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Performance Analysis of Ejector Based Solar Air Conditioning System

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Abstract

Conventional air conditioning system use a lot of high grade energy mostly generated from fossil fuels. The Analytical investigation of the performance of the vapour ejector refrigeration system is described in this paper. The system uses R134a as the working fluid. This paper describes the concept and working of ejector air conditioning system. The influence of generator, evaporator and condenser temperatures is studied. This system operates with low grade energy such as solar energy or waste heat. In this experimentation the heat energy is obtained from a Scheffler reflector whose area is 9.2 m^2.

Keywords:*Ejector,Scheffler, Condenser, Generator, Evaporator, R134a, Coefficient Of Performance (COP), Entrainment Ratio*

1. Introduction

The first ejectorrefrigeration system in the world was made by Maurice Leblancin 1910 and gained in popularity till 1930's after which vapour compression refrigeration system became commercially available. Research and development continued however and the ejector technology found applications in many engineering fields particularly in the chemical and process industries. Systems range few KW to 60,000 kW of cooling capacity but still the COP of the system,is less than 0.2. Ejector refrigeration systems are not presently commercially available but a number of companies specialize in the design and application of bespoke steam ejector systems that use water as a refrigerant for cooling applications above 0°C. In the present literature, R134a is the working fluid, coupled with the heat energy obtained from a Scheffler Receiver. In this paper we determine the effect of generator, condenser and evaporator temperatures on the COP of the system.

Nomenclature

m_p primary flowmass flow rate (kg/s)
m_s secondary flowmass flow rate (kg/s)
ω Entrainment Ratio
T_g Generator temperature(°C)
T_e Evaporator temperature(°C)
T_c condenser temperature(°C)
NXP Nozzle Exit Plane (mm)
h_e Enthalpy of Evaporator (kJ/kg)
h_c Enthalpy of Condenser (kJ/kg)
h_b Enthalpy of Generator (kJ/kg)
R_c Compression ratio
CC Cooling capacity
COP Coefficient Of Performance

2. Ejector Refrigeration System

An Ejector Refrigeration System replaces the compressor in the VCS and instead uses an ejector that compresses the refrigerant for evaporator pressure to condenser pressure. The basic components of the ERS are evaporator, condenser, pump, expansion valve, supersonic ejector as shown in the figure. In the high temperature cycle of the system the heat energy of the hot water is used to vaporize the refrigerant in the generator. The high temperature and high pressure vapour flows through the primary nozzle, which is a convergent divergent type, is accelerated. In the throat of the nozzle the velocity reaches the sonic velocity. This phenomenon is known as the choking of the primary fluid. The secondary fluid in the evaporator is entrained because of the low pressure created by the primary nozzle. The two streams are then mixed in the constant area mixing chamber and pressure increases. This vapour is then given to the condenser where the heat is rejected to the environment.

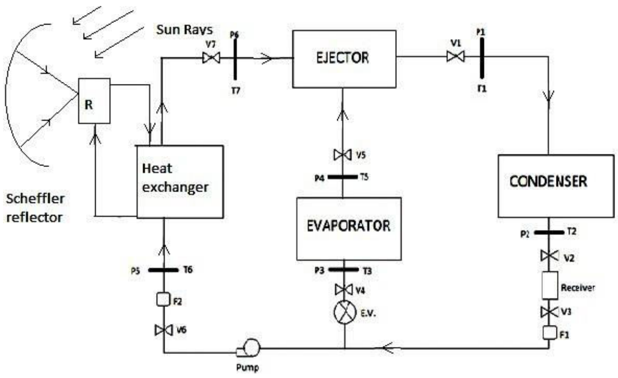

Fig 1. Schematic Diagram of System

The liquid refrigerant passes through the condenser is the divided into two streams of which one goes to evaporator where it evaporates and gives the desired refrigerating effect. Rest goes to the generator, with the help of a pump and completes the cycle.

