LABORATORY REFRIGERATION UNIT WITH STEAM-JET COMPRESSOR

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A laboratory refrigeration unit with steam-jet compressor has been developed. It features implementation of steam-jet compressor for chilling of water at positive boiling temperatures. The source of energy for negative refrigeration process is by means of heat input. The unit could be used for measuring and consequent analysis of energy transformation values of present method for different temperatures of heat source, cooling media and environment. The construction allows exploring of these for different traditional and novel single-compound refrigerants due to its changeable ejector and expansion valve.The unit is a step before its industrial application.

Keywords: Ejector, refrigeration.

1. Introduction

A thermal refrigeration system (TRS) can be an alternative for a traditional compressor-based refrigeration system (TCRS) to provide a significant reduction in electricity demand. Absorption refrigeration systems, adsorption refrigeration systems and ejector refrigeration systems (ERSs) are three kinds of TRSs [1]. An absorption refrigeration system can provide large cooling capacity with environmentally friendly working pairs. However, it requires large installation space and high capital cost. For an adsorption refrigeration system, its cooling capacity and performance are lower than the other two's although its heat source temperature can also be lower. An ERS has merits of simple construction, reliability, little maintenance, and low operation cost [1]. Moreover, like other TRSs, it can be powered by solar energy, industry waste heat and other low-grade energy although its performance is relative low in comparison with a TCRS. Therefore, ERS becomes one of the most attractive TRSs, and improving its performance under overall modes becomes a subject of great interests in its research and application [2].An ejector is a static component with no moving parts. Details on ejector geometry and operation are widely available in the literature [3]. There are many categories of ejector, classified according to different criteria [4]. Depending on the primary and secondary conditions inlets, the ejector may be single-phase or two-phase. The single-phase ejector is represented generally by the gas-gas type. Powered by low-grade energy such as solar or waste heat energy, a gas-gas ejector may be used as a thermal compressor in vapor compression refrigeration and heat pump cycles. Two-phase ejectors, providing low compression performance, except for the condensing ejector [5], are commonly proposed as expansion devices in order to reduce overall throttling losses by replacing the standard expansion valves in mechanical compression cycles [6].A basic ERS consists of an ejector, an evaporator, a generator, a condenser, an expansion valve and a pump. The ejector is a key component in an ERS and its performance is critical to the ERS because it acts as the compressor in a CRS. An ejector can be divided into following parts: a nozzle, a suction chamber, a mixing chamber and a diffuser. In the nozzle, the high-pressure high-temperature vapour (named primary flow) from the generator expands to a low pressure. When it exhausts into the suction chamber, it entrains the secondary flow which is the low-pressure low-temperature vapour from the evaporator. Then, the two streams mix in the mixing chamber and the pressure of the mixed flow experiences a sharp lift due to the action of shock waves. After a pressure recovery in the diffuser, the flow is discharged into the condenser to be condensed into liquid. Part of the condensate is pumped into the generator to be evaporated, the rest of the condensate expands through the expansion valve to decrease its pressure and temperature, then enters the evaporator to be evaporated into saturated vapour and thus produces cooling [2]. The ejector performance significantly depends on the working fluid and its operating and geometric parameters. Water, R141b and R134a are three important working fluids in the development of ERSs. Water was used early in ERSs and the performance of ERSs with water had been extensively investigated experimentally.The condensing temperature has significant influence on the ejector performance, and thus the effects of the condensing temperature at different area ratios and generating temperatures on the ejector performance are indispensable for research and application of ERSs[2].Although water is an environmentally friendly working fluid, ERSs with water could not penetrate the market application because the refrigeration cycle temperature would be limited to above 0 °C and large diameter pipes would be required to reduce pressure losses. ERSs with R141b could give out the best performance, but R141b will be weeded out due to its nonzero value of ODP and GWP [2].Since 1930, chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) that were responsible for the destruction of the ozone layer have been extensively utilized in air-conditioning and refrigeration equipment. These refrigerants, with their ozone depletion potential (ODP), should be phased out in accordance with the Montreal protocol proposed in 1987. In order to fill the gap caused by the phase out of CFCs and HCFCs, extensive research has been carried out to find environment-friendly alternative refrigerants whose ODP are zero. As a result, R134a has been successfully used in domestic refrigerators and mobile air conditioners and also in water chillers for the past two decades. As the consequences of global warming continue to become increasingly serious and evident, it is important to reduce the use of refrigerants that lead to global warming. The 100-year global warming potential (GWP) of R134a is 1300, compared with that of carbon dioxide. EU F-Gases Regulation and European mobile air-conditioner directives ban fluorinated gases with a GWP higher than 150 from automotive air conditioning systems (MACs) in new vehicles from January 1, 2011, as well as in all vehicles manufactured since January 1, 2017. As global warming intensifies, newer refrigerants should be researched to replace R134a in the near future [8].

