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Transportation of low-grade thermal energy over long distance by ammonia-water absorption

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This paper presents the importance and the cycle choice for long-distance transportation of low-grade thermal energy, and the thermodynamic and hydrodynamic feasibility of single-effect ammonia-water absorption system for heat or cold transportation over long distance are also involved. A model of a long-distance thermal energy transportation system is built and analyzed, which shows satisfactory and attractive results. When a steam heat source at 120℃ is available, the user site can get hot water output at about 55℃ with the thermal COP of about 0.6 and the electric COP of about 100 in winter, and cold water output at about 10℃ with the thermal COP of about 0.5 and the electric COP of 50 in summer. A small-size prototype is built to verify the performance analysis. Basically the experimental data show good accordance with the analysis results. The ammonia-water absorption system is a potential prospective solution for the heat or cold transportation over long distance.

long distance transport, ammonia-water absorption, waste heat utilization, low grade thermal energy

Energy conservation and environmental protection issues have gained more and more attentions all over the world, and the research to make more efficient use of renewable energy such as solar energy and waste heat from industry plants and power stations is getting a fast growth. However, the waste heat sites and the user sites are usually located apart from each other. In big industrial zones, a great amount of low-grade waste heat is produced that can not be consumed by the plants themselves and the nearby users but emitted to the environment. The waste heat from nuclear power stations is twice as much as the power generated, but the location of the nuclear plants is usually several tens of kilometers from the cities. The steam exhaust accompanied with the generating process is difficult to be utilized and this leads to an avoidable energy waste, even a burden to the environment. Up to the end of 2007, there have been 438 nuclear power stations running, whose capacity reached 372 million kilowatts, 16% of the total power generated all through the world. 60% of the nuclear power stations are built in USA, France and Japan, among which USA owns 104 nuclear reactors. France has the biggest nuclear power proportion-78% of the total power consumed. At present in China, there are 11 nuclear reactors with a capacity of 9.124 million kilowatts, which is only 1.7% of China's total power generated. In the following 15 years, China will invest at least 450 billion RMB to develop nuclear power stations in order to increase the proportion up to 4%—5%. The nuclear power has become the most practical choice on the background of energy insufficiency recently. However, an enormous deal of waste heat that is hard to be used is produced simultaneously. The waste heat from a power station can be usually recovered for various uses, the reasonable distance between the user site and the power station is usually less than 10 km, and such a system is

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normally called CHP system or CCHP system. But due to the long distances between the nuclear power station and the city, normal CHP system can not be realized. Therefore, how to transport the waste heat over long distance becomes a key point in energy conservation issues.

The hydrogen-absorbing alloys have been studied for the transportation of waste heat in Japan[1–3]. The hydrogen-absorbing alloys can react reversibly with hydrogen. Heat is released when the hydrogen is absorbed, while the hydrogen is released when the metal is heated. At the heat source site, the hydrogen is released and then transported over long distance to the user site where the hydrogen is absorbed to release heat. The source temperature needed is about 90℃. The PROMES and LOCIE in France introduced the solid-gas adsorption technology into the heat transportation over long distance[4–6]. The source temperature needed is from 60℃ to 300℃ according to the working pairs. Based on different working pairs and cycles, the user sites can get heating or cooling output, even heating and cooling at the same time. A new STA (Solution Transportation Absorption System) cycle based on the absorption heat pump technologies has been developed by the Japanese and Korean scientists[7,8]. The heat source needed is from 80℃ to 180℃. Compared with the adsorption technologies, the absorption refrigeration heat pump technologies have been better developed. From the technical viewpoint, the absorption systems are compact and more potential than the others. The STA cycle overcomes the drawback of the adsorption transportation system. The energy transportation density of liquid is much more than that of gas, consequently reduces the diameters of the pipelines and the power consumption. The absorption system operates continuously, but not intermittently.

From the viewpoint of thermodynamic properties and practical experiences, lithium bromide-water and ammonia-water are the candidates to be the working pair. Comparatively the absorption systems to transport heat over long distance require more for the working pairs as follows.

(1) Low cost due to large filling amount used.

(2) No crystallization problems through transportation.

(3) Capability of producing heating or cooling, and operation all through the year.

(4) No environmentally damaging effects.

(5) Matured technologies, components available. In addition, the cost of the equipments and materials should be economically acceptable.

All solutions of water, ammonia and alcohols with salts have a potential problem of crystallization through transportation at low ambient temperatures. The organic working pairs are not developed enough to put into practical applications. Consequently, the ammonia-water is the optimal choice. Ammonia is inexpensive and very easy to get, and it dissolves into water with arbitrary proportion thus no crystallization problem exists. The ammonia-water absorption systems are capable of producing heating or cooling. Ammonia is a natural working medium without global warming potential (GWP=0) or ozone depletion problem (ODP=0). However, ammonia is a little toxic and combustible in some conditions, so special cares should be taken.

