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Feasibility study on synthermal storage of two cryogens in a single tank with a metal common bulkhead

Wujie Zhang,
Jiaxu Zhang, Ruijiao Miao, Peng Li, Dongbao Wang,
Peijie Sun, Bin Wang, Wenbing Jiang and Yonghua Huang

Shanghai Jiao Tong University, China

Wed-24-07-24

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Introduction

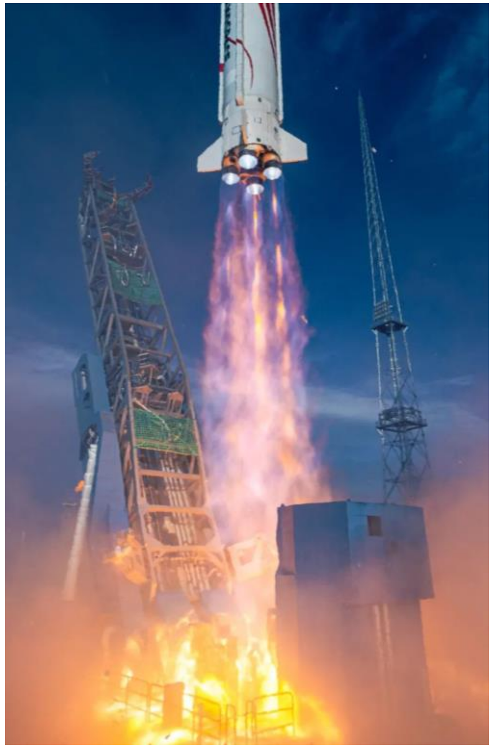
- **Liquid-oxygen/liquid-methane reusable rocket technology is currently a hot topic in the field of spaceflight.**

Engines

SpaceX
Raptor 2

JiuZhou Cloud Arrow
Lingyun Engine

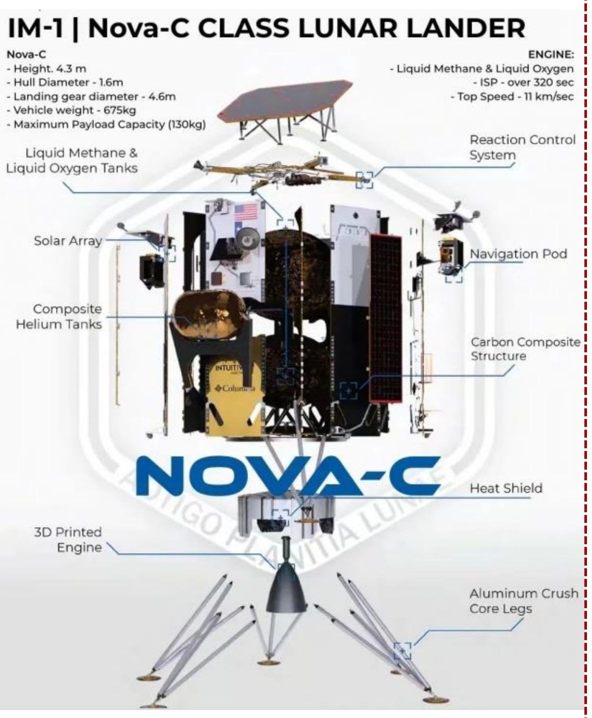
Launch vehicles



LandSpace
ZhuQue 2

SpaceX
Starship

Lunar lander

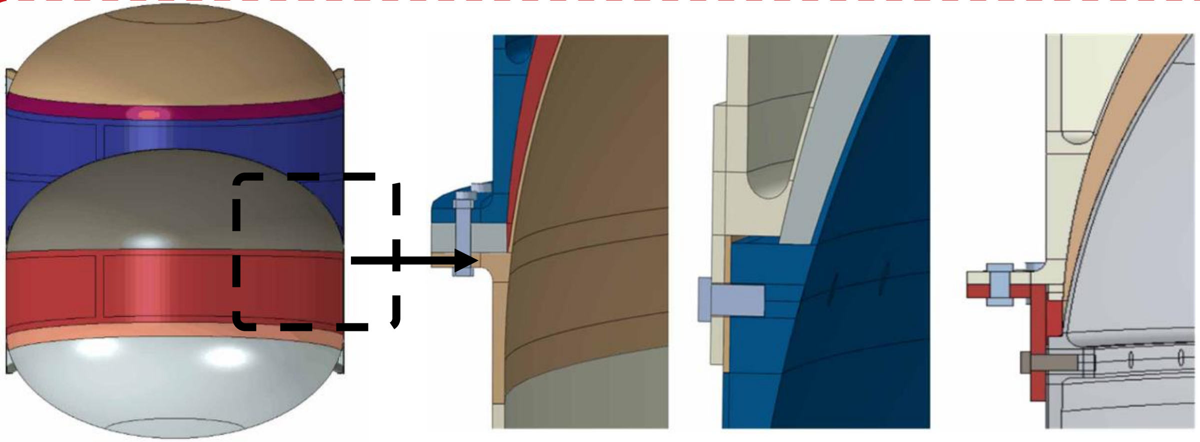


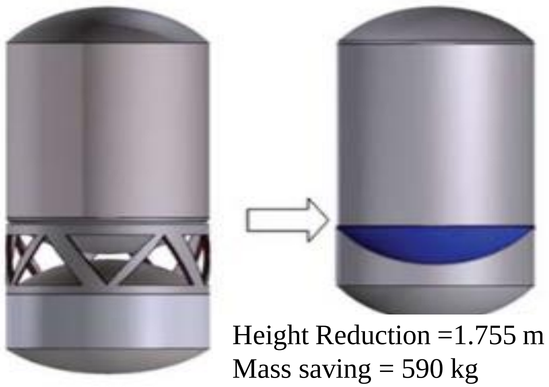
Intuitive Machines
Nova-C

Efficient storage method for the long-term storage of liquid oxygen and liquid methane is crucial for space exploration!

