EXPERIMENTAL STUDY ON AN ABSORPTION REFRIGERATION SYSTEM AT LOW TEMPERATURES[1]

Guangming Chen, Yijian He
Institute of Refrigeration and Cryogenics
Zhejiang University
Hangzhou, 310027, People’s Republic of China
Tel: 086-571-87951680; Fax: 086-571-87952464
E-mail: Gmchen@cmee.zju.edu.cn

Abstract

The heat-driven auto-cascade absorption refrigeration cycle can be used in low temperatures. A new auto-cascade absorption refrigeration system is proposed to achieve superior performances and refrigeration temperature as low as –50°C. The new system uses mixture R23+R32+R134a as refrigerant and DMF as absorbent. Study is carried out on characteristics of new system under different operation conditions. The new system has successfully achieved refrigeration temperature of – 47.2°C at generation temperature of 163°C. This temperature is far lower than that of traditional absorption refrigeration system. This is also rather lower than the temperature achieved by auto-cascade absorption refrigeration system using R32+R134a/DMF as working fluid. It clearly shows that new system has better performances than those of the system using R23+R134a/DMF as working pair. Among performances are larger rates of refrigeration temperature lowering. That is why there are reasons to dwell on just new system. The results of experimental analysis imply that this new absorption refrigeration system can be used in deep-freezing as low as –50°C by utilizing low-potential thermal power and has greater potential of engineering application in the future.

KEYWORDS

Heat-driven refrigeration cycle, absorption refrigeration, auto-cascade cycle, deep freezing

INTRODUCTION

Absorption refrigeration system, which can be driven by low-potential thermal power, like as solar energy, geothermal energy and wasted heat, etc., have advantages of saving in energy and using environment-friendly refrigerant, for example water/lithium bromide and ammonia/water. There are also a lot of deep freezing demands (lower than -40°C) in many industrial processes, such as food industry, pharmaceutical industry and chemical engineering, etc. [1-4]. However, with the traditional cycle is difficult to achieve refrigeration temperature below -20°C. The water/lithium bromide solution can be used for air-conditioning but not for cooling and refrigeration because of the limitation for the evaporator temperature (>0 °C) and such a system must operate under the vacuum condition. The ammonia/water mixture can be used for cooling and refrigeration (< 0°C) but generally for the temperatures exceeding -20°C. The system is under high pressure for operation and requires high-temperature heat sources. Ammonia has acceptable thermo-physical properties, but it is a toxic, strongly irritant, flammable refrigerant, and is destructively corrosive to copper.

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With a view to overcoming these limitations of traditional cycle, the auto-cascade absorption refrigeration cycle (ACAR cycle) is proposed [5 – 8] and the working fluids based on environmentally acceptable fluorocarbon (HFC) refrigerants and organic absorbents are investigated [9 – 14]. These refrigerants are not toxic or corrosive, and the organic working fluids are environmentally acceptable.

In this paper, a new superior system is proposed to achieve deep freezing which is lower than -40°C. This new system uses environment-friendly non-azeotropic mixture of trifluoromethane (R23), difluoromethane (R32) and 1,1,1,2-tetrafluoroethane (R134a) as refrigerant and N, N-dimethylformamide (DMF) as absorbent. Study of characteristics is undertaken using new ACAR system under different working conditions.

EXPERIMENTAL SYSTEM

The ACAR system is made up of two different circulations: solution circulation and refrigeration one. The solution circulation is similar with that of traditional absorption refrigeration cycle, and the refrigeration circulation is briefly described here. At first, the mixture refrigerant vapor bubbles up from the generator where strong DMF solution is heated and flows into the condenser. Once the vapor has been cooled by coolant in the condenser, it goes into the separator via throttling valve 2. The refrigerant is separated into vapor stream and liquid one in the separator. The main component of vapor stream is low-boiling point refrigerant (R23+R32) named S1 which flows out from the top of separator, while the main component of liquid stream is high-boiling point refrigerant (R134a+R32) named S2 which flows out from the bottom. Then, S2 flows into the low-pressure side of condenser-evaporator via throttling valve 3 where it vaporizes and refrigerates. Once S1 has been cooled in the high-pressure side of condenser-evaporator by S2, it passes through the regenerator, flows into the evaporator via throttling valve 4 and evaporates. Finally, S1 meets S2 which comes from the condenser-evaporator, enters into the absorber and is absorbed by weak DMF solution. It should be noted that, when valve 4 is closed, experimental system can operate as a traditional absorption refrigeration system. Its refrigeration temperature can be measured at the inlet and outlet of low-pressure side of condenser-evaporator, point 7 and point 8, just as shown in Fig. 1.

