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Design and Development of Compressor assisted Ejector Refrigeration System

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ABSTRACT

Refrigeration systems consume most of the total produced energy. It is necessary to develop energy-efficient systems to overcome this challenge of the energy crisis. The refrigeration system is the process of cooling a space/system to lower/maintain its temperature below the ambient temperature. The vapor compression refrigeration system is more power consuming for its function so we come up with an idea, the compressor assisted ejector refrigeration system. The ejector is the main component of the system, assisted by the compressor. Therefore, the work required from the compressor is less, hereby the electrical energy required to run the compressor is also less in this system. As work load on compressor reduced this system promises longer life of the compressorThis system helps to reduce energy consumption and also satisfy to meet required refrigeration effect

Keywords: Vapor-compression refrigeration cycle, Refrigerating effect, Ejector Refrigeration System

1. Introduction

The conventionalVCSconsistofonlyfour equipment's which arecompressor, condenser, expansion device and evaporator. The VCS is used for both refrigeration and air-conditioning applications. The process of compressing the vapor from evaporating pressure to the condensing pressure is called as lift of the compressor, air-conditioning system requires less lift than the refrigeration system and hence the COP of air-conditioners is more than the refrigeration systems. As we reduce the lift of the compressor, we can achieve greater COP. Andto do this, the ejector is introduced in the system. Performance enhancement of refrigeration systems by cycle modifications is an emerging research topicnowadaystoreduce the electricity consumed leading to mitigating the problems related to the environmentalpollution by utility power plants. Due to no moving parts, low cost, simple structure and low maintenance requirements, the use of ejector has become a promising cycle modification recently. The main advantage of ejector may be found as the reduction in compressor work by raising the suction pressure to a level higher than that in the evaporator leading to the improvement of COP.
Use of ejector will gives us following benefits:
Work recovery (COP improvement) , No maintenance issues (No moving parts), etc.
The aim of this paper is to provide the idea about performance of ejector assisted vapor compression system. By varying the evaporating and condensing temperatures we will get to know about the effects on the cooling capacity and the COP

2.Description of the test apparatus

The test apparatus, as shown schematically in fig.1 consists of ejector, compressor, condenser, evaporator, expansion device.The arrangement is such that the outlet of the compressor is connected to the primary nozzle of the ejector, the evaporator is connected to the secondary inlet of the ejector, the outlet of the ejector is partly sent to the compressor and condenser and from the condenser the refrigerator is sent to the evaporator through expansion device.

Refrigerant Main Circuit

The components and the design features of the refrigerant circuit are outlined as follows:

- Primary refrigerant circuit, which consist of compressor and ejector.
- Secondary refrigerant circuit consists of ejector, condenser and evaporator.
- Cooling water circuit, which consist of water cooler and condenser.

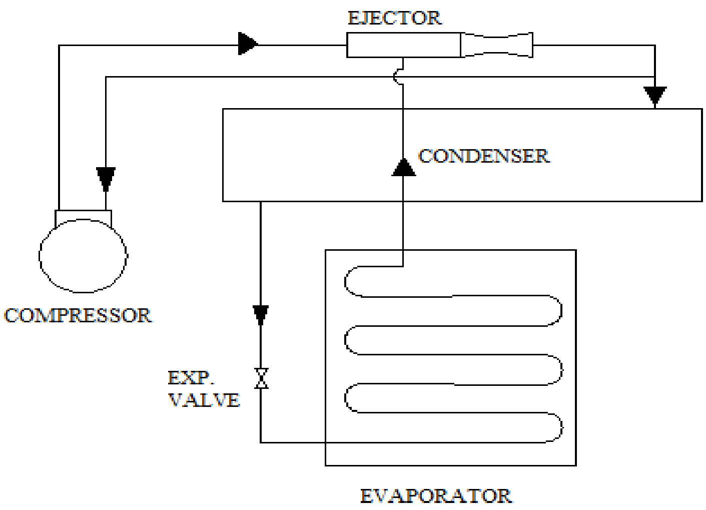

Fig. 1 Schematic diagram of Ejector assisted VCS

Compressor: -

The compressor used in this system is a two ton hermetically sealed compressor which is made by Emerson. The compressor runs on 220-230 V and 50 Hz single phase supply. The compressor which is generally used in air-conditioning is used in this setup. The exact location of the compressor is shown in the schematic diagram fig. 1.

