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Experimental investigation of a scroll expander for power generation part of a resorption cogeneration

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Abstract

For power generation systems, the expansion machine is one of the most crucial components. In this work, a scroll expander test rig has been constructed and tested to simulate the performance in a resorption cogeneration under similar working conditions. The relationship between the inlet pressure and the volume flow rate has been experimentally achieved and the volume ratio is around 2.80 under the tested conditions. A minimum start state to generate electricity from the scroll expander has been investigated, which is at least 145kPa. The isentropic efficiency of the scroll expander is around 0.6. Meanwhile the electrical efficiency achieved by this system is around 0.35 and 0.40 under the supply pressure at 238.0 kPa and 333.5 kPa, respectively.

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Keywords: low grade heat, power generation, scroll expander, isentropic efficiency, electricity efficiency

1. Introduction

Due to growing concerns about the energy crisis, utilising low-grade heat such as solar energy, industrial waste heat, geothermal energy, etc. attracts more and more attentions to reduce the consumption of conventional energies. Solid sorption is one of methods to convert low-grade heat into usable energy and this technology has been theoretically and experimentally investigated by several researchers for refrigeration generation since 1980s [1-7]. As an advanced adsorption cycle, resorption was first proposed by Spinner[8], in which mainly contains two adsorbent beds filled with different salts. Under the same equilibrium pressure, the salt who has higher equilibrium temperature is called high temperature salt (HTS) and the one is called low temperature salt (LTS). Heat source is directly connected with the HTS and refrigeration is collected from the LTS. Li et al. experimentally compared the resorption and

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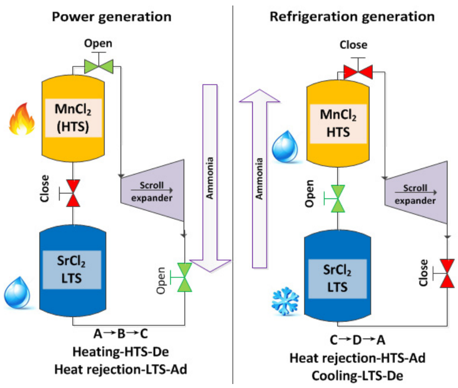
adsorption refrigeration cycle and results indicated the conversion rate during the regeneration phase was higher than that in the adsorption cycle [9].

A novel resorption cogeneration was first proposed by Wang et al. [10]generating both electricity and refrigeration from low grade heat source. The pressure difference between the HTS and the LTS during the regeneration phase was utilised to generate work by adding an expansion machine in the original resorption refrigeration system[11]. Based on the original resorption cogeneration, Lu et al. [12]proposed an optimised with mass and heat recovery processes to further improve the performance. Results indicated the resorption working pair-$SrCl_2$, $MnCl_2$ has the highest refrigeration performance among the twelve working pairs. The total exergy efficiency of the system with $SrCl_2$-$MnCl_2$ as working pair was achieved at 100 ^oC, which is as high as 0.37. In this cogeneration, the most vital component for the power generation is the expansion machine, which has the similar working conditions in Oragnic Rankine Cycle (ORC). It is therefore worth to investigate the performance of scroll expander for this cogeneration system, which has been widely applied in ORC [13-16].

In this paper, a scroll expander test bench was constructed and tested with compressed air under the same working conditions of the resorption cogeneration to estimate the power generation performance of the system.

2. Experimental investigation of a scroll expander for a resorption cogeneration

2.1. Description of the resorption cogeneration



Step 1 Step 2
Fig. 1. Principle of the resorption cogeneration

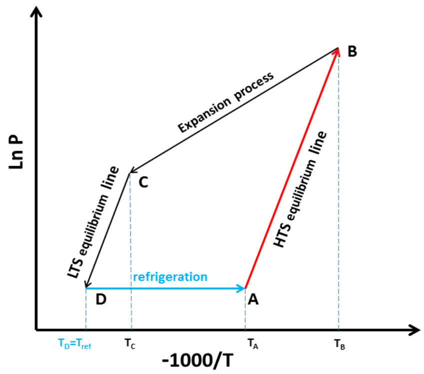


Fig.2. Clausius-Clapeyron diagram of the resorption cogeneration

Table. 1. Pressure of the HTS-$MnCl_2$ with different heat source temperature from 70 ^oC to 125 ^oC

