Performance Analysis of A Cryogenic Liquid Air Energy Storage System Coupled with LNG Cold Utilization and ORC

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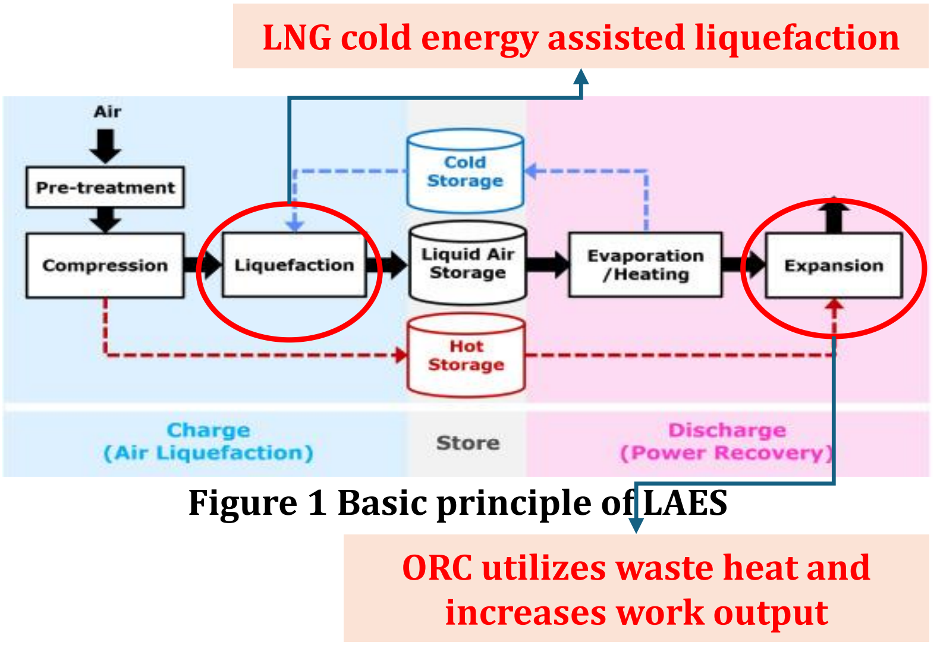
1. Introduction and Highlights

- The LAES system has problems such as low thermal storage utilization efficiency, low electrical conversion efficiency, and significant loss of liquefied cold energy.
- Most existing research only focuses on the cooling or external heating of LAES. It is worth discussing how to improve efficiency while minimizing energy loss.
- This article proposes an LAES system that combines LNG cold energy utilization with waste heat ORC power generation, reducing cold storage losses and improving thermal utilization efficiency. The optimal performance of the system is also studied.



LNG cold energy assisted liquefaction

Figure 1 Basic principle of LAES

ORC utilizes waste heat and increases work output

2. Thermodynamic Assumptions and Models

2.1 Thermodynamic assumptions

This section establishes a simulation model based on Aspen Plus for the research object. he following assumptions are made:

(1) The system is in a stable stage before the power ramp up and ramp down.

(2) Neglecting the thermal energy loss of equipment and connecting pipelines caused by environmental conditions. Ignore the circulating pump power consumption.

(3) The input parameters of compressors, turbines, pumps, etc. are selected based on engineering experience.

(4) The energy storage time and energy release time of the system are equal, both taking 6 hours.

(5) LNG is composed of 91.15% methane, 5.55% ethane, 2.16% propane, 0.51% n-butane, 0.51% isobutane, and 0.12% nitrogen; The ORC cycle working fluid is environmentally friendly working fluid R1233zd(E).