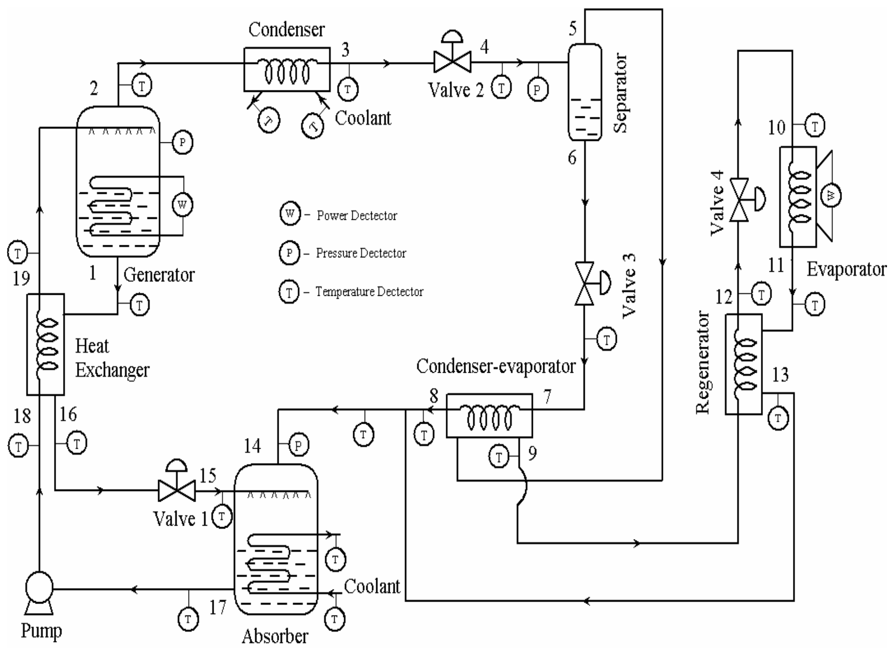

Fig.1. Schematic diagram of auto-cascade absorption refrigeration system

The measurement arrangement of the new refrigeration system, which includes measuring of temperature, pressure and heat load, is shown in Fig. 1. The temperature is measured by 4-wire Pt100 probe + Agilent digital multi-meter with accuracy which is less than or equal to 0.1°C as calibrated by Zhejiang Measurement and Test Institute for Quality and Technique Supervision (Certificate No.: WD-20033446). The pressures, such as generating pressure (P_g) and absorption pressure (P_a) are measured by 0.4-grade precise pressure meter, whose measurable range is 0–2.5MPa. The heating load at the generator is supplied by 0–250V single-phase alternating current power and measured by 0.5-grade digital power meter, whose maximal measurable value is 2.75 kW. The refrigerating load at the evaporator is simulated by heating wire of 5Ω resistance, which uses (0–30V) low-voltage direct current power supplier. Its value is indirectly determined by measurements of the current passing through heating resistance and voltage between input and output ends of resistance and can be adjustable in the range zero to 160W. The data are automatically processed in real-time by a computer collection system.

In addition, the refrigerating load of leakage is estimated at the evaporator by heating-balance way and leaking load/°C is about 0.42 W between ambient and refrigerating temperatures. Accordingly, the leaking refrigerating load can be approximavely calculated at any refrigerating temperature level.

EXPERIMENTAL RESULTS

The relationship between refrigeration temperature and time is obtained and shown in Fig. 2 for new R23+R32+R134a/DMF system. The temperatures T_{10} and T_{11} are inlet and outlet temperatures at the evaporator, which are as low as –47.2°C. We succeeded in attainment of generation temperature T_g, condensing temperature T_c and absorption temperature T_a which respectively are equal to 163°C, 20°C and 33°C. The used refrigerant is R23:R32:R134a=0.16:0.24:0.6 and its evaporation pressure is 190 kPa (absolute pressure) under the experiment conditions. As regards other operation parameters, inputted heating power is 2.2 kW at the generator and refrigerating capacity is about 28.5 W at the lowest temperature, which is gained on the basis of aforementioned calculating way of leakage load at the evaporator. Consequently, the COP is about 0.013 for R23+R32+R134a/DMF system at –47.2°C refrigeration temperature.

