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UNIVERSITY OF SHANGHAI FOR SCIENCE AND TECHNOLOGY

Solar-driven vapor-compression refrigeration system coupled with chemisorption energy storage

Associate Prof. Peng Gao

University of Shanghai for Science and Technology, China

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Self-introduction

Prof. Liwei Wang

■ Education and work experience:

- 2020.03-now Associate Prof. University of Shanghai for Science and Technology
- 2018.03-2020.02 Postdoctor Tongji University
- **2012.09-2018.03 Master+Ph.D Shanghai Jiaotong University**
- 2008.09-2012.06 Bachelor Jilin University

■ Award winning experience:

- eurammon Natural Refrigerated Award 2017, **First prize**
- Shanghai Sailing Program 2020

Self-introduction

- University of Shanghai for Science and Technology (USST) is a multidisciplinary key applied research-oriented university with engineering as its core.
- The history of USST goes back to the University of Shanghai established in 1906.
- USST produced Chinese first PhD degree in refrigeration and cryogenic engineering.

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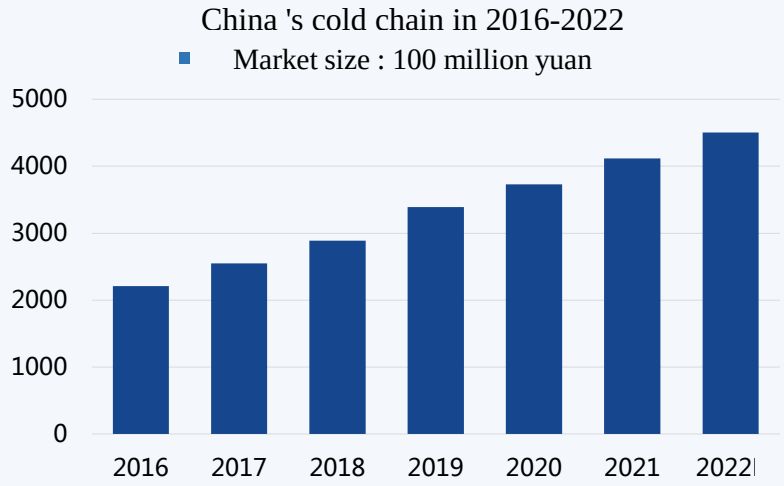
Background

Rapid growth in cold chain market size



- Fruits and vegetables are essential foods in our lives
- China is a major producer of fruits and vegetables
- Its production is among the highest in the world

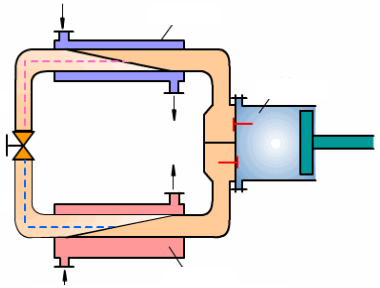
Loss rate of fruits and vegetables in China remains high

- In China, it is **above 15%**
- In some developed countries, it is **below 5%**
- Annual economic losses caused by spoilage of fruits and vegetables in China is 100 billion yuan

An effective method is to build refrigerated warehouses in the production areas to precool freshly harvested fruits and vegetables.

Background

Vapor-compression refrigeration for refrigerated warehouses



- Simple structure
- A relatively low space temperature of refrigerated warehouse will inevitably **result in a lower COP and a higher power consumption**

Weak power supply capacity in rural areas

- Rural areas are widely spread with farmland and fruit forests
- These areas often face the problem of **weak power supply capacity**

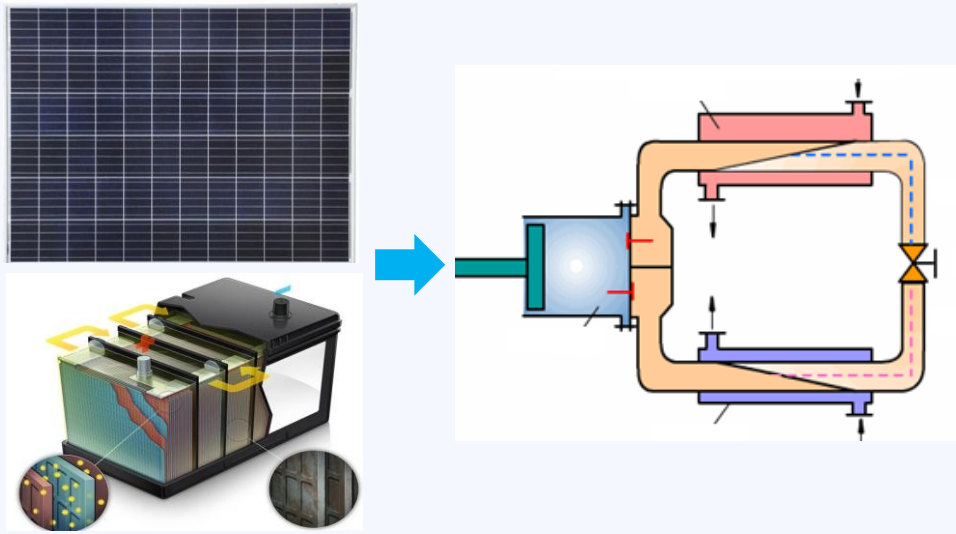
In rural areas, it is difficult to meet the electricity demand of refrigerated warehouses

Background

Abundant solar energy in rural areas

- Solar refrigeration technology is a promising method to solve the problems
- **Solar photovoltaic (PV) refrigeration**
- **Solar thermal refrigeration**

Solar PV refrigeration system

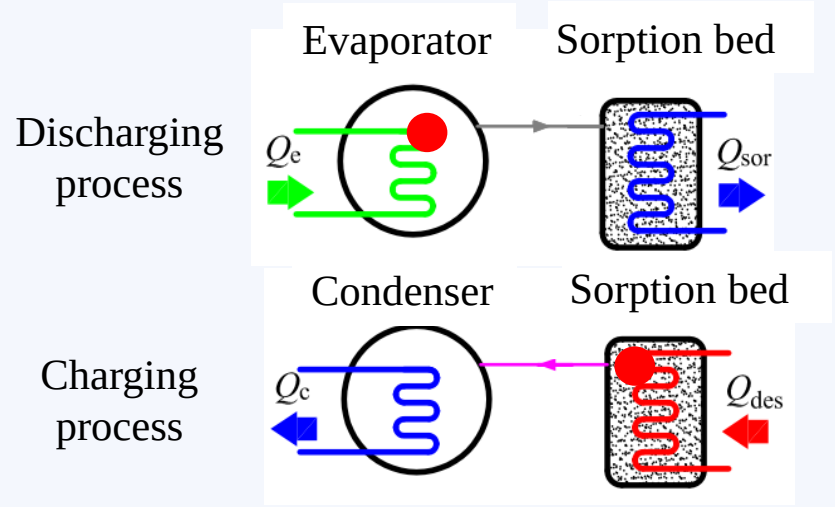


- PV cells converts solar energy into electrical energy to drive vapor-compression refrigeration
- Refrigerated warehouses require continuous cooling capacity

A solar PV refrigeration system in combination with an energy storage unit is required, while using batteries for energy storage is a costly affair.

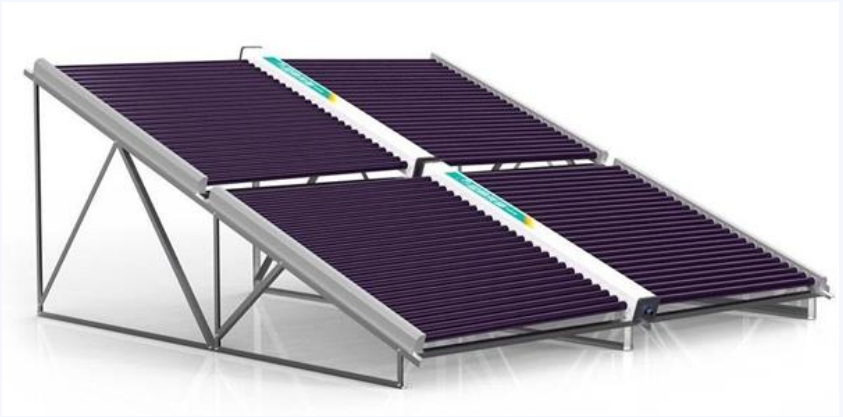
Background

Thermal-driven chemisorption energy storage



- No moving parts and simple structure
- Flexibly adjustable refrigerating temperature
- **Generally require the driving heat source above 100°C at an evaporating temperature below 0°C**

Solar hot water



- **Low-cost non-concentrating solar collectors**
- Solar hot water temperature : 60~95°C
- Solar hot water fluctuates during the daytime

A novel solar-driven vapor-compression refrigeration system coupled with chemisorption energy storage for precooling freshly harvested fruits and vegetables is proposed and designed.

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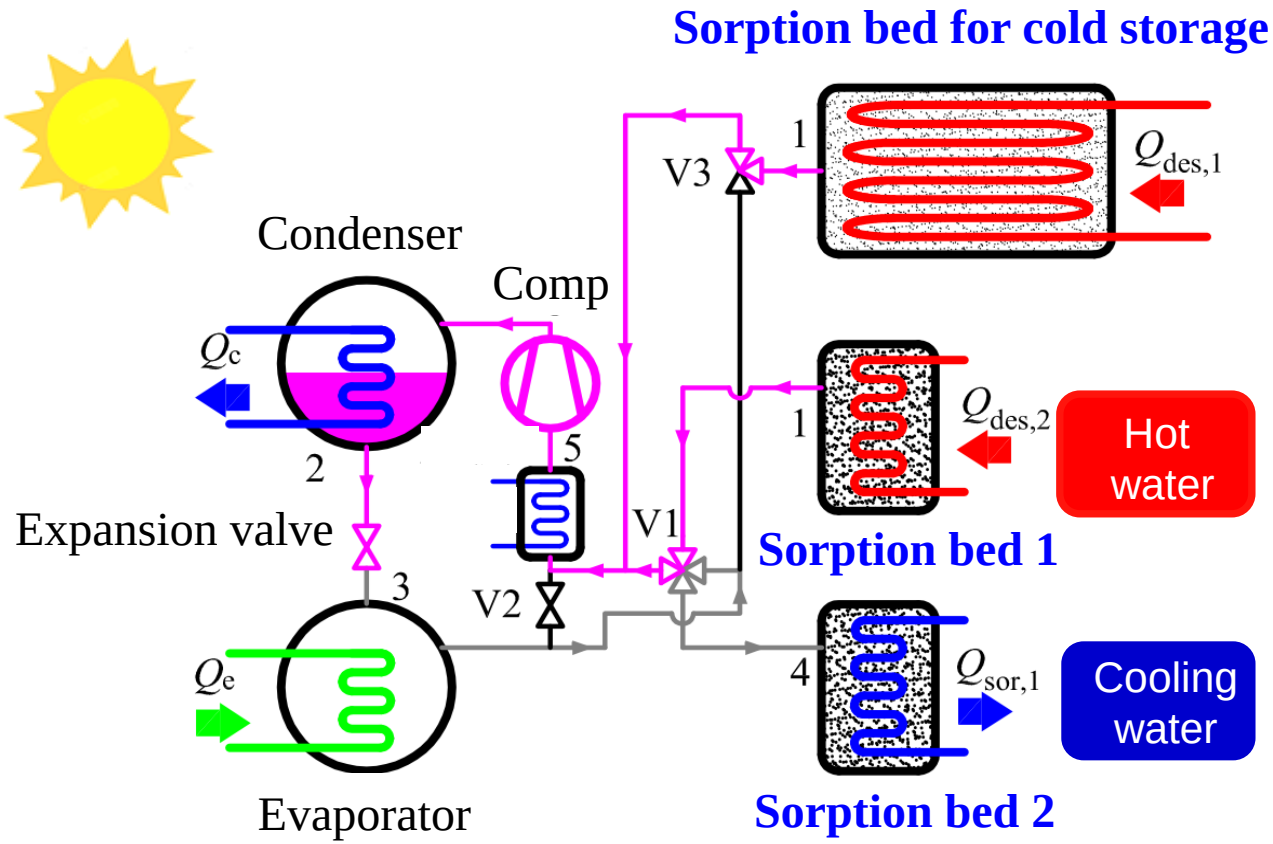
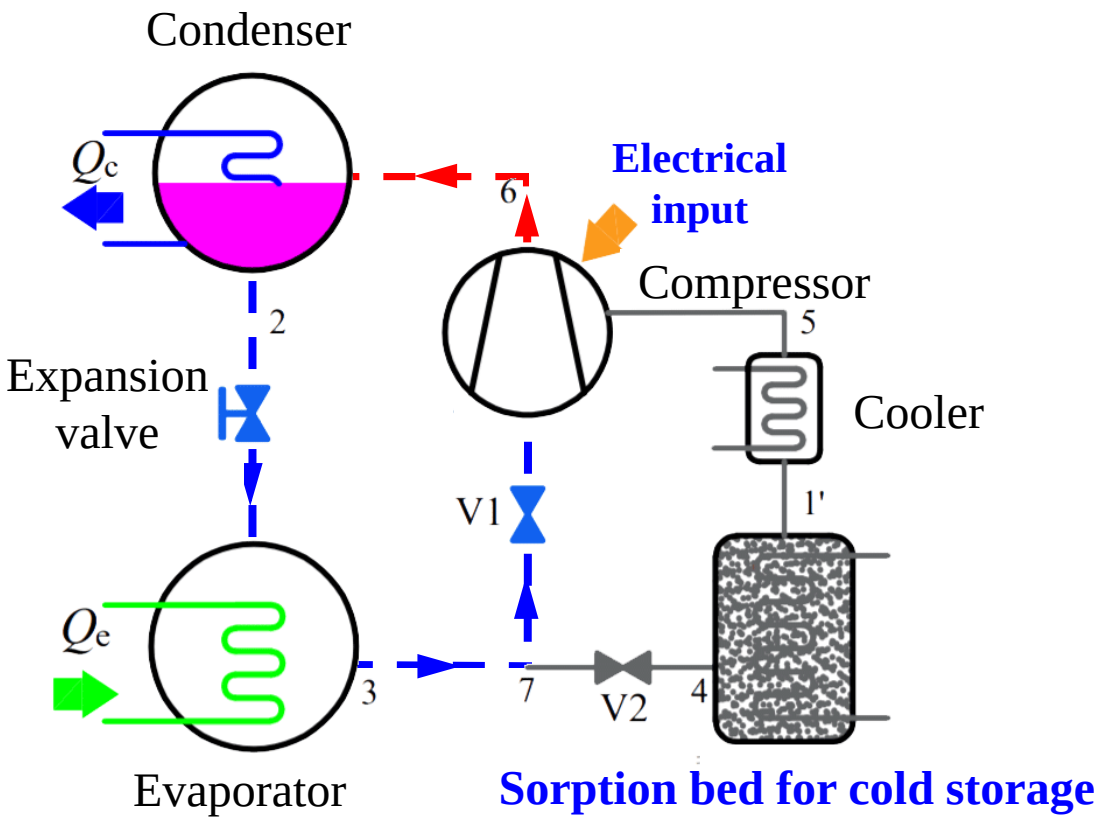
Cycle description