Common bulkhead storage

- **Common bulkhead (CBH) storage is one of the most compact and promising storage methods.**





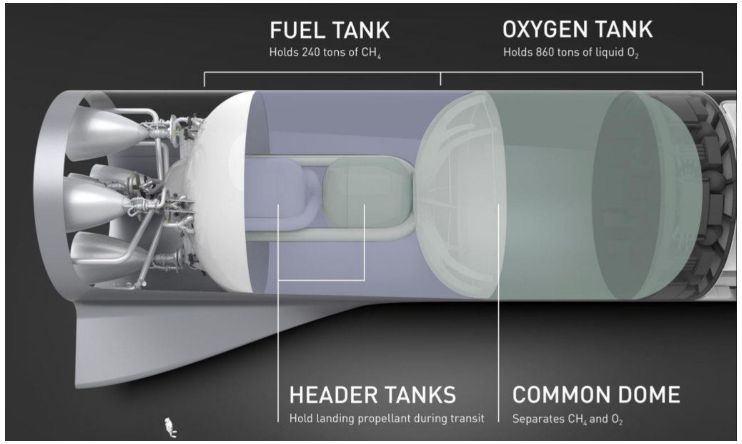
Height Reduction =1.755 m
Mass saving = 590 kg

Designed for

- LOX /Kerosene
- LOX/LH_2

Current common bulkhead tanks with insulated sandwich common bulkhead domes

LOX and LCH_4 are storing in different compartments

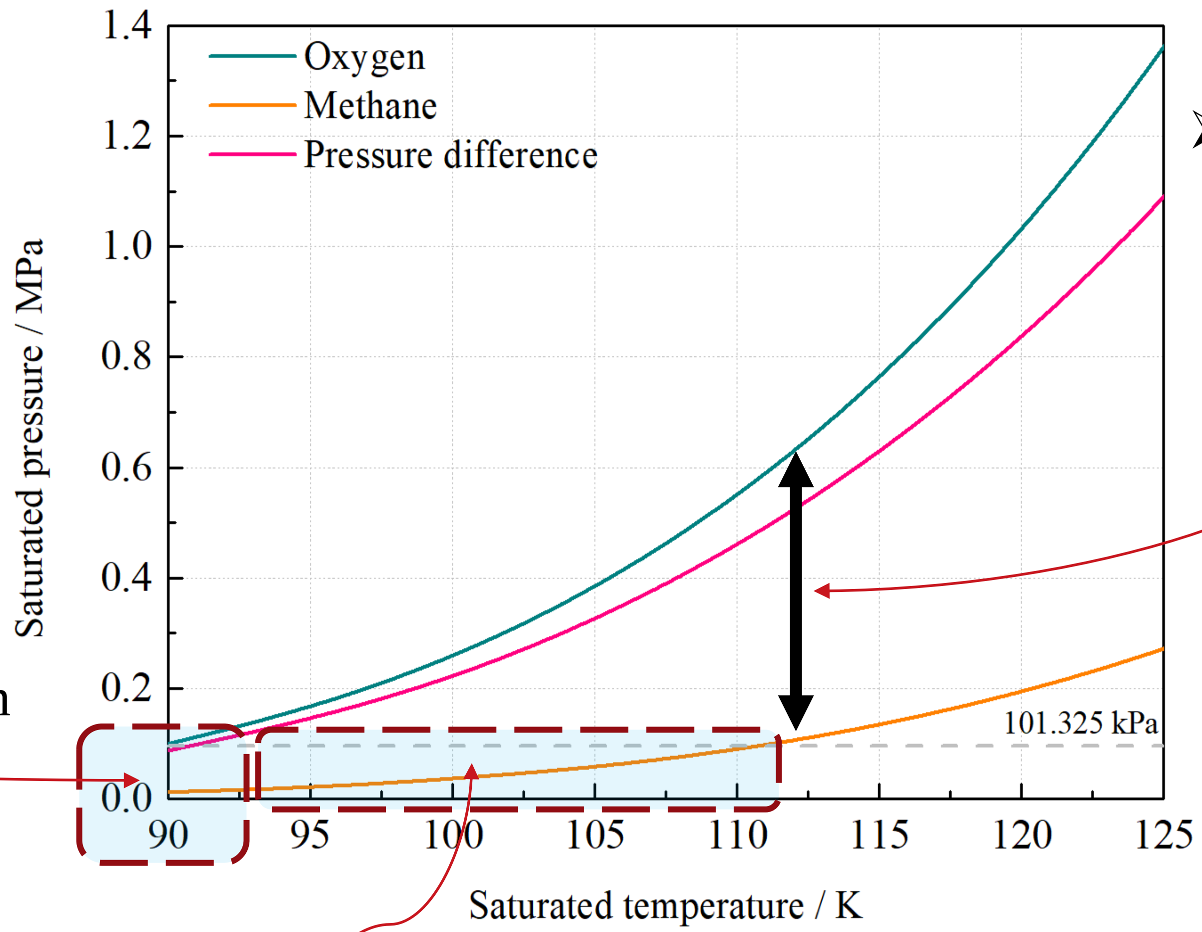


How to achieve a stable and long-term storage?

A look inside the 2017 version of SpaceX's 9m-diameter nonadiabatic CBH tank in Starship

Challenge and Motivation

Fig. 1 Thermophysical properties of oxygen and methane



- Significant pressure difference between two compartments
- Methane solidification
- Subatmospheric pressure in the LCH_4 compartment

An active helium pressurization method:

- Achieving stable common bulkhead storage in a nonadiabatic common bulkhead tank;
- Revealing the relationship between the heat leakage and the typical thermal behaviors.