1 Choice of proper cycles for transportation of low-grade thermal energy over long distance

1.1 Single effect ammonia-water absorption cycle

In 1859, Ferdinand Carre invented the absorption refrigerator using ammonia-water as working pair, and he got a patent of USA in 1860. From then on, the ammonia-water absorption refrigeration technology had been on the way to practical use. In the past three decades, the absorption refrigeration technology has been well developed. The oil crisis in the year of 1973 promoted the research process of absorption devices which were used in the absorption heat pump and the combined cooling, heating and power systems. After the Montreal Protocol on substances that deplete the ozone layer was issued in 1987, the absorption technology has got further developed, which used the natural refrigerant and had no damaging effect on the environment. The absorption refrigeration has been regarded as a substitutable technology, and the working pair of ammonia-water has been reconsidered and recommended. All of this provides the advantage of ammonia-water absorption systems for transportation of low-grade thermal energy over long distances. In order to apply the ammonia-water absorption systems to the transportation of thermal energy over long distances properly, one should consider the following three points.

(1) The transported medium should be liquid because

transporting liquid needs smaller diameters and less power consumptions than gas.

(2) The system should supply heating or cooling in different seasons upon demands in order to get high-usage and be easy to maintain.

(3) The heat source site is far from the user site, so no secondary heat source should be required at the user site.

The principle of the single effect absorption cycle is shown in Figure 1. The rich solution (for ammonia) from the absorber goes into the rectifier. In the lower part of the rectifier, the heat and mass transfer takes place between the rich solution and the mixed vapor from the generator. In the upper part of the rectifier, the heat and mass transfer take place between the ammonia liquid from the partial condenser and the mixed vapor. In this way, the liquid condensed in the main condenser is almost pure ammonia, and the rich solution is diluted as the weak solution at the bottom of the rectifier. The partial condenser and the generator give the liquid phase and gas phase which are required in the rectifier, respectively. The liquid ammonia from the main condenser goes into the evaporator to be vaporized to produce cooling, and then the ammonia vapor is absorbed by the weak solution from the generator. The absorption is an exothermic process. The solution pump and two throttle valves are used to balance the high pressure and low pressure. The solution heat exchanger recovers heat from the weak solution and the ammonia heat exchanger recovers cold from the ammonia vapor, so they are very important for improving the performance.

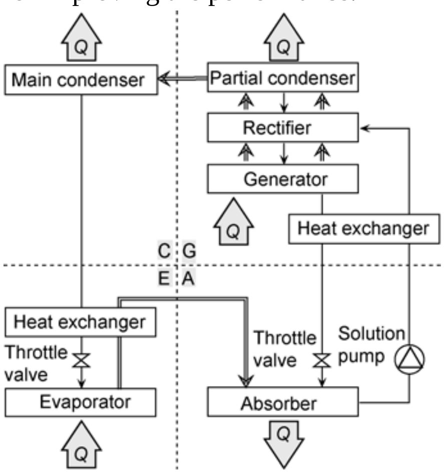

Figure 1 Single effect ammonia-water absorption cycle and its components.

In the viewpoint of long distance transportation, there are four main components as shown in Figure 1. There are six modes to divide the components, which are listed in Table 1. Mode 1 has to transport high pressure ammonia gas, so it does not meet the requirement of energy conservation. Modes 3, 4, 5 and 6 also have to transport ammonia gas, and are incapable of producing heating or cooling in different seasons upon demands. Only mode 2, which locates the generator and the condenser at the source site while the absorber and the evaporator at the user site, is a reasonable choice.

Table 1 Modes to transport heat over long distance by single effect ammonia-water absorption cycle

Index	Source site	User site	Function	Fluids to transport
1	G	C E A	Cooling (E) Heating (A)	High-pressure rich solution High-pressure weak solution High-pressure ammonia gas
2	G C	E A	Cooling (E) Heating (A)	High-pressure rich solution High-pressure weak solution High-pressure ammonia liquid
3	G A	C E	Cooling (E) Heating (×)	High-pressure ammonia gas Low-pressure ammonia gas
4	G C E	A	Cooling (×) Heating (A)	High-pressure ammonia gas High-pressure ammonia liquid
5	G C A	E	Cooling (E) Heating (×)	High-pressure rich solution High-pressure weak solution Low-pressure ammonia gas
6	G E A	C	Cooling (×) Heating (×)	High-pressure ammonia liquid Low-pressure ammonia gas

1.2 Double effect ammonia-water absorption cycle

The main objective of the double effect ammonia-water absorption cycle is to increase the efficiency, especially when the high temperature heat source is available. Double effect means that the heat rejected from a high temperature stage is used as the heat input of a relatively low temperature stage for generation. By doing this, an additional cooling effect can be produced. Figure 2

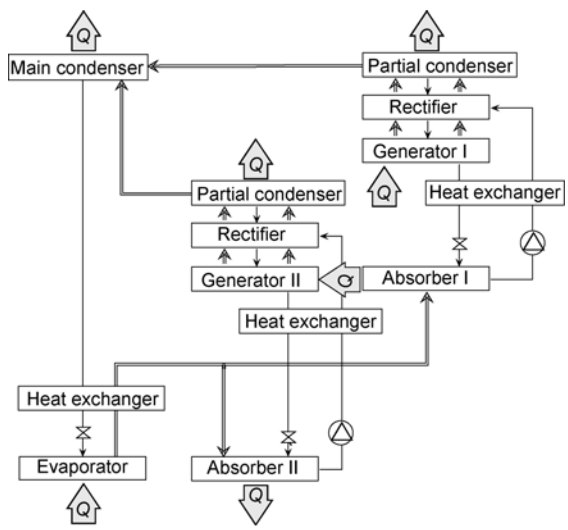

Figure 2 Double effect ammonia-water absorption cycle.

shows a typical double effect ammonia-water absorption cycle which uses the heat from the medium-pressure absorber to drive the medium-pressure generator. The main components are linked with each other by gas circuits, so they are impossible to get separated. Consequently, the double effect absorption cycle is not suitable for long distance transportation.

