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Experimental Investigation on Subcooled Vapour Compression Refigeration System (SVCRS) using Diffuser at Condenser Inlet and Thermo Electric Module at Condenser Outlet

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Abstract: *In present scenario, the use of Vapour Compression Refrigeration Systems (VCRS) has been increased drastically due to the need of increase in cooling capacity. In this context, the performance of VCRS has to be increased. This paper, focus mainly to increase coefficient of performance (COP) of the VCRS. COP can be increased by reducing compressor work and by increasing refrigeration effect. Compressor work can be reduced by using diffuser at the outlet of compressor for same refrigeration effect. The refrigeration effect can be increased by sub cooling the refrigerant coming out from the condenser. Sub cooling can be achieved by various methods such as liquid subcooler, integrated and mechanical subcooling. In the present work it is chosen to use thermo electric module which works on Peltier effect for sub cooling the refrigerant. A diffuser is incorporated at the inlet of condenser, and a set of two Peltier modules are arranged at the outlet of condenser. The power supply for the Peltier module is given from batteries. The cold side of the module is exposed to refrigeration line and hot side is exposed to atmosphere. The system performance is studied experimentally by varying the operating voltage of the module. A critical comparison is done by varying the voltages for finding the better COP at operating voltage.*

1. Introduction

Refrigeration is a global renound technology used in various applications such as medical field, food preservation, for cooling electronic devices, space air conditioning etc. However the conventional Vapour Compression Refrigeration System (VCRS) will consumes more electrical power in terms of compressor work. Furthermore, it ultimately leads to increase in global warming by releasing more CO_2. Hence, development of pollution free VCRS with higher COP is needed. In the past, the need of Thermoelectric refrigerator is studied by Bondre et al [1],[2]. Even though there are advantages over conventional VCRS , fewer COP and capability of high heat flux restricted the use of Thermoelectric refrigerator. Further, Sandip Kumar Singh et al [3] discussed about the development of Solar based Thermoelectric refrigerator. Furthermore, Sujith et al [4] investigated about the incasing the COP of the Thermoelectric refrigerator by using the thermosiphon system. Even though, there are different methods to increase the COP, Subcooling is the better method.

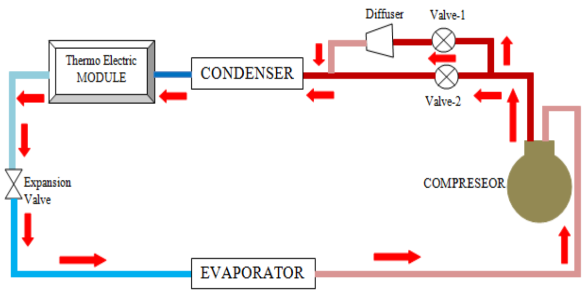

Figure 1 Schematic of SVCRS with diffuser and Thermoelectric module

The effect of Condenser Subcooling in increasing the efficiency is investigated [5], [6] by using different refrigerants. Further, by alternative Subcooling and Superheating COP of refrigerator is increased [7], [8]. However, thermoelectric VCRS with the Diffuser is not yet studied. In this paper, the enhancement of COP is investigated experimentally by using diffuser of angle 1.5^0, without diffuser and diffuser with subcooling with different voltages such as 2.8V, 4.2V and 5.6V. The COP, Net Refrigeration effect, Electrical energy consumption and percentage increase in the net refrigeration effect for various voltages under subcooling are calculated. Figure 1shows the schematic of SVCRS with diffuser and Thermoelectric module

2. Methodology

The experimental investigation on SVCRS is carried by developing the model shown in Figure 3. The experimental setup, procedure and the solution methodology are explained in this section.

2.1. Experimental Test Rig

The experimental test rig constitutes of a water cooler equipped VCRS containing an evaporator coil, a hermetically sealed reciprocating compressor, an air cooled type condenser and a capillary tube connected in sequence respectively by copper tubes. A Diffuser is fitted in parallel with the pipe connecting compressor and condenser as shown in figure. Two Valves are fitted, one before diffuser and another parallel to the valve 1 and integrated with Condenser. A Thermo electric module is placed after condenser such that the cooling side is towards the refrigerant and hot side is exposed to atmosphere. The thermo electric module picks heat and makes refrigerant sub cooled and rejects heat to the atmosphere so that refrigerant gets sub cooled and net refrigeration effect will be increased with reduced work input. Thermo electric module is insulated with insulation sheet, to prevent heat exchange with the atmospheric temperature towards cold side and more over thermo electric module is connected to cell for various power input observed COP at every stage.

