C2PoA-06 : Research of the cold shield in cryogenic liquid storage

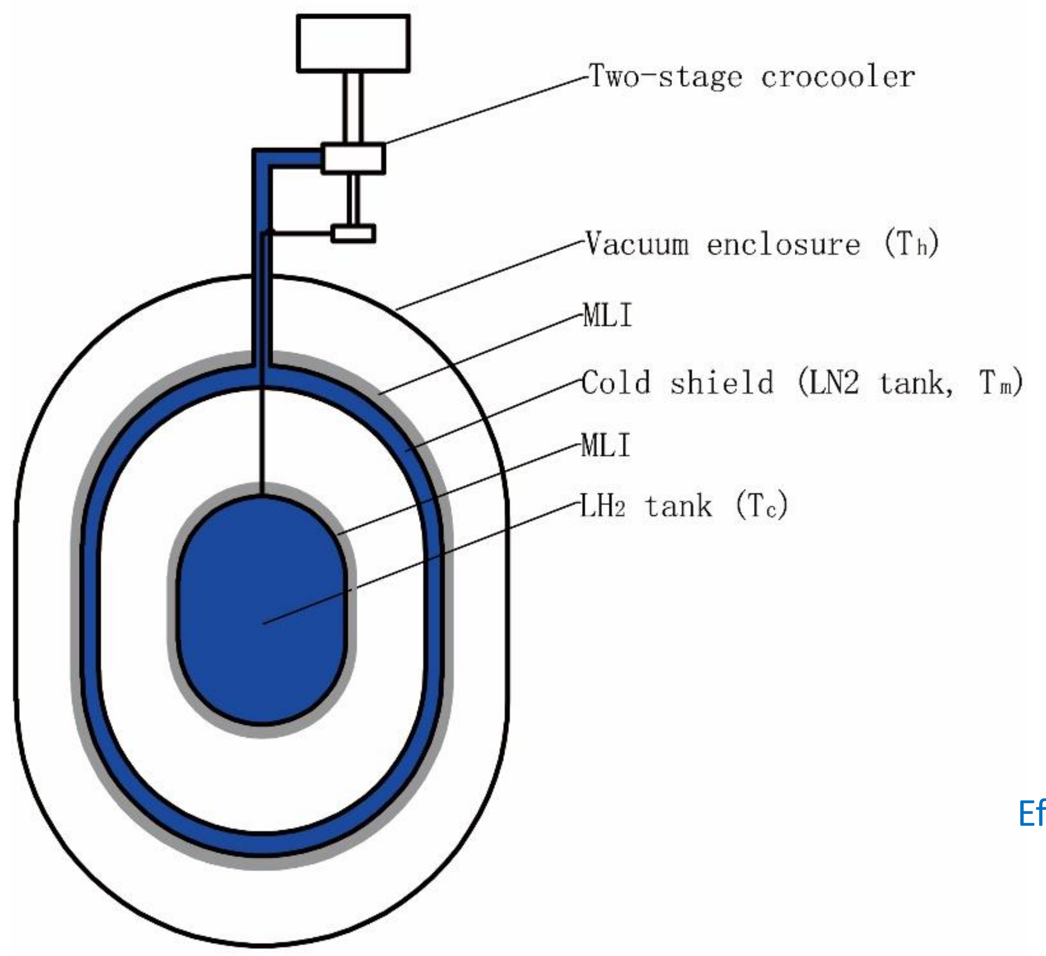
Chen Liubiao[1, 2], Zheng Jianpeng[1, 2], Cui Chen[1], Zhou Yuan[1, 2] and Wang Junjie[1, 2]

[1] Chinese Academy of Sciences Key Laboratory of Cryogenics, Technical Institute of Physics and Chemistry, Beijing, China; [2] University of Chinese Academy of Sciences, Beijing, China