1.3 Two stage ammonia-water absorption cycle

The two stage ammonia-water absorption cycle is also called the half effect absorption cycle because the heat is input twice into two generators. For a fixed heat source it can be used to produce cooling at lower temperatures compared with the single stage one, for example, –50℃, or it can be driven by a relatively low temperature heat source in comparison with the single stage cycle. The two stage ammonia-water absorption cycle is shown in Figure 3. This absorption cycle can produce cooling at low temperatures. However, the performance is degraded because there are two generators which require heat input.

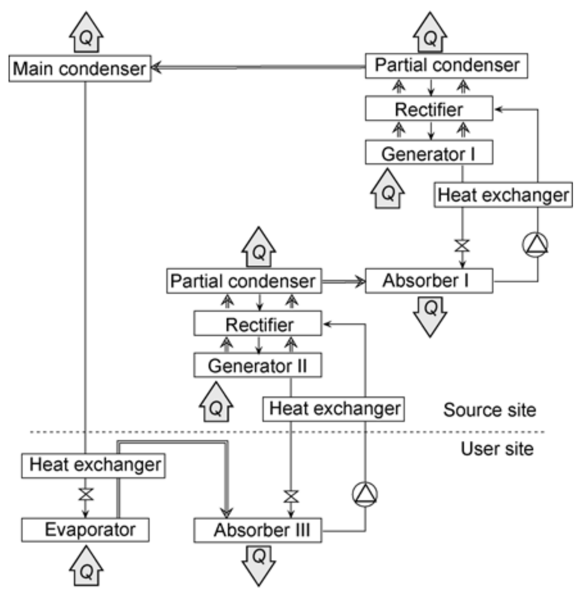

Figure 3 Two stage ammonia-water absorption cycle.

Figure 3 shows a possible mode to transport heat over long distance. On one hand, the cooling requirement for residential air-conditioning use is usually from 7℃ to 15℃, and the lower temperature cold is not used widely. On the other hand, the efficiency is much less than the single effect cycle. Therefore, the two stage cycle is not suggested.

1.4 Combined ammonia-water absorption cycles

Generally there are two kinds of combined absorption cycles, one with the vapor compression, and the other with the ejector, as shown in Figure 4.

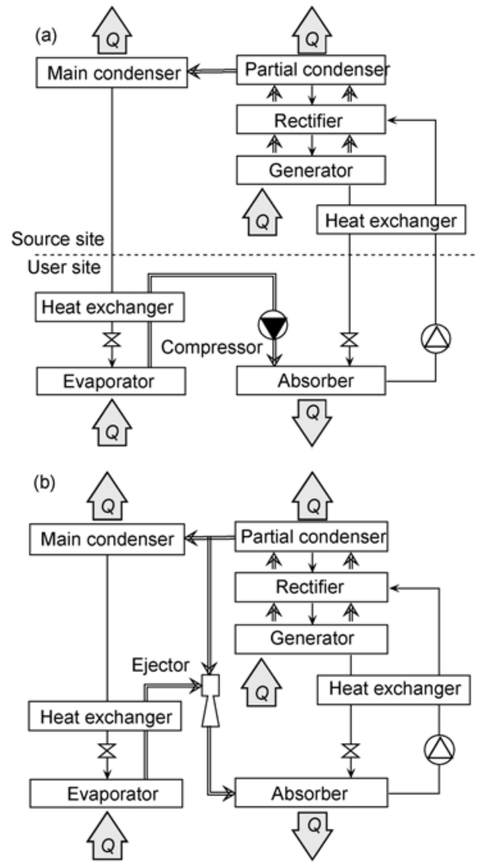

Figure 4 Combined absorption cycles. (a) Combined absorption-compression cycle. (b) Combined absorption-ejector cycle.

The purpose of designing a combined absorption cycle is to increase the absorber pressure, consequently widen the operating range. The combined absorption-compression cycle adds a compressor between the evaporator and the absorber, through which the pressure difference is much greater than a conventional absorption system, while the combined absorption-ejector cycle adds an ejector using the high pressure gas from the rectifier as working fluid. Both of the cycles can decrease the pressure of the ammonia gas from the evaporator, as a result, the refrigeration temperatures are kept as low as required even when the temperature of cooling water is rising higher.