Cycle structure

- **Working principles of the cycle**
  - **Refrigeration mode during the daytime**
  - **Cold energy charging mode during the daytime**
  - **Cold energy discharging mode at night**
- **Working pair**
  - **$SrCl_2$-NH_3**

Cycle description



Cycle structure

- **Working principles of the cycle**
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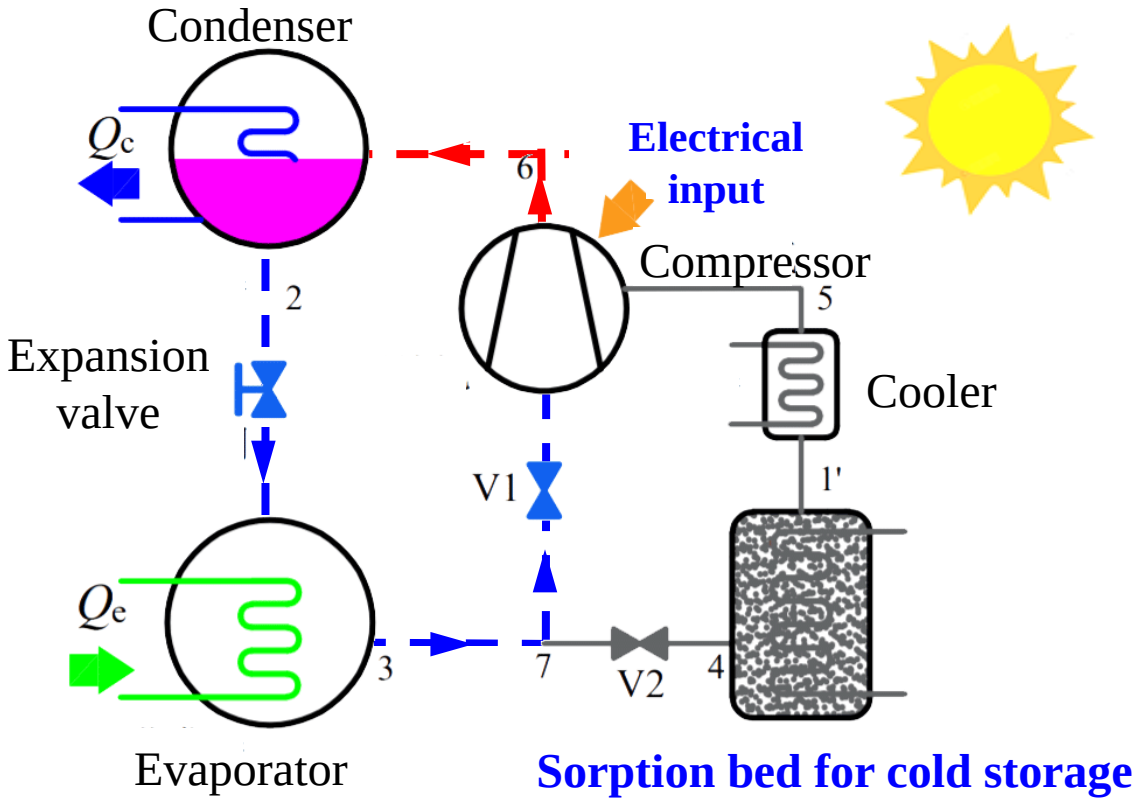
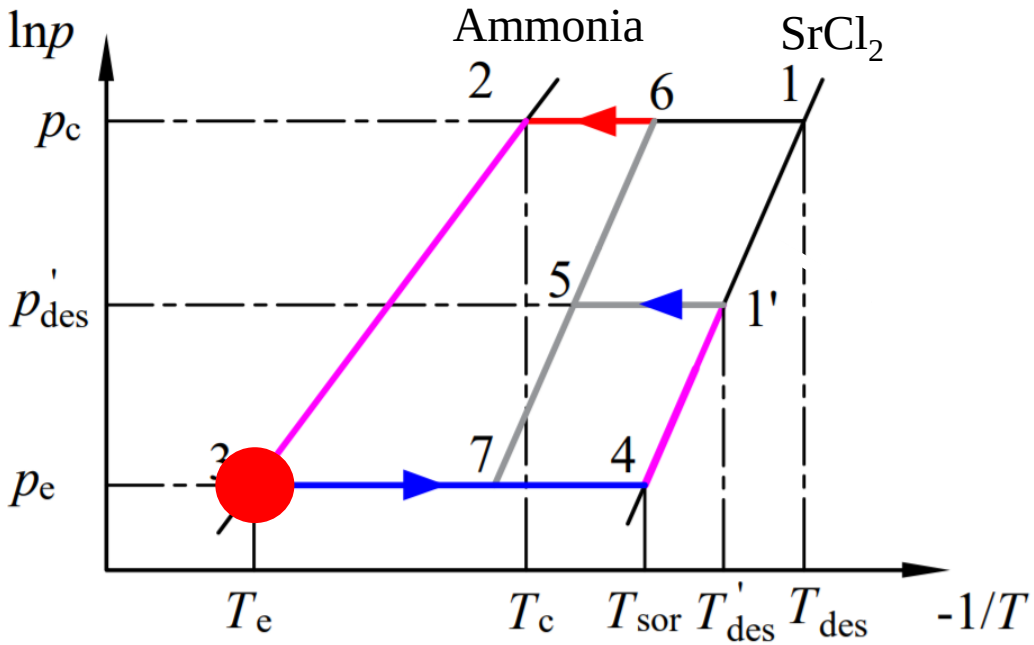
Cycle description

