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A Solar Powered Air Conditioning System for Daytime Offices based on Ejector Cycle: An Alternate of Conventional Air Conditioning Systems

Jagveer*, Deepak Kumar, Tarun Gupta
Department of mechanical engineering, NGFCET, Palwal, India
singhjagveer27@gmail.com

Abstracts

Solar cooling is comprised of many attractive features and is one path towards a more sustainable energy system. The performance of solar cooling systems is strongly dependent on local conditions. Solar cooling systems can be efficiently operated in locations where sufficient solar radiation and good heat sink are available. A low temperature heat source could be used to drive the ejector refrigeration system, making this system suitable for integration with the solar thermal energy. The analysis of the solar driven ejector system is followed by steady state analysis condition. The system performance depends on the working fluid (refrigerant) chosen, operating conditions and ejector geometry. An ejector refrigeration cycle, when, using natural working fluids generates good performance and lower environmental impact, rather than traditional working fluids, as CFC's and HFC's are strong climate gases. Exergy analysis illustrates that the distribution of the irrervsibilities in the cycle between components depends strongly on the working parameters. The most significant losses in the system are in the solar collector and ejector. The final section of the paper will deal with the calculation results for one fixed ejector dimension using R11 as the refrigerant are also included.

Keywords: Solar Cooling; Solar-Driven Refrigeration System; Ejector; Ejector Refrigeration Cycle.

Introduction

Residential and commercial air-conditioning consumes over 15% of all electric energy generated and creates two sources of environmental pollution: one is the ozone-depletion effect of traditional refrigerants belonging to CFC groups, and another is the emission of greenhouse gases connected with the electricity generation. Additionally, with energy cost rising constantly, industry is looking to reduce electricity expenses as a means of lowering their fixed costs in order to stay competitive.

The described system is a modification of a well-known vapour compression cycle and it uses our previously developed ejector device for non-mechanical compression. Instead of pressurizing the refrigerant by a mechanical compressor, a pump compresses the liquefied refrigerant, then heat is added to evaporate it and finally the refrigerant is re-compressed in an ejector without any mechanical energy spent.[1] The main difference between this cycle and the conventional refrigeration cycle, is that it requires three heat sources at different temperatures rather than two, namely at the generator level, which is the temperature of the solar energy, at a condensing level, which is the atmosphere temperature (heat sink) and the evaporator temperature required for cooling effect. This invention relates to heat transfer apparatus therefore, and more particularly to ejector type refrigeration systems employing heat as a source of power. Heretofore many types of refrigeration systems have been provided. The various types are determined by the grade of energy required to power them. For instance, one type, the mechanical compressor refrigeration system requires mechanical or electrical energy to power it, the mechanical or electrical energy being the highest grade of energy and is reversibly convertible, however, in many instances high grade energy is not economical to use for powering refrigeration systems.[2,3] Thus, another type of refrigeration system currently being used is the absorption type refrigeration system which is powered from heat energy which, however, must be at a fairly high temperature level. Still another type of refrigeration system is the ejector type refrigeration system which is likewise powered from heat energy at a fairly high temperature level. Thus, from the foregoing it can be realized it would be desirable to provide a refrigeration system which could be powered by heat energy at a lower temperature level than required by the present absorption type and ejector type refrigeration systems.

A solar-driven ejector refrigeration system has been selected as a case study for a further detailed investigation. A low grade heat source could be used to drive the ejector refrigeration cycle, making the system suitable for the solar thermal collector. System performance depends on the choice of working fluid (refrigerant), operating conditions and ejector geometry.

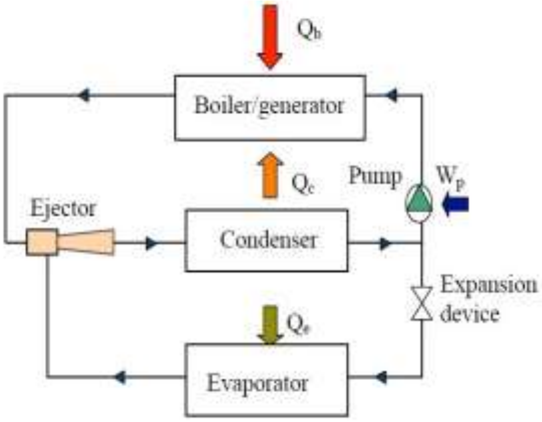

Figure 2.1: General layout of Ejector refrigeration system.