2.1 Working Principle of the Ejector

Ejector has three parts, primary nozzle, mixing chamber and diffuser. Stream velocity and pressure as a function of location inside the ejector is shown in Fig. 2. Primary fluid enters the ejectorat subsonic flow. When passed through the primary nozzle, pressure decreases and velocity increases. At the throat, velocity reaches to sonic velocity. This is known as choking of the primary fluid.In the diverging section of the primary nozzle, velocity reaches supersonic velocity at the NXP. Here the pressure of the primary fluid becomes lower than the secondary vapor and then the secondary steam gets sucked the mixing chamber. After this, mixing of the fluids takes place up to some distance. It is assumed that the mixing of the fluids in the ejector occurs at a constant pressure before entering into constant area chamber. A shock occurs in the constant area mixing chamber. The shock increases the mixture pressure and decreases the mixture velocity to subsonic condition. Pressure increases further as the fluid flows through the diverging section. At the exit of the diffuser, mixture pressure is slightly greater than the back pressure of the condenser.

2.2 COP of the System [9]

The Coefficient Of Performance is the normal performance index used in any refrigeration system. In the present experiment the heat and friction losses are not considered.

The COP is given by
COP= (Refrigeration effect) / (heat input to the generator + power consumption by the pump)

$$COP = \omega \times \frac{(he-hc)}{(hb-hc)}$$

ω = Entrainment Ratio
h_e= Enthalpy of Evaporator
h_c= Enthalpy of Condenser
h_b= Enthalpy of Generator

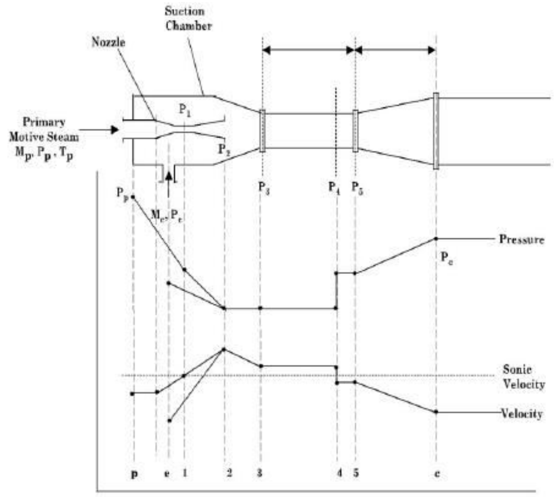

Fig 2. Typical Ejector Geometry, Pressure and Velocity Profilesalong Ejector Length.

3. Ejector Geometry

The ejector adopted in the experiment is a "constant pressure mixing ejector" which means the primary nozzle exit is located within the suction chamber. The suction chamber is located in front of the constant area mixing chamber. The geometric parameters are given in the figure.

- The primary throat diameter Do was taken as 2.5mm. The remaining dimensions were calculated empirically. [2]
- Primary throat diameter = 2.5mm
- Area of the mixing region = 4.36mm
- Mixing length =23.34mm
- Diffuser length = 70mm
- Nozzle exit plane = 6.79mm
- Material : SS 316

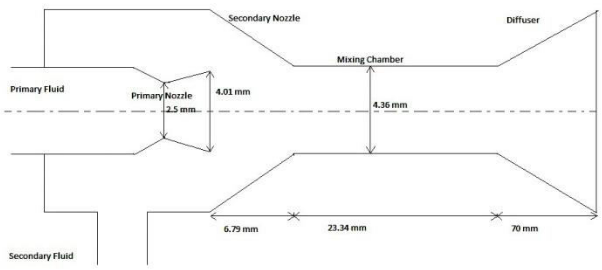

Fig 4. Ejector Dimensions

4. Description of the Experimental Setup

Fig. 1 shows the schematic diagram of the experimental setup. It consists of a generator, which is a plate heat exchanger, ejector, evaporator, condenser, liquid receiver, expansion valve, pump, temperature sensors, flow meters, pressure gauges. Also it has scheffler receiver system which concentrates the solar energy of the sun on to a receiver that heats up the water which is supplied to the generator to heat up the refrigerant.