Refrigeration mode during the daytime

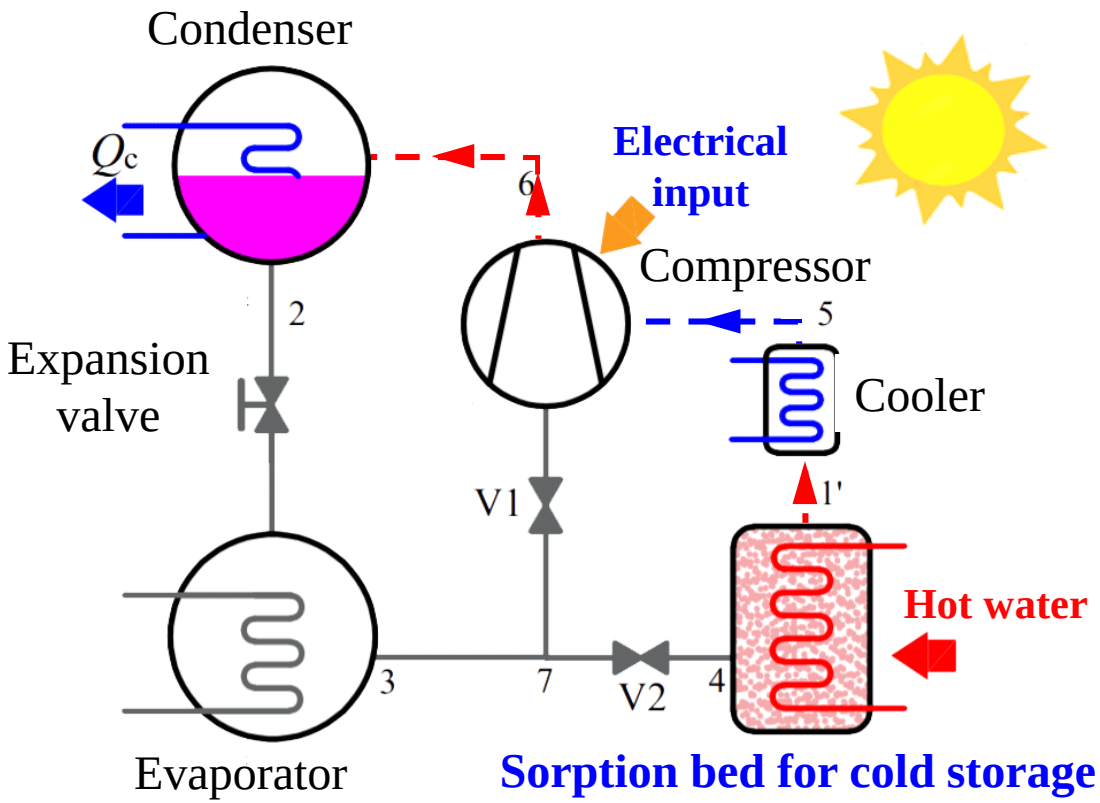


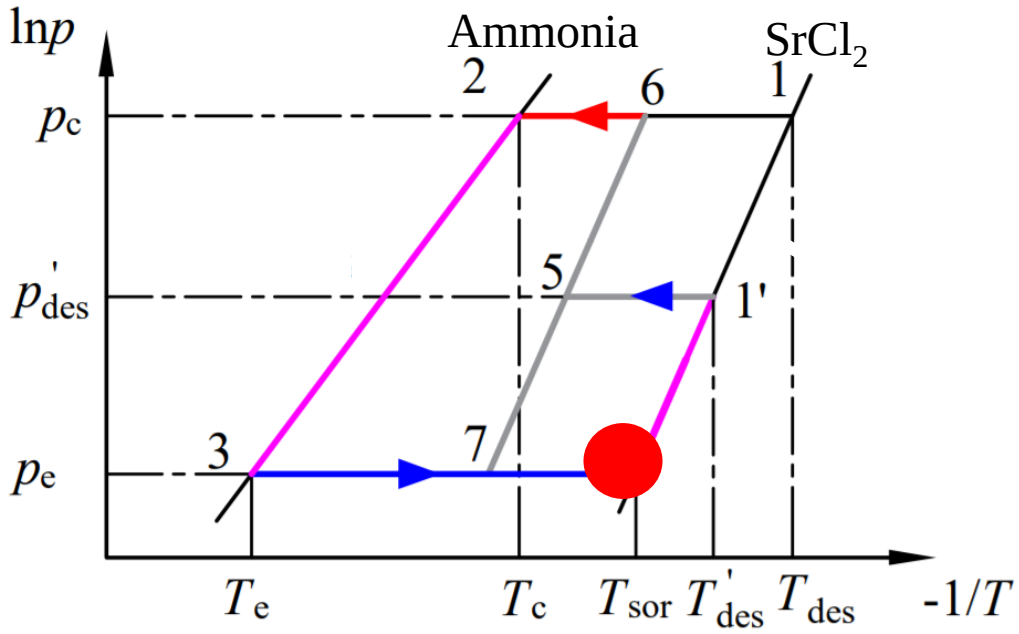


Compression - Condensation - Throttling - Evaporation

Cycle description

Cold energy charging mode during the daytime

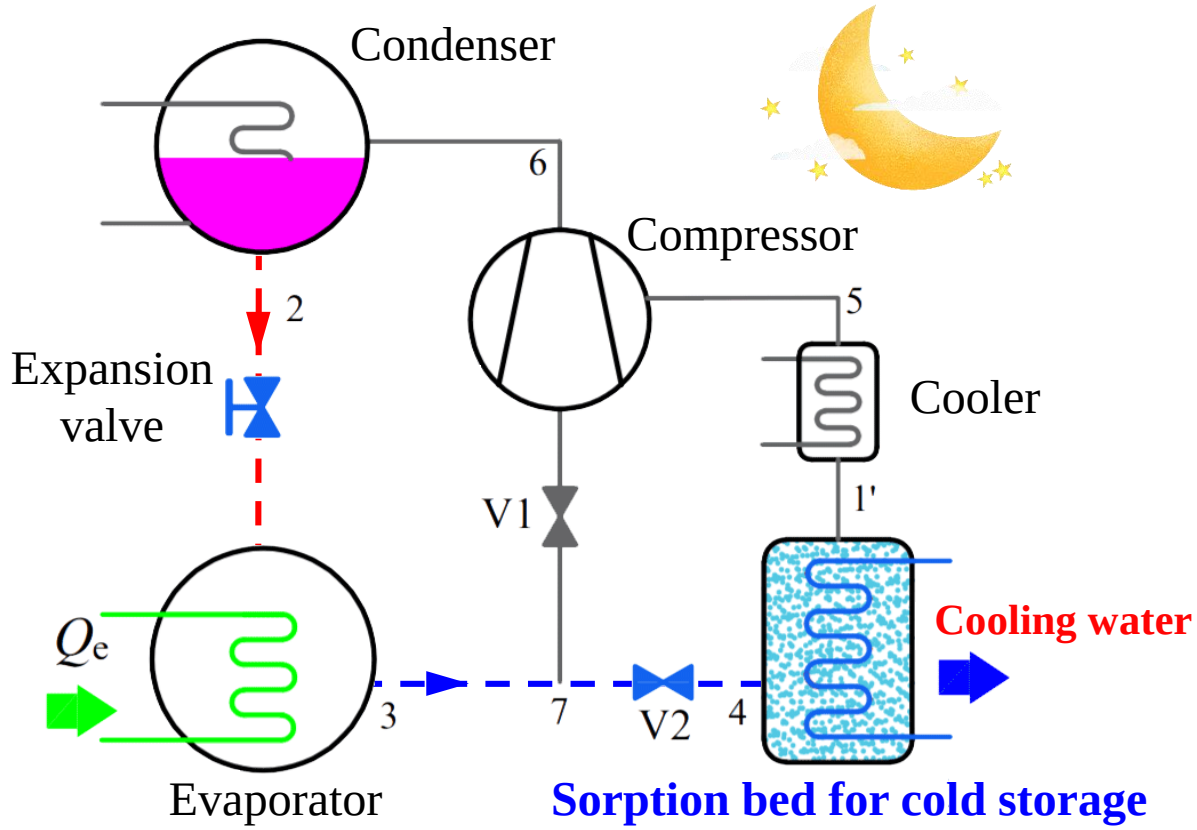


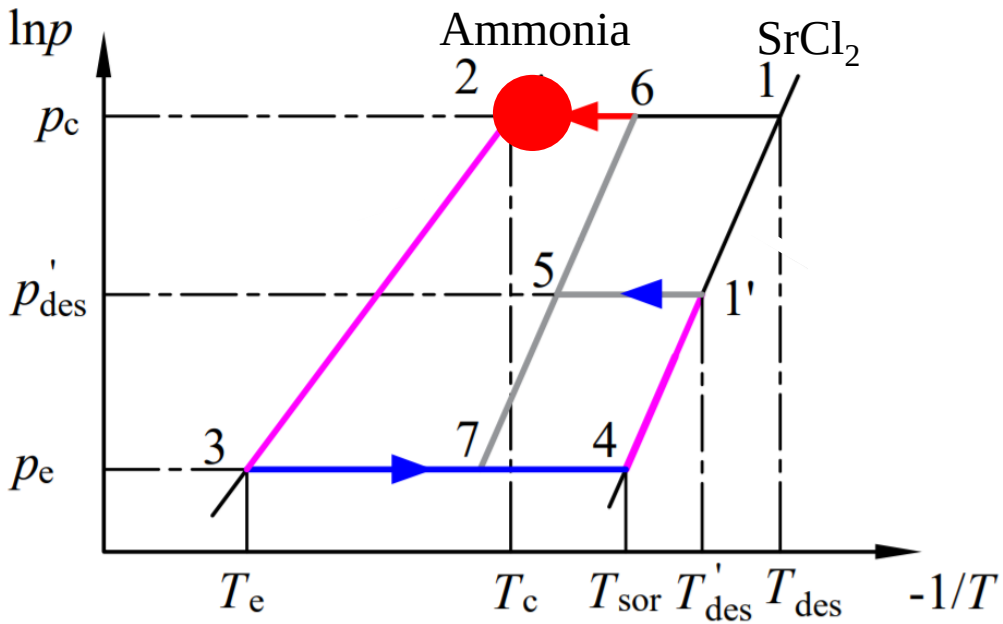


Desorption - Cooling- Compression - Condensation

Cycle description

Cold energy discharging mode at night

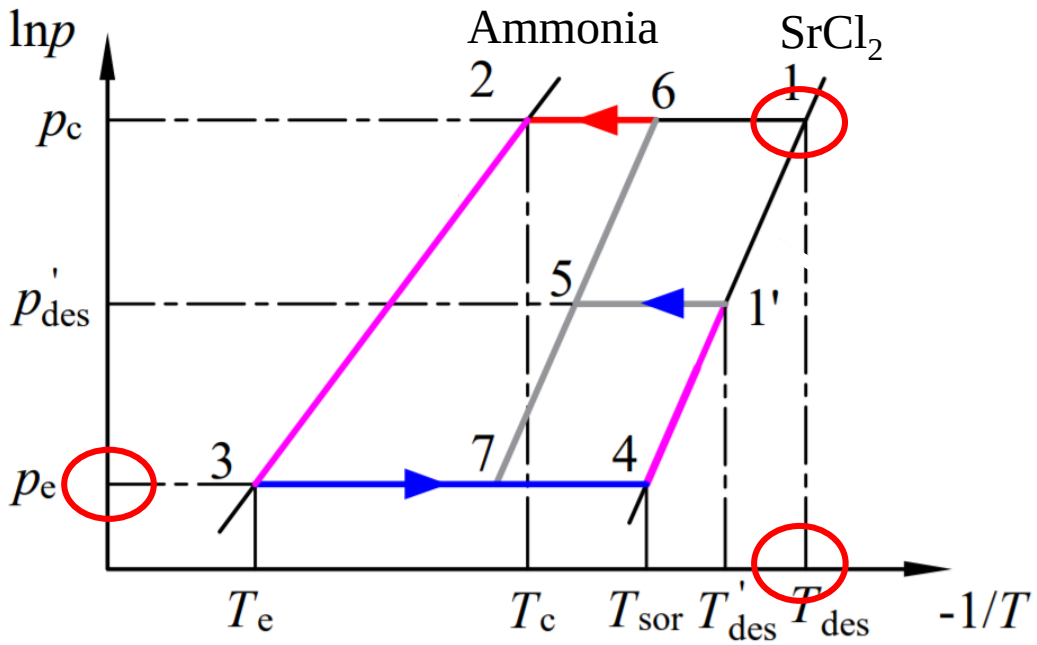


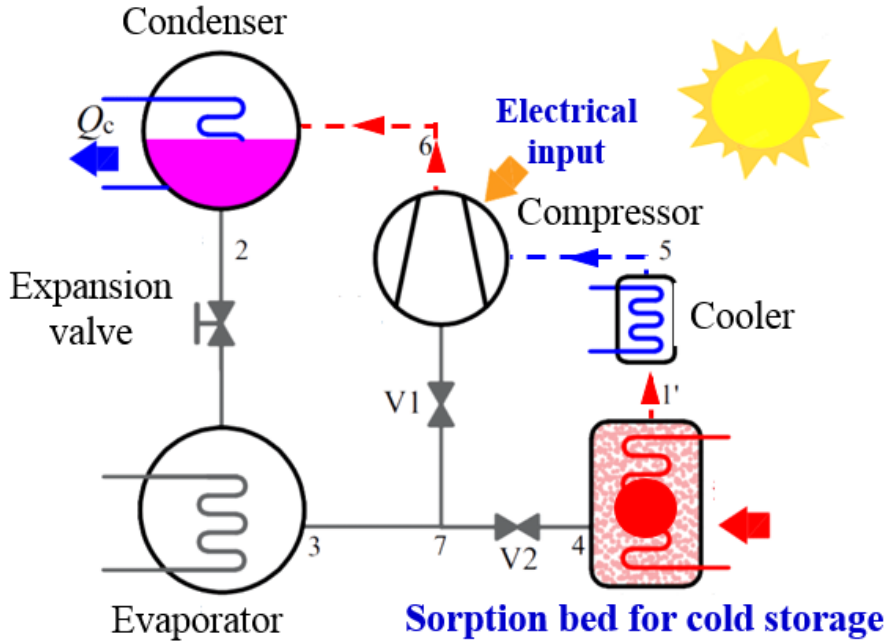


Condensation - Throttling - Evaporation

Advantage 1

Compression-assisted desorption technology

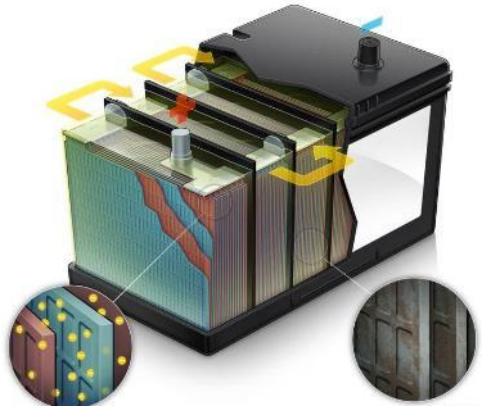


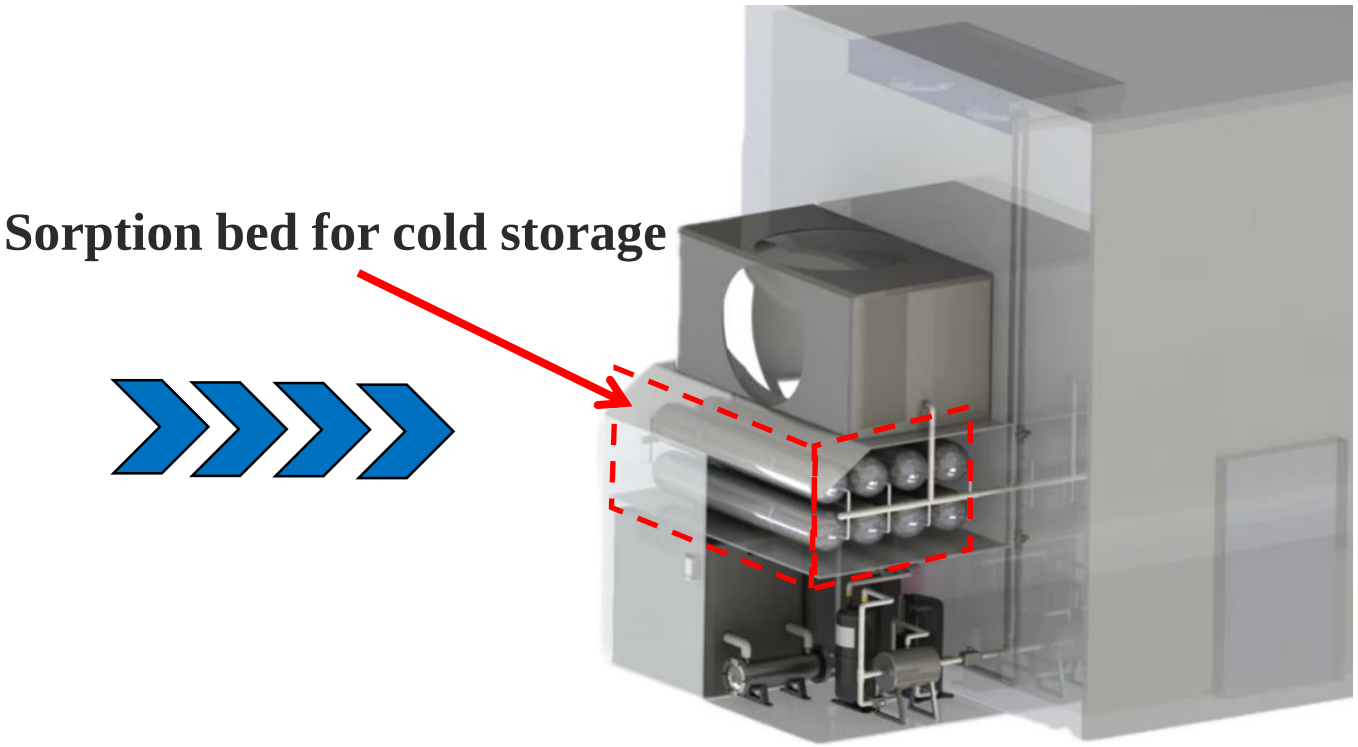


- **Compression-assisted desorption effectively reduce the driving heat source temperature**
- Desorption reaction increases suction pressure of compressor, reducing its pressure ratio and power consumption in comparison to conventional vapor-compression one