2.2 Thermodynamic models

Electrical conversion efficiency

$$\eta_{A\text{-}A}=\frac{\int_0^{t_{dis}}(W_{TM}+W_{LTM}+W_{ORCM}-W_{LAPM}-W_{P-ORCM})\,dt}{\int_0^{t_{ch}}W_{CM}\,dt}$$

Cycle efficiency

$$\eta_{RTE}=\frac{\int_0^{t_{dis}}(W_{TM}+W_{LTM}+W_{ORCM}+Q_{Heating}+E_{Cold})\,dt}{\int_0^{t_{ch}}(W_{CM}+W_{LAPM}+W_{P\text{-}ORCM}+E_{LNG})\,dt}$$

Thermal utilization efficiency

$$\eta_{Thermal}=\frac{Q_{TS}+Q_{HE-ORC}+Q_{Heating}}{Q_{CS}}$$

liquefaction rate

$$\chi=\frac{G_{A12}}{G_{A10}}$$

Table 1. Parameter settings for typical design conditions.

Parameters	Value	Parameters	Value
Annually average ambient temperature/K	293	Minimum temperature difference of intermediate heat exchanger/K	5
Ambient pressure/MPa	0.101	LNG temperature/K	-435.15
Air mass flow rate/kg/s	30	Isentropic coefficient of compressor/turbine/%	0.86/0.90
Compressor outlet pressure/MPa	8.0	Adiabatic efficiency of pump/%	0.70
Energy release pressure/MPa	8.0	Mechanical efficiency of the motor/alternator/%	0.98
HEC outlet temperature/K	303	ORC cycle evaporation pressure and condensation pressure/MPa	0.2/1.8

4. Conclusions

- This paper proposes a cryogenic liquid air energy storage system (LAES-LNG-ORC) that couples LNG cold energy utilization and waste heat type ORC to solve the problems of large air liquefaction throttling loss, insufficient utilization of thermal storage capacity, and low system electrical conversion efficiency in conventional LAES.
- The research results show that the cycle efficiency of the optimized LAES-LNG-ORC system can reach 86.2%, which is about 30% higher than the benchmark LAES system; The thermal utilization efficiency can reach 80.0%; The additional energy increment of the ORC system can achieve an electrical conversion efficiency of 58.1%, which is approximately 5.2% higher than the benchmark LAES system.
- There are optimal values for energy storage pressure and thermal storage temperature to maximize electrical conversion efficiency, but they have little effect on the liquefaction rate.

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3. System Description and Results