Heat source temperature/^oC	70	75	80	85	90	95	100	105	110	115	120	125
Pressure of $MnCl_2$ /kPa	49.8	63.3	79.8	100.0	124.6	154.2	189.8	232.4	282.9	342.8	413.3	495.9

This resorption cogeneration includes two parts- power generation and refrigeration generation, which is shown in Fig. 1. During the power generation process (Step 1), the vapour phase ammonia evaporates from the HTS, which is heated by the heat source, while the LTS releases the adsorption heat to the environment. The pressure differential between the HTS and the LTS starts the scroll expander to generate power. In the end of the power generation process, the system switches to generate refrigeration (Step 2). In refrigeration process, the ammonia flows from the LTS to the HTS, where the HTS releases the adsorption heat to the environment and the desorption heat from the LTS serves as the cooling production. The control methods of the power and refrigeration generation are shown in Fig. 1.

The Clausius-Clapeyron diagram of this cogeneration is shown in Fig. 2, in which A-B and C-D are the equilibrium lines of HTS and LTS, respectively. The expansion process is illustrated as B-C in Fig. 2. The environmental temperature is set at 20 ^oC (T_c) while the equilibrium pressure of the LTS-$SrCl_2$ is 37.2 kPa. The working condition of the HTS -$MnCl_2$ under the heat source temperature from 70 ^oC to 125 ^oC is list in Table. 1.

2.2. Description of the test rig

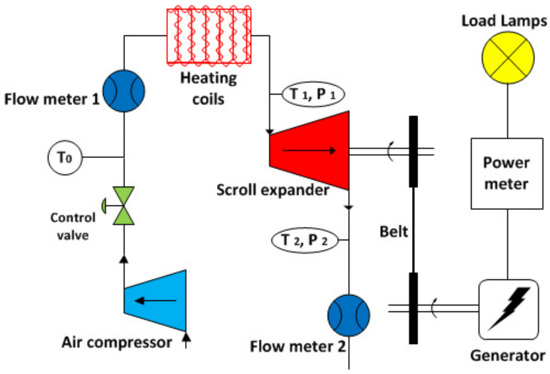


Fig. 3. Schematic diagram of a scroll expander test bench

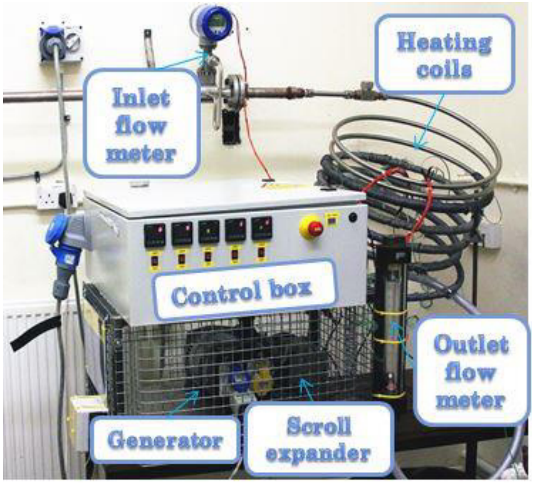


Fig. 4. Picture of the scroll expander test bench

A scroll expander test bench was designed and constructed in lab, which mainly contains an air compressor, two flow meters, heating coils, a scroll expander, a generator, load lamps, etc. shown in Fig. 3 and Fig. 4. The tested scroll expander was modified from an automotive A/C compressor (TRSA-09). The one-way valve inside the scroll compressor was removed to allow the machine running reversely as expansion mode. The outlet of the scroll expander was connected directly to the environment. Therefore the outlet pressure was very hard to collect. The flow meter 2 was installed at the outlet of the scroll expander to solve the problem. The pressure at the outlet of the scroll expander was calculated from the density and temperature of air. The isentropic efficiency is one of the most important parameters of the scroll expander, which reveals the relationship between reversible work and irreversible work. The isentropic efficiency of the scroll expander is calculated by

$$\eta_{isen} = \frac{h_1 - h_2}{h_1 - h_{2s}} \tag{1}$$

Where h_1 and h_2 are the enthalpy of the air at the inlet and outlet of the expander

h_{2s} is the enthalpy of the air at the outlet of the scroll expander when the expansion process is isentropic

The shaft of the scroll expander is connected with a generator by an automotive belt. The electricity production of the scroll expander is measured by a power meter. The electrical efficiency of the scroll expander using this generator is calculated by

$$\eta_{el} = \frac{E}{W} = \frac{\mathrm{E}}{\dot{m} * (h_1 - h_2)} \tag{2}$$

Where m is the mass flow rate of the air and E is the total electricity output collected by the power meter.