Ejector: -

It consists of primary nozzle through which the primary flow from ejector comes; this flow is mixed with the secondary flow from evaporator which has relatively less pressure. After mixing of both the enthalpy and pressure are increased in the throat section of the ejector. The outlet of ejector is then given to the inlet of the condenser. The working of ejector pressure considered is 2.17 bars.

Mathematical model

There are two basic approaches for ejector design. These include mixing of the motive vapor and entrained vapors either at constant pressure or at constant area. Design models of stream mixing at constant pressure gives a better performance as compare to constant area model. The basis for modeling the constant pressure. In this study the constant pressure model is developed.

The geometry of the ejector is as shown in fig. 2. To design the ejector there are some assumptions and baseline conditions which are given in the table no.1. Based on these conditions the ejector is designed, the dimensions of the ejector are given in the table no.2.

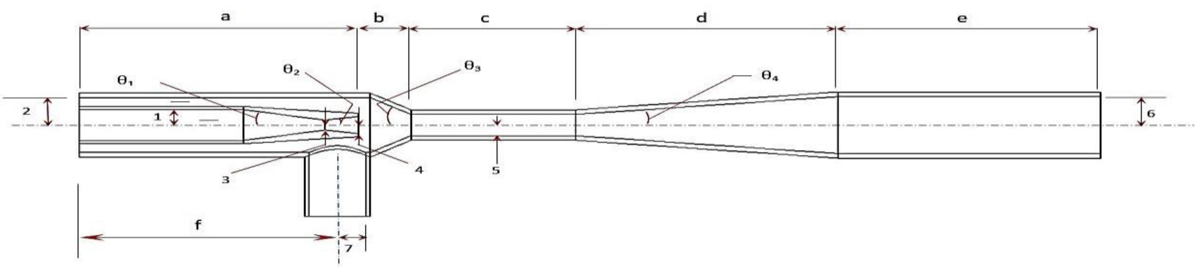

Fig 2. Ejector geometry

Table 1. Baseline condition used for ejector design

Operating condition	Value
Refrigerant	R134a
Generator temperature	95^0C
Condenser temperature	35^0C
Evaporator temperature	8^0C
Cooling Capacity	0.5TR
Nozzle efficiency	90%
Diffuser efficiency	78%
Entrainment efficiency	63%
Entrainment ratio	0.45

Table 2. Dimension of ejector

Length (L)	value (mm)	Radius (r)	Value (mm)
a	63	1	5.517
b	9.2	2	1.4198
c	32.2	3	1.4265
d	51.5	4	7.828
e	51.5	5	3.20
f	55	6	6.3498
L_{Total}	239.6		
Primary nozzle convergent angle			$\theta_1 = 12^0$
Primary nozzle divergent angle			$\theta_2 = 7.5^0$
Secondary nozzle convergent angle			$\theta_3 = 30^0$
Secondary nozzle convergent angle			$\theta_4 = 3.5^0$

Condenser: -

After mixing of the flow in ejector, the refrigerant is given to condenser where phase change occurs. Vapor refrigerant is converted into liquid refrigerant. Condenser works on temperature 35ºC. Also, degree of subcooling of 10ºC is considered at the outlet of condenser. Outlet of condenser is given to the evaporator through expansion valve.

Condensers are typically constructed according to certain specifications set by the client. These specifications are typically included on a manufacturer's sheet for condenser design and selection.

The function of the condenser is to remove the heat of the hot vapor refrigerant.But here the condenser is designed first as per the procedure given in the Prakash Matta [2]. The specifications of the condenser are given in the table no.3.

Table 3. Thermal Design data for Condenser

Type	Shell and tube
Cooling load on the condenser	7034kW
No of tubes (NT)	9
Tube outer diameter, mm	25
Tube inner diameter, mm	20
Tube length, m	1

Expansion device: -

Expansion valve expands the refrigerants that are it decreases its pressure and then it given to evaporator.

Thermostatic expansion valve or TEV is one of the most commonly used throttling devices in the refrigerator and air conditioning systems.