3.1 System description

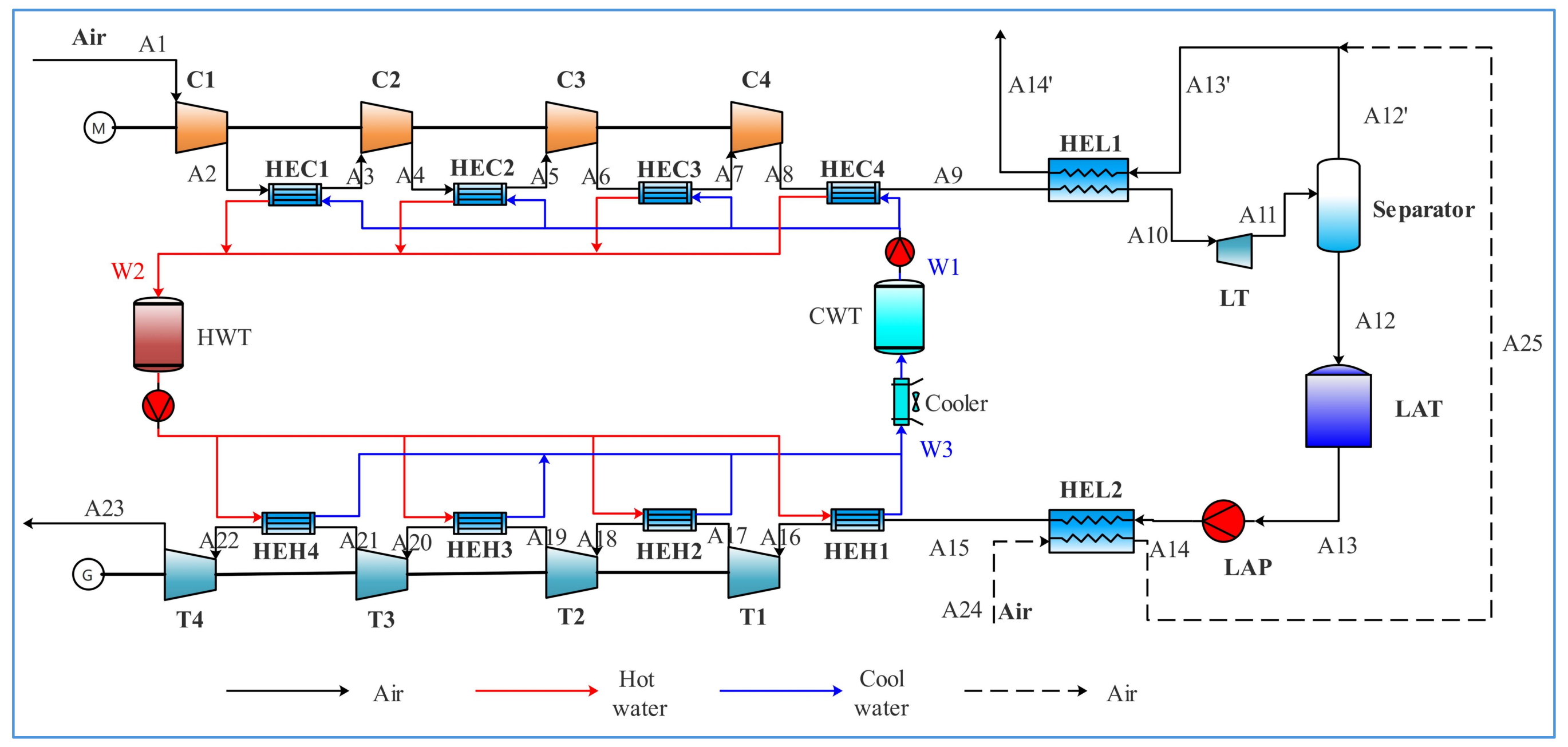


Figure 2. Schematic diagram of the basic LAES system.