The function of the combined absorption cycle is similar to the two stage one. However, its complexity is significantly reduced. The combined absorption-ejector cycle is not suitable for long distance transportation because all main components are linked with each other by gas circuits. The combined absorption-compression cycle is very similar to the single effect cycle, so it can be regarded as an extra choice.

1.5 Other ammonia-water absorption cycles

In 1913, Altenkirch introduced the GAX (Generator-absorber heat exchange) cycle. In the absorption cycles whose concentration difference between the rich solution and the weak solution is big enough, when the temperature of the generating process and the absorbing process largely overlaps, it is possible to use the heat from the absorbing process into the generating process. The ammonia-water absorption systems can realize the GAX cycle. In the traditional single effect ammonia-water absorption cycle, the concentration difference is usually from 6% to 8%, while in the efficient GAX cycle, the concentration difference can reach 50%. When the evaporating temperature is 3℃ and the condensing temperature is 33℃, the GAX cycle can get theoretically a COP value of 1.34. The COP of the GAX heat pump developed by Philips Company reaches practically 0.82—0.95. Unfortunately in the GAX cycle, the generator and the absorber is bound together, so it is impossible to transport heat over long distance.

In 1928, C. Munters and B. V. Platen invented the diffusion-absorption cycle using ternary working mediums, in which ammonia works as the refrigerant, water as the absorbent and hydrogen as the auxiliary gas. The pressure in the system keeps the same, thus no throttling process is involved. The capacity of the diffusion-absorption cycle is normally small, so it is usually used in particular places. As concerning the enormous long distance transportation system, the diffusion-absorption cycle is evidently incompetent.

1.6 The proper cycle for heat transportation over long distance

The analysis aforementioned shows that the single effect ammonia-water absorption cycle is suitable for transportation of low-grade thermal energy over long distance. Figure 5 shows the schematic diagram. An extra solution heat exchanger is added at the user site to recovery the heat of the rich solution from the absorber. By doing this, the three liquids can be transported by pumps at ambient temperatures and no thermal insulation is required.

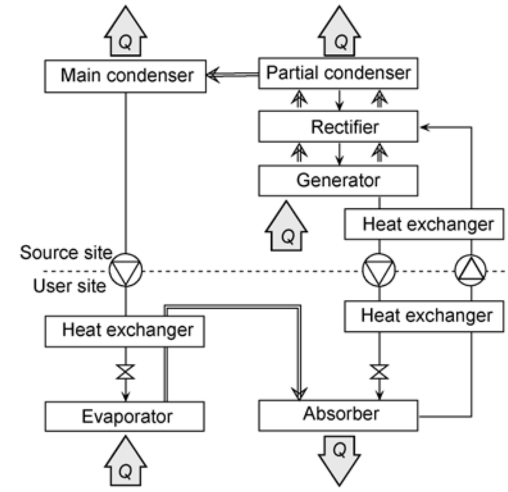

Figure 5 Schematic diagram of the single ammonia-water absorption cycle for transportation of low-grade thermal energy over long distance.

2 Modeling description of the ammonia-water absorption thermal energy transportation cycle

The performance analysis is based on the conservation of mass and energy. Figure 6 shows the main status points.

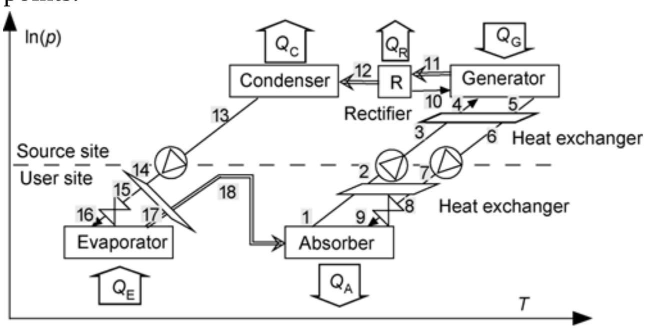

Figure 6 Status points of ammonia-water absorption long-distance heat energy transportation system.

The mass and energy conservation are described as,

For the generator,

$$\dot{m}_4 + \dot{m}_{10} = \dot{m}_5 + \dot{m}_{11}, \tag{1}$$

$$\dot{m}_4 X_4 + \dot{m}_{10} X_{10} = \dot{m}_5 X_5 + \dot{m}_{11} X_{11}, \tag{2}$$

$$Q_G = \dot{m}_5 h_5 + \dot{m}_{11} h_{11} - \dot{m}_4 h_4 - \dot{m}_{10} h_{10}. \tag{3}$$

For the rectifier,

$$\dot{m}_{11} = \dot{m}_{10} + \dot{m}_{12}, \tag{4}$$

$$\dot{m}_{11} X_{11} = \dot{m}_{10} X_{10} + \dot{m}_{12} X_{12}, \tag{5}$$

$$Q_R = \dot{m}_{11} h_{11} - \dot{m}_{10} h_{10} - \dot{m}_{12} h_{12}. \tag{6}$$