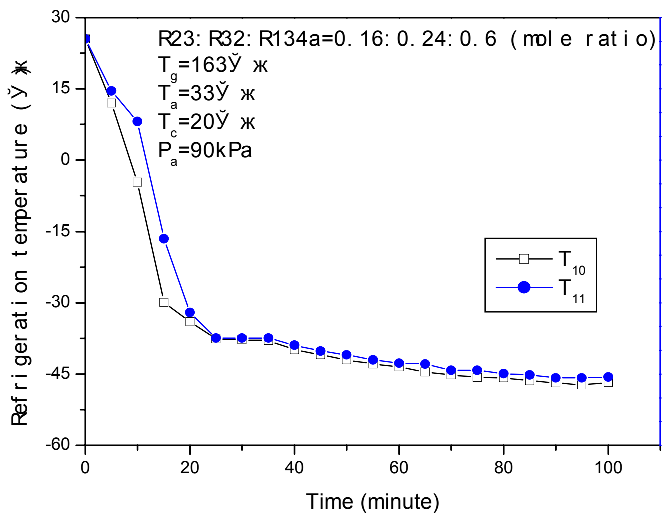

Fig.2. Relationship between refrigeration temperature and time in ACAR system using R23+R32+R134a/DMF

The comparison of characteristics is carried out for the new system, traditional system and R32+R134a/DMF system, etc. The relationship between refrigeration temperature and time is shown in Fig. 3 for traditional absorption refrigeration system using R23+R32+R134a/DMF as working pair. The composition of R23+R32+R134a mixture refrigerant is the same as for refrigerant used in ACAR system. When generation temperature T_g, condensing temperature T_c and absorption temperature T_a respectively are equal to 167°C, 25.4°C and 30.9°C, the evaporation pressure is 180 kPa (absolute pressure) and the lowest refrigeration temperature T_7 is as low as –24.5°C, which takes place at the inlet of condenser-evaporator as shown in Fig. 1. The traditional system can achieve far higher refrigeration temperature under the same condition, just as reported in [7]. Because of the intrinsic limitation determined by the configuration of traditional absorption refrigeration cycle, the refrigerants, such as R23+R32+R134a, R23+R134a and R32+R134a, etc., are out of Joule-Thomson refrigerating area to achieve low temperature, and traditional absorption refrigeration cycle cannot show good refrigeration performances, such as low refrigeration temperature.

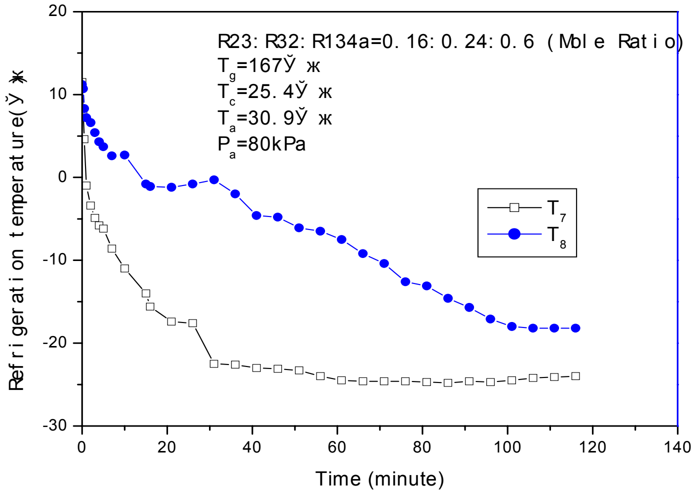

Fig.3. Relationship between refrigeration temperature and time in the traditional absorption refrigeration system using R23+R32+R134a/DMF