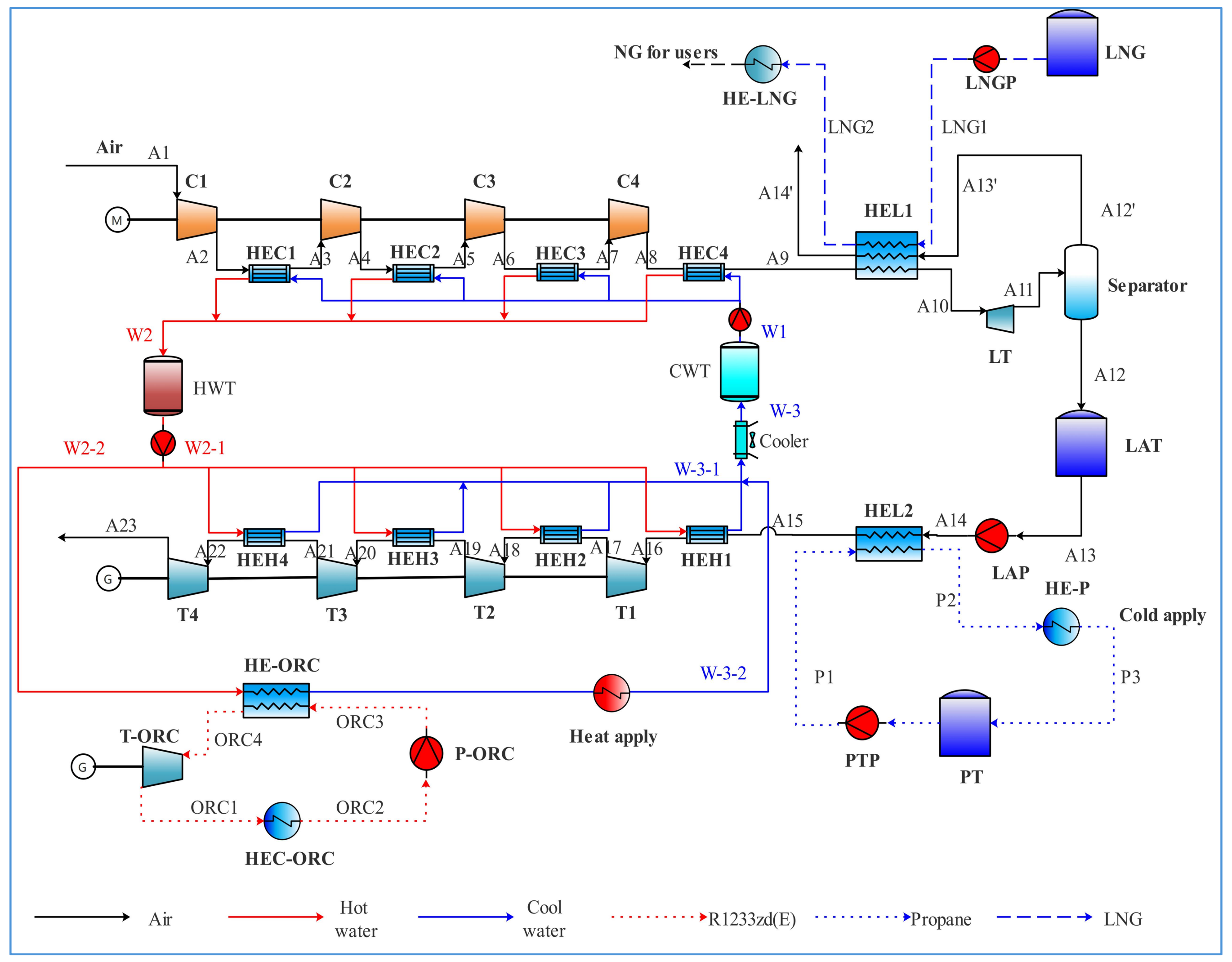


Figure 3. Schematic diagram of the LAES-LNG-ORC system.

3.2 Results and Discussions

Table 2. The results of system calculation.

Basic LAES performance criteria	Value	LAES-LNG-ORC performance criteria	Value
$\eta_{A\text{-}A}$/%	52.9	$\eta_{A\text{-}A}$/%	58.1
$\eta_{Thermal}$/%	56.8	$\eta_{Thermal}$/%	80.0
η_{RTE}/%	53.7	η_{RTE}/%	86.2
χ/%	64.2	χ/%	69.7

LAES-LNG-ORC significantly improves the system's thermal utilization efficiency and cycle efficiency. Due to the high waste heat temperature and limited evaporation temperature range of R1233zd(E), only the heat between 426-371K in hot water is absorbed by ORC, resulting in relatively less ORC power generation.