2.Technical description of ejector refrigeration system (ERS)

Figure 1 shows an ejector refrigeration system (ERS) with supersonic ejector. The system is gravitational type – it works through height differences between High pressure receiver (1) and Medium pressure receiver (24). All processes in refrigeration unit can be observed on the schematic view.

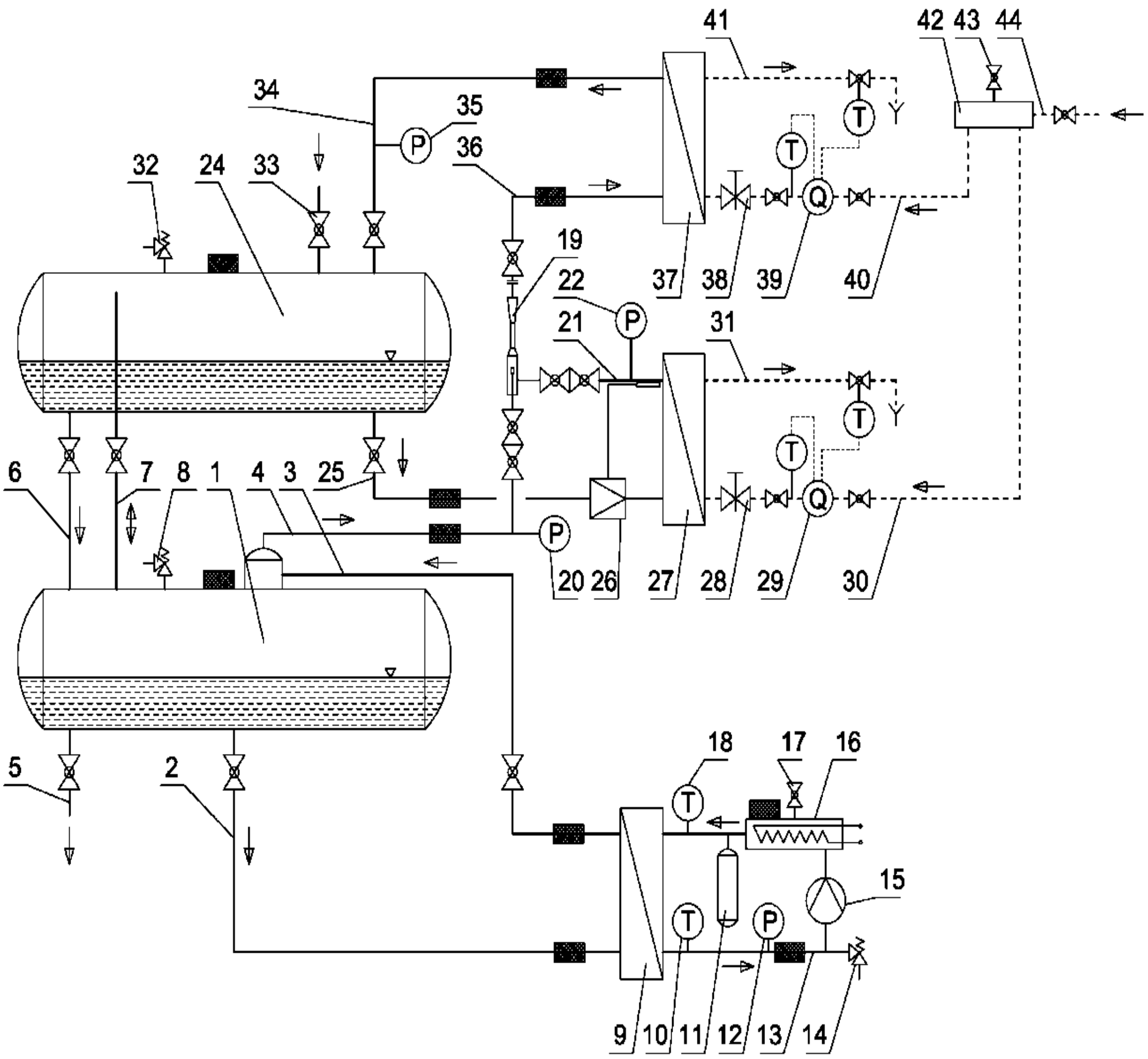

Figure 1. Layout of Steam-Jet Compressor Refrigeration Unit

1 – High pressure receiver
2 – Refrigerant high pressure down-stream line
3 – Refrigerant high pressure up-stream line
4 - Refrigerant high pressure steam line
5 – Refrigerant draining line
6 – Refrigerant liquid transfer line
7 - Refrigerant vapor transfer line
8 – Refrigerant safety valve
9 – Steam generator
10 – Hot water outlet thermometer
11 – Expansion vessel
12 – Hot water manometer
13 – Hot water return line
14 – Hot water safety valve
15 – Hot water circulator
16 – Electric heater
17 – Air release/filling valve
18 - Hot water inlet thermometer
19 – Steam – jet compressor
20 - High pressure manometer
21 – Low pressure suction line
22 – Low pressure manometer
24 - Medium pressure receiver
25 – Medium pressure supply line
26 – Expansion valve
27 – Evaporator
28 – Chilling water regulating valve
29 – Chilling water heat meter
30 – Chilling water supply line
31 - Chilling water return line
32 - Refrigerant safety valve
33 – Refrigerant filling line
34 – Medium pressure liquid line
35 – Medium pressure manometer
36 - Medium pressure vapors line
37 – Condenser
38 - Cooling water regulating valve
39 - Cooling water heat meter
40 - Cooling water supply line
41 - Cooling water return line