An ejector refrigeration cycle using suitable working fluids generates good performance and lower environmental impact. Further, exergy analysis is used as a tool in identifying optimum operating conditions and investigating losses in the system. In practice, the cooling load characteristic and solar radiation are not constant. Therefore, a dynamic analysis is useful for determining the characteristics of the system, and dimensioning the important components of the solar collector subsystem, such as solar plates. Preliminary calculation results for one fixed ejector considered as a black box using R11 as the refrigerant is also included.

Need of system

This invention relates to heat transfer apparatus therefore, and more particularly to ejector type refrigeration systems or heat pump systems employing heat as a source of power. Heretofore many types of refrigeration or heat pump systems have been provided. The various types are determined by the grade of energy required to power them. For instance, one type, the mechanical compressor refrigeration system requires mechanical or electrical energy to power it, the mechanical or electrical energy being the highest grade of energy and is reversibly convertible. However, in many instances high grade energy is not economical to use for powering refrigeration systems. Thus, another type of refrigeration system currently being used is the absorption type refrigeration system which is powered from heat energy which, however, must be at a fairly high temperature level. Still another type of refrigeration system is the ejector type refrigeration system which is likewise powered from heat energy at a fairly high temperature level. Thus, from the foregoing it can be realized it would be desirable to provide a refrigeration system which could be powered by heat energy at a lower temperature level than required by the present absorption type and ejector type refrigeration systems.

Description of technology

Ejector refrigeration is a thermally driven technology that has been used for cooling applications for many times. In their present state of development they have a much lower COP than vapour compression systems but offer advantages of simplicity and no moving parts.[23] Their greatest advantage is their capability to produce refrigeration using waste heat or solar energy as a heat source at temperatures above 80°C. the schematic diagram shows the operation of the system as given below:

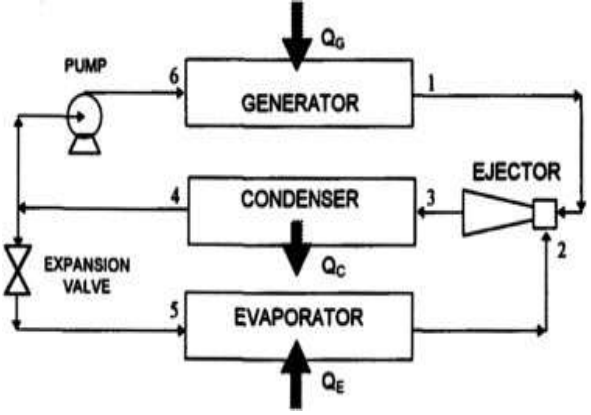

Figure : Line Diagram of ERC.

Working Steps:

- The system consists of two loops, the power loop and the refrigeration loop.
- In the power loop, low-grade heat, Q_G, is used to evaporate high pressure liquid refrigerant (process 6-1).
- The high pressure vapour generated (primary fluid) flows through the ejector where it accelerates through the nozzle.
- The decrease in pressure that occurs induces vapour from the evaporator (secondary fluid) at point 2.
- The fluid stream (mixed) then flows to the condenser where it is condensed rejecting heat to the environment, Qc.
- A major portion of the liquid refrigerant exiting the condenser at point 4 is then pumped to the generator for the completion of the power cycle.
- The remaining liquid refrigerant is expanded through an expansion device.

- After that it enters the evaporator of the refrigeration loop at point 5 as a mixture of liquid and vapour.
- The refrigerant evaporates in the evaporator producing a refrigeration effect, QE.
- The resulting vapour obtained from evaporator is then drawn into the ejector at point 2 for the completion of the refrigeration cycle.

Refrigerant used

There are several refrigerants are available which could be used in ejector air conditioning system. Many studies were made (mentioned in literature review) regarding ejector system in which are R-134a, R-717, R-718, or R-123 could be used as a working substance for producing refrigerating effect. In current work R-11 is used as a refrigerant. Some physical properties of R-11 are given below due to which it is easy to choose the refrigerant for this purpose. [4]

- It is stable, non-flammable and non-toxic.
- The boiling point at atmospheric pressure is 23.77 °C.
- It has a low side pressure of 0.202 bar at -15 °C.
- The latent heat at -15°C is 195 kJ/kg.
- The leak may be detected by using a soap solution of by electrode detector.

System Analysis. The operational cycle contains two loops one is refrigeration loop and another is power loop. The refrigeration loop also known as low pressure loop while power loop is known is high pressure loop. In this system ejector is considered as a black box.

Loop 1 (Power loop)

[a]. Pump work (W_P). The liquid refrigerant release from condenser at point 4 and divided into two parts one is in refrigeration loop and another is in power loop. In power loop this liquid refrigerant gets compressed in refrigeration pump (shown in figure). The liquid refrigerant gets pressurized from point 4 to point 6. The work required to obtained such pressure of refrigerant can be calculated with the help of given expression:

Pump work (W_P) $= v_f\,(p_6 - p_4) \times$ mass flow rate.