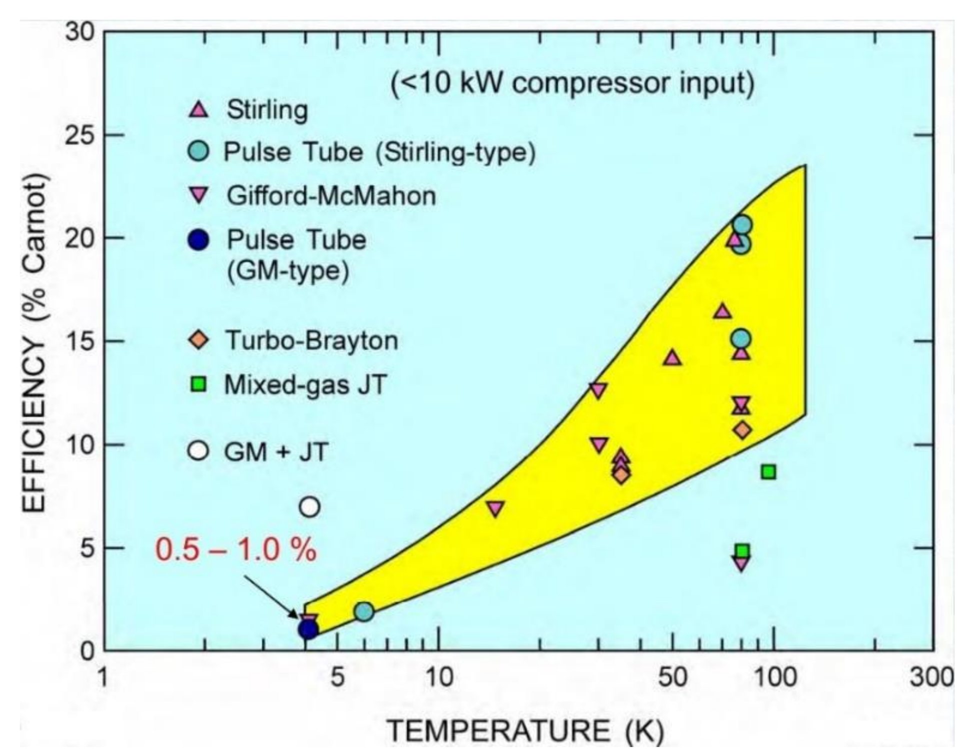
Introduction

- Due to a large temperature difference between the ambient and the cryogenic liquid, the heat leakage is inevitable. Insulation technology can be divided into two categories, one is a passive technique such as multi-layer insulation, spray foam insulation and vapor cold shield. The other is an active insulation technology, in which cryocooler will be connected to the tank to pumped out the heat leakage.
- To realize zero boil-off storage, a cryocooler that can achieve a temperature below the boiling point temperature of the cryogenic liquid is generally needed. For example, a 20 K cryocooler should be adopted in LH_2 storage.
- Taking into account that the efficiency of the cryocooler will be higher at a higher operating temperature, a novel thermal insulation system that using a sandwich container filled with cryogenic liquid with a higher boiling point as a cold radiation shield between the cryogenic tank and the vacuum shield in room temperature has been proposed to reduce the the electricity power consumption in this paper. A two-stage cryocooler or two separate cryocoolers are adopted to condense the evaporated gas from the cold shield and the cryogenic tank.

