The application of cryogens in the liquid fluid energy storage systems

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Background

With the rapid development of the renewable energy systems, the importance of large scale energy storage systems has been recognized since its ability to smooth the natural intermittency of renewable energy (e.g. wind or solar). Compressed air energy storage (CAES) systems are widely concerned in recent years, but the geographical limitation is the major barrier to the implementation of the CAES systems. Liquid fluid energy storage systems have been proposed considering the high energy density of cryogens to solve the problem of geographical limitation and lower the capital cost.

Focus

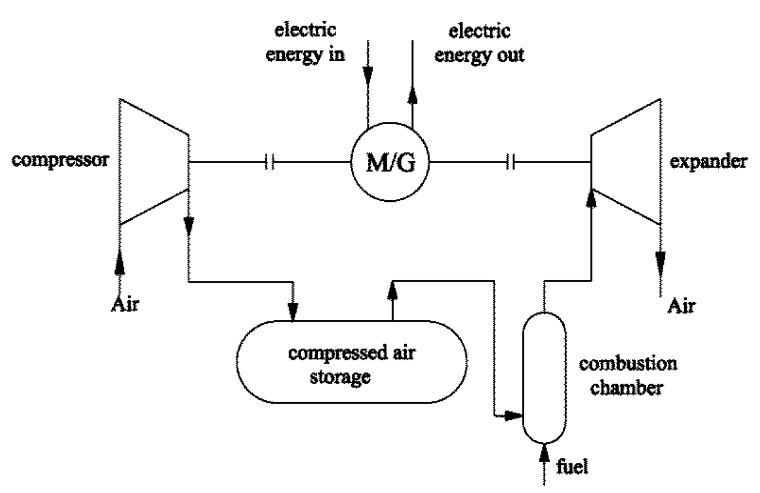
- Comparisons between the liquid fluid energy storage systems and the conventional compressed air energy storage systems.
- Analysis of the characteristics of different cryogens used in the liquid fluid energy storage systems.

Conclusion

- The energy density of liquid fluid energy storage systems is 4.23-8.52 times than the CAES systems and the liquid fluid energy storage systems represent the approach to realize no geographical limitation for large energy storage systems.
- The liquid air and liquid nitrogen are suitable for the liquid fluid energy storage systems, and the energy density is 287.1KJ/L and 255.8 KJ/L of them.
- Furthermore, integrating heat supplement with waste heat utilization can improve the systems energy density.

Simplified structure

Compressed Air Energy Storage systems



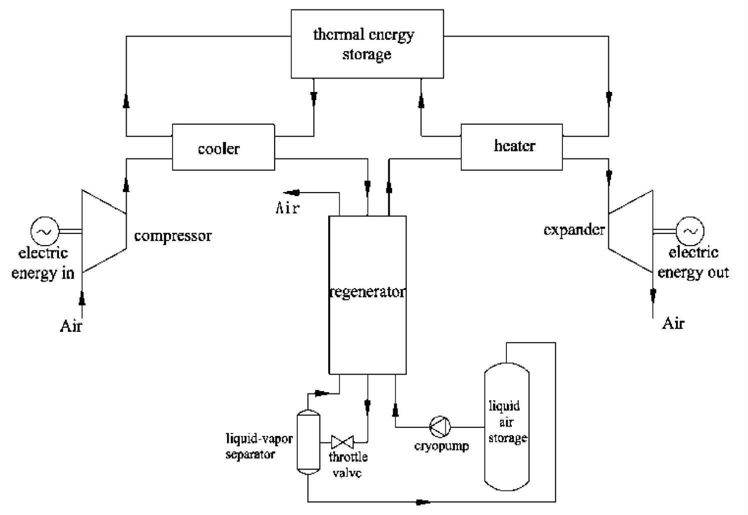
Compression process:
electricity is consumed and converted into potential energy by compressor, and compressed air is stored in air container.

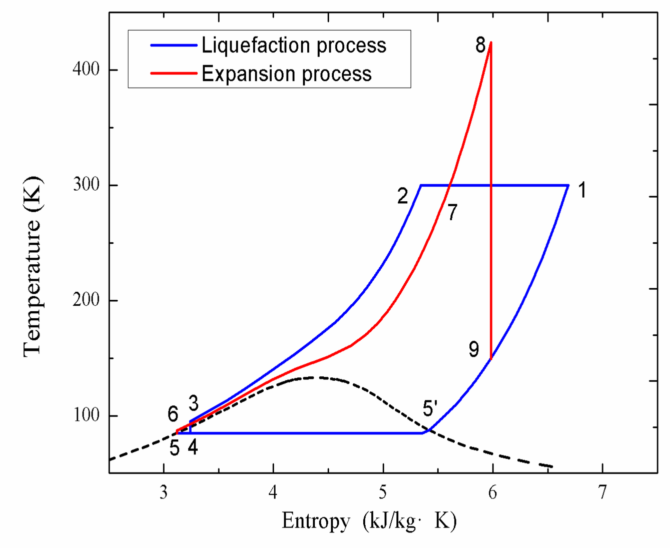
Expansion process：
compressed air expands in gas turbine after combusting with fuel in combustor and the stored electricity is regenerated

Geographical limitation:
the huge volume for storing the pressurized air is the major limitation for CAES systems, which is only economically feasible nearby rock mines or salt caverns.