01 Introduction

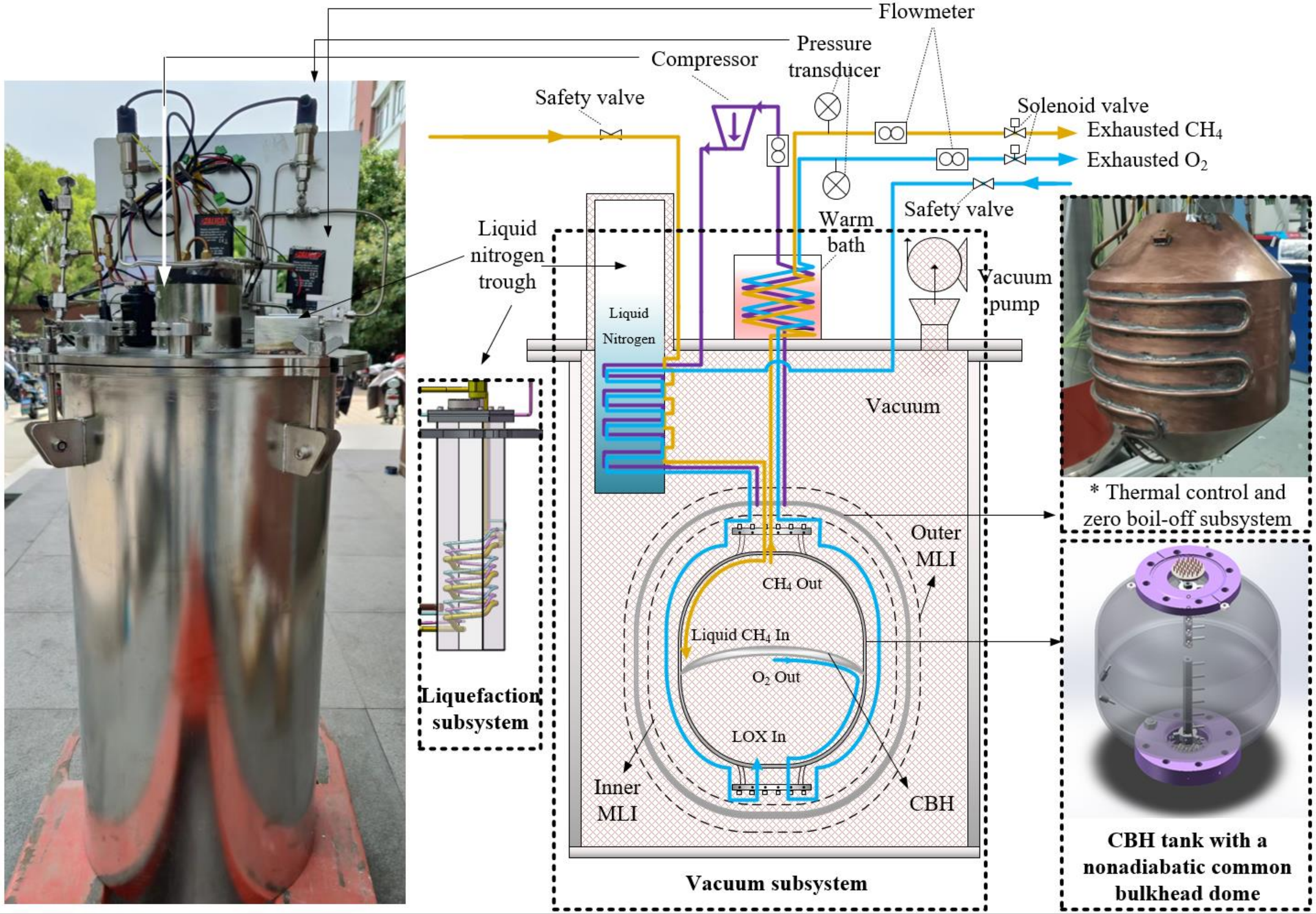
02 **Experiment**

03 Results & discussion

04 Conclusions

Common bulkhead storage experimental system

Schematic of the small-scale common bulkhead storage experimental system



Common bulkhead storage experimental system

Table 1 Main parameters of the CBH tank

Parameters	Value	Unit
Inner diameter	194	mm
Wall thickness	3	mm
Height	200	mm
Total volume	4.25	L
Volume for LOX	2	L
Volume for LCH_4	2.25	L
Material of CBH	Stainless-steel single-layer partition	

Table 2 Main measurement instruments

Parameters	Instrument	Range	Uncertainly
Temperature	PT-100	77 K-400 K	±0.1 K
Pressure	Gefran Pressure transducer	0 kPa-600 kPa	0.25% FS
Mass flow rate	Alicat® Flowmeter	0 -250 SLPM	± 0.8% of reading and ± 0.2% FS
CBH temperature	LakeShore model335	4 K-400 K	±0.05 K

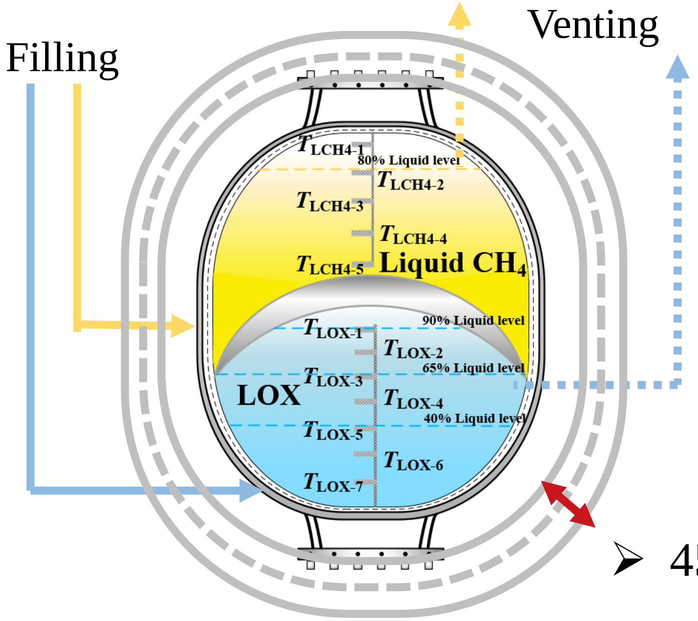


Fig. 1 Thermometer distribution

- Total volume (LOX + LCH_4 compartments): 4.25 L
- Insulated in a vacuum chamber
- 45 layers of multi-layer insulation (MLI).