For the condenser,

$$\dot{m}_{12} = \dot{m}_{13}, \tag{7}$$

$$Q_C = \dot{m}_{12}h_{12} - \dot{m}_{13}h_{13}. \quad (8)$$

For the evaporator,

$$\dot{m}_{16} = \dot{m}_{17}, \quad (9)$$

$$Q_E = \dot{m}_{17}h_{17} - \dot{m}_{16}h_{16}. \quad (10)$$

For the absorber,

$$\dot{m}_{18} + \dot{m}_9 = \dot{m}_1, \quad (11)$$

$$\dot{m}_{18}X_{18} + \dot{m}_9 X_9 = \dot{m}_1 X_1, \quad (12)$$

$$Q_A = \dot{m}_{18}h_{18} + \dot{m}_9 h_9 - \dot{m}_1 h_1. \quad (13)$$

For the throttle valves,

$$h_8 = h_9, \quad h_{15} = h_{16}. \quad (14)$$

For the solution heat exchangers, the efficiency is assumed to be 0.9.

For the pumping power (only consider the straight pipe pressure loss, not local pressure loss), it is evaluated by,

$$W_P = \sum \frac{V\Delta p}{\eta} = \frac{\dot{m}_r \frac{\Delta p_r}{\rho_r} + \dot{m}_w \frac{\Delta p_w}{\rho_w} + \dot{m}_a \frac{\Delta p_a}{\rho_a}}{\eta}. \quad (15)$$

In which，for rich solution pump,

$$\Delta p_r = \lambda_r \rho_r \frac{L}{D_r}\frac{u_r^2}{2} + (p_G - p_A). \quad (16)$$

For weak solution pump,

$$\Delta p_w = \lambda_w \rho_w \frac{L}{D_w}\frac{u_w^2}{2}. \quad (17)$$

For liquid ammonia pump,

$$\Delta p_a = \lambda_a \rho_a \frac{L}{D_a}\frac{u_a^2}{2}. \quad (18)$$

And,

$$\lambda = \frac{64}{\text{Re}} \quad (\text{Re} <= 2000), \quad (19)$$

$$\frac{1}{\sqrt{\lambda}} = 1.74 - 2\log_{10}\left(\frac{2\varepsilon}{D} + \frac{18.7}{\text{Re}\sqrt{\lambda}}\right) (\text{Re}>2000)^{[9]}. \quad (20)$$

The thermal COP and electrical COP are used to evaluate the performance of the cycle.

The thermal coefficient of performance for heating (heating TCOP) and cooling (cooling TCOP) are,

$$\text{TCOP}_c = \frac{Q_E}{Q_G}, \quad (21)$$

$$\text{TCOP}_h = \frac{Q_A}{Q_G}. \quad (22)$$

The electric coefficient of performance for heating (heating ECOP) and cooling (cooling ECOP) are,

$$\text{ECOP}_c = \frac{Q_E}{W_P}, \quad (23)$$

$$\text{ECOP}_h = \frac{Q_A}{W_P}. \quad (24)$$

The system coefficient of performance for heating (heating COP) and cooling (cooling COP) are,

$$\text{COP}_c = \frac{Q_E}{Q_G + W_P} = \frac{1}{\frac{1}{\text{TCOP}_c} + \frac{1}{\text{ECOP}_c}}, \quad (25)$$

$$\text{COP}_h = \frac{Q_A}{Q_G + W_P} = \frac{1}{\frac{1}{\text{TCOP}_h} + \frac{1}{\text{ECOP}_h}}. \quad (26)$$

The properties data are from Pátek[10] and Sun[11]. The temperature range is from –80℃ to 180℃, and the pressure range is from 0.002 MPa to 2 MPa. When the solution concentration is greater than 0.2, the relative error of the calculation from the experimental data is within 1%. When the solution concentration is smaller than 0.2, the relative error is not greater than 5%. In the calculation, the relationship between the mass concentration and the mole concentration is,

$$X_m = \frac{17.03X_{mol}}{17.03X_{mol} + 18.015(1 - X_{mol})}. \quad (27)$$

The basic conditions are listed in Table 2.

Table 2 Basic conditions for performance analysis

Parameters	Symbol	Basic value	Unit
Ambient temperature	T_{amb}	0, 10, 25, 35	℃
Generator temperature	T_G	105	℃
Condenser temperature	T_C	T_{amb}+5	℃
Evaporator temperature	T_E	T_{amb} -5	℃
Absorber temperature	T_A	T_{amb}+5	℃
Waste Heat source	Q_G	500	MW
Transportation distance	L	50	Km
Pipe diameter of rich solution	D_r	1.2	m
Pipe diameter of rich solution	D_w	1.0	m
Pipe diameter of ammonia liquid	D_a	0.6	m

3 Analysis results and discussion

Figure 7 shows the performance of the model to transport heat at different ambient temperatures. At ambient temperature from 25℃ to 35℃, and the evaporator temperature of 5℃ (the output cooling temperature can reach 10℃), the thermal COP_c reaches 0.5, and the electric COP_c reaches more than 50. The cooling produced is suitable for domestic air-conditioning, office buildings and food preservation. At ambient temperature from 0℃ to 10℃, and the absorber temperature of 60℃ (the output heating temperature can reach 55℃), the thermal COP_h reaches 0.6, and the electric COP_h reaches more than 100. The heating produced is suitable for domestic hot water supply and floor heating.