Advantage 2

- **Sorption bed for cold storage** is added to replace battery to achieve continuous cooling capacity





- Help solar PV refrigeration system output cooling capacity in the absence of solar energy
- **Initial investment is reduced** and the applicability become stronger
- A highly effective and environmental sound technology

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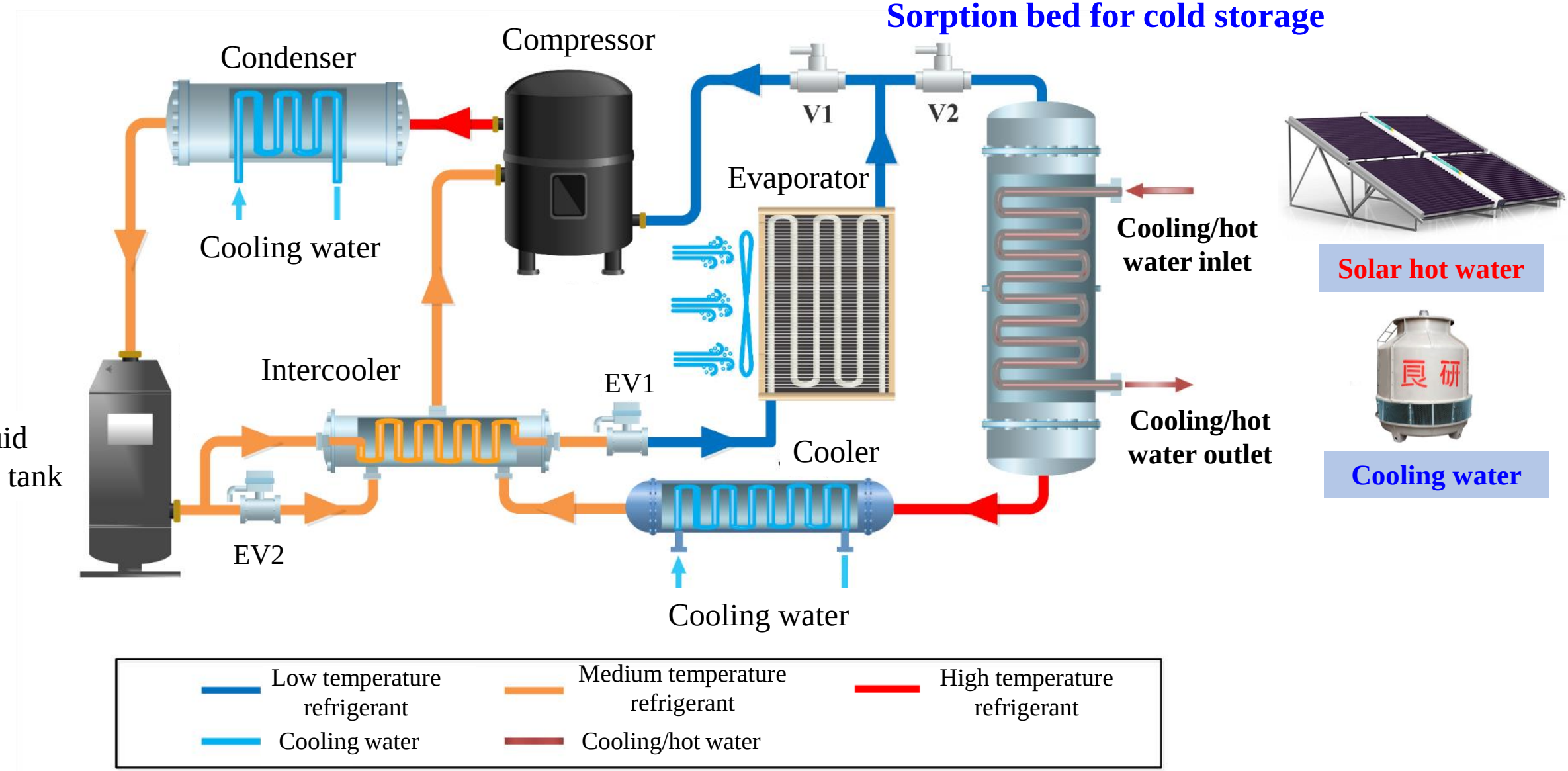
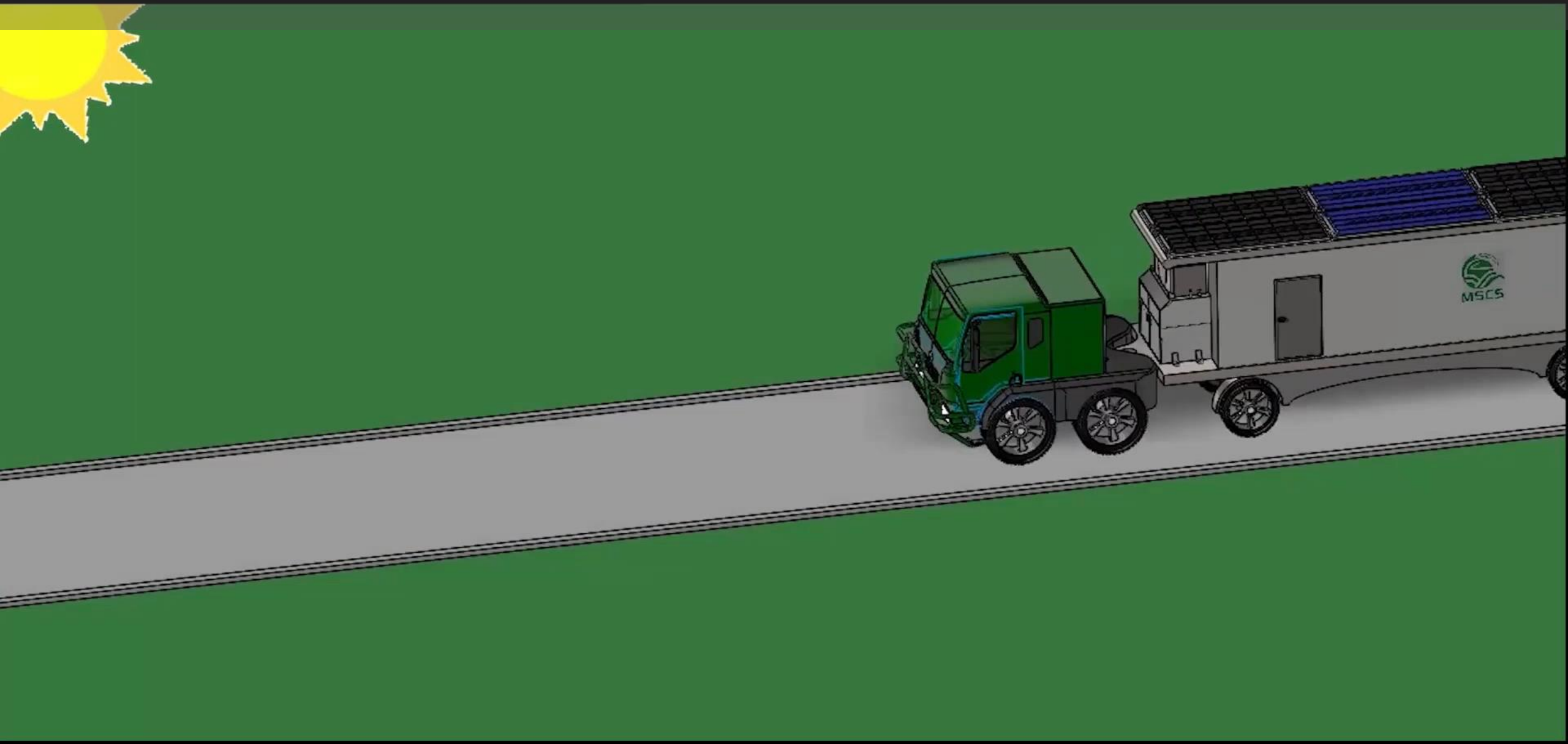
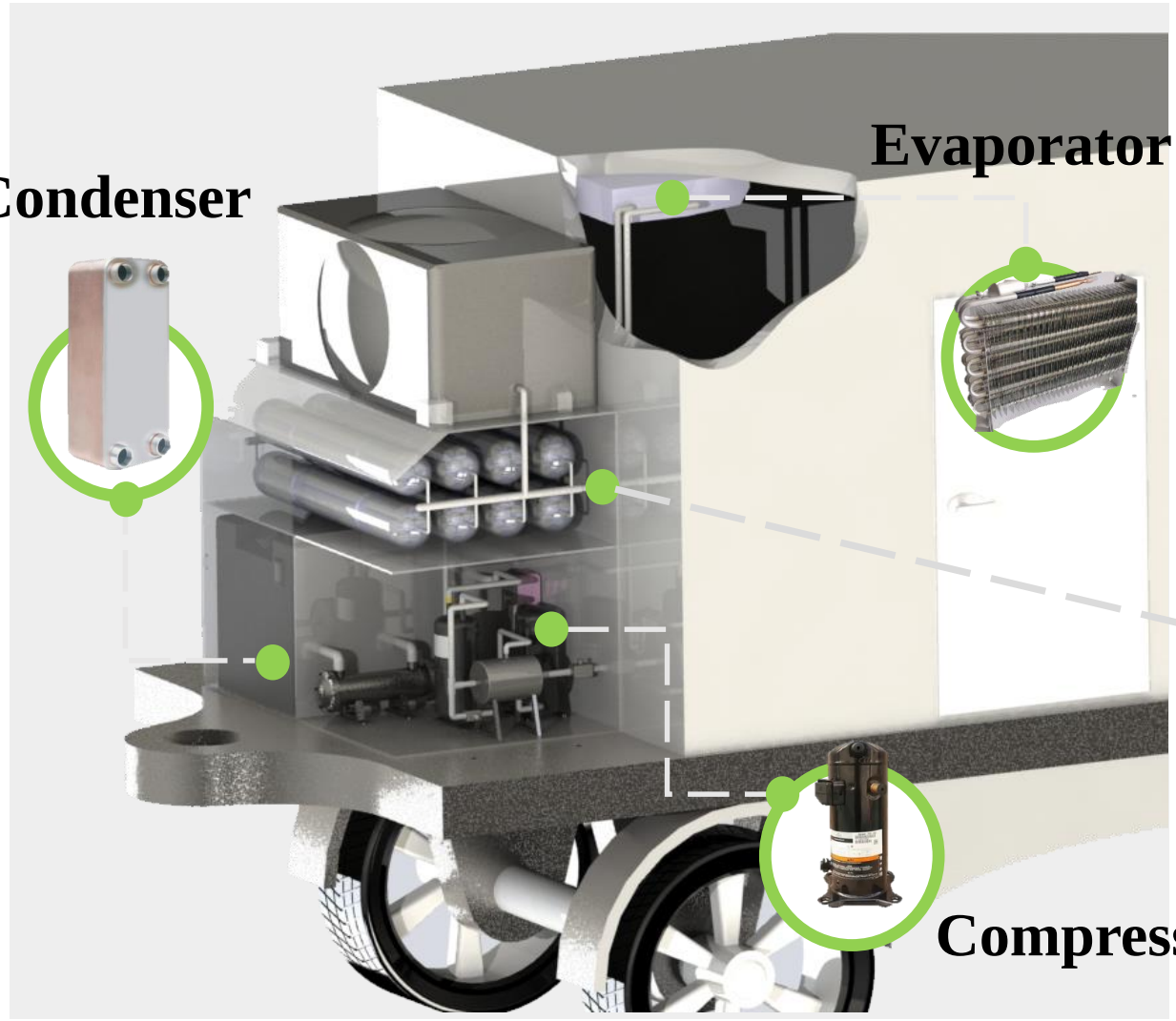
System Design

