

有望な磁気熱量効果材料を用いた磁気水素液化システムの評価

Evaluation of magnetic hydrogen liquefaction system using potential magnetocaloric materials

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1. Introduction

Magnetic refrigeration systems are widely recognized as efficient, compact, and environmentally friendly, given their trivial effect on ozone-depleting or greenhouse gases (e.g., CFCs, HFCs, and HFOs). After the success of liquefying hydrogen by Sir James Dewar in the late 19th century, several liquefaction technologies have been developed. Conventional liquefaction systems involve Joule-Thomson and turbine expansion systems. However, those systems are energy-intensive, which entails about 10-20 kWh/kg for H_2 liquefaction. Magnetic refrigeration systems have recently been employed as a potential alternative to conventional liquefaction systems. Magnetic refrigeration relies on the magnetocaloric effect (MCE), whereby the temperature of a magnetic material changes in response to variations in the magnetic field [1]. This study targets examining different magnetocaloric materials for H_2 liquefaction.

2. System description and principles

The AMR cycle includes four processes: (i) magnetization, (ii) cold-to-hot blow, (iii) demagnetization, and (iv) hot-to-cold blow (cf. Fig. 1). During the cold-to-hot end, the helium flow is allowed to reject heat to the hot-end heat exchanger (HHEX). During the hot-to-cold blow, helium gas is used to cover a cooling load via the cold-end heat exchanger (CHEX). Consecutive cycle operations enable a continual cooling effect.

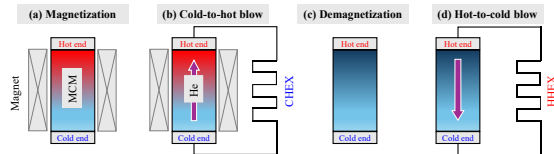


Fig.1 AMR cycle principles.

Different magnetocaloric materials have been proposed for hydrogen liquefaction. Amongst them, $HoAl_2$, HoB_2 , and $ErAl_2$ have a strong MCE near to the hydrogen liquefaction temperature of 20.3 K [2]. Each candidate has its local operating temperature ranges between the heat rejection and absorption reservoirs. In Fig. 2, $HoAl_2$ shows a strong MCE near to the hot-end temperature of 30 K. Besides, it has a wide distribution of MCE, making it more suitable for hydrogen liquefaction applications. However, $HoAl_2$ can be more expensive than $ErAl_2$, but cheaper to HoB_2 .

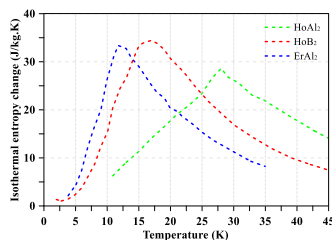


Fig.2 Entropy change for $HoAl_2$, HoB_2 , and $ErAl_2$, at a magnetic field change of 0-5 T.

3. Methods

A transient axisymmetric two-dimensional model of the active magnetic regenerator (AMR) was developed and solved via COMSOL Multiphysics 6.4. The AMR regenerator is homogeneously packed with different magnetocaloric particles with a particle diameter of 300 μm , and subjected to a peak magnetic flux intensity of 5 T.

4. Results and discussion

Figure 3 illustrates the effect of mass flow rate from 80 to 160 g/s on cooling capacity (Q_c), coefficient of performance (COP), figure of merit (FOM), and hydrogen production for $HoAl_2$, HoB_2 , and $ErAl_2$ materials, under peak 5 T. As mass flow rate increases, Q_c rises for all materials, with $HoAl_2$ showing the highest values (55-112 W), while $ErAl_2$ and HoB_2 remain significantly lower. The COP plot indicates that $HoAl_2$ maintains superior efficiency (1.03-1.22), whereas $ErAl_2$ slightly decreases and HoB_2 gradually increases but stays below 0.25. Similar to the COP trend, the FOM reaches 61% for $HoAl_2$, while attaining a hydrogen liquefaction yield of 20 kg/day for $HoAl_2$, compared with 7.5 kg/day for $ErAl_2$ and 7.6 kg/day for HoB_2 . $HoAl_2$ can attain a minimum cold-end temperature of 16.6 K, compared to 8.6 K for HoB_2 and 8 K for $ErAl_2$, making HoB_2 and $ErAl_2$ more suitable for lower cold-end temperatures. Overall, $HoAl_2$ demonstrates the best thermodynamic and hydrogen generation performance.

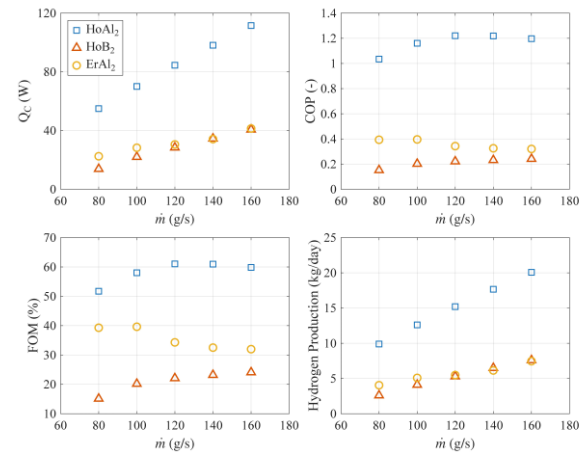


Fig.3 performance of $HoAl_2$, $ErAl_2$, and HoB_2 : cooling power, COP, FOM, and hydrogen liquefaction yield.

Acknowledgement

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References

1. K.A. Gschneidner, V.K. Pecharsky: Int. J. Refrig. Vol. 31 (2008) pp.945-961.
2. M.G. Gado, T. Shirai, Y. Yoshida, A. Uchida, T. Hirayama, T. Numazawa, K. Natsume, K. Kamiya: Cryogenics (Guildf). Vol.158 (2026) PP.104347.