As shown in Figure 7, the electric COPs are more than 100 times of the thermal COPs, so the system COPs are mainly determined by the thermal COPs. The effect of the electric COPs on the system COPs are less than 1%, as shown as follows.

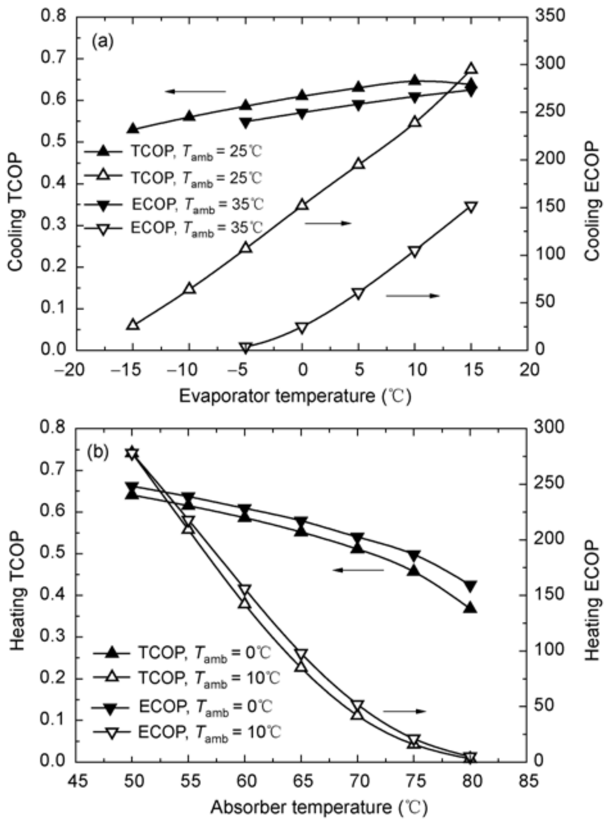

Figure 7 TCOP and ECOP of thermal energy transportation at different ambient temperatures. (a) TCOP and ECOP for cooling. (b) TCOP and ECOP for heating.

$$\frac{\text{TCOP}-\text{COP}}{\text{COP}}=\frac{\text{TCOP}}{\text{ECOP}}<0.01 \quad (28)$$

The three liquids transported over long distance are exposed at ambient temperatures, this leads to a mount of heat loss. Suppose heat with absorbing temperature of 60℃ is produced at the user site when the ambient temperature is lower than 20℃ and cooing with evaporating temperature of 0℃ is produced when the ambient temperature is higher than 25℃, Figure 8 shows the relative loss (ratio of the heat loss through transportation to the heat inputted into the generator) of the three liquids transported. The circulating ratio (ratio of flow rate of rich solution to ammonia liquid) is also shown in Figure 8.

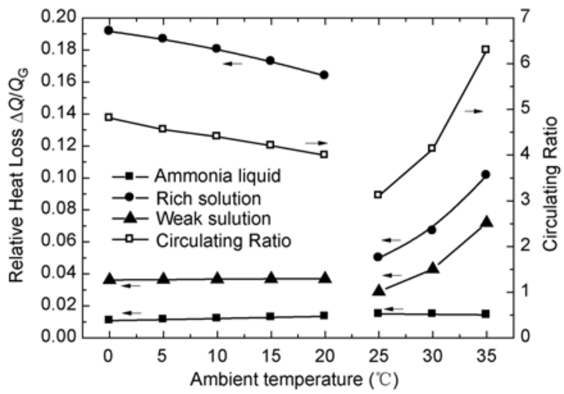

Figure 8 Relative heat loss through transportation at different ambient temperatures.

The heat loss of the rich solution through transportation is obviously more than that of the ammonia liquid and the weak solution due to the inadequate heat exchange by the solution heat exchanger at the user site. When heating is produced at low ambient temperatures, the flow rate and the specific heat of the rich solution are greater than those of the weak solution, so the temperature of the rich solution flowing out of the heat exchanger is fairly higher than that of the ambient. This leads to a big amount of heat loss. When cooling is produced at high ambient temperatures, the heat exchanger at the user site does not work, and the heat loss is mainly affected by the flow rate, i.e. the circulating ratio.

Figure 9 shows the pressure drop and the relative power consumption (ratio of the power consumption through transportation to the heat input into the generator) of the liquids transported, in which the pressure difference between the generator and the absorber is included. When the diameters are fixed, the pressure drop and the power consumption are mainly affected by the flow rates, i.e. the circulating ratio. The pressure of each liquid is normally not more than 1.5MPa, and the power consumption is not more than 1% of the heat input into the generator. This result is accordant with formula (28).