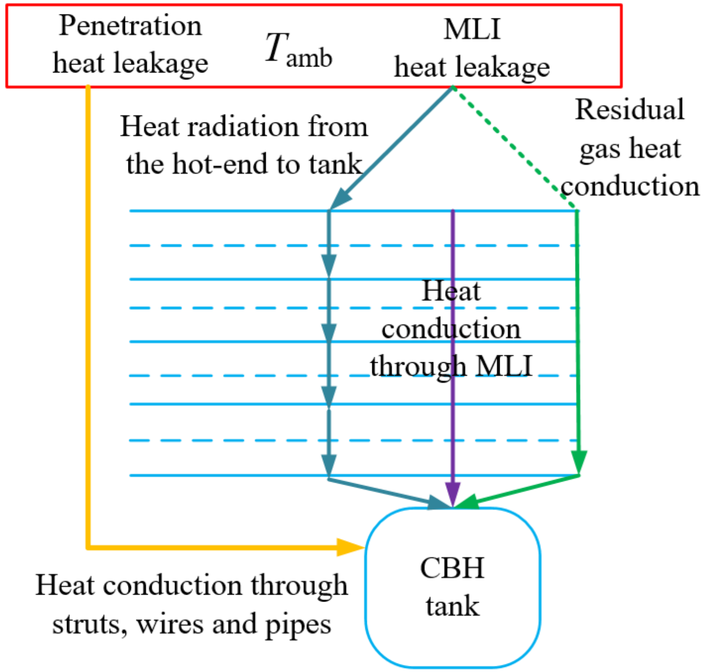


Fig. 2 Thermal resistance network

Heat leakage and storage pressure

Table 1 Test matrix of the common bulkhead storage

Scheme	Filling ratios of LOX&LCH_4	Thermal boundary	CBH temperature	Helium gas fraction	Pressure control band
No-helium	LOX: 90% & LCH_4: 80%	303 K	105.8 K	0%	For the LOX compartment: 500 kPa ± 50 kPa For the LCH_4 compartment: 300 kPa ± 50 kPa
Helium-mixing				56.2%	

Fig. 1 Thermal conductivity

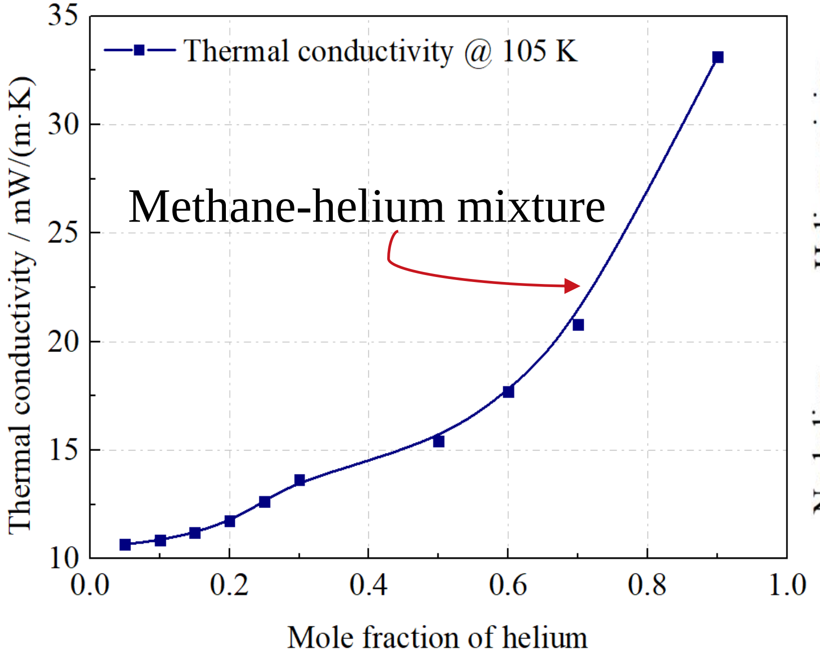


Fig. 2 Storage pressure

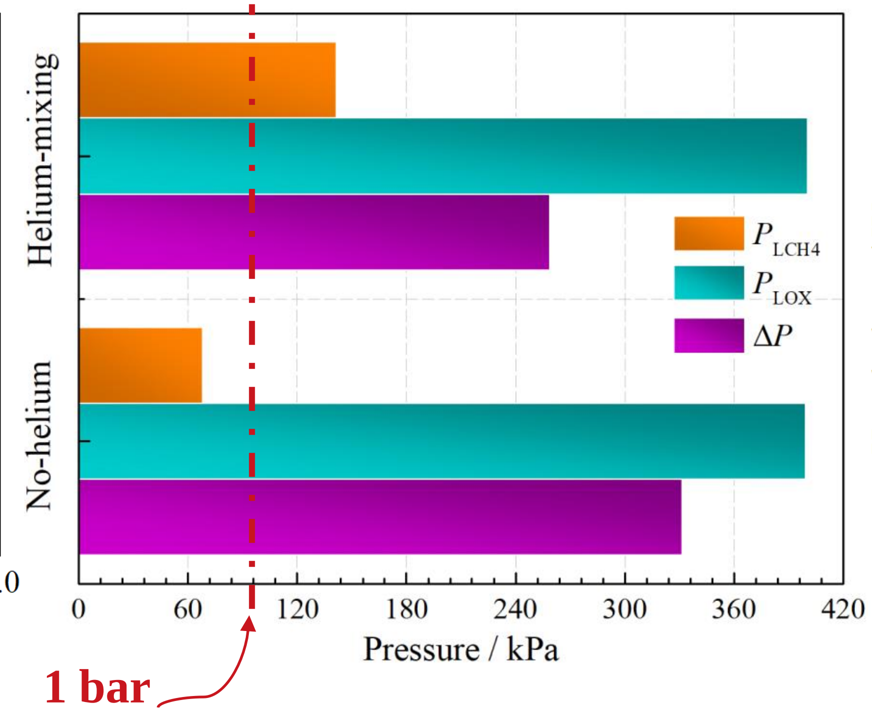
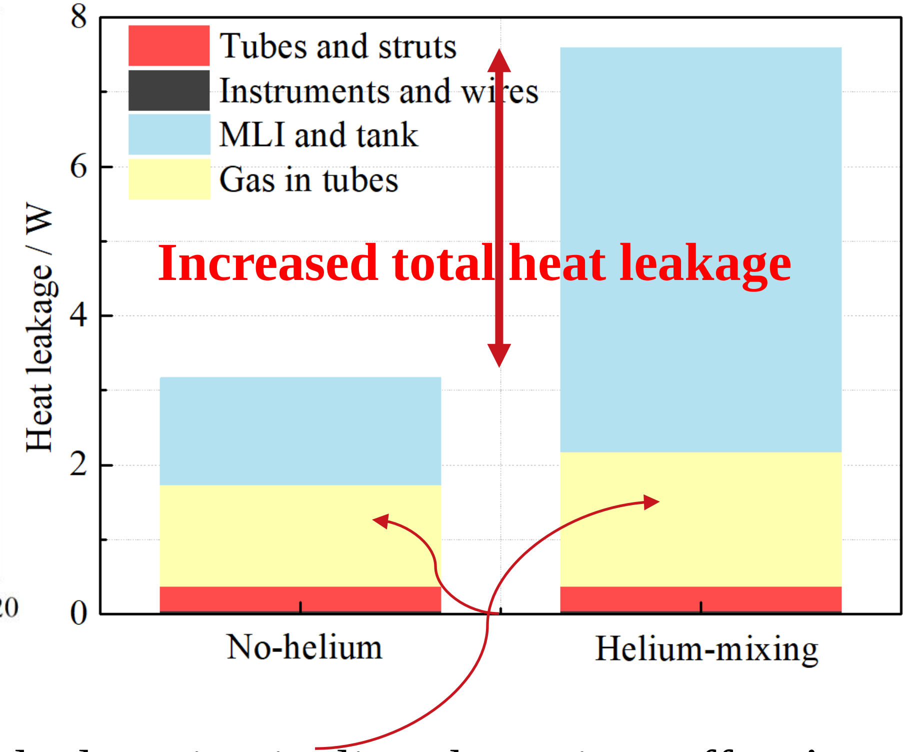