The ejector is connected with the generator using a 1/2" copper pipe. The outlet of the evaporator is connected with the secondary inlet of the ejector with 5/8" copper pipe. The Condenser inlet is connected to the ejector outlet with 1/2" copper pipe. The condenser rejects the latent heat to the atmosphere thus liquefying the refrigerant. The outlet of the condenser in connected to the receiver which accumulates the refrigerant. The receiver outlet is connected to a T junction joint which splits the refrigerant to the evaporatorand to the pump. After the receiver a flow meter is connected that measures the flow of the refrigerant thus giving the total amount of refrigerant flowing through the ejector. One part after the T junction is connected to the evaporator through the expansion valve. A standard 3/8" copper pipe is used. Another part of the T junction is connected to the generator. The pump pumps the liquid refrigerant to the generator with the help of a standard 3/8" copper pipe. The generator is plate heat exchanger which utilizes hot water from the scheffler receiver to heat the liquid refrigerant. Before the generator a flow meter is connected that measures the amount of refrigerant flowing through the generator thus giving us the mass flow rate of the refrigerant through the primary nozzle of the ejector. Pressure gauges and temperature sensors and hand operated control valves are placed at various entry and exit points of the components.

Scheffler Reflector

Scheffler fixed focus concentrators are used for medium temperature applications. These concentrators have paraboloidlateral sections which provides fixed focus away from the path of incident beam radiations round the year. The scheffler used in this experiment is mounted on the terrace of the building. It has an effective surface area of 9.2 m².

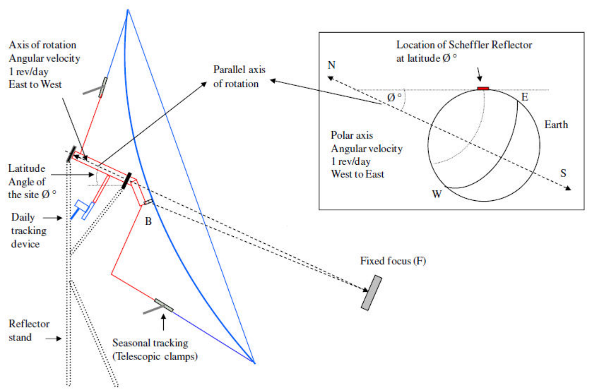

Fig 5. Scheffler Concentrator

5. Instrumentation

The main parameters measured during experiment were temperature, pressure and volume flow rates. Type K (chromel-alumel) was used to measure the temperature in the experiment. Type K is the most common general purpose thermocouples with a fairly good sensitivity. These temperature sensors have an accuracy of ± 2.2°C or ±75%. The data from the thermocouples was fed to a display monitor to take down the readings at various points. Connections from eight thermocouples can be fed to the monitor. The pressures were measured with the help of six bourdon gauges of which three were low pressure and remaining three were high pressure gauges. The range of high pressure gauges is 0-35 kg/cm² and that of low pressure gauges is 0-17.5 kg/cm². The temperature and pressure gauges pair are mounted at ejector inlet and outlet, one pair at condenser outlet, two pairs on evaporator inlet and outlet and one pair at generator inlet. Flow meters were used to measure the flow rate of the refrigerants. They are measured in Kg/s. The range of the flow meters is from 0-0.036 Kg/s. the float is made of SS304. The accuracy of the flow meters is ±2% of full scale deflection. One of the flow meter is at condenser outlet and other is at the inlet of the generator.

6. Experimental Procedure

The system was firstly evacuated using the vacuum pump to remove the non condensable gases and impurities from the system. Then the refrigerant R134a was charged in the liquid form in the system through the receiver. The plate heat exchanger is coupled to the scheffler's receiver with the help of flexible connectors. The height of the water supply tank is sufficiently high to make the water flow through the receiver and the PHE due to gravity. The refrigerant is then heated and pressurized. The valve after the generator is then opened and the high pressure gas passes through the primary nozzle and entrains the secondary fluid. The vapour after the ejector is fully converted into liquid in the condenser and flows to the liquid receiver. When the system becomes stable the measurements are taken for the generator, condenser and evaporator.