Contaminating emission：
the traditional CAES systems has to be associated with gas turbine and the requirement of combusting fossil fuels causes the contaminating emission.

Liquid Fluid Energy Storage systems





(example: liquid air energy storage)

Liquefaction processes:
(1) Compression process 1-2 in which the air is compressed from the atmosphere with the interstage cooling process simplified to the isothermal compression.

(2) Cooling process 2-3 with the pressurized air being cooled isobarically in the regenerator.

(3) Throttling process 3-4 in which the air is liquefied partially with the liquid air being stored and the process 5'-1 in which the cryogenic gaseous air flows to cool the pressurized air.

Expansion processes:
(1) Pumping process 5-6 in which the air is pumped to the high pressure.

(2) Heating process 6-7-8 with the air being heated in the regenerator 6-7 and further heated 7-8 isobarically in the heating exchanger.

(3) Expansion process 8-9 with the air expanding.

Energy Density

Energy Density:
the energy density can be defined as the amount of electricity energy generation per unit volume of fluid.

$$e = \frac{w_{expansion}}{\rho_{fluid}} = \frac{h_8 - h_9}{\rho_{fluid}}$$

$w_{expansion}$ represents the electricity energy generation which is affected by the thermodynamic cycle of expansion, here the definition is made as the Equation to compare the energy density of different fluids at the same expansion process without interstage reheating.

In the Equation, h_8 is mainly affected by the heating temperature T_8 and ρ_{liquid} is affected by the liquid storing state. Considering the easier approach to the thermal energy storage, the T_8 is 150℃ when compared to the CAES.

Results

Comparison of CAES and liquid fluid energy storage

	Density kg/m3	Energy Density KJ/Litre
Compressed air (100bar, 150℃)	115.40	34.80
Compressed air (200bar, 150℃)	221.84	70.07
Liquid air (1bar，saturation)	983.56	296.6

The results show that the density of liquid air at 1bar (saturation state) is 8.5 times of compressed air at 100bar (150℃) and 4.4 times of compressed air at 200bar (150℃) which means the storage volume is 4.4-8.5 times less than the compressed air to store the same weight. The energy density of liquid air at 1bar (saturation state) is 8.52 times of compressed air at 100bar (150℃) and 4.23 times of compressed air at 200bar (150℃).

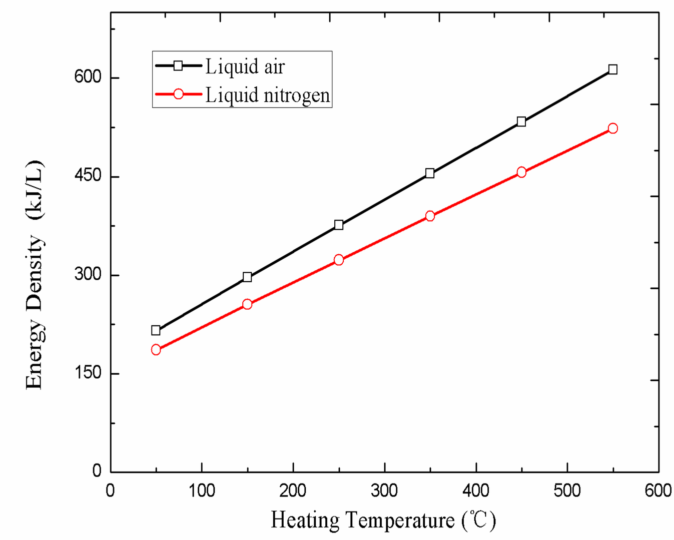
Comparison of different cryogens

	Density kg/m3	Boiling Temperature ℃	Energy Density KJ/Litre
Liquid air (1bar)	984	-192	296.6
Liquid nitrogen (1bar)	808	-196	255.8
Liquid carbon dioxide (10bar)	1117	-40	53.46

The boiling temperature of liquid air and liquid nitrogen is 81K and 77k at atmosphere. The energy density of liquid air and liquid nitrogen is 287.1KJ/L and 255.8 KJ/L.

For the nitrogen, the energy storage systems should be closed systems of which the design is different from the air.

The energy density of liquid carbon dioxide (10bar) is 53.46KJ/L which is lower than the liquid air and liquid nitrogen because of the limitation of expansion ratio, as the triple point pressure of carbon dioxide (5.2bar) is higher than the ambient pressure.



The energy density of both liquid air and liquid nitrogen increases with increasing heating temperature. This means that integrating heat supplement with waste heat utilization is favorable for the liquid fluid energy storage systems.

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