Fig. 3 Heat leakage



Subatmospheric pressure is eliminated!

The residual gas in pipelines has minor effect!

Thermal stratification in the CBH tank

- **Helium gas has a minimal impact on the temperature of LOX, whereas it causes a temperature rise in the LCH_4 compartment.**

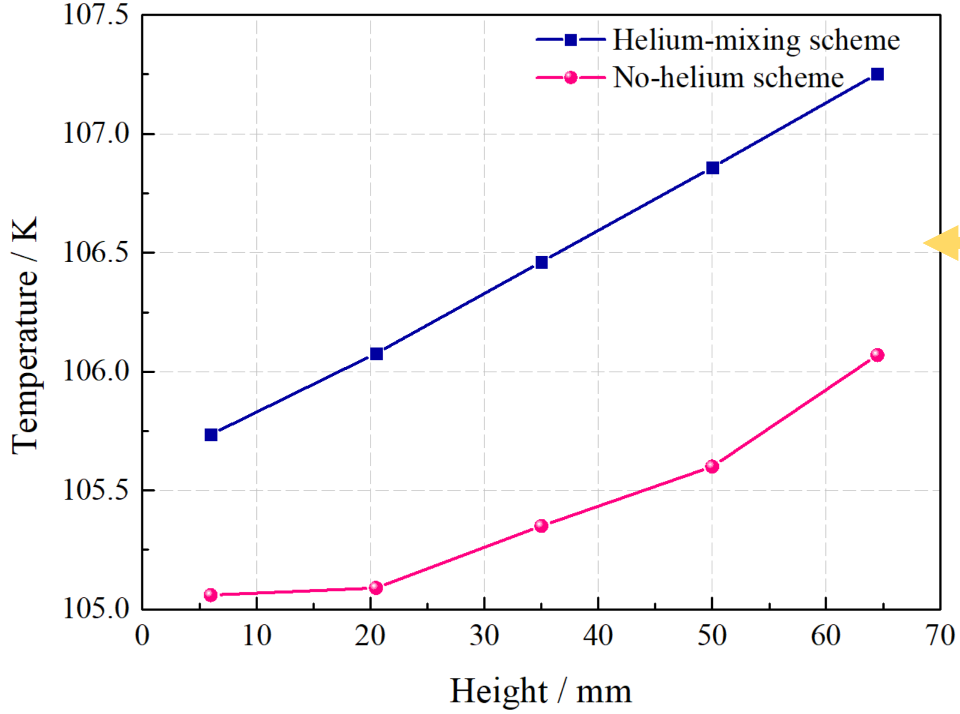
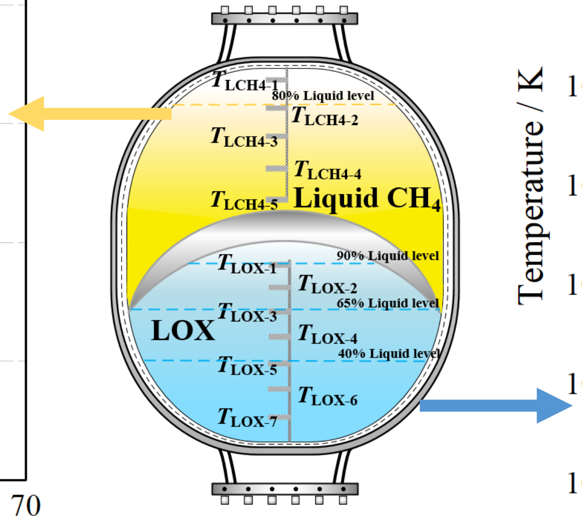