7. Performance Parameters

Several parameters are used to describe the performance of ejectors in refrigeration cycles, as provided below.

1. Entrainment Ratio

The entrainment ratio, ω, is the ratio between the secondary flow mass flow rate,$\dot{m}_s$, and the primary flow mass flow rate,$\dot{m}_p$:

$$\omega = \frac{\dot{m}_s}{\dot{m}_p}$$

2. Compression Ratio

The compression ratio, Rc, is the static pressure at the exit of the diffuser, pc, divided by the static pressure of the secondary flow, pe:

$$Rc = \frac{P_c}{P_e}$$

The entrainment ratio evaluates the refrigeration cycle efficiency, and the pressure lift ratio is a measure of the operative range of the cycle.

3. Coefficient of Performance

The coefficient of performance, COP, is the ratio between evaporation heat energy, Qe (cooling effect), and the total incoming energy into the cycle (Qg + Lp).

$$COP=\frac{Q_e}{Q_g+L_p}$$

4. Cooling Capacity
The cooling capacity, CC, is given by

$$CC=m_s\,(h_{e,out}-h_{e,in})$$

8. Results
The results have been calculated analytically forthe entrainment ratio of 0.24 to 0.27 and the given temperature ranges for the generator, condenser and evaporator and generator pressure of 20and 25 bar.

8.1 Effect of Generator Temperature on COP
Here the Generator Pressure of 20 bar, Condenser Temperature of 55°C and Evaporator Temperature 5°C were kept constant. Maximum COP was obtained at Generator Temperature of 80°C.

Table1. Effect of Generator Temperature on COP at 20 bar generator pressure

Tg (°C)	COP (0.24)	COP (0.25)	COP (0.26)	COP (0.27)
80	0.176	0.183	0.191	0.198
85	0.170	0.177	0.184	0.191
90	0.164	0.170	0.177	0.184

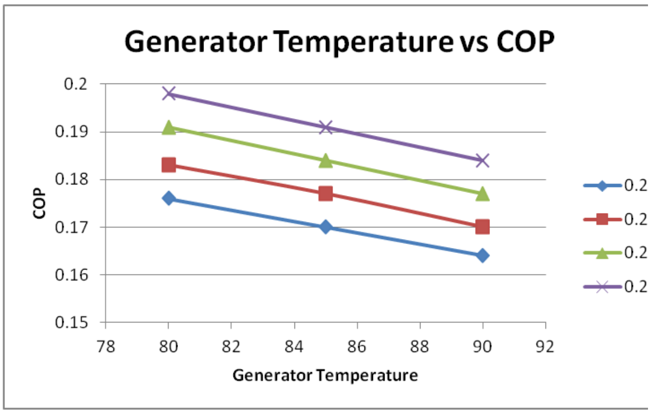

Fig 6. Generator Temperature vs COP at 20 bar Generator Pressure

Again the Generator Pressure was now increased to 25bar, Condenser Temperature of 55°C and Evaporator Temperature 5°C were kept constant. Maximum COP was obtained at Generator Temperature of 80°C and 0.27 entrainment ratio.