42 – Cooling water header
43 – Air release
44 – General cooling water supply line

The hot vapour coming from high pressure receiver (1) proceeds into ejector nozzle (19).Then the potential pressure energy transforms itself into kinetic energy, which is expressed in high velocity of the primary flow. In the mixing chamber becomes the isobaric mixture of the streams (the primary and the secondary one) as well as the secondary flow high velocity acceleration. At pressure recovery into diffuser the velocity of mixture is decreased at the expense of increasing the pressure into condenser (37).In condenser the vapors condense at constant pressure to liquid and proceed to medium pressure receiver. The liquid phase from receiver (24) flows onto Refrigerant liquid transfer line (6) to high pressure receiver and from Medium pressure supply line (25) to Expansion valve (26). Through expansion valve liquid phase decrease its pressure, so that the process of evaporation to start. Then the low pressure vapors from evaporator are sucked in from ejector.

The liquid phase from high pressure receiver fills the Steam Generator (9) onto Refrigerant high pressure down-stream line (2), and evaporates thanks to the heat delivered by Electric heater (16). The generated steam penetrates through high pressure receiver and goes into supersonic nozzle of ejector, which performs the negative Carnot cycle.

The pressure between receivers (high and medium pressure) is equalized by Refrigerant vapor transfer line (7). The steam generator uses hot water for energy source, which comes from boiler (electric heater). The water lines are supplied from sanitation system.