Fig. 1 LCH_4 compartment



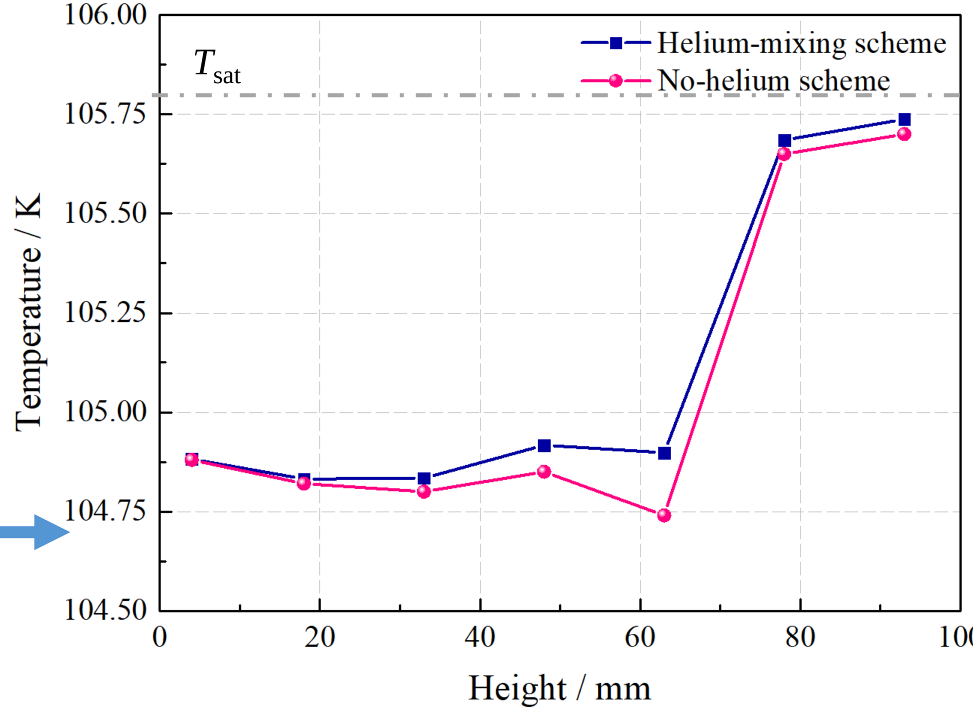


Fig. 2 LOX compartment.

- Average temperature and the temperature gradient in the LCH_4 compartment increase by 1.1 K and 8.9%, respectively.
- A distinct thermal stratification occurs in the liquid oxygen region inside the liquid oxygen compartment.

Storage duration and venting frequency

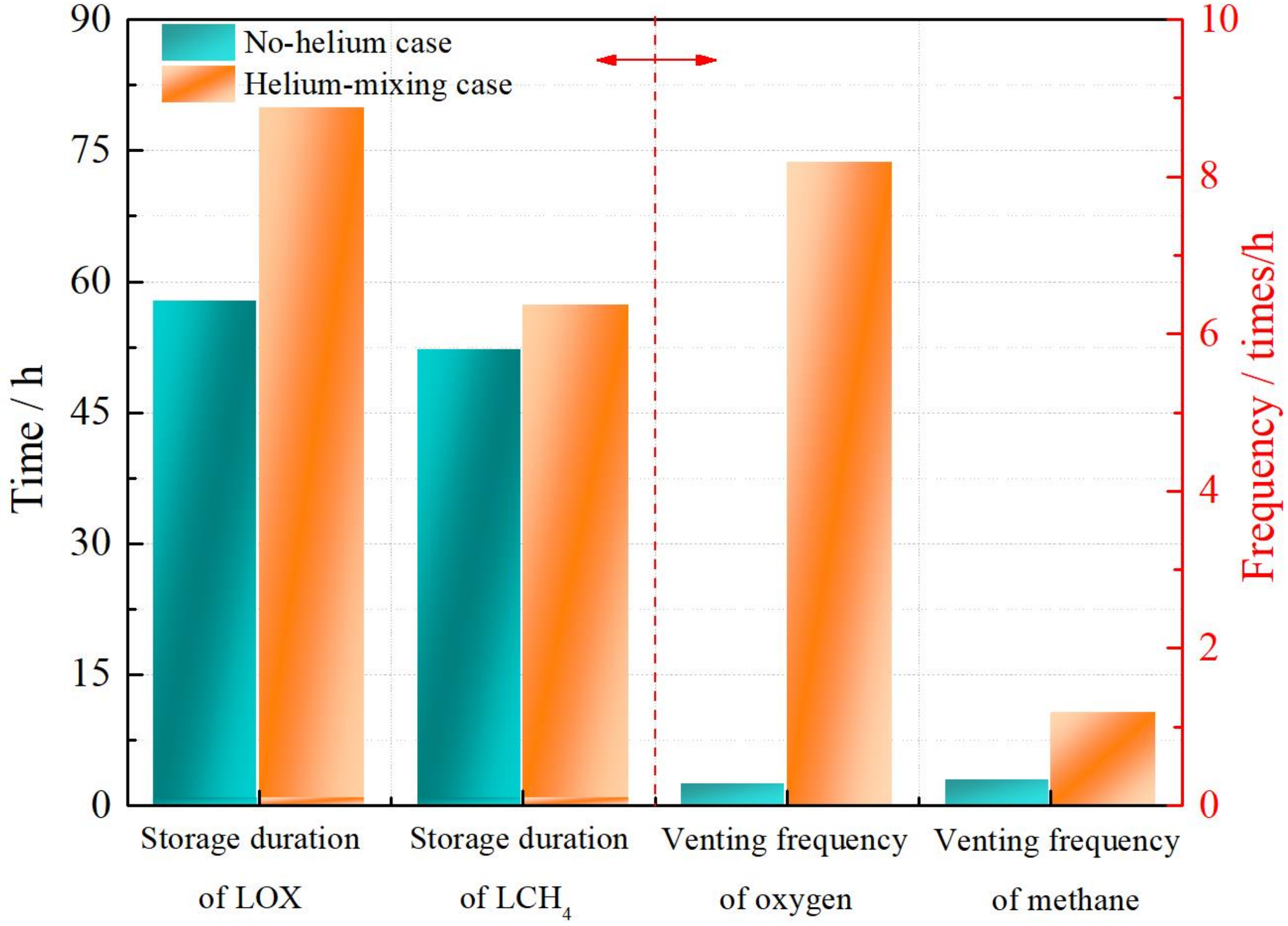
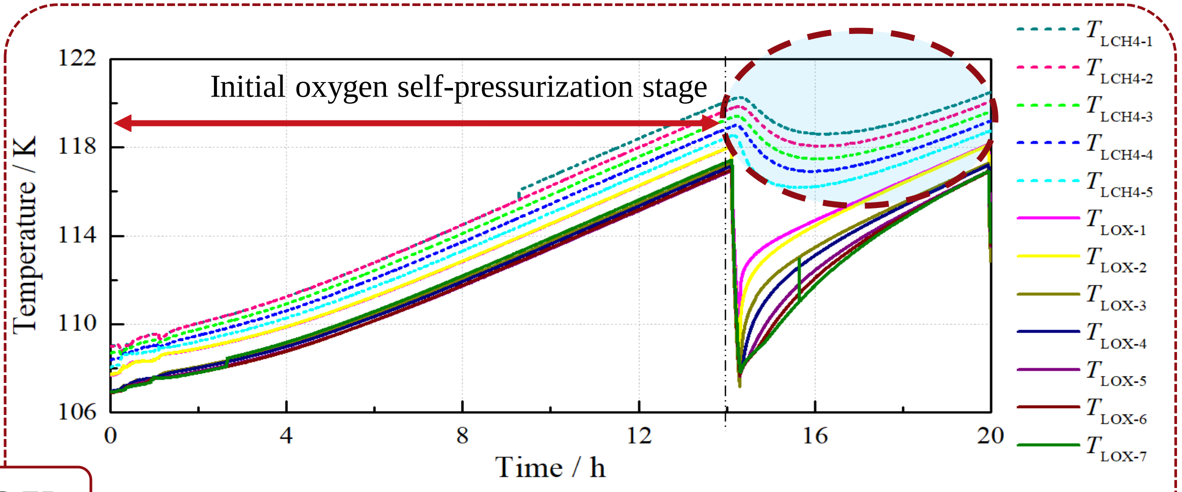