3. Results and discussion

Because the outlet of the scroll expander is connected directly to the environment, it is difficult to measure the pressure at the outlet port, which is very close to atmospheric pressure. The scroll expander was first tested without switching on the heating coil to reveal the relationship between the inlet pressure and volume flow rate, which was shown in Fig. 5. The volume ratio was defined by Volume ratio = Outlet volume flow rate/Inlet volume flow rate to calculate the outlet pressure of the scroll expander. The density of the air at outlet port can be calculated from the volume ratio and the temperature at two flow meters. Then the pressure at the outlet port can be calculated from the two thermodynamic factors. Experimental results showed the inlet volume flow rate increases with the increase of inlet pressure. The volume ratio was around 2.80 under different supply pressure. The electricity production of the scroll expander was also collected to determine the minimum start conditions. Under the supply pressure from 100 kPa to 400 kPa, this scroll expander started to generate electricity from 145 kPa.

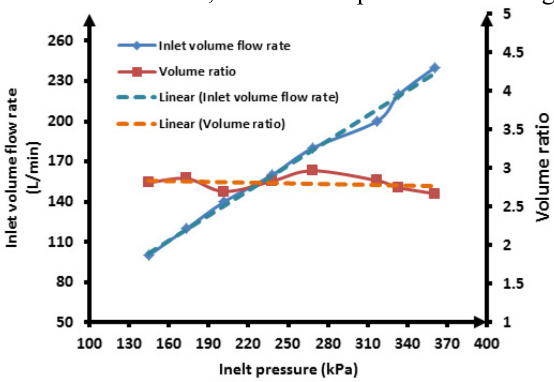


Fig. 5. Relationship between the inlet pressure and volume flow rate

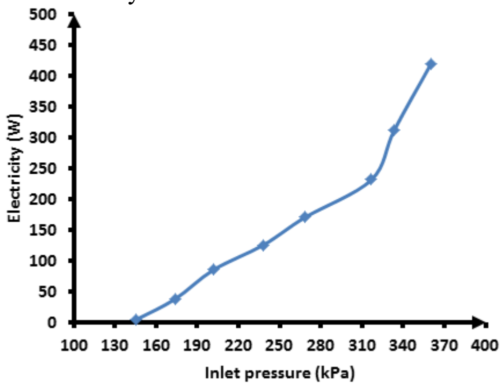


Fig. 6. Relationship between the inlet pressure and electricity without heating

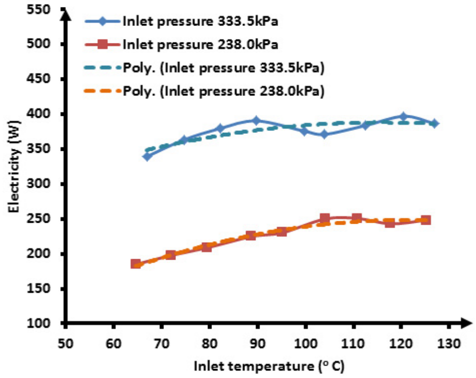


Fig. 7. Relationship between the inlet temperature and electricity

To simulate the real conditions of the resorption cogeneration with $MnCl_2$-$SrCl_2$ as working pair, the compressed air was heated by the heat coils with the temperature at the inlet port from 65 ^oC to 125 ^oC. Fig. 7 showed the results achieved from the test bench with two different inlet pressures. As the temperature increases, the electricity production of the scroll expander increases under both supply inlet pressures. The electricity produced from the expander under the inlet pressure at 238.0 kPa and 333.5 kPa are around 220W and 360W, respectively.