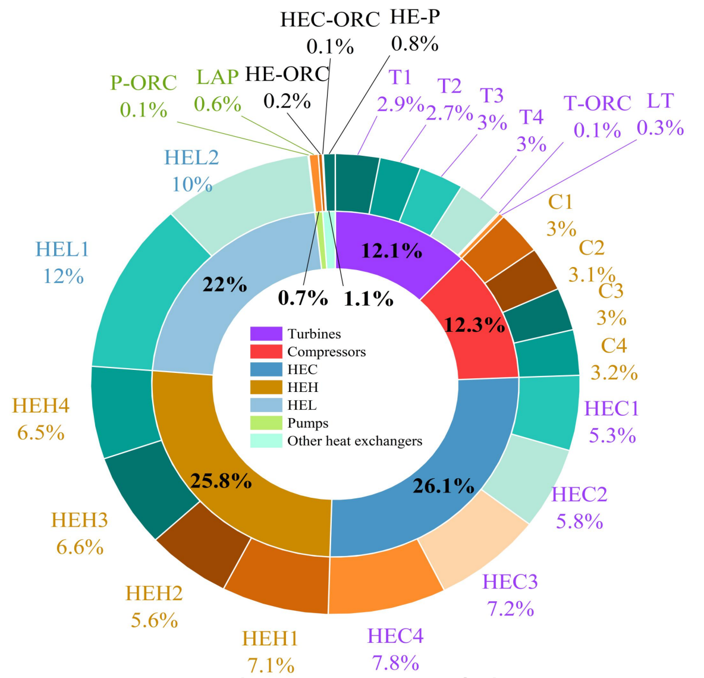
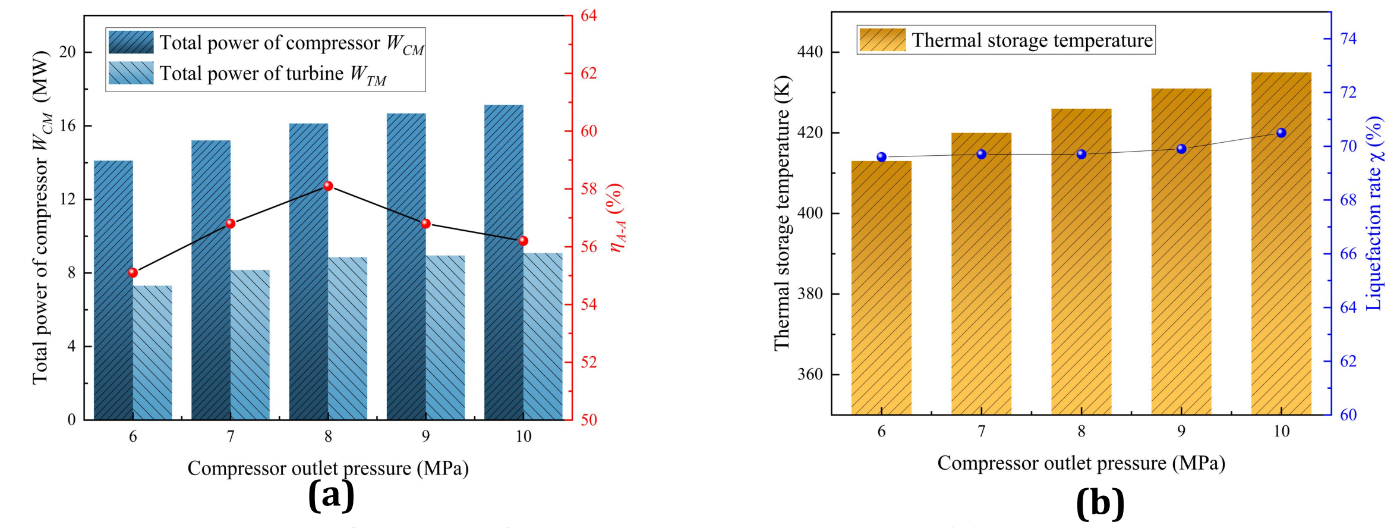


Figure 4. Exergy destruction of the LAES-LNG-ORC system under typical design conditions.

The total exergy destruction is 20.08MW, mainly generated by HEC, HEH, and HEL, accounting for 65.0%. HEC and HEH are mostly due to insufficient heat transfer caused by the minimum heat transfer temperature difference. For HEL1 and HEL2 is the air temperatures are significantly lower than ambient temperature and air phase change. The direction is reducing the minimum temperature difference and the cold energy loss.



(a) (b)

Figure 5. The influence of energy storage pressure (a) and thermal storage temperature (b) on system.

Energy storage pressure and thermal storage temperature are key parameters that affect the performance of LAES-LNG-ORC. As the outlet pressure of the compressor increases, both the total power of the compressor and the total power of the turbine increase, but the growth trend of the total power of the turbine gradually slows down, which also leads to a peak value of ηA-A at an energy storage pressure of 8 MPa. An increase in energy storage pressure will inevitably lead to an increase in compressor discharge temperature and thermal storage temperature. The liquefaction rate is less affected by energy storage pressure, mainly because the depressurization process of air during liquefaction is in a liquid state with dense isentropic lines. So, the selection of energy storage pressure has an economic value.

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