The ammonia-water absorption heat transportation system consumes only small quantity of power to transport a great amount of waste heat over long distance, and it can produce heating or cooling according to the demands in different seasons. The simulation shows that it has great potential to make good use of the waste heat

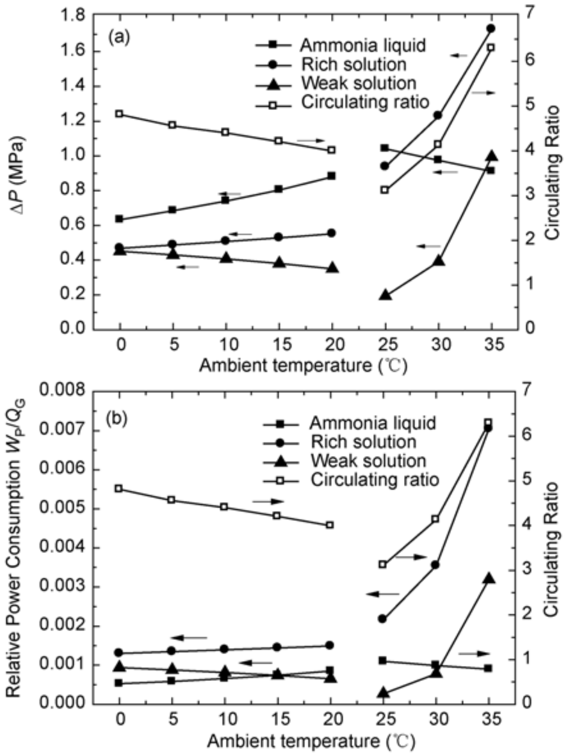

Figure 9 Pressure drop and relative power consumption through transportation at different ambient temperatures. (a) Pressure drop. (b) Power consumption.

from the industry zones or power stations to save primary energy.

4 Experimental design and results

4.1 Prototype design and setup

A small-size prototype is built to investigate the performance of the long-distance heat transportation system by ammonia-water absorption. Figure 10 shows the schematics of the experimental prototype.

The prototype is composed of ten main components, i.e. the generator, the rectifier, the partial condenser, the main condenser, the evaporator, the absorber, the solution pump, the solution heat exchangers at the source site and the other at the user site, and the long-distance transportation coils (length of 30 m with the inner diameters of 5 mm as a demonstration).

The generator is driven by an electric heater. Heating is transmitted to the inner side of the generator by radiation, and then the solution is heated thereby boiled. The rectifier is a packed column, in which the wire-mesh packing is used. The partial condenser, the main condenser, the evaporator and the absorber are all designed as falling-film heat exchangers. The solution heat exchangers are designed as modified countercurrent coil exchangers. The solution pump is a flow control membrane pump, whose flow rate can be adjusted from 10% to 100% within the operating range. The three pipelines

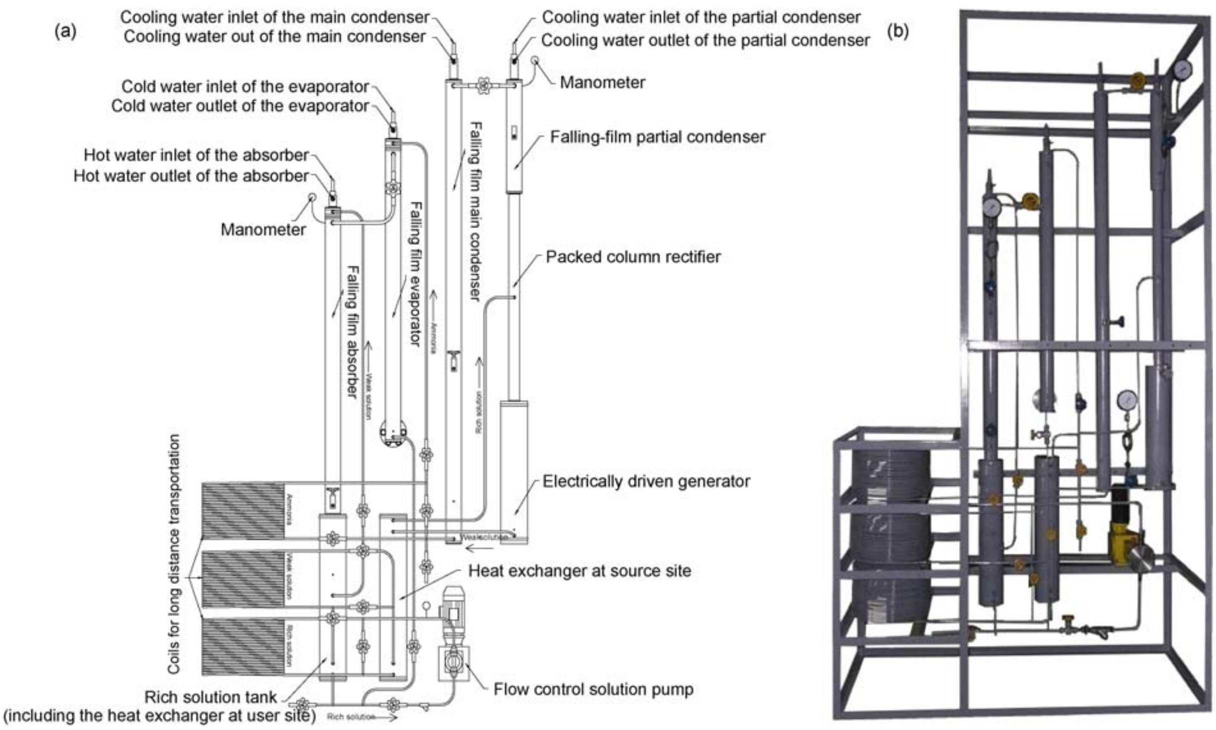

Figure 10 Schematics of the experimental prototype. (a) Design; (b) setup

of 30 m for long-distance transportation are designed as three coils. Their inner diameters are 5 mm, and the velocity of the liquids varies from 1 to 3 m/s according to different operating conditions. In order to simplify the system, the ammonia heat exchanger is not included. And, the transporting pumps of the ammonia liquid and the weak solution is not either included, because the pressure difference between the generator and the absorber is great enough to drive the two liquids in this prototype.