Fig. 1 Storage duration and venting frequency

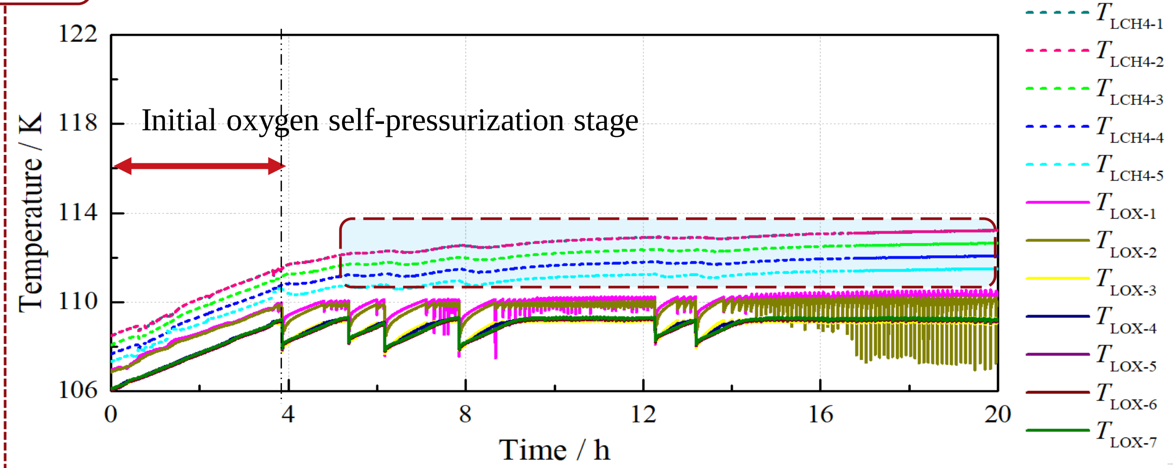
- Owing to the increase of the enhanced internal heat leakage through the common bulkhead partition, the oxygen venting and methane venting occur more frequently.

Self-pressurization and venting process

LOX

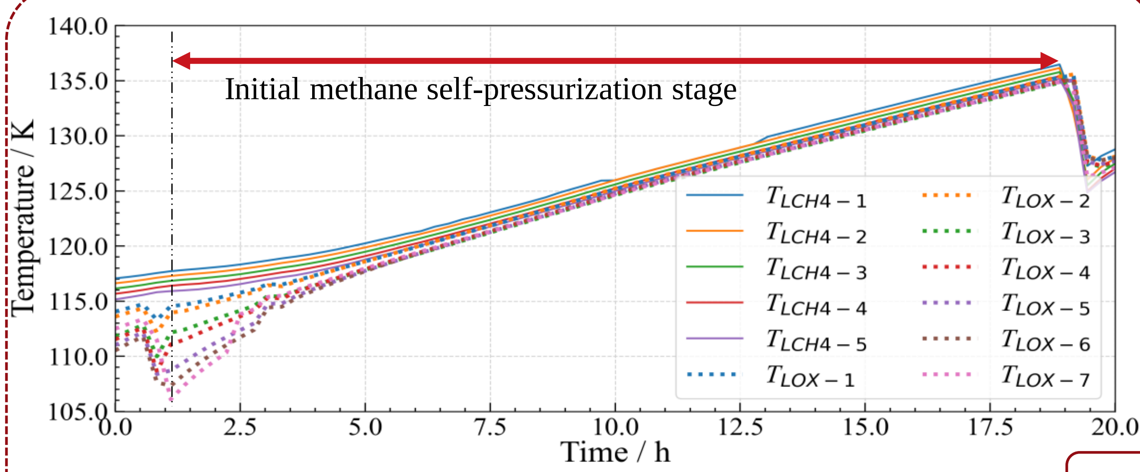


(a) No-helium scheme (LOX)