• The thermostatic expansion valve is the automatic valve that maintains proper flow of the refrigerant in the evaporator as per the load inside the evaporator.

• If the load inside the evaporator is higher it allows the increase in flow of the refrigerant and when the load reduces it allows the reduction in the flow of the refrigerant.

• This leads to highly efficient working of the compressor and the whole refrigeration and the air conditioning plant.

Evaporator: -

Secondary flow is constituted by the evaporator. In it the liquid refrigerant is converted into vapor. The working temperature of evaporator is considered to be 7.2^{o}C and 40^{o}C of superheat is considered.

Evaporator is an important component in a refrigeration system where the liquid refrigerant is evaporated.

An evaporator is a device in a process used to turn the liquid form of a chemical substance such as water into its gaseous-form/vapor. The liquid is evaporated, or vaporized, into a gas form of the targeted substance in that process.

The evaporator used in the system is shell and coil type evaporator. The design of the evaporator is done with assuming the pipe diameter to be 0.0127m and the design procedure is referred from Ali H. Tarrad [3].

The specifications of the evaporator are given in the table no.4

Table 4. Thermal Design data for Evaporator

Type	Shell and coil evaporator
Cooling load on coil	1758.5kW
Tube OD ,cm	1.5
Tube ID,cm	1.27
Length of coil, m	11
No of coils (N_C)	12
Depth of coil(D), mm	152.4

Heater:-The reason of adding the heater to the system is find the heat absorbed in the evaporator. The power consumed by the heater while the system is running is the amount of heat absorbed by the evaporator. The heater used is a normal water heater which runs on 220-230 V, 50 Hz supply.

Cooling Water Circuit

Water cooler: -

A water dispenser, known as water cooler (if used for cooling only), is a machine that cools and dispenses water with a refrigeration unit. It is commonly located near the restroom due to closer access to plumbing. A drain line is also provided from the water cooler into the sewer system.

Water coolers come in a variety of form factors, ranging from wall-mounted to bottle filler water cooler combination units, to bi-level units and other formats. They are generally broken up in two categories: point-of-use (POU) water coolers and bottled water coolers.

POU Water coolers are connected to a water supply, while bottled water coolers require delivery (or self-pick-up) of water in large bottles from vendors. Bottled water coolers can be top-mounted or bottom-loaded; depending on the design of the model. Cooling capacity of the water cooler is 2 TR.

Cooling water pump: -

Pump has many advantages over compressor as it uses less power. It is used to pump the liquid refrigerant into the generator.Water pump in the system is required for circulating the water from water cooler to condenser and back. It is mounted with the water cooler.The actual experimental facility is as shown in fig.3.

3Data Reduction:

The data-analysis procedure determines the overall performance of system------

Cooling Capacity$\dot{Q}_L = m\dot{}.C_{p.}\ (\Delta T)$ _ (1)

Where,

$m = \rho * V$ .... (2)

Work Input $\dot{W} = \frac{3600\ *REV}{C*TIME}$

Where,

C = Energy meter constant.

Coefficient of performance, COP can be calculated as follows;

$$COP = \frac{\dot{Q}_L}{\dot{W}}$$

Specific Power Consumption

$$kW/TR = \frac{\dot{W}x3.517}{\dot{Q}_L}$$

4 Results and discussion:

From break even analysis Ejector refrigeration system can work more efficiently at higher condensing temperature than simple vapor compression refrigeration system working between similar operating condition as that of compressor assisted ejector refrigeration system

Table5 is all about, calculation of all the possible enthalpies based on readings obtained from pressure gauge and temperature sensors. For particular mass flow rate controlled through flow control valve opening all the reading from gauges and temperature sensor panels are noted down in the table. Compressor inlet enthalpy which cannot be directly obtained is calculated with the help of measuring other properties

