Solar Energy Thermal Jet Refrigeration System

Li Cai*[1], Xinyu Wang*, Nina Dai*, Qian Huang*, and Zefu Tan*

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Abstract – *Solar energy refrigeration technology is a hot research topic in recent years. Traditional solar refrigeration technology is based on the principle of photovoltaic, but it has not been widely used because of its low energy conversion efficiency and large energy consumption of the compressor. A jet refrigeration system based on solar photothermal principle is proposed in this paper. The overall structure and working principle of the system are introduced. And a mathematical model for heat exchange of the core components was established. Then the major components of the photothermal subsystem and the refrigeration subsystem are designed. The selection and design method of the core equipment such as solar collector, generator and ejector are expounded. The engineering test shows that the engineering errors of the COP theoretical value of the solar thermal jet system are less than 5%, it is 3 times as large as traditional solar refrigeration technology, and the better cooling effect can be achieved.*

Keywords – cost of power, ejector, heat exchange model, photothermal cooling, solar energy.

1. INTRODUCTION

Solar energy is recognized as clean energy and has a low cost advantage. Thanks to the rapid development of solar devices manufacturing technology and technology, solar energy has been widely used in social production and life. At present, the development and utilization of solar energy resources are mainly concentrated in power generation, heating in two major areas: China as an example, in 2016 the new photovoltaic power generation capacity of 34.54GW, the world's first photovoltaic power increment, a total of more than the country's total generating capacity of 1%, the national total installed solar collector area has been ranked first in the world, 13th Five-Year is expected to reach 100 million square meters.

Since 2009, academia has begun to study the application of solar thermal refrigeration technology. Technological Educational Institution of Athens Petros J. Axaopoulos Greek [1] proposed a solar refrigerating device in the "solar" magazine, the device with the voltage of solar photovoltaic module driven compressor refrigeration function, but the efficiency is lower than 10%, does not have the engineering practicability; since 2011, research on the efficiency of domestic and foreign scholars focus on solar heating device, the [2] presents a new mathematical model of PV refrigeration, reference [3] method is proposed for dynamic simulation of the efficiency of the photovoltaic refrigeration system, improved solar energy transfer paper [4] coupling method, calculation results show that it can improve the efficiency of the refrigeration system of energy efficiency of about 5% [5] is a novel polymer solar cell prepared by adding polyethylene glycol (PEG) into the active layer of solar cells, which improves the energy conversion efficiency by 38.5% compared with the conventional solar cells.

Although the existing through different methods, the implementation of solar refrigeration, but the main technical route is "solar PV, traditional refrigeration compressor, research has been the bottleneck that different techniques to improve the efficiency of solar refrigeration system such as the limited range, the system of the literature [7], [8]. Although the conversion efficiency is increased by 38.5%, the absolute value is only 3.07%. This design uses the "solar - thermal - heat exchange refrigeration" as technology route, design and implementation of a solar ejector refrigeration system. The system consists of thermal subsystem to absorb and store solar energy generator, heat exchange and mixed refrigerant cycle working fluid, the injector fluid mixing, condenser cooling, achieve the purpose of cooling.

2. MATERIAL AND METHODS

2.1 System Architecture

The overall design of the solar thermal ejector refrigeration system is shown in Figure 1. The system consists of a photothermal subsystem and a refrigeration subsystem. The main components of the photothermal subsystem are solar collector, heat storage water tank and circulating water pump. The main components of the refrigeration subsystem are ejector, generator, condenser, evaporator, throttling component and working fluid pump.

The working principle is shown in Figure 1: the solar collector (a) absorbs solar energy and converts it into heat energy. The heat storage water tank (b) stores heat energy and provides energy sources for the refrigeration system. The heat flow in the heat storage water tank flows through the generator (c) for heat

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exchange to produce high temperature and high pressure refrigerant steam, which is ejected from the nozzle after entering the ejector (d). Because the high speed refrigerant steam ejected, and the ambient air temperature, so the ejected moment near the nozzle produces a partial vacuum, vacuum pressure difference and low pressure refrigerant vapor injection outlet from the evaporator, so as to realize refrigeration. The working fluid and the injected fluid are fully mixed and pressurized in the injector chamber and then into the condenser (e), which becomes saturated refrigerant liquid after heat release and condensation. After evaporation of the refrigerant into two roads, 1 road from the throttle valve throttling finally enters the evaporator, the 2 road increase in the refrigerant pump pressure and finally into the generator, absorbs heat, vaporization of refrigerant [7] into high temperature and high pressure. In actual work, the process is repeated over and over again.