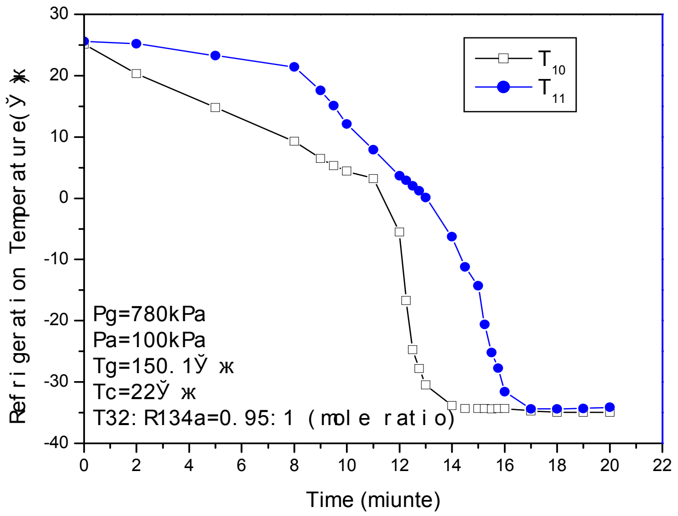

Fig.4. Relationship between refrigeration temperature and time in the ACAR system using R32+R134a/DMF

The lowest refrigeration temperature obtained by the system using R32+R134a/DMF as working pair is shown in Figure 4 [6]. In regard to the ACAR system using R23+R134a/DMF, the relationship between refrigeration temperature and time can be obtained from the literature [7] (see Fig. 5).The refrigeration temperature of the new system using R23+R32+R134a/DMF is far lower than that of the system using R32+R134a under the much the same operation conditions. There is reason to believe that boiling point of R23 is much lower than that of R32 under the same evaporation pressure. Consequently, it is essential to use R23 as a component of refrigerant mixture for ACAR cycle. The time it takes for lowering to the lowest temperature in the system using R23+R32+R134a/DMF, is almost halved, though refrigeration temperatures for the mentioned systems are equal under similar operation conditions. Because of additional of component R32 to the refrigerant mixture for the new system, the cooling temperatures, T_7 and T_8, are lower at the condenser-evaporator. The temperature T_7 ranges from -21°C to -25°C in the new system and from -16°C to -20°C in the R23+R134a system. Accordingly, the temperature of refrigerant in the new system at point 12 is lower than that of R23+R134a system. Therefore, refrigeration temperature can more quickly reach the lowest point. Based on the experimental results of system using R23+R134a/DMF, the refrigeration capacity is about 27.4 W at the lowest refrigeration temperature and the generation heat load is 2.4 kW. The experimental COP of R23+R134a system is 0.011 at -47.3°C, which is equal in the order of magnitude to that of R23+R32+R134a system, namely, about 15% less than the latter..

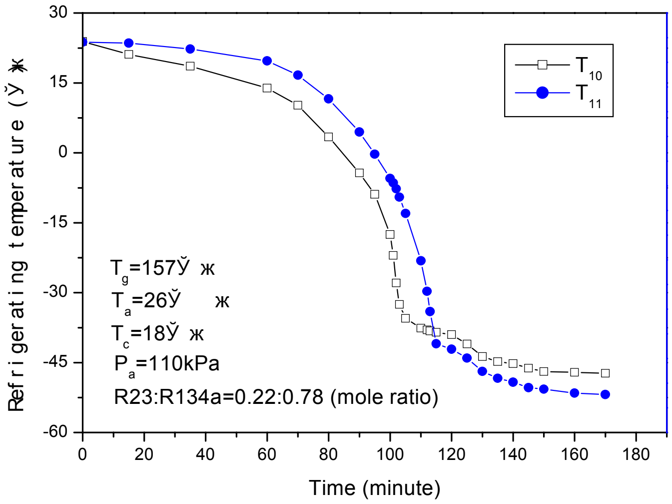

Fig.5. Relationship between refrigeration temperature and time in ACAR system using R23+R134a/DMF

CONCLUSIONS

Some experiments are successfully undertaken on ACAR system and traditional refrigeration system. The comparison is carried out between different systems. Based on the analysis of experimental results, we conclude that:

1. The experimental results prove that ACAR system can achieve much lower refrigeration temperature under the same operation conditions;
2. The new system achieves refrigeration temperature of –47.2°C, which is one of lowest refrigeration temperatures obtained by absorption refrigeration system. This is suitable for deep freezing as low as –50°C by utilizing low-potential thermal power;

3. The working pair has an important effect on the performances of ACAR cycle and R23+R32+R134a/DMF working pair, where refrigerant R32 with a moderate boiling point is present, shows better performances;
4. The improved performances may be achieved on ACAR cycle in the future researches.

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