Fig.2 Picture of Laboratory refrigeration unit with supersonic jet-compressor.

3.Measurement and control

The system adjustment is accomplished manually.

The lab steam vapor refrigeration machine is a gravitational type, which requires its periodic rather than continuous operation. For this reason, experiments that will be carried out will be over time in about 5 minutes. During this time, the high pressure receiver is emptied and the system stops working due to the sudden drop in the pressure of the primary stream.The output of the steam generator is manually adjusted by switching on and off of the electric heater. During this process a constant monitoring of the pressure and temperature in the high-pressure receiver is necessary. The system operation and the taking of the working quantities will be done in the following sequence:

First, the cooling water is turned on by opening all the taps on the water line, then follows the system startup. Initially, most of the refrigerant is in the high-pressure receiver. By starting of the electric heater, only the taps connecting the receiver to the steam generator (located on the 2 - Refrigerant high pressure downstream line) are opened.The high pressure manometer (20 - High pressure manometer) and the boiler’s thermometers (10 - Hot water outlet thermometer and 18 - Hot water inlet thermometer) should be constantly monitored. When the appropriate pressure is reached, the inlets of the steam injector and the ones of the lines 21 – Low pressure suction line, 25 – Medium pressure supply line, 36 - Medium pressure vapors line are opened. The system is started under these conditions and the working quantities can be taken.When manometers’ values are equalized (20 - High pressure manometer 35 - Medium pressure manometer), the electric heater should be switched off and all the taps throughout the system should be also turned off. The main quantities measured by the system operation are the heat quantities released into the condenser and the evaporator. On their basis, the steam-jet compressor’s rate is also calculated. The average amount of heat can be reported after the completion of an operational cycle of the installation of both the electronic heat meters (29 - Chilling water heat meter and 39 - Cooling water heat meter).

4. Materials and methods

All unit parts are heat insulated in order to minimize heat losses and disregard their values on refrigeration cycle heat balance.

Coefficient of performance (COP) is calculated as ratio between current values of heat flow in evaporator and electric power of generator heater. Following energy balance the sum of evaporator heat flow and generator electric power is equal to condenser heat flow.

$$COP = \ Q_e/N$$

Where Qe is cooling capacity of evaporator , N is electrical consumption of electric heater.

Table 1. Unit components

Number	Part	Model
1	Electric heater	Eltop Praha (Czeck republic) 3 x 1.5 kW
2	Circulation pump	Willo Pico 25/6 (Germany)
3	Expansion vessel	Elbi Sani 1,5 l (Italy)
4	Tressure measurement transmitters type	Transducer Cincinnati (OH) (513) 583-9491
5	Heat/cool meter	Siemens 2WR6… range 1,5 m3/h
6	Heat/cool meter	Siemens 2WR6… range 0,6 m3/h
7	Volume of high and medium pressure receiver	18l.
8	Expansion valve	is Danfoss TEN-1 with throat No1
9	Generator and evaporator heat exchanger	Danfoss D-22/16
10	Condenser heat exchanger	Danfoss D-54/8

5. Different regimes for system operation

Several different modes will be possible to get by future installation work. They will be reached by changing of the temperature of the heat sources – chilling water for condenser and evaporator, and hot water for steam generator. The final goal is to see the influence of the different temperatures of heat sources of the steam-jet compressor on its efficiency.

The steam-jet compressor is designed that to be fully replaceable part of unit. By ejector subrogation will be explored the influence of different geometry forms and area ratios on its efficiency. This will be the next step of developing of system.

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7. Conclusions

It has made a laboratory ejector refrigeration system (ERS) with supersonic Laval`s nozzle. The nozzle and the ejector are fully replacement parts, which permits the usage of different constructions and exploring of their working efficiency.

The system uses three heat sources with changeable temperatures – cooling water for evaporator and condenser, and heated water for generator. This construction permits achievement for different operational modes with various cooling efficiency.

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