4.2 Experimental results

The experimental work includes two parts, one is to produce heating, and the other is to produce cooling. In the condition of heating, the hot water from the absorber is the output of heating, and the cooling water is put into the partial condenser, the main condenser and the evaporator, while in the condition of cooling, the cold water from the evaporator is the output of cooling, and the cooling water is put into the partial condenser, the main condenser and the absorber. The generating temperature is kept at about 95℃.

The thermal coefficient of performance is calculated as follows according to the experimental data.

$$\mathrm{TCOP_h} = \frac{Q_\mathrm{A}}{Q_\mathrm{G}} = \frac{\dot{m}_\mathrm{A,wat} c_\mathrm{wat} (T_\mathrm{A,wat,out} - T_\mathrm{A,wat,in})}{Q_\mathrm{G}}, \quad (29)$$

$$\mathrm{TCOP_c} = \frac{Q_\mathrm{E}}{Q_\mathrm{G}} = \frac{\dot{m}_\mathrm{E,\,wat} c_\mathrm{wat} (T_\mathrm{E,\,wat,\,in} - T_\mathrm{E,\,wat,\,out})}{Q_\mathrm{G}}. \quad (30)$$

Figure 11 shows the thermal COP for heating and cooling at different cooling water temperatures. It can been seen from Figure 11(a) that the thermal COP for heating is over 0.5 when the output hot water temperature is not higher than 55℃, which is proper for domestic hot water supply and floor heating. Figure 11(b) shows that the thermal COP for cooling is over 0.4 when the output cold water temperature is not lower than 5℃, which is proper for domestic air-conditioning and food preservation. The electric COP is not considered because the efficiency of the solution pump for this small-size prototype is too low, and it is very difficult to simulate the actual long-distance transportation application.

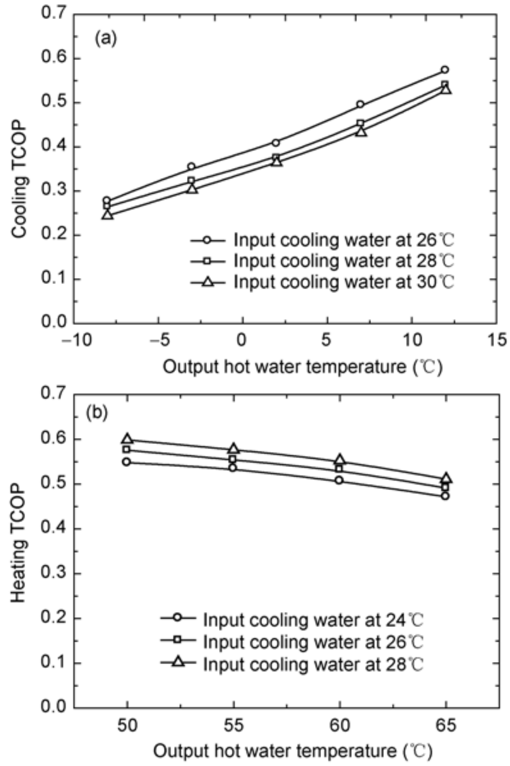

Figure 11 Experimental performance of the small-size prototype. (a) TCOP for cooling. (b) TCOP for heating.

5 Conclusions

This study develops a model of heat energy transportation over long distance by ammonia-water absorption and the performance analysis shows satisfactory results. The following conclusions are drawn.

(1) The single effect ammonia-water absorption cycle is suitable for low-grade thermal energy transportation over long distances.

(2) This energy transportation can get heating or cooling in the practical temperature ranges, and the transportation efficiency is acceptable. In the temperature range for domestic use, for example, around 55℃ for hot water supply and floor heating, and around 10℃ for air-conditioning and food preservation, the thermal coefficient of performance can both reach 0.5, and the electrical coefficient of performance can both be higher than 50.

A small-size prototype for heat energy transportation over long distance is built to verify the performance analysis. In the practical temperature range for domestic use, around 55℃ for heating and around 8℃ for cooling, the experimental and the analytical results show good agreements.

This work shows that the ammonia-water absorption system is suitable to transport thermal energy over long distances. The power consumption in big cities for air-condition in summer, heating in winter and hot water supply all through the year can be greatly reduced if the waste heat can be transported from the waste heat sites, for example, nuclear power stations and big industry zones, which are located several tens of kilometers away from the user sites.

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