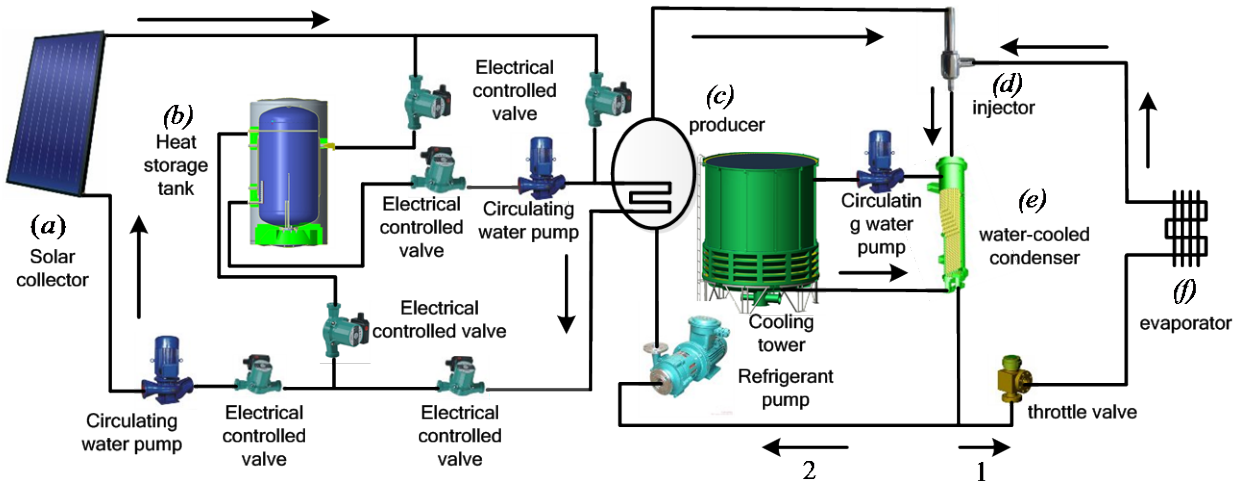

Fig. 1. System work flow chart.

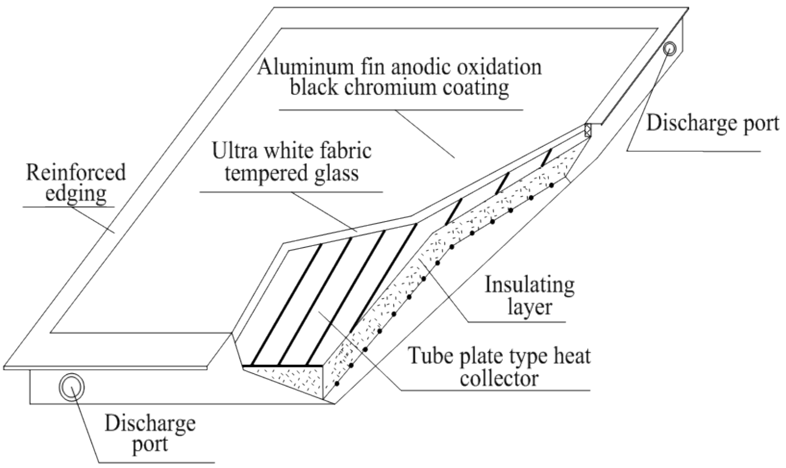

Fig. 2. Solar collector.

3. SYSTEM DESIGN AND REALIZATION

3.1 Photothermal Subsystem

There are two types of solar collectors: flat plate heat collector and tube plate heat collector. A new type of tube plate structure is designed in this paper. The collector is shown in Figure 2. With a laser welding device will be wide plate copper welding the copper pipe, brushed aluminum wing anodized black chromium coating, coated with polyurethane foam as the overall collector thermal insulation layer, the outer covering of toughened super patterned glass, further improve the solar transmittance, light absorption rate.

