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Optimisation of a novel resorption cogeneration using mass and heat recovery

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Abstract

The paper proposed an optimised resorption cogeneration with a stabilisation unit and effective mass and heat recovery to further improve the performance of the original resorption cogeneration first proposed by Liwei Wang et al. It combines the ammonia resorption technology and expansion machine to utilise low grade heat such as solar energy or waste heat for continuous and simultaneous production of refrigeration and electricity. It has been theoretically proved competent to improve the overall exergy efficiency by 40%-60% compared with Goswami cycle under the same working conditions. In this work, a buffer was designed to place before the expansion machine to mitigate the dramatically varying reaction rate, and two sets of resorption cycle were arranged to overcome the intermittent performance of the chemisorption. The cycle was investigated based on the first and second law of thermodynamics using Engineering Equation Solver. Twelve resorption working pairs of salt complex candidates were analysed under different working conditions. The energy and exergy analysis identified the ideal working pair among the chosen working pairs under the driven temperature from 373K to 473K.

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1. Introduction

With the growing concerns of energy crisis, using low-grade heat such as solar energy, industrial waste heat, etc. attracts growing attentions to reduce the energy consumption of the conventional energy. The Rankine cycle is one of the choices to produce extra work from low-grade heat. However, the performance of Rankine cycle cannot match the variable temperature of the heat source because of its single working fluid. The Kalina cycle was first proposed by Kalina [1] to solve this problem by using ammonia-water mixture as working fluid. In comparison with the simple Rankine cycle, the Kalina cycle

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can produce up to 32% more power from the industrial waste heat and show higher exergy efficiency when the heat source temperature is below 537°C [2]. Goswami developed the Kalina cycle into a combined power and refrigeration cycle, which can supply power and refrigeration constantly in a loop. However, the Goswami cycle suffers from its poor performance of cooling generation[3]. The novel resorption cogeneration was first proposed by Liwei Wang et al[4], which also aimed at producing power and refrigeration simultaneously. The wide selection of chloride salts which can reversibly react with ammonia allows the resorption cogeneration being powered by various temperature sources. Nevertheless, the chemisorption technology cannot supply stable pressure to the expansion machine like the absorption technology does, which will reduce the performance of power generation. In this paper, a buffer was added before the expansion machine to maintain stable pressure supply and two sets of resorption cogeneration were designed to overcome the intermittent performance of the chemisorption. Furthermore, mass and heat recovery has also been applied to further improve the performance.

2. Optimised resorption cogeneration

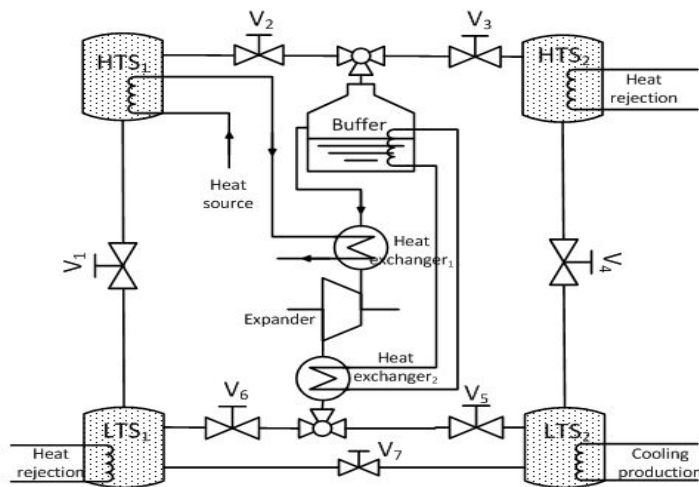


Fig. 1. Diagram of the novel resorption cogeneration cycle with mass and heat recovery

The resorption cogeneration mainly contains two high temperature salt (HTS) beds, two low temperature salt (LTS) beds, two heat exchangers, one buffer and one expander, which is shown in Fig.1.

- Step 1-Left side power; Right side refrigeration, Close V_1, V_3, V_5, V_7 ; Open V_2, V_4, V_6
When HTS1 is heated by the heat source, the desorbed ammonia flows into the buffer where the ammonia remains at saturated state. The vapour phase of ammonia passes through the expander and is adsorbed by the LTS1. The adsorption heat is rejected to the environment from LTS1. On the other side, the cooling production can be obtained when HTS2 adsorbs the ammonia from LTS2. The heat exchanger 1 and 2 are designed to recover the heat from the HTS1 and expander, respectively, and in some case increase the system performance.
- Step 2-Mass recovery, Close V_2, V_3, V_5, V_6
Open V_1, V_7 and close V_4 for about 1-minute. And then close V_1, V_7 and open V_4 .
- Step 3-Left side refrigeration; Right side power, Close V_2, V_4, V_6, V_7 ; Open V_1, V_3, V_5
- Step 4-Mass recovery, Close V_2, V_3, V_5, V_6
Open V_4, V_7 and close V_1 for about 1-minute. And then close V_4, V_7 and open V_1 .

Apply the same as Step 2. Repeat from step 1 to step 4, the resorption cogeneration can supply power and refrigeration consecutively.