Flow to		CONDENSOR INLET						CONDENSOR OUTLET					EVAPORATOR OUTLET		
Compressor	PRESSURE		Temp	Enthalpy h5	Cp		PRESSURE		Temp	Enthalpy h7		PRESSURE		Temp	Enthaply h8
	PSI	BAR		(website)	(website)		PSI	BAR		(website)		PSI	BAR		(website)
12.50%	80	5.515808	48	437.2196	0.9639		87	5.998441	18.5	225.3667		84	5.791598	26	395.2743
25%	85	5.860546	51	439.4852	0.9724		89	6.136336	18.3	225.0925		85	5.860546	24	388.8698
37.50%	90	6.205284	43	430.9788	0.9887		95	6.550022	18.9	225.9281		88	6.067389	24.6	384.0137
50%	100	6.89476	31.6	425.2791	0.9931		107	7.377393	21.7	229.8429		90	6.205284	24.5	379.6047
62.50%	104	7.17055	30.9	425.6289	0.997		108	7.446341	20.9	228.7222		92	6.343179	25.3	377.8175
75%	102	7.032655	30.5	425.364	0.994		110	7.584236	21.5	229.5664		94	6.481074	25.6	374.7766
87.50%	104	7.17055	31.3	425.6432	0.9984		107	7.377393	20.8	228.5807		95	6.550022	24.7	370.1999
100%	105	7.239498	31.4	425.7462	1.0003		109	7.515288	21.5	229.5645		94	6.481074	25.6	374.7766

COMPRESSOR OUTLET PRESSURE PSI	BAR	Temp	Enthalpy h2 (website)	entropy sup(website)	COMPRESSOR INLET Enthalpy h1	condenser level properties to calculate h1 enthalpy: enthalpy sat	entropy sat	Cp	Tsat	Tsup	COP Theoretical
85	5.860546	57.1	445.3957	1.8342	411.4537	409.134	1.7184	0.9639	18.853	21.25961	0.555647
108	7.446341	71.4	475.0829	1.8528	413.0939	410.093	1.71755	0.9724	20.6805	23.76657	0.660509
165	11.37635	82.3	462.7776	1.8344	413.8215	411.017	1.7168	0.9887	22.458	25.2946	1.356236
225	15.51321	65.7	438.0695	1.7415	413.4387	412.76	1.7156	0.9931	25.863	26.54638	4.012969
230	15.85795	70.2	441.6973	1.7614	414.7018	413.418	1.715232	0.997	27.169	28.4567	5.522976
237	16.34058	75.4	446.8976	1.7815	414.9041	413.0918	1.715408	0.994	26.52	28.34328	6.80812
239	16.47848	68.2	439.12	1.8372	416.9427	413.418	1.715232	0.9984	27.169	30.69931	14.89798
240	16.54742	75.4	446.4793	1.7367	414.1778	413.579	1.71515	1.0003	27.4905	28.08917	17.98211

Table 5. Calculation of Theoretical COP

Flow To Compressor	Time	m	CP	ΔT T8	ΔT T7	QL	Meter Constant	N	C	T	WC	COP
12.50%	1800	52.7	4.187	30.8	24.6	0.760034	3600	903	3200	1800	0.564375	1.346682
25%	1800	52.7	4.187	30.5	16.5	1.716205	3600	1723	3200	1800	1.076875	1.59369
37.50%	1800	52.7	4.187	32.2	14.2	2.206549	3600	1522	3200	1800	0.95125	2.319631
50%	1800	52.7	4.187	35.5	12	2.880772	3600	1860	3200	1800	1.1625	2.478084
62.50%	1800	52.7	4.187	30.7	13.1	2.157515	3600	1250	3200	1800	0.78125	2.761619
75%	1800	52.7	4.187	35.8	10.1	3.150462	3600	1782	3200	1800	1.11375	2.828697
87.50%	1800	52.7	4.187	36.2	11.2	3.064651	3600	1680	3200	1800	1.05	2.918716
100%	1800	52.7	4.187	35.6	6.2	3.60403	3600	1950	3200	1800	1.21875	2.957153

Table 6. Calculation of Actual COP

Conclusion:

In today's progressive era highly energy efficient systems are in demand to fulfill this requirement compressor assisted ejector refrigeration system is developed. This compressor assisted ejector refrigeration system saves the energy and produce maximum work output by reducing energy consumption required for compressor. This system utilized mechanical device that is, ejector as a prime device to save energy consumption.