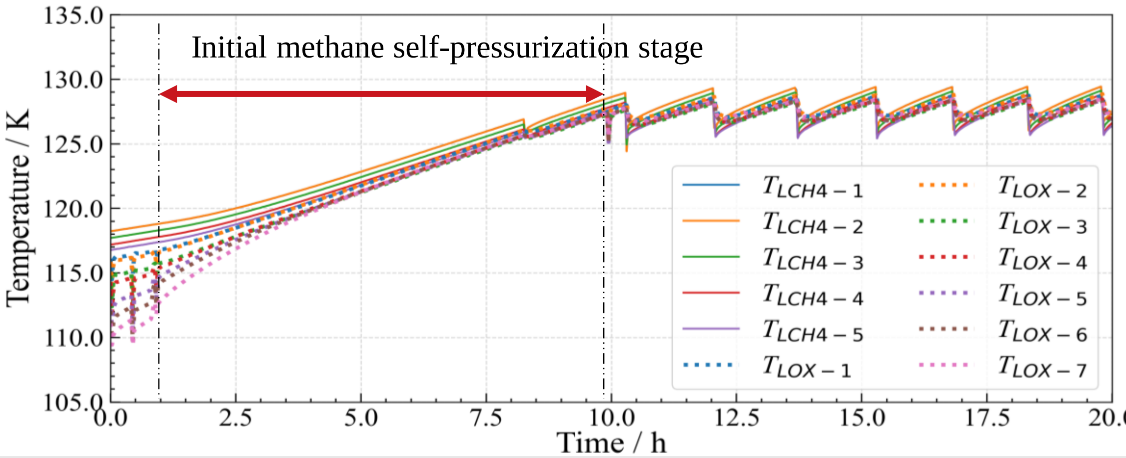


(b) Helium-mixing scheme (LOX)

LCH_4



(c) No-helium scheme (LCH_4)



(d) Helium-mixing scheme (LCH_4)

- Frequent oxygen venting suppresses the temperature fluctuations in the LCH_4 compartment
- In the helium-mixing scheme, the initial self-pressurization stages in the helium-mixing scheme are shorter.

Mass loss during the self-pressurization and venting process

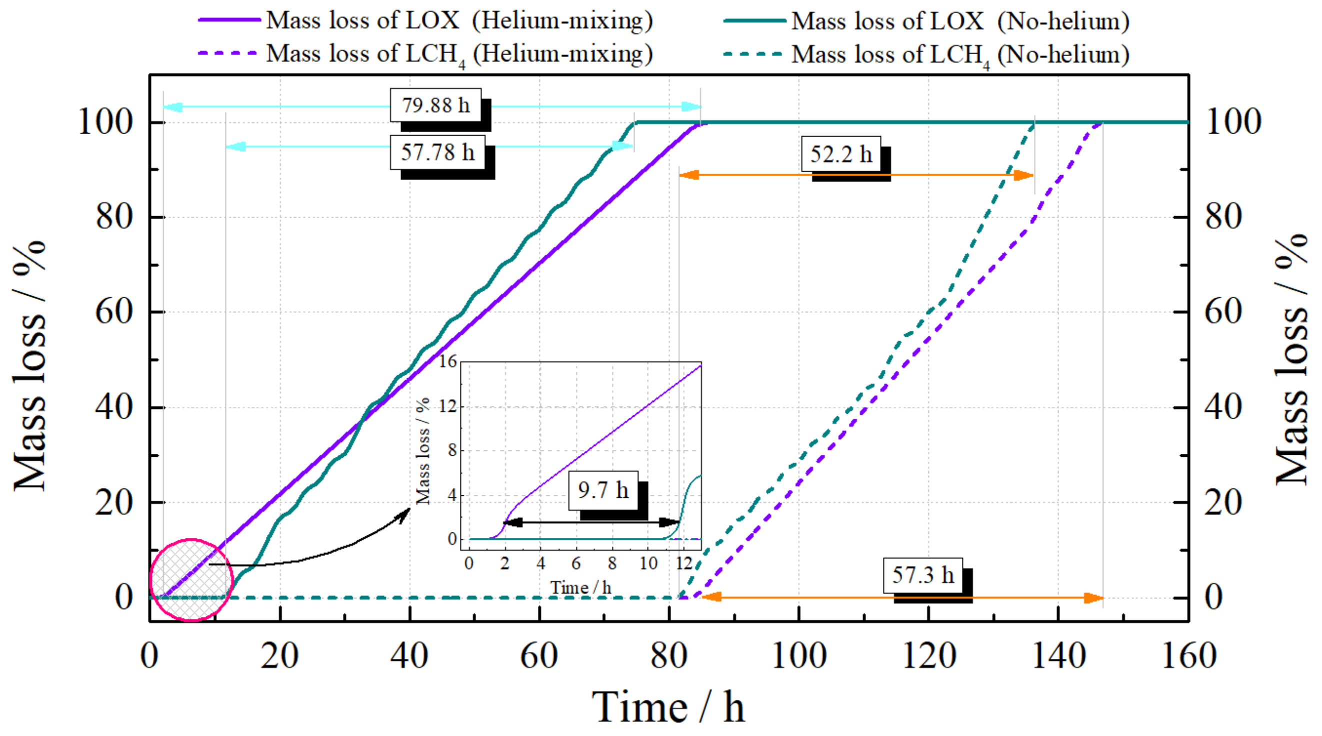


Fig. 1 Mass loss variation during the storage process.

- The mass loss rate LOX is lower.
- The mass loss of liquid methane occurs after the completion of the oxygen self-pressurization and venting process.

In the helium-mixture scheme, the self-pressurization and venting storage durations for LOX and LCH_4 increase by 38.30% and 9.77%, respectively.

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Conclusions

- **A helium-mixing scheme is proposed to improve the pressure performance in a nonadiabatic common bulkhead tank designed for storing liquid oxygen and liquid methane.**

- **Helium-mixing scheme shows a promising potential to enhance the storage performance**
- The subatmospheric pressure in the LCH_4 compartment is eliminated.
- Minor effect on the thermal stratification of the LOX compartment
- Prolonging storage durations of both LOX and LCH_4
- The nonadiabatic common bulkhead contributes to prolonging the total storage duration of liquid methane
- Not only prevents the methane venting behavior but also suppresses the temperature fluctuations in the liquid methane compartment

Q&A

饮 水 思 源 · 爱 国 荣 校

E-mail: huangyh@sjtu.edu.cn