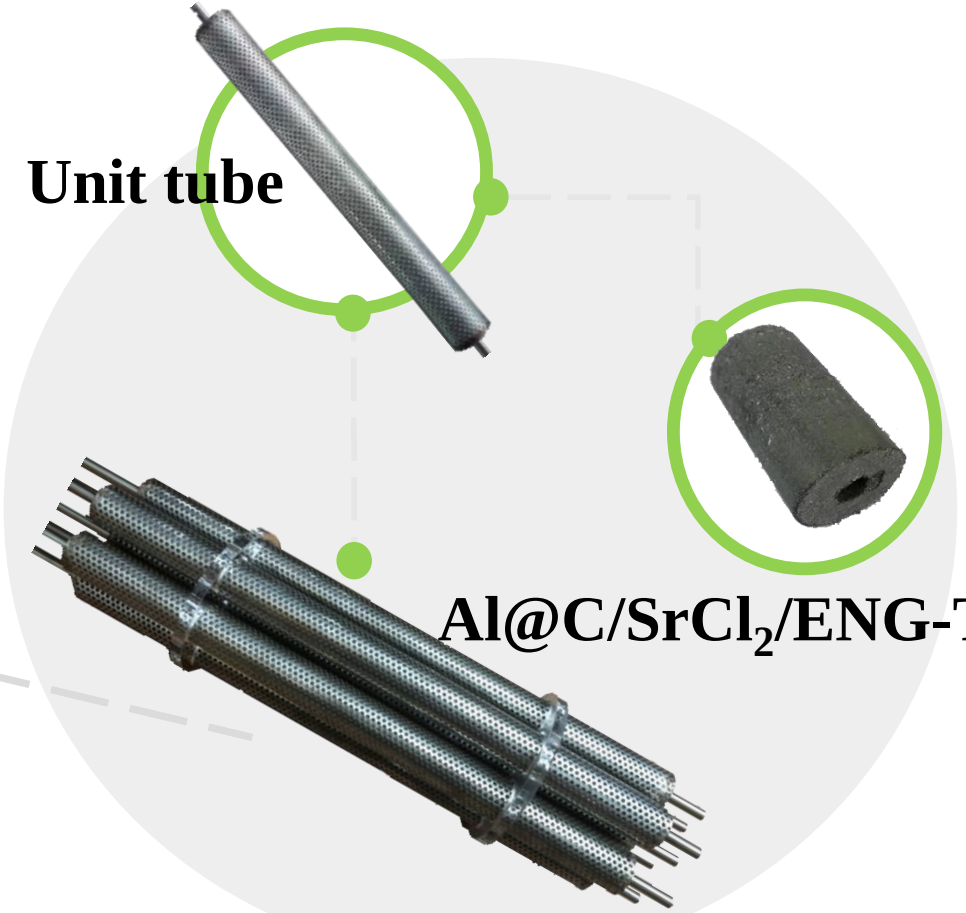


Solar-driven vapor-compression refrigeration system coupled with chemisorption energy storage



System Component Design



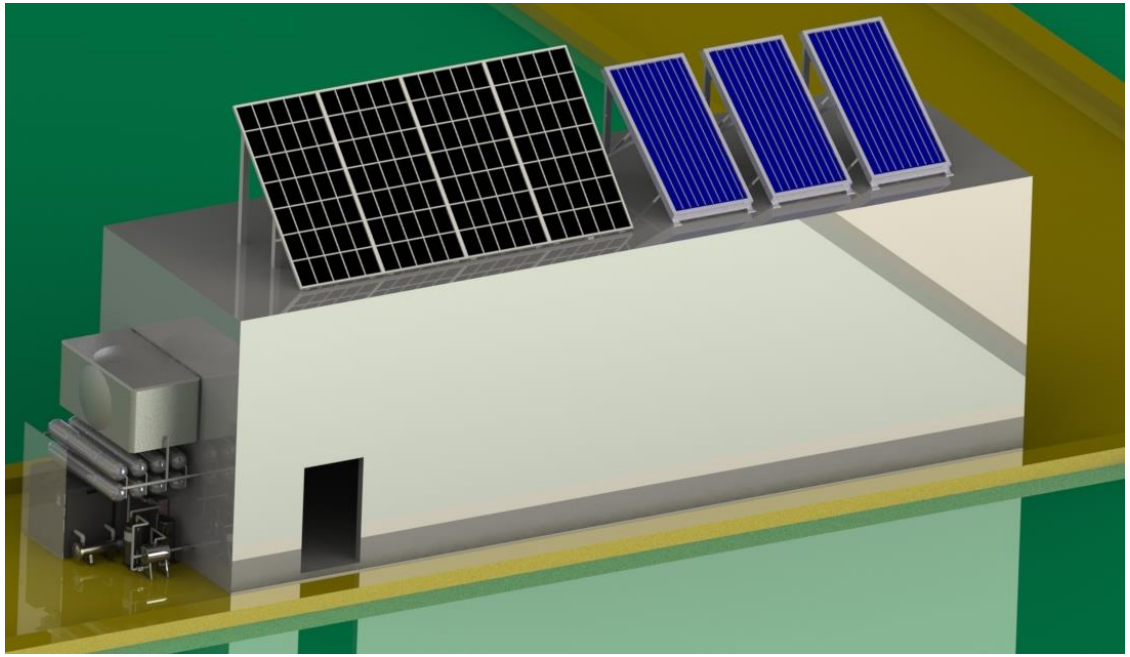


System Design

- 6.0×2.4×2.6 m refrigerated warehouse

Movable refrigerated warehouse

Stationary refrigerated warehouse



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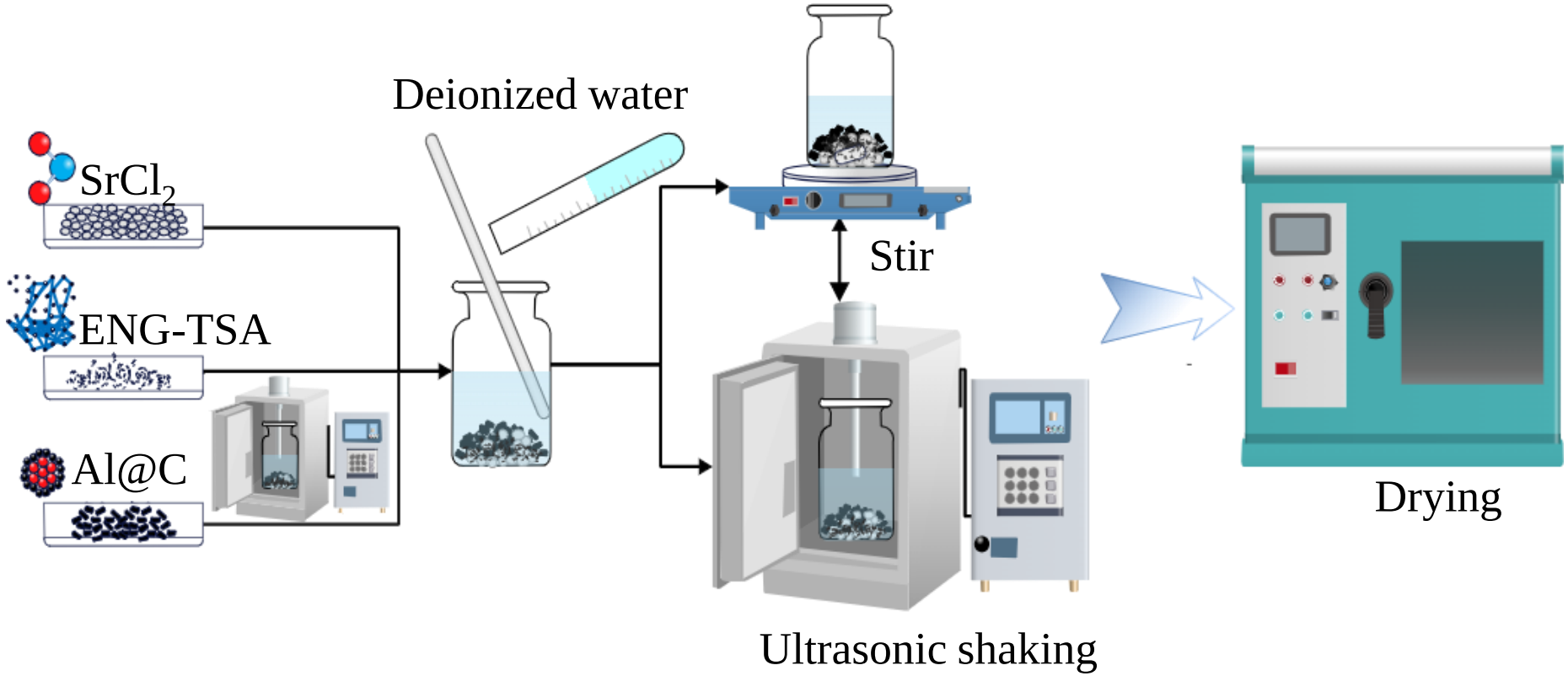
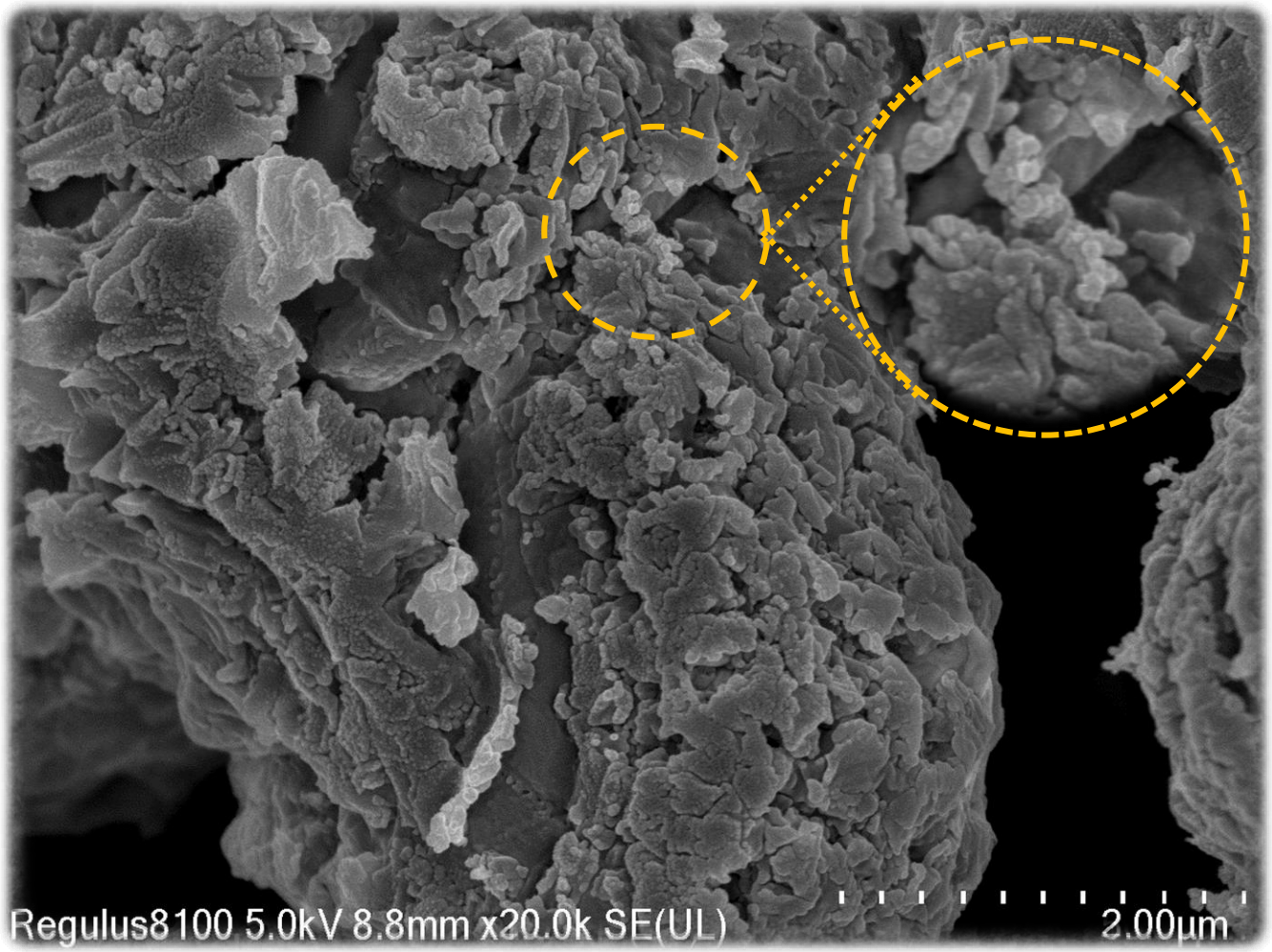
Composite sorbent

- To further enhance heat and mass transfer, **nano-composite sorbent** of Al@C/$SrCl_2$/ENG-TSA was prepared.

