Thermodynamic and exergetic evaluation of CO_2 liquefaction for ship transport

C2Po1C-01

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Introduction

As a crucial component of carbon capture, utilization and storage (CCUS) projects, CO_2 transport makes sense for expanding the scale of CO_2 utilization. And CO_2 liquefaction is significant to ensure transportation safety and improve efficiency. A typical flow diagram of CCUS chain is presented in Fig.1.

Fig.1 The flow diagram of CCUS chain

In the demand for long-distance transport on the sea, using ship instead of pipeline is generally considered more competitive. Ship transport is widely used in sea on a small scale with the transport pressure varying from 14 to 20 bar. The efficient liquefaction method under target pressure is particularly important.

Several common and innovative schemes were compared in this work. Furthermore, the power consumption, liquefaction efficiency and exergy efficiency were calculated and analysed.

System description

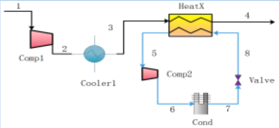

Fig.2 The compression refrigeration system (System A)

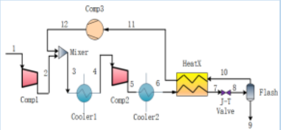

Fig.3 The Linde Hampson system (System B)

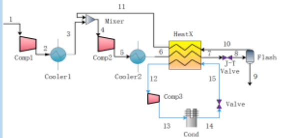

Fig.4 The precooled Linde Hampson system (System C)

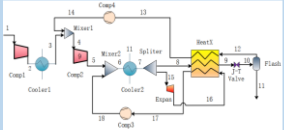

Fig.5 The Claude system (System D)

Method

- **Thermodynamic analysis**

- Total power consumption

$$W_{tot} = W_{pre} + W_{liq}$$

- Liquefaction efficiency

$$\eta_l = \frac{m_{co_2}\left(h_{co_2}^{in} - h_{co_2}^{out}\right)}{W_{tot}}$$

- **Exergy analysis**

- Exergy penalty

$$E_x = E_{in} - E_{out}$$

- Exergy efficiency

$$\eta_e = \frac{E_{co_2}^{out} - E_{co_2}^{in}}{W_{tot}}$$

Results

- **Design working conditions**

Parameter	Value
Ambient temperature K	298
Ambient pressure bar	1
Mass flow rate of CO_2 kg/s	1
Pressure drop in heat exchanger %	1
Isentropic efficiency of compressor	0.85
Isentropic efficiency of liquid CO_2 expander	0.90
Target transport pressure bar	15
Heat transfer temperature difference K	5

- **Analysis**

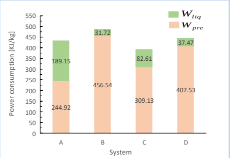

Fig.6 The power consumption of the four systems

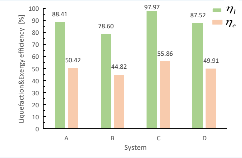

Fig.7 The liquefaction efficiency and exergy efficiency of the four systems

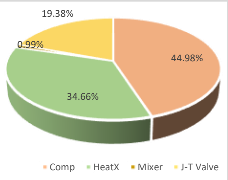

Fig.8 Exergy penalty distribution of system B

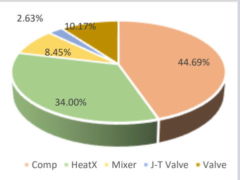

Fig.9 Exergy penalty distribution of system C

Conclusions

- The precooled Linde Hampson system presented the best overall performance. The total power consumption, liquefaction efficiency and exergy efficiency were 391.74 kJ/kg, 97.97 % and 55.86 %, respectively.
- The results of exergy penalty distribution showed that compressors caused the largest loss of available energy. The key was to improve the isentropic efficiency by more advanced manufacturing technology.
- Using liquid expander instead of J-T valve was able to reduce exergy loss effectively. And the effect of this improvement was proportional to the pressure difference before and after the throttle.

Furture work

- More efficient liquefaction process design and more appropriate operating parameters are crucial ways to reduce power consumption and increase efficiency.
- In addition to thermodynamic analysis, economic considerations and multi-objective optimization considering environment, efficiency and economy are the research focuses.
- The combination with multiple scenes may bring new breakthroughs.