$= 0.000696(2.36 - 1.75) \times 10^5 \times 0.65$

$\mathbf{= 27.5\ J/min}$

Also, $W_P = m(h_6 - h_4)$

From (1) and (2),

$0.65(h_6 - 67.76) = 0.0275$

$\mathbf{h_6\ = 67.80\ kJ/kg}$

[b]. Heat required for generator. After pressurizing the liquid refrigerant entering to a closed chamber, called generator, at point 6. In the generator the refrigerant get heated by means of solar heater and converted into vapour form. The vapour refrigerant is exit at point 1 as shown in figures. The amount of heat required for evaporate the liquid refrigerant can be calculated by the expression:

(let the vapour exit from the generator is dry saturated)

$Q_G = m(h_1 - h_4)$

$= 0.65(248.53 - 67.76)$ kJ/min

= 117.47 kJ/min OR 1.96 kW

Loop 2 (Refrigeration loop).

(Considering non-isentropic expansion)

[a]. Heat absorbed in evaporator. The liquid refrigerant enters to the evaporator at point 5 and after absorbing the latent heat from the surroundings; the liquid refrigerant get evaporates and converted into vapour. Along with the assumption that the refrigerant get dry saturated after absorbing its latent heat in evaporator. Hence, From Figure, the heat absorbed in the evaporator, is given by the expression:

$\mathbf{Q_E = m\ (h_2 - h_5)\ kJ/min}$

Hence, $h_5 = h_{f4} = 67.76$ kJ/kg

Assuming the refrigerant 95% dry after absorbing heat in evaporator. Hence,

$h_2 = h_{f2} + xh_{fg}$

$h_2 = 33.22 + (0.95 \times 190.42)$

$h_2 = 214.12$ kJ/kg

$Q_E = m\ (h_2 - h_5)$ kJ/min

$= 0.65(214.12 - 67.76)$

$\mathbf{Q_E\ = 95.134\ kJ/min}$

[b]. Heat rejected in condenser. Assuming that the vapour refrigerant get superheated by 10 °C in mixing chamber. Hence in condenser the refrigerant release its sensible heat and becomes dry saturated vapour after that its latent heat to the atmosphere and converted in liquid form. After that the condensed refrigerant is exit from the condenser at point 4.

The amount of heat rejected by the refrigerant in the condenser is calculated as:

$h_3 = h_g + mC_p\ \Delta T$

$h_3 = 243.69 + \{0.65 \times 0.578\ (10)\}$

$h_3 = 247.45$ kJ/kg.

$Q_C\ = m\ (h_3 - h_4)$ kJ/min

$= (0.65 + 0.65)(247.45 - 67.76)$

$\mathbf{Q_C\ = 233.59\ kJ/min}$

Heat Supplied. As the calculation shows that amount of heat required for proper running is approx 1.9 kW. To fulfil the requirement of heat a 2000 watt heater is assembled in generator. This amount of power required for heater is supplied by a 2 kW solar panel. The required solar panel contains combination of four plates having electricity production capacity of 500 each.

Co-Efficient of performance

The coefficient of performance of the system can be calculated as:

$$(COP) = \frac{Q_E}{Q_G+W_P}$$

$$= \frac{95.134}{117.47+0.0275} = \mathbf{0.81}$$

Cooling capacity:

Refrigerating effect produced by the system = 95.134 kJ/min

Hence, cooling capacity in terms of tones of refrigeration can be calculated as,

Cooling capacity of the system (in terms of TR) = $\frac{\mathbf{95.134}}{\mathbf{210}}$ = **0.45 TR**

Result and conclusion

As we can see above that solar powered ejector air conditioning system is based on the principle, similar to vapour absorption refrigeration system. The calculated COP is **0.81** along with the cooling capacities of **0.45 TR.** The source for running the system is 2 kW solar panel along with solar heater kit. Considering the impact of Ozone Depletion Potential(ODP) & Global Warming Potential (GWP) solar driven vapour absorption system shows a very prospective alternative in refrigeration system. Solar energy is available free & environment friendly. Also solar energy intensity is high in northern part of India. That gives it the tremendous future potential as environment friendly energy source. Solar absorption air-conditioning has the advantage of both the supply of the sunshine and the need for refrigeration reach maximum levels in the same season. According to current scenario the system can be used in two different conditions one is system could be used satisfactorily in day time offices without installation of battery for backup, another is battery having suitable load carrying capacity may also be installed for backup in case of night use

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