Figure 2 Sub-cooling setup

Table 1 Specifications of Thermo Electric Module

Type	TEC-12706 Peltier Module
Operating voltage	6 V (DC)
Operating current	2 Amp
Power	12 Watts
Dimensions	40 X 40 X 3.5 mm
No. of Modules used	2

Figure 3 Experimental setup of SVCRS

2.2. Designing and Fabrication of Diffuser

Diffuser is a device which converts the available kinetic energy of a fluid into pressure energy. Diffuser is just an inverted nozzle whose inlet diameter is smaller than its outlet diameter. Using a diffuser the pressure energy of a flowing fluid can be increased. In the present work diffusers with circular cross section having divergent angles used. The design of the diffusers is explained below.

D_i = Diameter of the diffuser at inlet
D_o = diameter of the diffuser at exit
L = Length of the diffuser
Ø = Angle of divergence
Tan Ø = (Exit diameter – Inlet diameter) / 2 * Length of the diffuser
Length of the diffuser $L = (Do - D_i) / 2 \tan Ø$
Diameter of the diffuser at inlet D_i= 6.35 mm
Diameter of the diffuser at exit D_o = 7.937 mm
$\tan Ø = (Do - D_i) / 2 * L$
$L = (7.937 – 6.35) / 2 \tan(1.5)$
Length of the diffuser L = 30.16 mm

Figure 4 Diffuser inlet and outlet

The diffusers are machined out from a copper rod of diameter 10 mm using a CNC Lathe machine. These diffusers are fitted into the refrigeration system as shown in the above figure using Oxy-acetylene gas welding.

2.3. Solution Methodology

2.3.1. Performance calculation without Diffuser

Refrigeration effect = h_1-h_4
Compressor work = h_2-h_1
Coefficient of performance (COP) = h_1-h_4/ h_2-h_1

2.3.2. Performance calculation with Diffuser

Enthalpy raise due to diffuser = h_2'- h_2
Reduction in compressor work = Enthalpy raise due to diffuser
Refrigeration effect = h_1-h_4
Reduced Compressor work = (h_2 - h_1) - (h_2'- h_2)
COP = Refrigeration effect/Reduced Compressor work
COP =(h_1-h_4)/ [(h_2 - h_1) - (h_2'- h_2)]
% reduction in compressor work = (Reduction in compressor work/ compressor work without diffuser) *100

2.3.3. Performance calculation with Diffuser and subcooling system

Enthalpy raise due to diffuser = h_2'- h_2
Reduction in compressor work = Enthalpy raise due to diffuser
Refrigeration effect = h_1-$h_{4'}$
Input power = Reduced compressor work + electrical power consumption in TE module
Electrical power consumption = P = v*i*t
Mass flow rate = (210kg/min)/Refrigeration effect (kJ/kg)
Reduced Compressor work = (h_2 - h_1) - (h_2'- h_2)
COP = Refrigeration effect/Reduced Compressor work
COP =(h_1-h_4)/ [(h_2 - h_1) - (h_2'- h_2)+P]
% reduction in compressor work = (Reduction in compressor work/ compressor work without diffuser) * 100
Where, h_1= Enthalpy at evaporator outlet, h_2 =Enthalpy at compressor outlet, h_4 = Enthalpy at evaporator inlet, h_2'= Enthalpy at diffuser outlet, t = Time taken for1kg of mass flow, P_s= Suction Pressure in bar, P_d= Discharge pressure in bar.