Theoretical work is carried out on compressor assisted ejector refrigeration system this work is mainly based upon condensing temperature parameter. this parameter is used as a prime condition for producing highly efficient system as compared to simple vapour compression system. This theoretical work has shown that keeping all the similar operating condition by increasing the condensing temperature the performance of CAER system increases while that of simple vcc reduces.

By investigating optimum parameter for higher efficiency of the system from theoretical analysis it is deduced that working of CAER system on condensing temperature at 55 degrees Celsius reduces its compressor work hereby saving the energy consumption and also, rest of the work is minimized by help of ejector since this device is not available in simple vcc working at higher temperature above 55-degree Celsius increase compressor work and reduced performance of entire system.

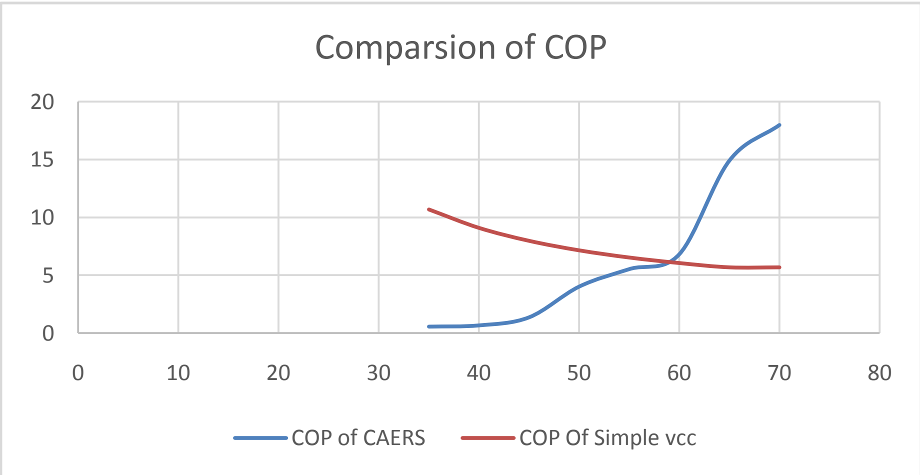

Fig.3 COP comparison of both system from theoretical analysis

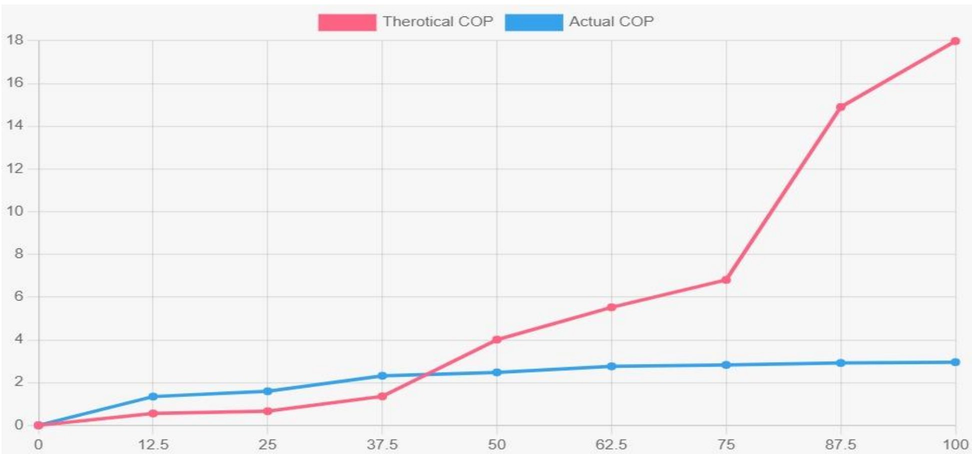

Fig.4 Comparison of Actual and Theoretical COP

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Nomenclature (Sample)

C	Energy meter constant (kWh)
COP	Coefficient of performance
h_1	Enthalpy of the vapor at the inlet of compressor (kJ/Kg)
h_2	Enthalpy of the vapor at the outlet of compressor (kJ/Kg)
h_7	Enthalpy of the vapor at the inlet of evaporator (kJ/Kg)
h_8	Enthalpy of the vapor at the outlet of evaporator (kJ/Kg)
Q_L	Cooling capacity (kW)
W_C	Compressor power input (kW)
ρ_R	Density of the refrigerant (Kg/m^3)