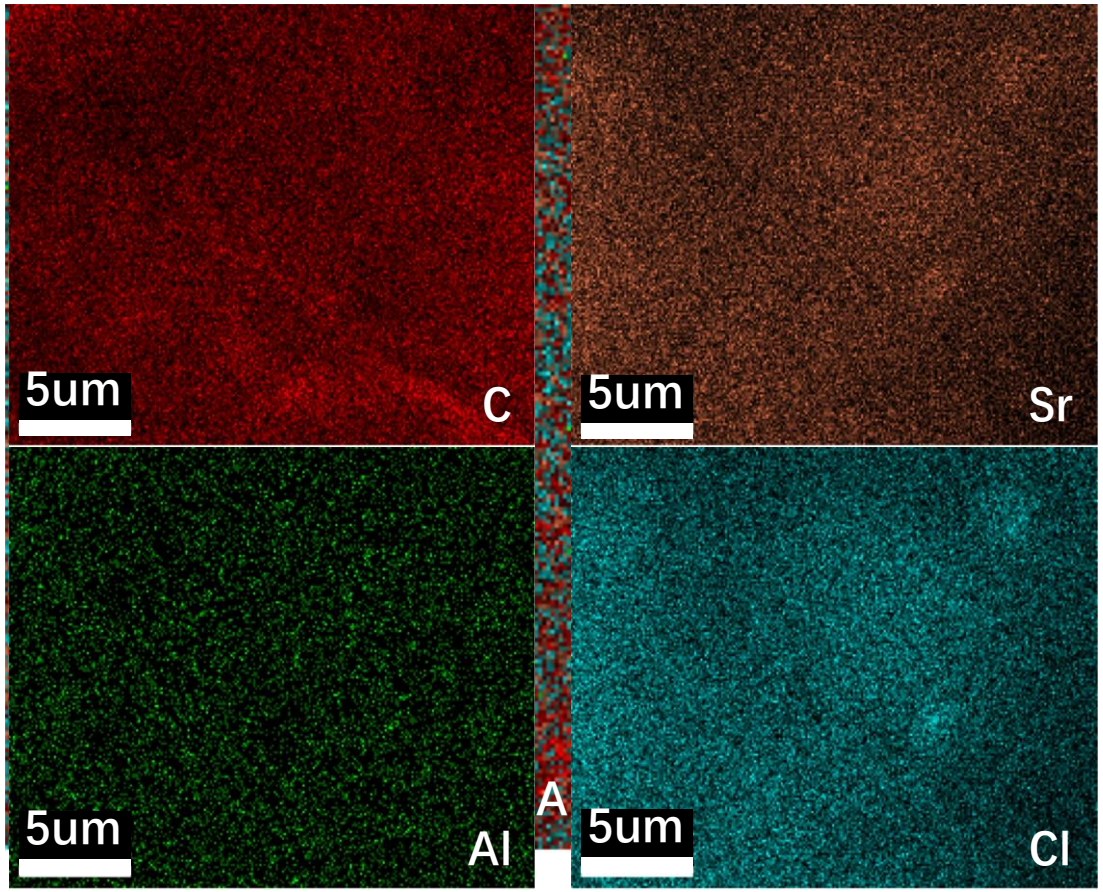


Preparation process of nano-composite sorbent

Analysis and characterization of Al@C/$SrCl_2$/ENG-TSA

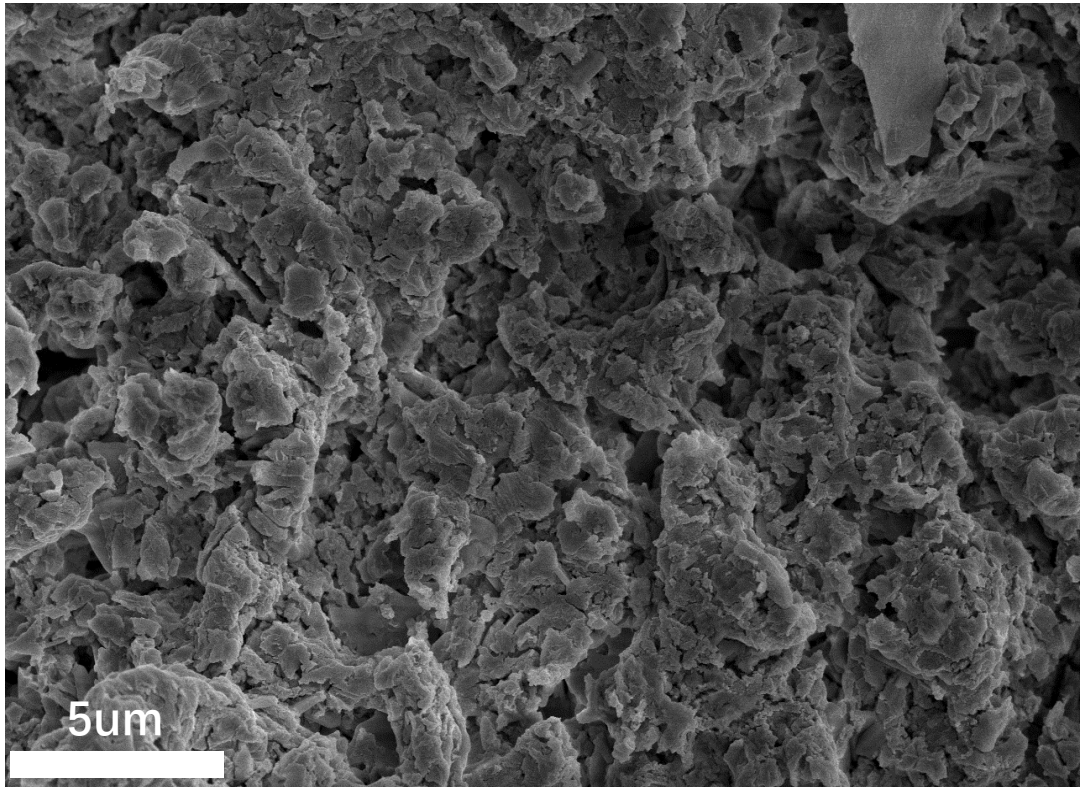


SEM

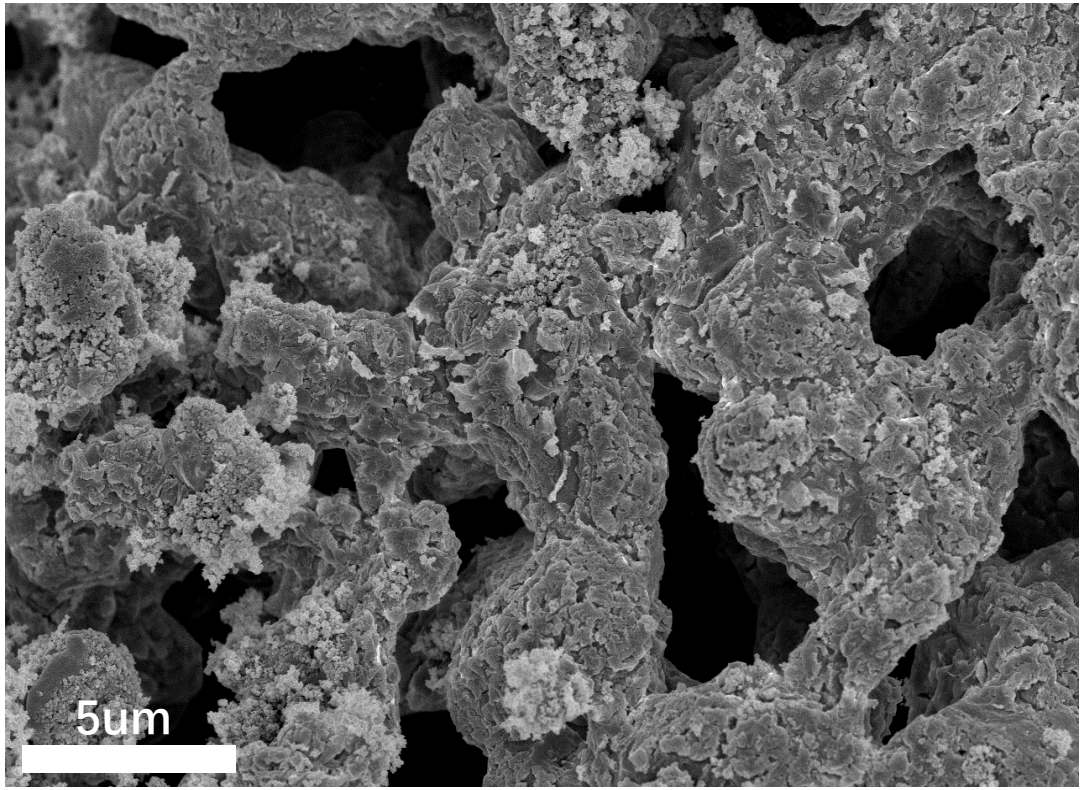


EDX

Analysis and characterization of Al@C/$SrCl_2$/ENG-TSA



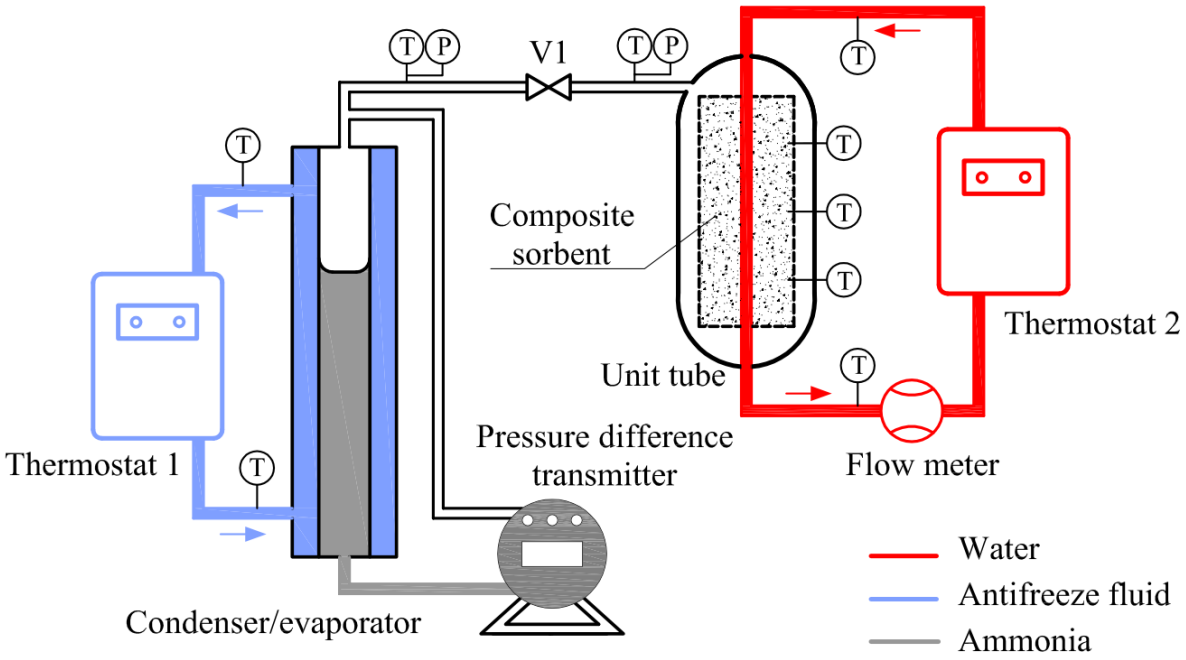
SEM of $SrCl_2$/ENG-TSA



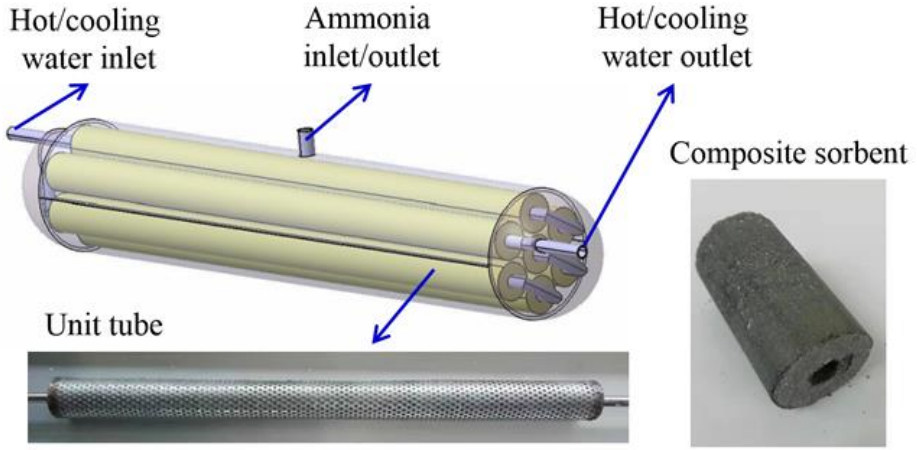
SEM of Al@C/$SrCl_2$/ENG-TSA

- 2%Al@C to $SrCl_2$/ENG-TSA composite sorbent
- More porous structure, easy to ammonia refrigerant mass transfer
- Al@C Particles enhance heat transfer