3. Experimental Procedure

The experimental setup is connected to electrical power supply. The temperature indicators are connected at the exit of evaporator, exit of compressor, exit of condenser and at the inlet of evaporator. The initial temperature readings at the inlet of compressor exit of compressor, exit of condenser and at the inlet of evaporator are noted down. Pressure values at the suction of compressor and at the exit of the compressor are noted down. The electrical switch is turned on. The water cooler is allowed to run and the temperature and pressure readings are noted down for every 5 minutes time duration. The procedure is repeated until the refrigeration cycle reaches a stable condition i.e., until all the temperature and pressure gauges show constant values. The temperature and pressure values are plotted on the R-134A refrigeration chart, the enthalpy values of the refrigerant are obtained and performance parameters of the refrigeration cycle are calculated.

3.1.1. Performance values without Diffuser

Time	P_s	P_d	Temperature in (^{0}C)				
			T_1	T_2	T_3	T_4	T_5
0	5	5	32.1	32.1	32.1	32.1	32.1
10	0.4	7.35	30.3	38.5	34.9	8.1	14.3
20	0.4	7.35	28.3	40.9	35.1	6.7	2.8
35	0.4	7.35	27.5	42.2	35.2	6.6	-1.1
50	0.4	7.35	26.5	43.2	34.8	7.2	-2.3
65	0.4	7.35	24.2	44.1	34.6	7.1	-3.9
80	0.4	7.35	24.0	44.5	34.5	6.1	-4.8
95	0.4	7.35	22.8	44.9	34.5	6.9	-4.1
110	0.4	7.35	22.0	45.3	34.4	7.1	-3.4
125	0.4	7.35	21.3	45.5	34.4	7.5	-3.0
140	0.4	7.35	21.3	45.5	34.5	7.5	-3.1

3.1.2. Performance values With Diffuser Angle of 1.5^o

Time	P_s	P_d	Temperature in (^{0}C)				
			T_1	T_2	T_3	T_4	T_5
0	5.0	5.0	33.9	34.0	34.0	33.9	33.9
15	0.4	9.0	28.2	40.1	35.8	4.5	1.9
30	0.4	9.0	25.3	42.2	35.9	3.8	-8.2
45	0.4	9.0	24.2	43.0	35.8	3.9	-10.2
60	0.4	9.0	23.4	44.3	35.6	3.5	-11.2
75	0.4	9.0	23.2	45.5	35.5	3.3	-12.3
90	0.4	9.0	22.9	46.3	35.4	3.3	-13.0
105	0.4	9.0	22.5	46.8	35.4	3.2	-14.2
120	0.4	9.0	22.0	46.9	34.6	3.0	-15.2
135	0.4	9.0	22.0	46.8	34.2	3.0	-15.9
150	0.4	9.0	20.0	46.8	34.2	3.0	-15.9

3.2. Performance Parameters

S.no	Parameters	Without diffuser	With diffuser	With diffuser and subcooling various voltages		
				2.8 volts	4.2 volts	5.6 volts
1	Coefficient of performance (COP)	3.95	4.578	4.619	4.658	4.564
2	Refrigeration effect(kJ/kg)	174	174	176	178	175
3	Work supplied (kJ/kg) (Compressor + Electrical)	44	38	38.098	38.213	38.336
4	Mass Flow Rate (kg/s)	-	-	0.0198	0.0196	0.020
5	Enthalpy Rise (kJ/kg)	-	6	8	10	7
6	% Increase in NRE	-	-	1.149	2.298	0.574

