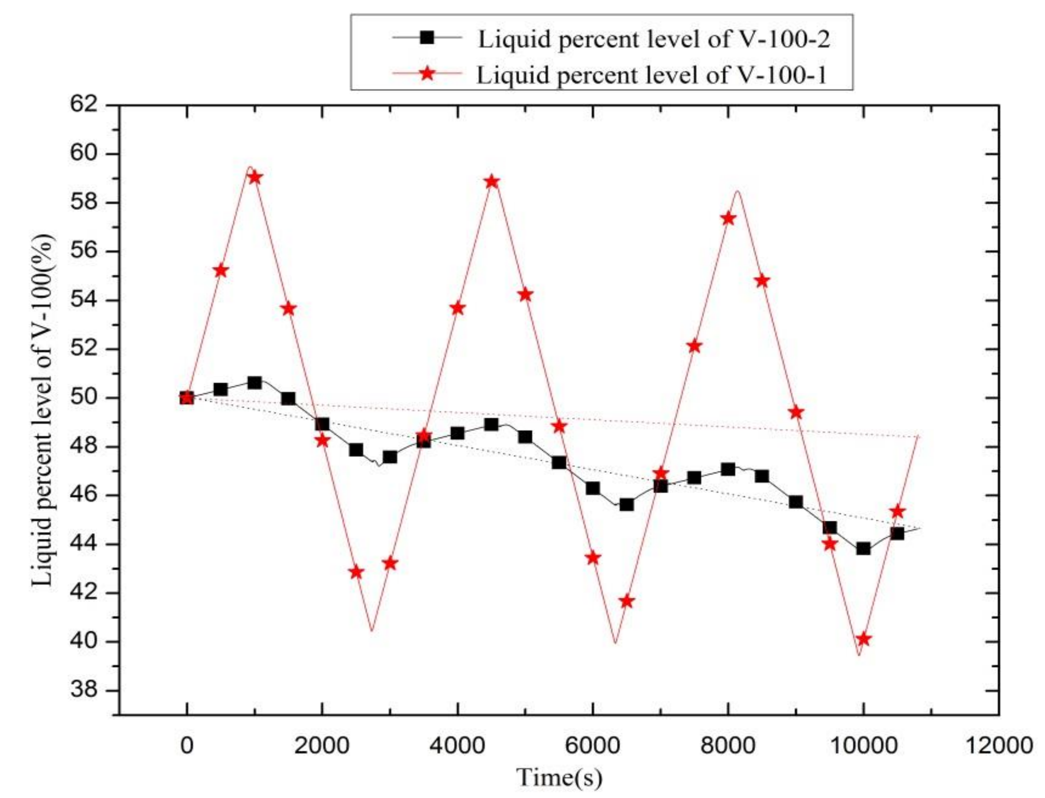


The comparisons between the usual ('-1')and modified ('-2')configuration were as following:

- The return mass flow rate of the usual cycle in high and low heat load was 2326.4g/s, 1989g/s, respectively .
- In modified cold end, the return mass flow rate was 2187g/s, 2145g/s during high and low heat load.
- The 81.3%, 93.98%-mitigation had been achieved in modified cycle during the high and low heat load conditions.

The reasons of the fluctuations when the loads were switched were listed as following:
1) the numerical instability during the variation of the valve.
2) the thermal inertia of HEX2 resulted in the mismatch between the cooling capacity and the heat loads.

Variation of the liquid percent level of dewar in 3 periods



- The liquid percent level decreased in one period about 0.54% and 1.78% in usual ('-1') and modified ('-2') configurations.
- It's necessary to improve the design capacity to make up the variation of liquid inventory.
- One main reason of the decrease of the plant capacity may be the time delay of re-establishing the new balance condition of the heat exchangers when the heat load was switched.

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