The isentropic efficiency achieved by this scroll expander fluctuates from 0.56 to 0.64 under two different inlet pressures, which is shown in Fig. 8. The isentropic efficiency of the inlet pressure 333.5 kPa is slightly higher than that of the inlet pressure 238.0 kPa. The overall isentropic efficiency of the scroll expander under the tested conditions is around 0.6, which is very close as reported in the literature[13]. There are two main losses of scroll machine- internal leakage and heat loss. This tested scroll expander was modified from an original scroll compressor, which should be running with lubricate oil. The lubricate oil was added to reduce the friction between the contact faces of the two scrolls and seal the working fluid during the expansion process. On the other hand, the scroll expander was installed without insulation, which could cause large amount of heat loss from the scroll expander to the environment.

The electrical efficiency was measured to reflect the conversion rate from the scroll expander to the electricity, which is mainly determined by the performance of the generator. The experimental results showed the electrical efficiency under the inlet pressure at 238.0 kPa was around 0.35. When the inlet pressure was 333.5 kPa, the electrical efficiency was showed stable under the inlet temperature ranging from 65 ^{o}C to 90 ^{o}C and started to drop from 90 ^{o}C to 125 ^{o}C. Results indicated the ratio of the heat loss under the supply pressure at 333.5 kPa was higher than that at 238.0 kPa, when the inlet temperature was higher than 90 ^{o}C. This phenomenon proved the heat loss of the expander is one of the main losses affecting the power generation of the expander.

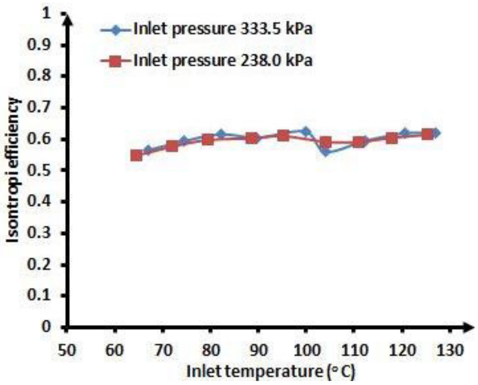


Fig. 8. Isentropic efficiency and inlet temperature

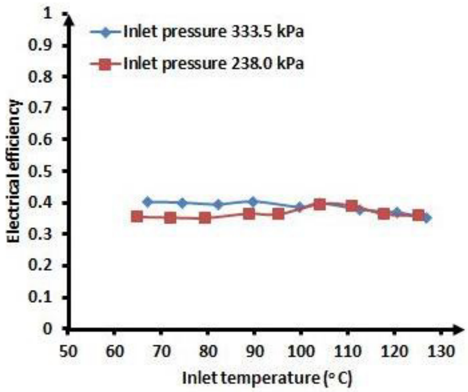


Fig. 9. Electrical efficiency and inlet temperature

4. Conclusion

To investigate the power generation performance of a resorption cogeneration, a scroll expander test bench running with compressed air constructed and tested under similar working conditions. Based on the achieved results, the following conclusions can be drawn,

- The modified scroll expander is first test without switching on the heat coils to reveal the relationship between the inlet pressure and the volume flow rate, which is a critical part to calculate the outlet pressure of the scroll expander. Results show there is a linear relation between the inlet pressure and inlet volume flow rate. The Volume ratio is concluded from the results, which is around 2.8.
- Moreover, a minimum start state of the scroll expander to produce electricity is required according to the experimental results. The lowest supply pressure for this scroll expander is 145 kPa.
- To simulate the working conditions of the power generation part of the resorption cogeneration, the scroll expander is tested under two different inlet pressures with different inlet temperatures. The obtained electricity from the generator is around 220 W and 360 W under the inlet port pressure at 238.0 kPa and 333. 5 kPa, respectively.

- The isentropic efficiency of this expander fluctuates from 0.56 to 0.64 under tested conditions, which can be caused by the internal leakage and heat loss from the scroll expander. The electrical efficiency shows the conversion rate from the work of the expander to the generator. When the inlet temperature is higher than 90 ^{o}C, the electrical efficiency drops from 0.4 to 0.35 under the inlet pressure at 333.5 kPa. On the other hand, the electrical efficiency at 238.0 kPa shows a stable tendency with the increase of inlet temperature, which is around 0.35.

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