Optimizing pre-cooling methods for liquid air energy storage power stations: A focus on cooling of tanks

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Abstract

Liquid Air Energy Storage (LAES), characterized by its large-scale energy storage capacity and geographical flexibility, represents a promising solution to address the intermittency and volatility of renewable energy. In the construction phase of a LAES power station, the pre-cooling procedure for the cold energy storage fluid and its corresponding tank assumes critical significance, as it profoundly impacts both the round-trip efficiency and the overall economic viability of the station. Hence, it is crucial to pre-cool the tanks and pipelines to the appropriate temperatures. In this study, liquid nitrogen spraying is used to pre-cool the storage tank, and the pre-cooling model is established. In addition, this study analyses the effects of the pre-cooling rate, ambient temperature and wind speed on liquid nitrogen consumption.

Model

- The cooling capacity required to cool the gas inside the tank:

$$Q_{gas} = C_{p1} \cdot \frac{P \cdot V}{Z \cdot R_g \cdot T} \cdot \frac{dT}{dt}$$

- The cooling capacity to cool the inner wall of the tank and ceiling:

$$Q_{inner} = -\left(C_{p2} \cdot m_2 + C_{p3} \cdot m_3\right) \cdot \frac{dT}{dt}$$

- The cooling capacity to cool the insulation materials:

$$Q_{insulate} = -\left(\alpha_4 \cdot C_{p4} \cdot m_4 + \cdots + \alpha_7 \cdot C_{p7} \cdot m_7\right) \cdot \frac{dT}{dt}$$

$$\alpha = \frac{T_0 - T_{average}}{T_0 - T_{last}}$$

- The cooling capacity to offset heat leakage:

$$Q_{leak} = Q_{bottom} + Q_{wall} + Q_{top}$$

- The cooling capacity of the liquid nitrogen input:

$$Q_{LN_2} = m_{LN_2}\left[\gamma + C_{P-LN_2} \cdot (T - T_{last})\right]$$

- The temperature of the pre-cooling process:

$$T = at^3 + bt^2 + ct + d$$
$$T(0) = T_0$$
$$T(t_{last}) = T_{last} = 94.95K$$

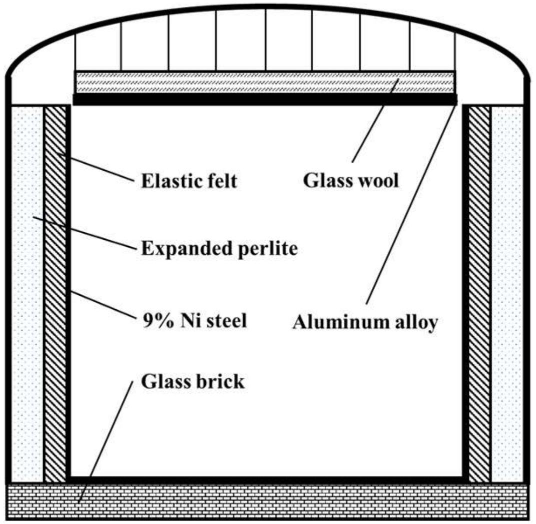

Fig 1. The tank structure diagram.

Item	Unit	Value	Item	Unit	Value
m_2	kg	335853	m_3	kg	7061
m_4	kg	10510	m_5	kg	777196
m_6	kg	1041683	m_7	kg	57340
C_{p2}	$J/(kg \cdot K)$	1.640T-4.670	C_{p3}	$J/(kg \cdot K)$	2.970T+41.000
C_{p4}	$J/(kg \cdot K)$	1.479T-60.093	C_{p5}	$J/(kg \cdot K)$	1.100T+57.926
C_{p6}	$J/(kg \cdot K)$	1.479T-60.093	C_{p7}	$J/(kg \cdot K)$	1.479T-60.093
δ_1	m	0.9	δ_2	m	0.4
δ_3	m	0.6	λ_1	$W/(m \cdot K)$	0.099
λ_2	$W/(m \cdot K)$	0.033	λ_3	$W/(m \cdot K)$	0.0424
R_{int}	m	13	R_{ext}	m	14
ε_1		0.7	ε_2		0.6

Results and Conclusion

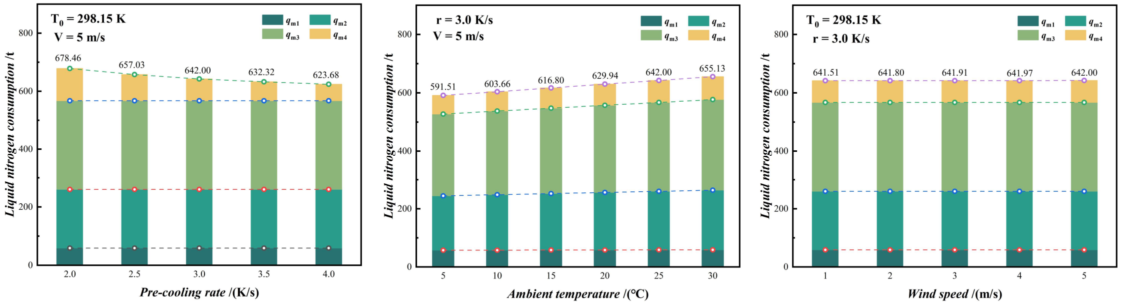

Fig 2. The liquid nitrogen consumption under different pre-cooling rate, ambient temperature and wind speed.

☐ This study proposes an energy model for the pre-cooling process of tanks and analyses the effects of pre-cooling rate, ambient temperature and wind speed on liquid nitrogen consumption

☐ As the pre-cooling rate increases from 2.0 K/s to 4.0 K/s, liquid nitrogen consumption decreases from 678.46 tons to 623.68 tons.

☐ As ambient temperature rises from 5°C to 30°C, liquid nitrogen consumption increases from 591.51 tons to 655.13 tons.

☐ The influence of wind speed on liquid nitrogen consumption is minimal.