LH_2 tank model and calculation method



The schematic of the proposed thermal insulation system



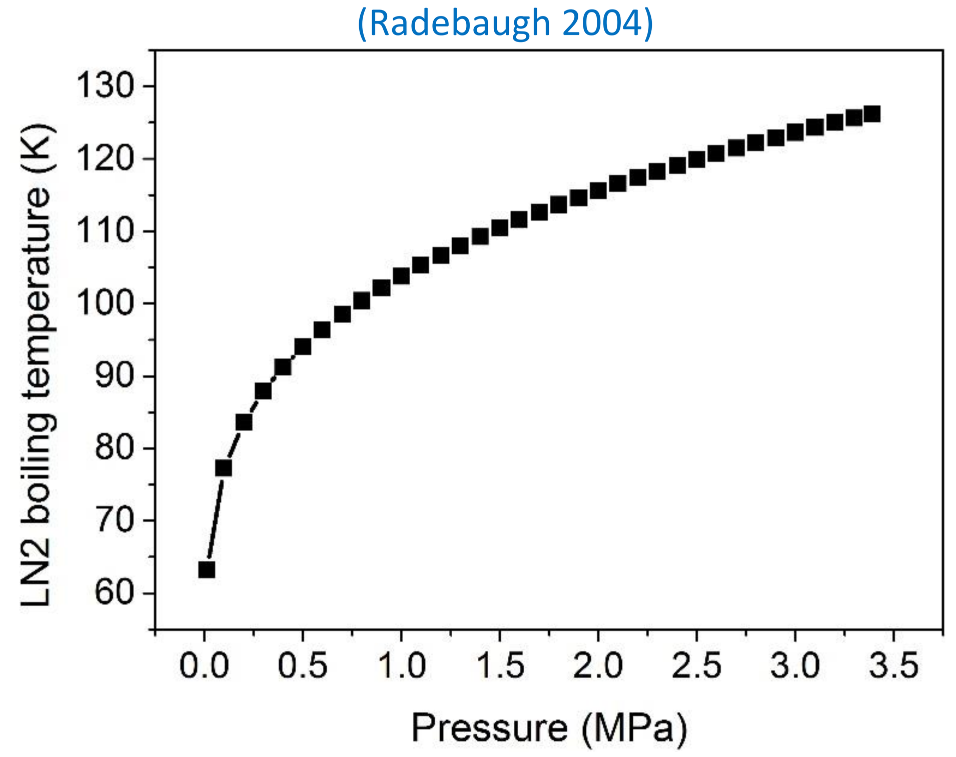
Efficiency of cryocoolers as a function of operating temperature (Radebaugh 2004)

The Lockheed method is used to simulate MLI performance: thermal radiation, gas conduction, and solid conduction