Table2. Effect of Generator Temperature on COP at 25 bar generator pressure

Tg (°C)	COP (0.24)	COP (0.25)	COP (0.26)	COP (0.27)
80	0.190	0.198	0.206	0.214
85	0.181	0.188	0.196	0.203
90	0.174	0.179	0.187	0.194

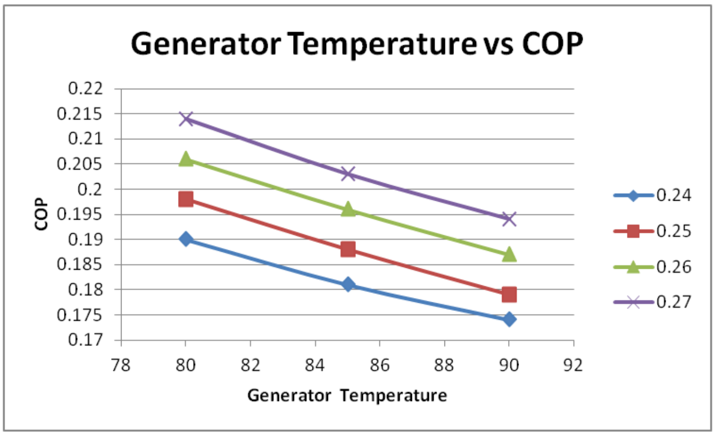

Fig 7. Generator Temperature vs COP at 25 bar Generator Pressure

8.2 Effect of Condenser Temperature on COP
Here the generator temperature of 80°C and evaporator Temperature 5°C were kept constant. Maximum COP was obtained at Condenser Temperature of 40°C. The generator pressure was 20 bar.

Table3. Effect of Condenser Temperature on COP at 20 bar generator pressure

Tc (°C)	COP (0.24)	COP (0.25)	COP (0.26)	COP (0.27)
40	0.184	0.192	0.199	0.207
45	0.1825	0.189	0.197	0.204
50	0.179	0.186	0.193	0.201
55	0.176	0.183	0.191	0.198

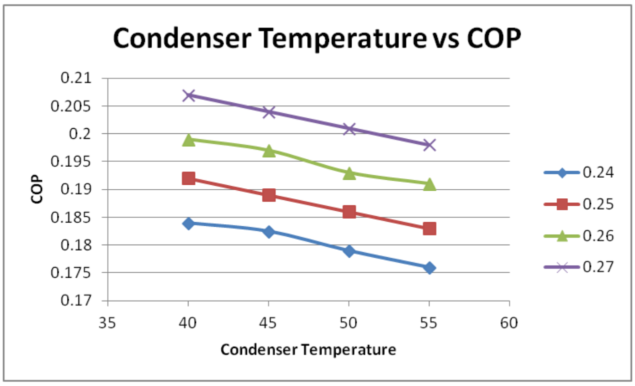

Fig 8. Condenser Temperature vs COP at 20 bar generator pressure

Keeping the same conditions of generator temperature of 80°C and evaporator Temperature 5°C were kept constant, only increasing the generator pressure to 25 bar. Maximum COP was obtained at Condenser Temperature of 40°C.

Table4. Effect of Condenser Temperature on COP at 25 bar generator pressure

Tc (°C)	COP (0.24)	COP (0.25)	COP (0.26)	COP (0.27)
40	0.197	0.205	0.213	0.221
45	0.195	0.204	0.211	0.219
50	0.193	0.201	0.209	0.216
55	0.192	0.198	0.206	0.214

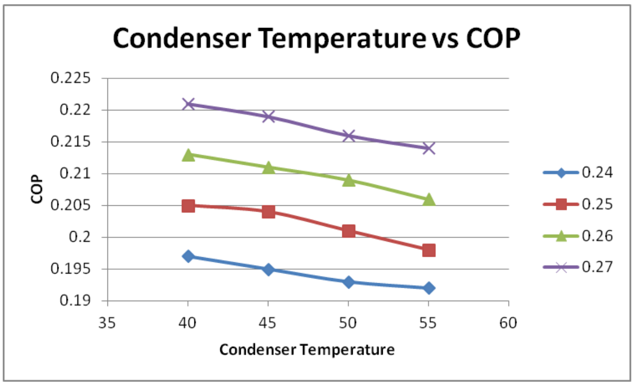

Fig 9. Condenser Temperature vs COP at 25 bar generator pressure

8.3Effect of Evaporator Temperature on COP

Here the generator temperature of 80°C and condensertemperature 40°C were kept constant. Maximum COP was obtained at Evaporator Temperature of 15°C, entrainment ratio of 0.27.