The heat storage water tank usually has two kinds of concrete water tank and stainless steel water tank, and the design uses stainless steel water tank. The design of cylindrical tank, taking into account the moisture-proof, anti rust, leakage and other factors, the outside of the water tank bladder is made of 304# stainless steel, SUS304-2B stainless steel inner liner is arranged between the inner liner, 100mm insulation, thermal insulation pouring polyurethane foam material, in order to ensure the insulation effect of foaming material density is greater than or equal to 45kg/m³. The design sets the number of heat storage water nodes to 4, that is, the water tank is divided into 5 layers to ensure the energy storage effect

In order to achieve better injection effect, a booster pump with larger head and larger flow is needed. In order to ensure the stability of the system, the work temperature of the positive pressure pump should be higher. The selection of 15PBG-10-N type stainless steel mute booster water pump, input / output power is 220W, maximum head 10 meters, flow rate 45L/min, the highest working temperature are less than 110°C

3.2 Refrigeration Subsystem

The generator is an important part of heat exchange, the hot water of the heat storage water tank enters into the tube of the generator, and the refrigerant outside the pipe carries out quick heat exchange to produce high temperature and high pressure refrigerant steam. The traditional generator uses the direct surface contact to carry on the heat exchange, the effect is not good, this design has carried on the improvement to it. According to the vortex equation (1):

$$\triangle p_c \propto v_i^2 \qquad (1)$$

△pc and V_i is pressure drop and velocity of hot water in the heat storage tank enter into the generator, respectively. Obviously, the higher the pressure difference is, the faster the injection speeds is.

To achieve these objectives, a new dual chamber scroll generator is designed, as shown in Figure 3.

A new type of dual chamber scroll generator consists of a low-pressure chamber, a high-pressure chamber and an injector. The lower and upper low pressure chamber is tapered cylindrical type, intermediate seamless welded together, in order to guarantee the effect and high injection pressure vortex occurs, the cone angle is less than or equal to 20o. The high-pressure chamber is cylindrical. Between the low pressure chamber and a high-pressure chamber connected by flange, the special nozzle is arranged on the lower end of the double chamber vortex generator, cylindrical jet nozzle and the tangent line for the low pressure chamber, the fluid to cut into to produce swirl chamber motion [8]. Unlike the conventional absorption generator, there is no heating plate and heating tube inside the twin chamber scroll generator, and the generator is completely insulated from the outside.

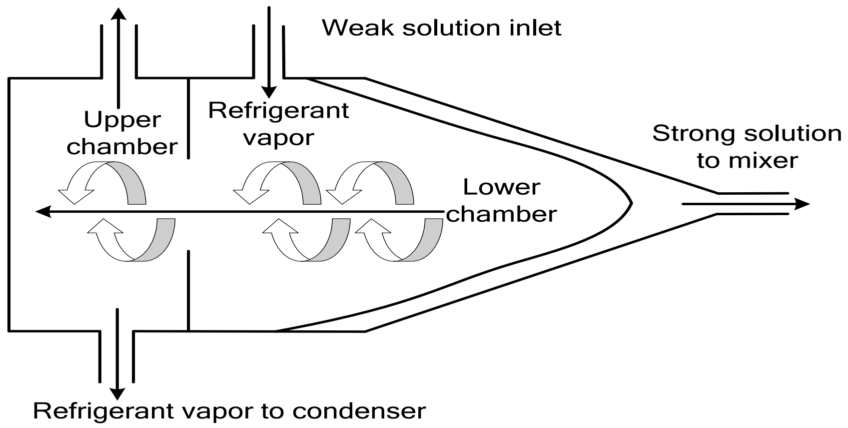

Fig. 3. Structure of double chamber vortex generator.

3.3 Ejector Subsystem

The ejector is one of the core components of the solar thermal refrigeration system. The working fluid and the injected fluid perform the process of internal compression, expansion and mixing in it.

Ideally, the process is a non isentropic process with a one-dimensional steady state without loss of heat. According to the above requirements, the copper casting ejector ejector set working fluid ejector two, fluid entrance, body absorption chamber, the mixing chamber and the expansion chamber consists of three chambers, and is arranged on the inner wall of a heat insulation coating, as far as possible to ensure the heat loss. See Figure 4 of the injector section.

The evaporator uses low temperature liquid refrigerant to evaporate at low pressure, changes into steam and absorbs the heat of the cooling medium, so as to achieve the purpose of refrigeration. It must have good heat dissipation and thermal conductivity. In view of the good thermal conductivity of aluminum (210 W/m^2.°C), aluminum alloy is welded in seamless form to make the cooling pipe. The refrigerant is rapidly circulated, cooled and cooled in the cooling pipe, and is naturally convection with the cooled air, and the heat exchange is completed with the refrigerant through the contact surface. In order to greatly increase the contact area and enhance the cooling effect, the outer sleeve of the cooling pipe is welded with a copper fin tube set.

The function of the refrigerant pump is to spray the refrigerant to the next link, and the choice of refrigerant

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and pump is the core of the design. The current study shows that, compared with the traditional R134a and R600a refrigerant R161 refrigerant COP (Cost of Power) was the highest, with green environmental protection and other features of [8], so this paper chooses R161 as refrigerant refrigerant selection in Section 4.1 of the 15PBG-10-N type stainless steel mute booster pump as a refrigerant pump.