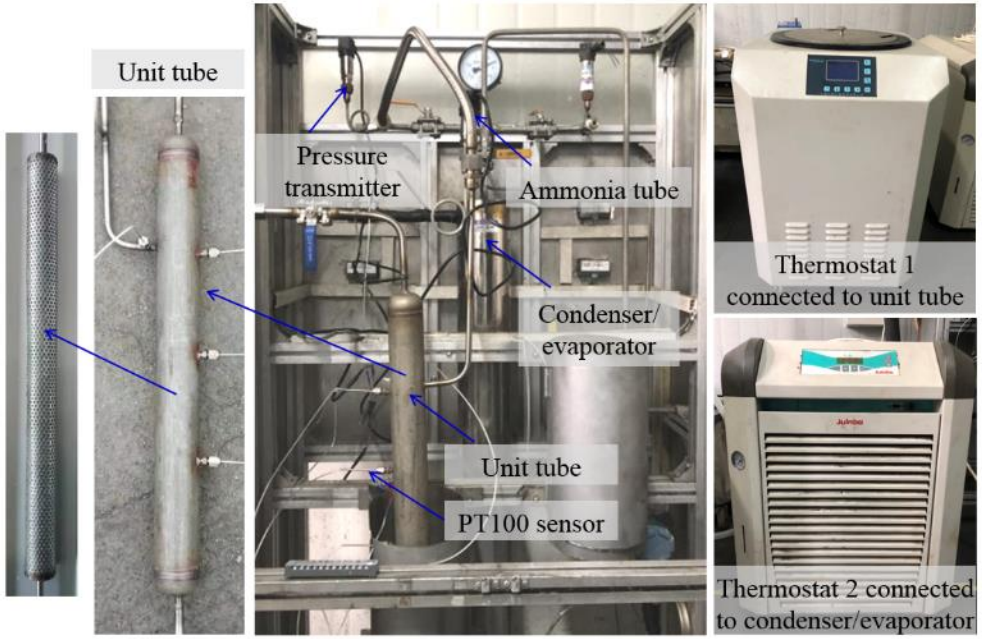
Performance test bench of the reactor unit tube



Schematic



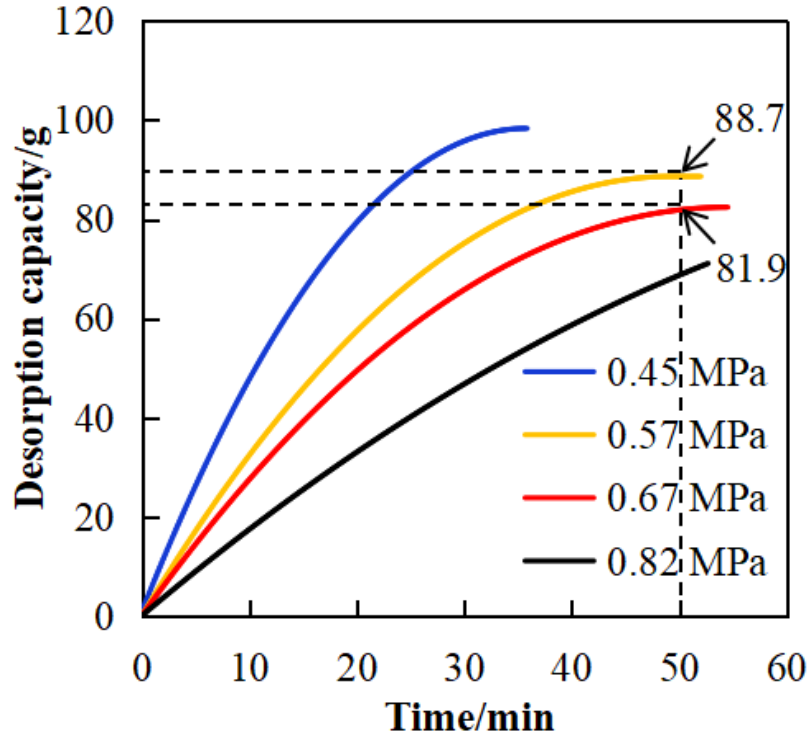
Reactor unit tube

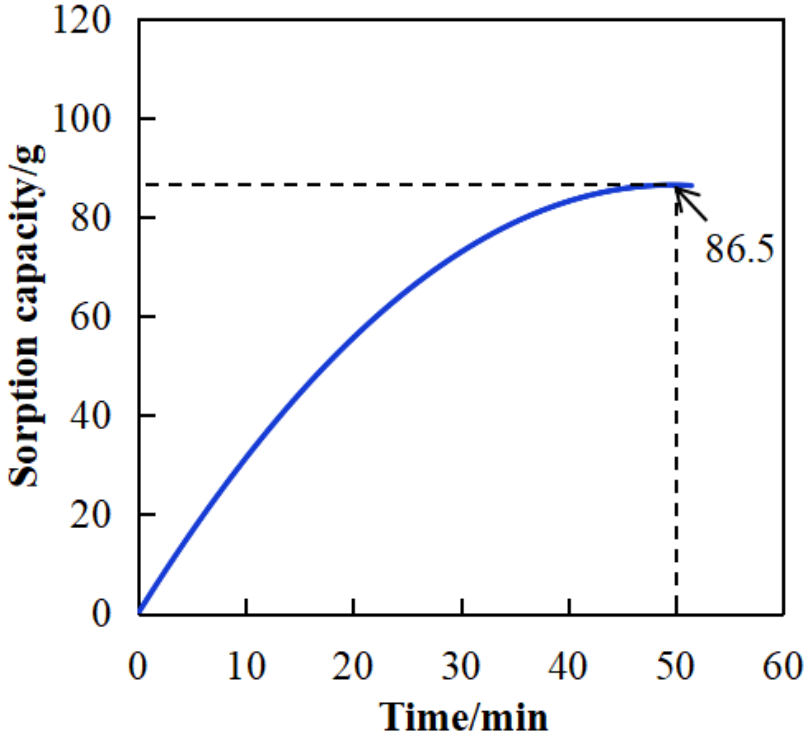


Experimental system

Performance test bench of the reactor unit tube

- **The desorption pressure is a key operating parameter for the desorption reaction.**
- The desorption time of the composite sorbent should be slightly less than its sorption time, and its desorption capacity should be larger than the sorption capacity.

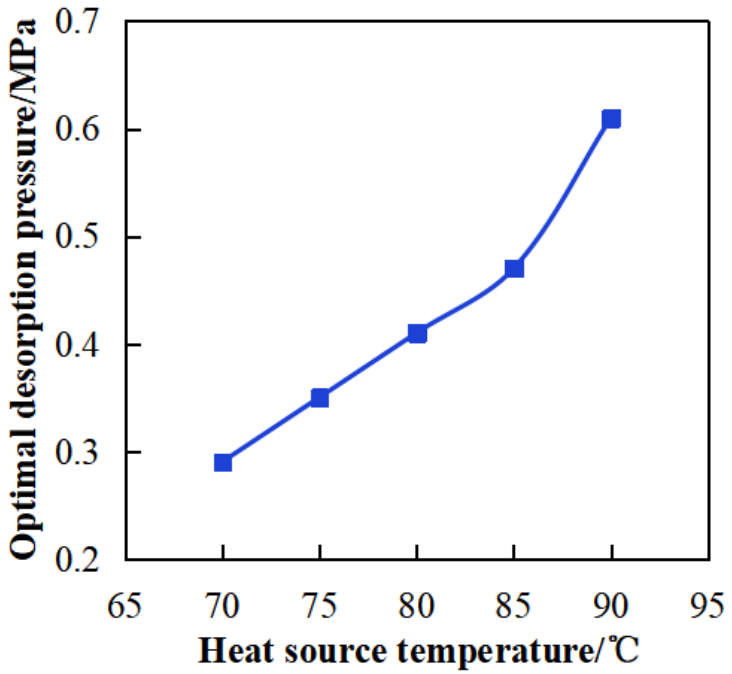




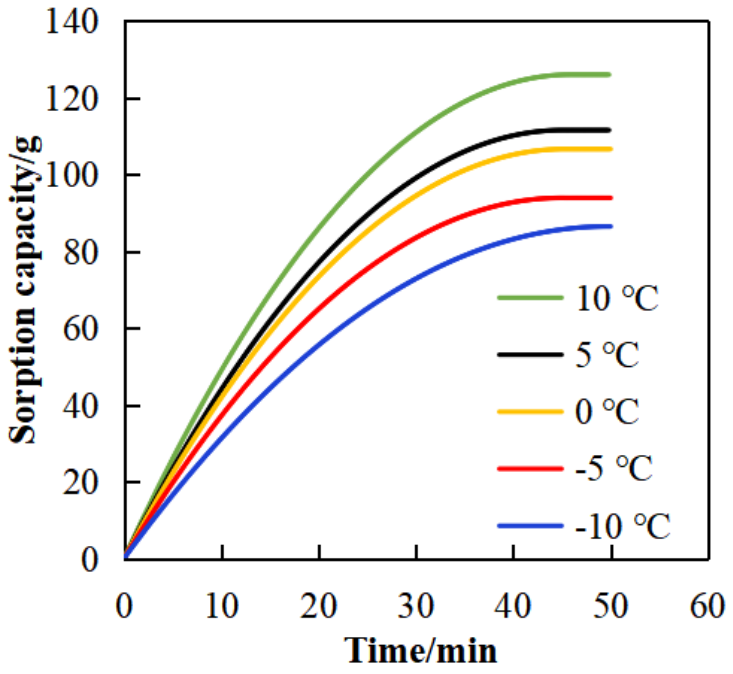
Performance of composite sorbent under the conditions of 90°C hot water temperature, 32°C cooling water temperature and -10°C evaporating temperature: **(a) desorption capacity at different reaction pressure; (b) sorption capacity**

Performance test bench of the reactor unit tube

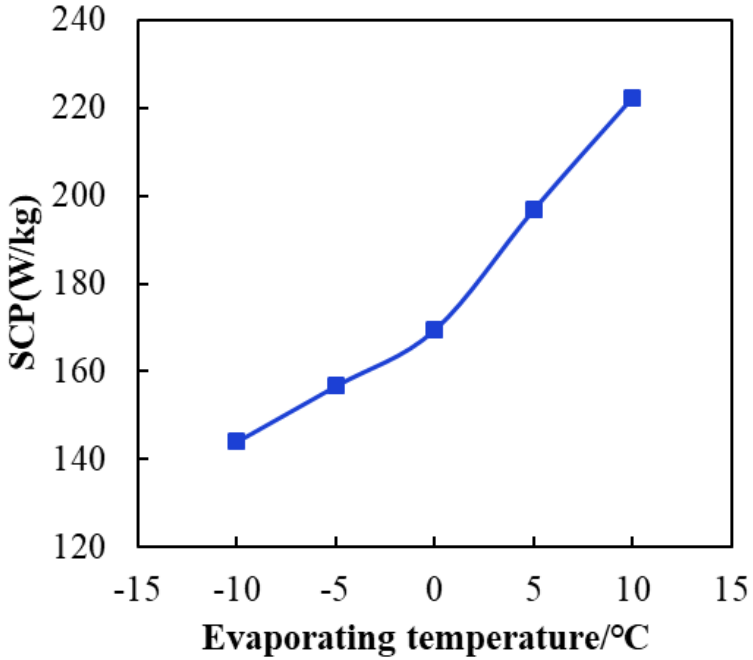
- When the hot water temperatures are 75°C and 85°C, the optimal desorption pressures are 0.35 MPa and 0.47 MPa, respectively.
- Ammonia sorption capacity of the composite sorbent increases with the increase in evaporation temperature.
- When the evaporating temperature rises from -10°C to 10°C, SCP changes from 145 W/kg to 222 W/kg.