3. Analysis of the resorption cogeneration

The equilibrium reaction lines and thermodynamic features of the resorption cogeneration is shown in Fig.2. B-C is the heating process of the ammonia desorbed from LTS. The isentropic expansion process in expander is shown as C-D and D-A is a part of the equilibrium reaction line of LTS. The refrigeration production of the resorption cogeneration is obtained form A-B. The energy and exergy efficiency of twelve resorption working pairs have been compared under the driven temperature from 373K to 473K. The chosen salts are as follows, HTS- (MnCl₂, FeCl₃, NiCl₂) and LTS- (PbCl₂, BaCl₂, CaCl₂,SrCl₂).

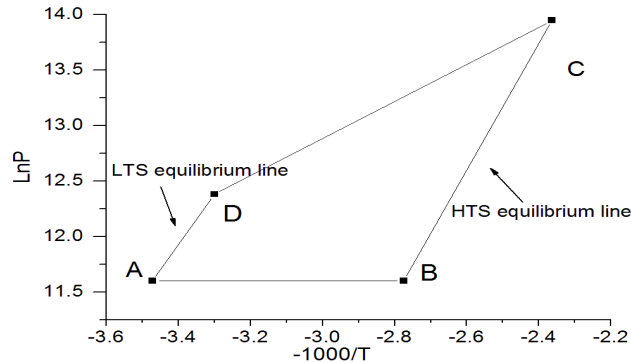
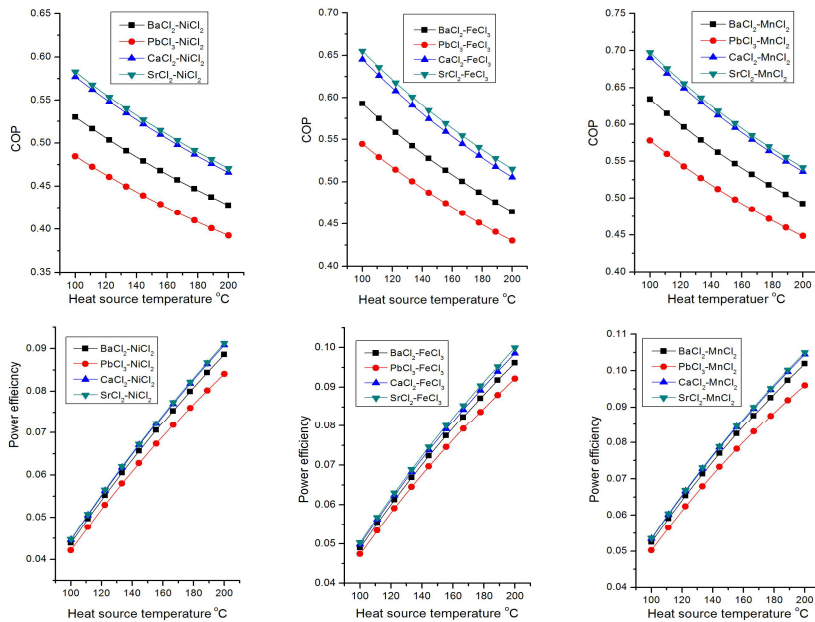


Fig. 2. Schematic Clausius-Clapeyron diagram of the resorption cogeneration

4. Results and Discussions



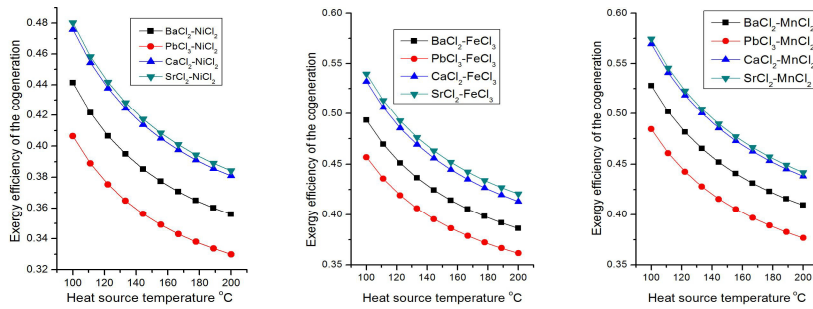


Fig. 3. COP, Power efficiency and exergy efficiency of the resorption cogeneration

The analysis on this resorption cogeneration is conducted based on first and second law analysis to identify the best resorption working pair for the heat source ranging from 373K to 473K. Results show the COP of the system decreases and the power efficiency increases with the increase of heating temperature, which means this cycle can meet different user needs under different supply temperature. The working pair SrCl₂-MnCl₂ shows the best performance among the twelve candidates and achieves the highest exergy efficiency at 0.54 at the temperature of 373K. In this cogeneration, PbCl₂ is not suggested to be used as LTS, because its poor performance compare with the other chosen low temperature salts. In comparison with the formal resorption cogeneration the COP of the new system has been increased about 0.04 with the help of heat and mass recovery.

5. Conclusion

By adding a buffer in the system, this optimised resorption cogeneration can effectively combine the adsorption technology with the expansion machine to produce stable power output. According to the thermodynamic analysis, the SrCl₂-MnCl₂ shows the best performance within the chosen working pairs by the heat source ranging from 373K to 473K. PbCl₂ should always be avoided serving as LTS in this cycle. Compared to the formal resorption cogeneration, this optimised cycle increases the refrigeration production by the application of mass and heat recovery. This cogeneration shows a potential application prospect in remote and isolated area because of its low supply temperature, easy construction, dual energy generation, high COP production, etc.

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