3. EXPERIMENT AND ANALYSIS

The system runs on the roof platform of the laboratory for 12 months, and intercepts the meteorological parameters and COP data from April 2016 to September, as shown in Table 1.

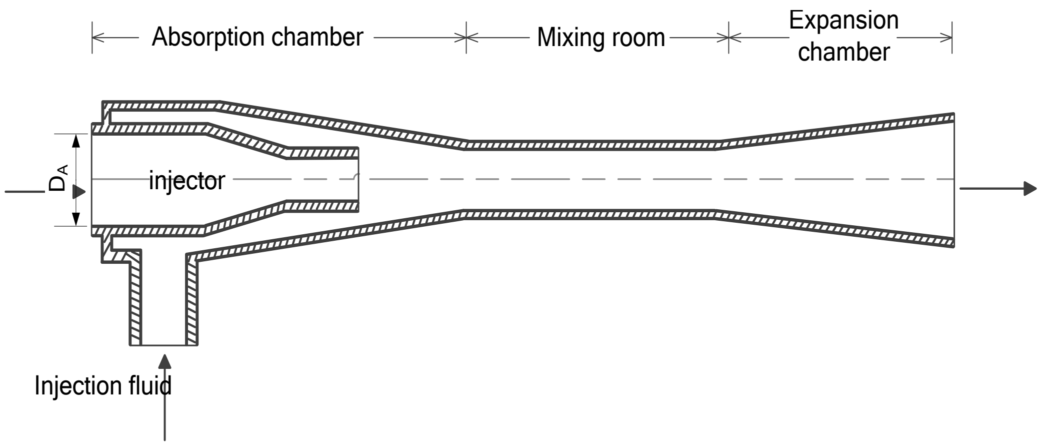

Fig. 4. Structure of injector cavity.

Fig. 5. Physical system.

Table 1.Weather parameters chart.

Weather parameters	unit	April	May	June	July	August
outdoor average temperature	°C	19.5	23.2	26.5	29.6	28.8
average light intensity	$W·m^2$	319.1	389.5	425.5	455.5	475.3
average cooling load	KW	8.2	8.9	10.1	12.2	13.5
COP	%	23.4	23.7	24.2	26.4	25.8

4. DISCUSSION

Set up the test paper [10] simulation platform, COP data measurement system during a certain period of time. At the same time using TRNSYS (Transient System Simulation program, version 17) as a software simulation tool, the reference [11] system testing procedures, engineering measurement and the simulation results are shown in Figure 6 (comparison of the ideal COP).

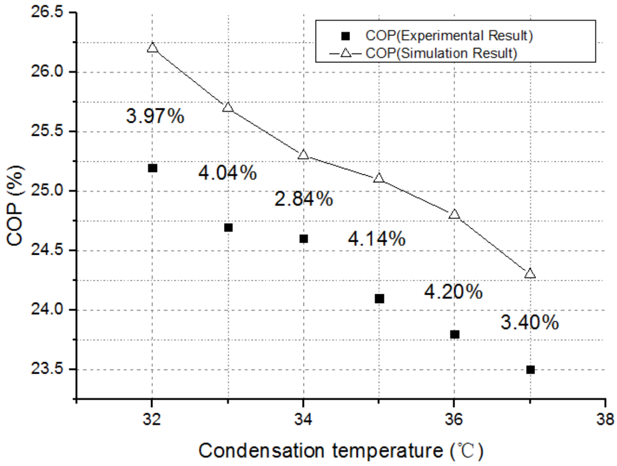

Fig. 6. COP comparison results.

It can be seen from Table 1, solar ejector refrigeration system can achieve the purpose of refrigeration, especially effective in outdoor high temperature, sun light irradiation intensity is large, COP is about 24%, is about three times of other existing photothermal refrigeration system [12]. As can be seen from Figure 6, the variation trend of COP of the solar thermal jet refrigeration system is consistent with the simulation theoretical value, and the engineering error of measured value and theoretical value is less than 5% [13].

5. CONCLUSIONS

A solar energy jet refrigeration system is designed and built. Unlike traditional photovoltaic refrigeration systems, the thermal jet refrigeration system works by ejector cooling and double chamber vortex generator heat exchange. The simulation experiment and engineering test show that the solar energy jet refrigeration system COP is higher than the photovoltaic refrigeration system, and can achieve better cooling effect.

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