Optimal desorption pressure



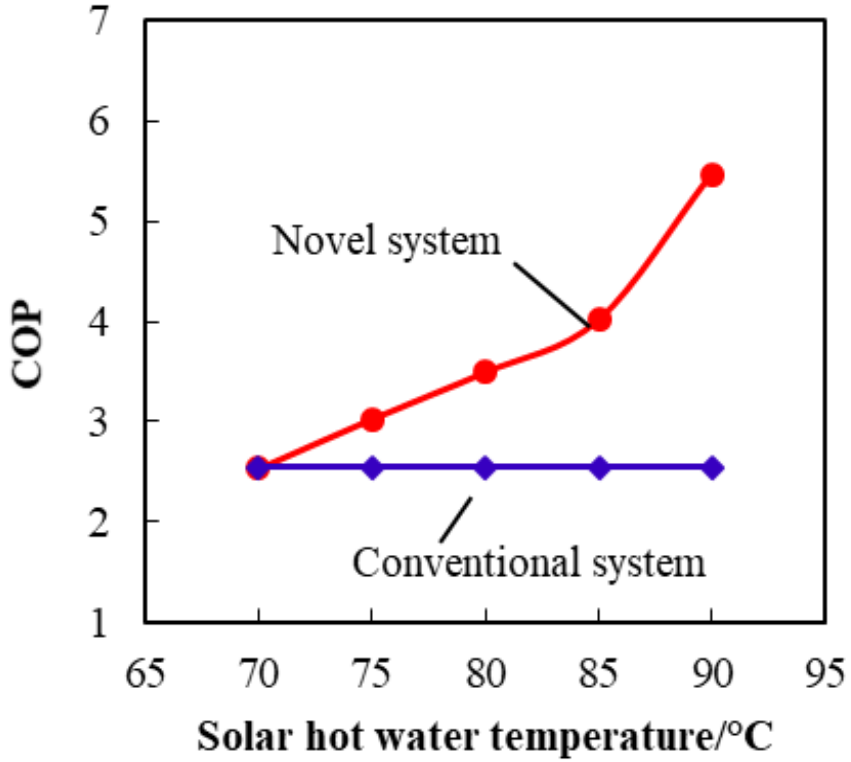
Sorption capacity



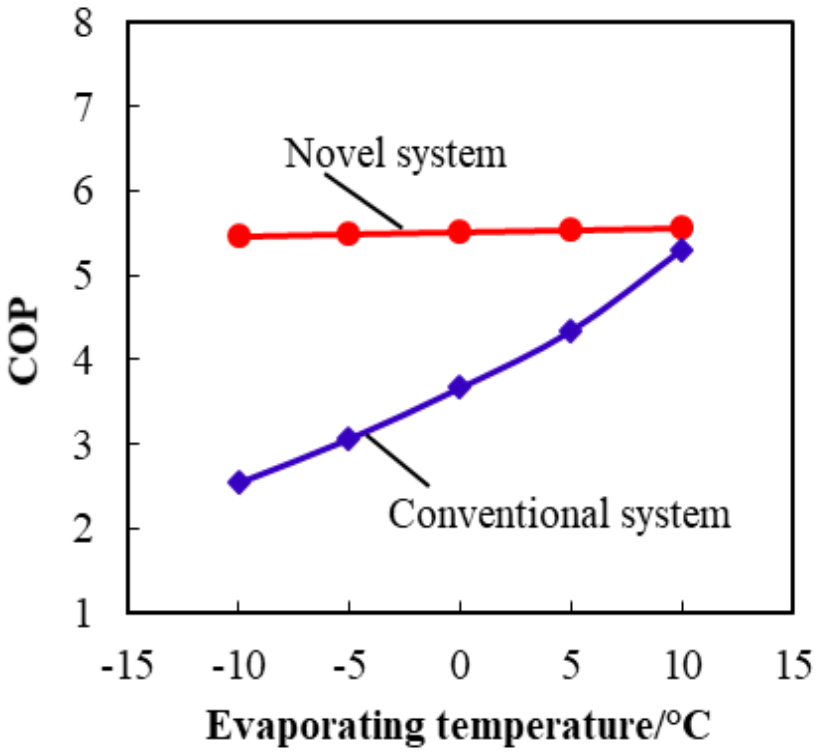
SCP

System performance of cold energy charging mode

- At evaporating and condensing temperatures of -10°C and 40°C, respectively, when the hot water exceeds 70°C, COP of novel system will be higher than that of conventional vapor-compression one.
- **The COP of novel system is as high as 5.5 at a hot water temperature of 90°C**.
- At a given heat source temperaturr, the COP of the novel system remains basically unchanged.



COP at different hot water temperatures



COP at different evaporating temperatures

A novel fruit and vegetable precooling equipment

Conventional mode

Lack of precooling devices in production areas, the loss rate of fruits and vegetables is higher

Novel mode

Precooling in production areas

Refrigerated transport

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Conclusions

1. A novel solar-driven vapor-compression refrigeration system coupled with chemisorption energy storage for precooling freshly harvested fruits and vegetables is proposed.

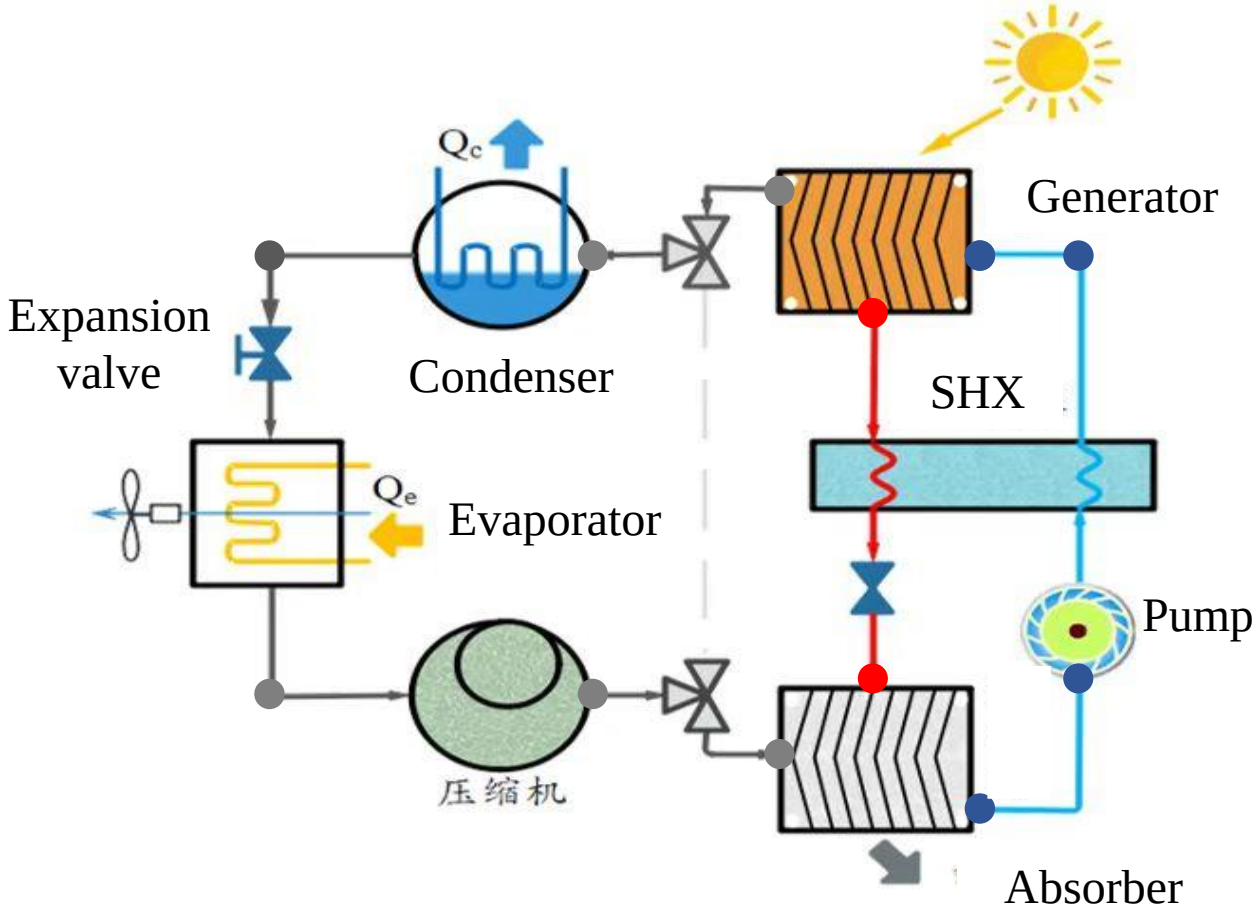
2. Compression-assisted desorption help the system **effectively utilize hot water 70~95°C as the driving heat source**.

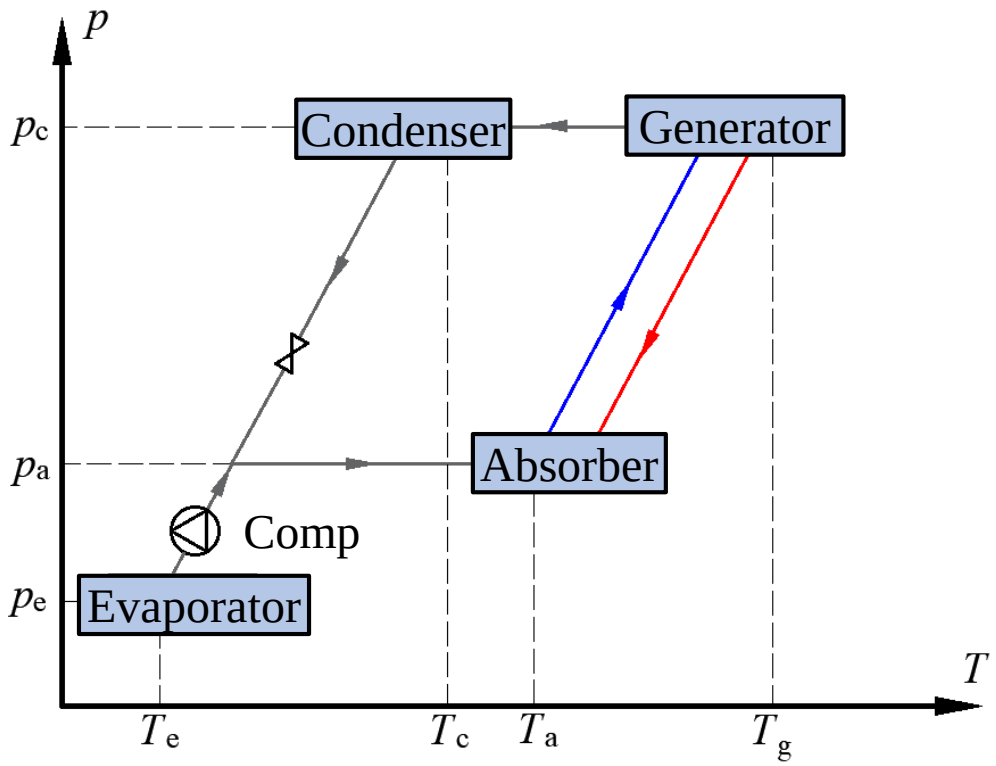
3. Desorption reaction increases the compressor suction pressure, **contributing to a higher COP**, **5.5 at** an evaporation temperature of -10°C and a condensation temperature of 40°C, while **the COP of vapor-compression system is 2.6**.

4. **The novel system is quite benefical to modern and high-efficiency agriculture.**

Outlook

- A hybrid absorption-compression refrigeration cycle utilizing R32-DMAC as the working pair
- A compressor is added between evaporator and absorber
- **Utilize hot water 50~70°C as the driving heat source**





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Prof. Liwei Wang

Thanks a lot for your attention.

Associate Prof. Peng Gao

p.gao@usst.edu.cn

University of Shanghai for Science and Technology, China

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