Table 5. Effect of Evaporator Temperature on COP at 20 bar Generator pressure

Te (°C)	COP (0.24)	COP (0.25)	COP (0.26)	COP (0.27)
5	0.184	0.192	0.199	0.207
10	0.187	0.195	0.203	0.211
15	0.191	0.199	0.207	0.215

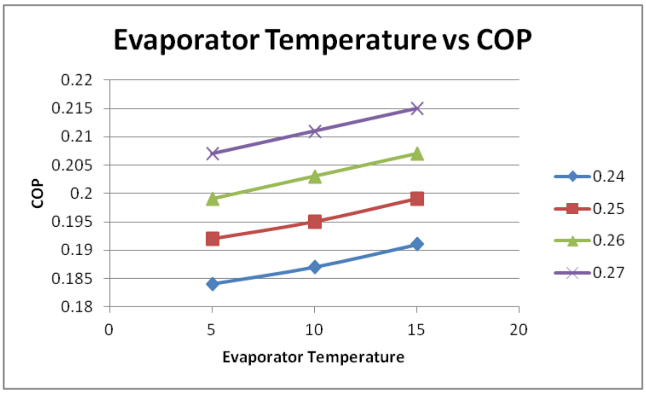

Fig 10. Evaporator Temperature vs COP at 20 bar generator pressure

The above conditions were repeated increasing the generator pressure to 25 bar. Max COP was found at 15°C evaporator temperature and 0.27 entrainment ratio.

Table 6. Effect of Evaporator Temperature on COP at 25 bar Generator pressure

Te (°C)	COP (0.24)	COP (0.25)	COP (0.26)	COP (0.27)
5	0.197	0.205	0.213	0.221
10	0.201	0.209	0.217	0.226
15	0.204	0.213	0.221	0.230

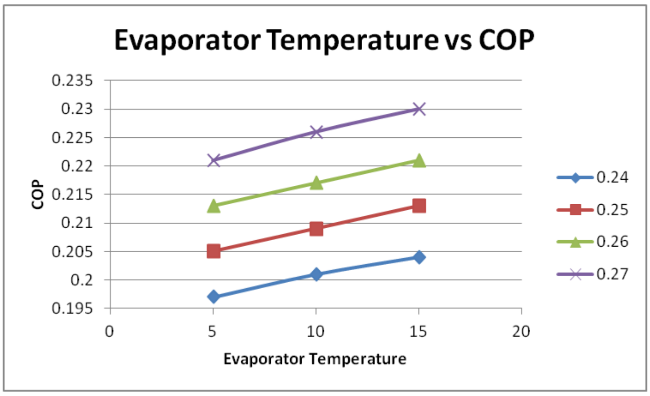

Fig 11. Evaporator Temperature vs COP at 25 bar generator pressure

9.Conclusion

The COP of the system depends on the Entrainment ratio, Generator temperatures, Evaporator Temperatures and Condenser Temperatures and generator pressure.

1. When generator temperature was increased from 80°C to 90°C, it was found that COP decreases. Maximum value of COP obtained was 0.214 at Generator temperature of 80°C, Generator pressure of 25 bar and entrainment ratio of 0.27.
2. When Condenser temperature was increased from 40°C to 55°C, it was found that COP decreases. Maximum value of COP obtained was 0.221 at Condenser temperature of 40°C, Generator pressure of 25 bar and entrainment ratio of 0.27.
3. When Evaporator temperature was increased from 5°C to 15°C, it was found that COP increases. Maximum value of COP obtained was 0.230at Evaporator temperature of 15°C, Generator pressure of 25 bar and entrainment ratio of 0.27.
4. Max COP is always found at max Entrainment ratio. Because more the entrainment ratio, more is the secondary fluid flowing through the evaporator and thus more cooling effect.

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