$$q_r = \frac{B\varepsilon\sigma(T_H^{4.67} - T_C^{4.67})}{N}$$

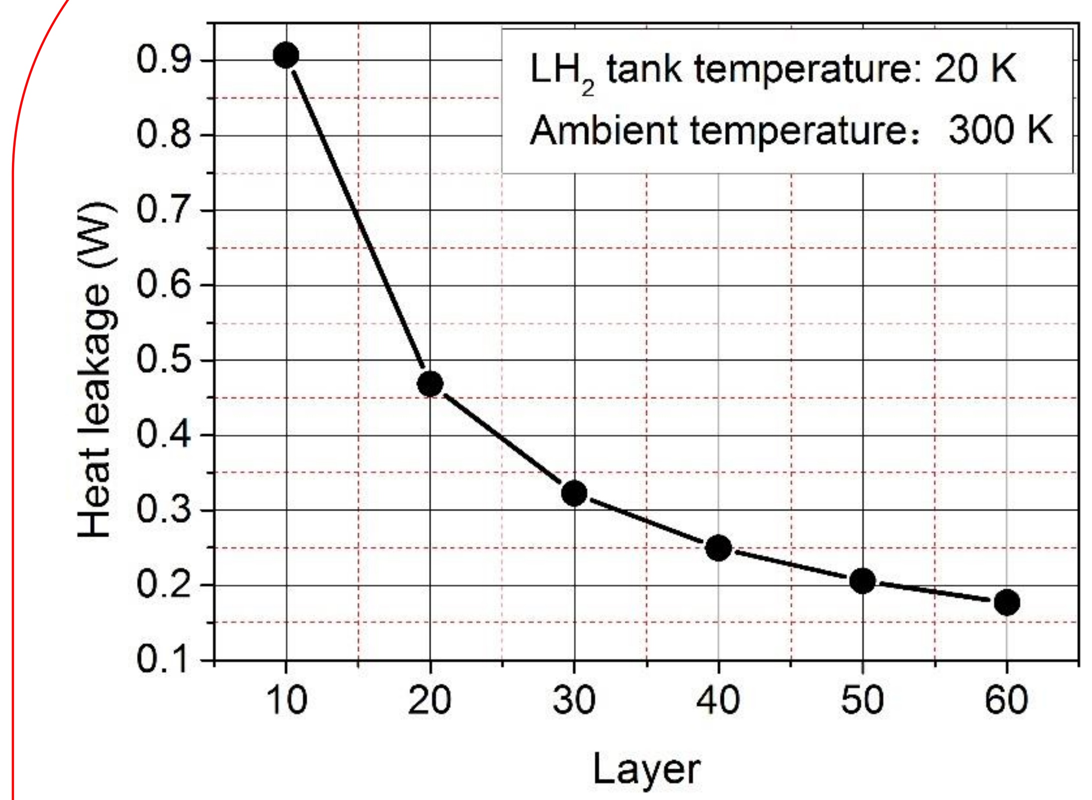
$$q_g = 0.5\omega C P(T_H - T_C)$$

$$q_s = \frac{A(N^*)^n\, T_m(T_H - T_C)}{N}$$

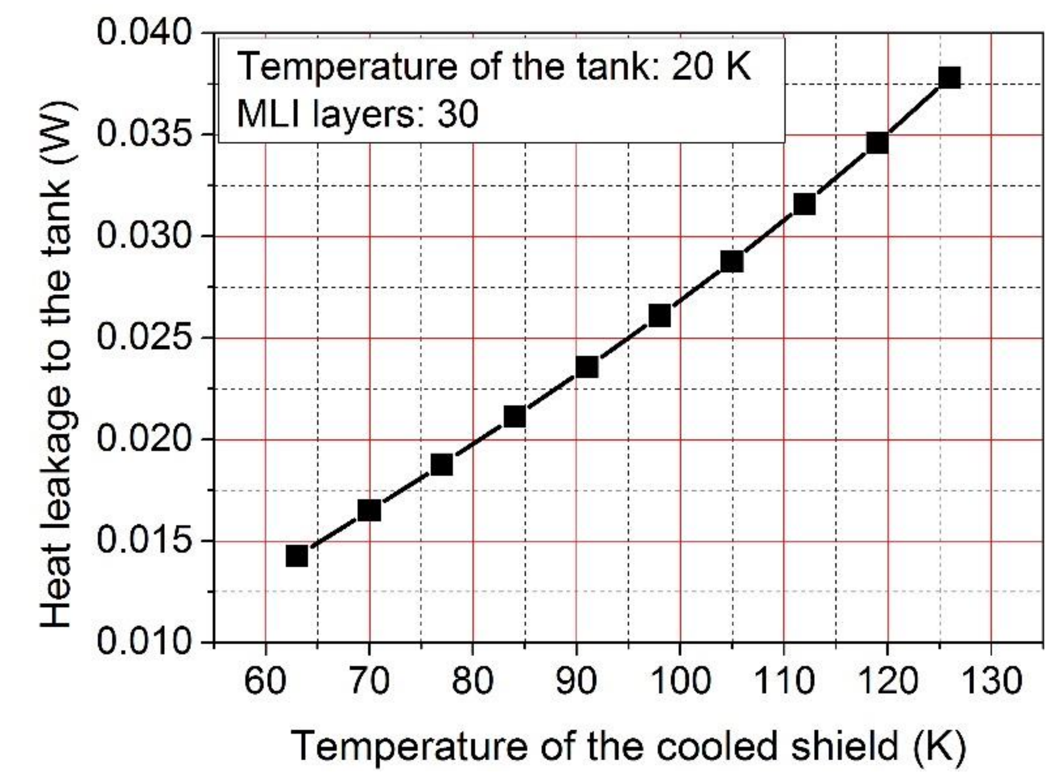


The relationship of the LN2 boiling temperature and pressure

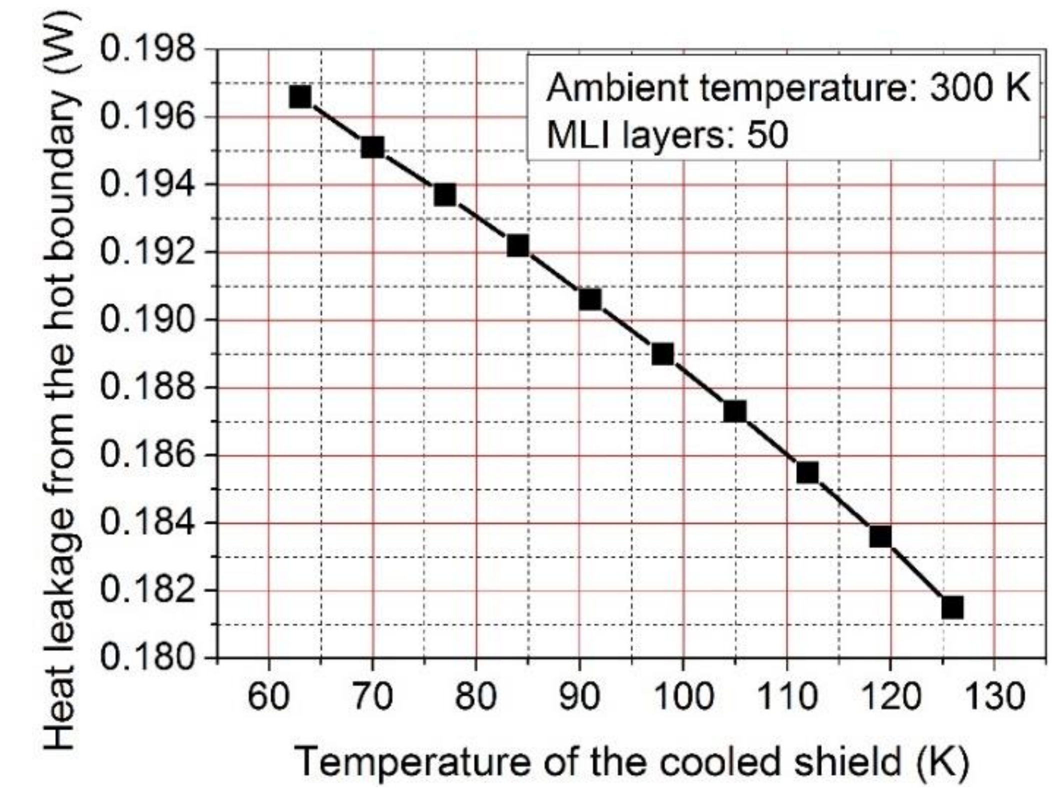
Results and discussions



Heat leakage between the LH2 tank and vacuum shield



Heat leakage between the LH2 tank and cold shield



Heat leakage between cold shield and vacuum shield

	LH_2 tank heat leakage	LN_2 cold shield heat leakage	Electricity power needed	Cryocooler used for calculation
without cold shield	200 mW (20-300K)	0	121.7 W	0.4W/20K, 240W; 2.3% of Carnot efficiency
with cold shield	20 mW (20-80 K)	193 mW (80-300 K)	14.4 W (12.2 W+2.2 W)	0.4W/20K, 240W; 2.3% of Carnot efficiency 26.4W/80K, 290W; 24.2% of Carnot efficiency

Conclusions

- The simulation results show that the required input electricity power can be reduced significantly by installing a sandwich container filled with an another cryogenic liquid with a higher boiling temperature between the cryogenic tank and the vacuum shield in room temperature.
- The calculation result of a 55 liter LH_2 tank with a LN_2 shield shows that only 14.4 W of electricity power is needed to make the evaporated gas condensation while 121.7 W will be needed without the cold shield.
- Due to the emissivity of the radiation-resistant material decreases with decreasing temperature, and its value is relatively small at low temperatures, thus the heat leakage difference caused by the temperature change of the cold shield is not significant. Thereby, it is feasible to increase the temperature of the cold shield by increasing the LN_2 pressure, so that the cryocooler can be operated in a higher temperature and consume a lower input electricity power.

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E-mail: chenliubiao@mail.ipc.ac.cn