4. Results and Discussion

4.1. Coefficient of performance for various systems

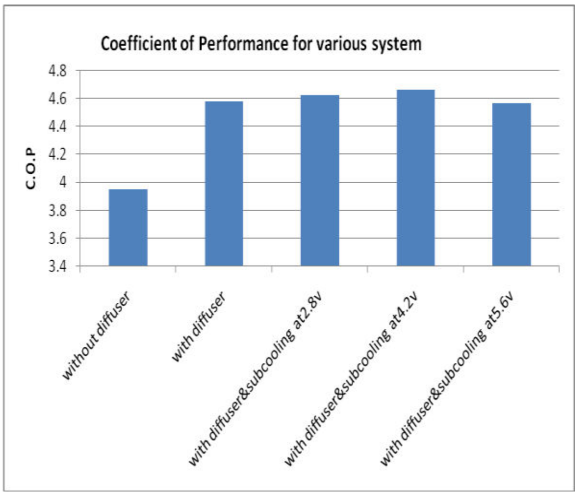

Figure 5 Coefficient of performance for various system

From the Figure 5, It is observed that, COP is 3.95 for refrigerator without diffuser and it is increased by using diffuser at the inlet of condenser. Further by using diffuser with subcooler increase the COP of the SVCRS. The maximum COP obtained is 4.658 at an operating voltage of 4.2V of thermoelectric module and further increase in voltage COP is decreased. The maximum percentage increase in C.O.P 17.92% for with diffuser and subcooling at 4.2 volts operating voltage of Thermo-electric module with respect to normal refrigeration. The minimum percentage increasing in C.O.P of 15.5% is obtained, when diffuser is used in addition to the subcooling at 5.6volts operating voltage of Thermo-electric module.

4.2. Variation of Net Refrigeration effect

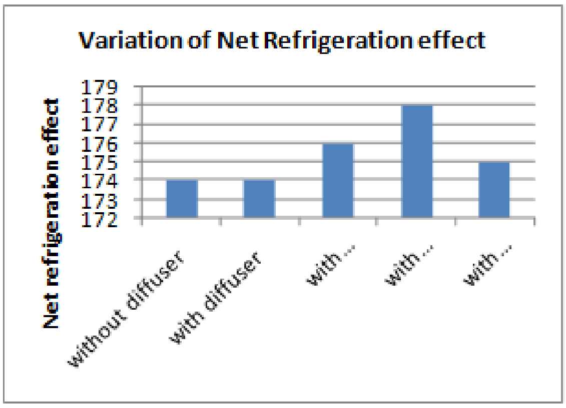

Figure 6 Variation of Net Refrigeration effect

Figure 6 shows the variation of net refrigeration effect for the existing refrigeration and with diffuser refrigeration system. Due to the insertion of diffuser, increase the recovery pressure and decreasing the compressor work. Further, it is observed that the trend increases, when subcooling is integrated with diffuser. The highest amount of Net refrigeration effect obtained at 4.2 volts operating voltage of subcooling in addition to diffuser and the decreasing trend followed with increase in voltage. The maximum percentage increase in Net refrigeration effect 2.29% obtained at 4.2volts operating voltage of Thermo-electric module subcooling and in addition to the diffuser with respect to the normal refrigeration system. The minimum percentage increasing in Net refrigeration effect is 0.574% at the 5.6 volts operating voltage thermo-electric module subcooling in addition to the diffuser.

4.3. Electrical energy consumption Vs degree of subcooling

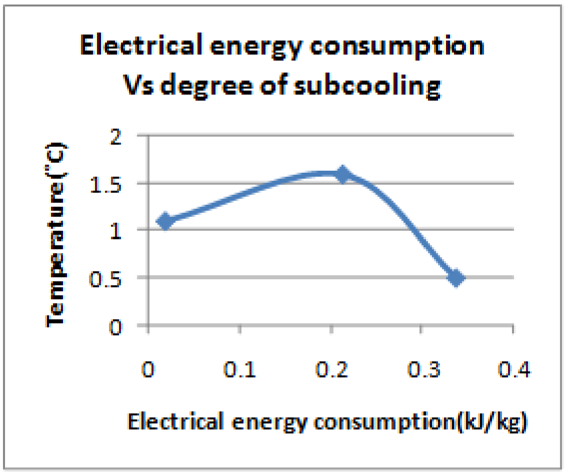

Figure 7 Electrical energy consumption Vs degree of subcooling

Figure 7 shows the electrical energy consumption with respect degree of subcooling . The highest degree of subcooling 1.6^{0}C obtained at 0.213 kJ/kg of electrical energy consumption and it is observed that trend increases and it decreases .The degree of subcooling 0.7^{0}C obtained at higher the electrical energy consumption of 0.336 kJ/kg ,because the Thermo-electrical is over heated and absorbing cooling from the cold side of the thermo-electric module.

4.4. Percentage Increase Net Refrigeration effect for various voltage of sub cooling

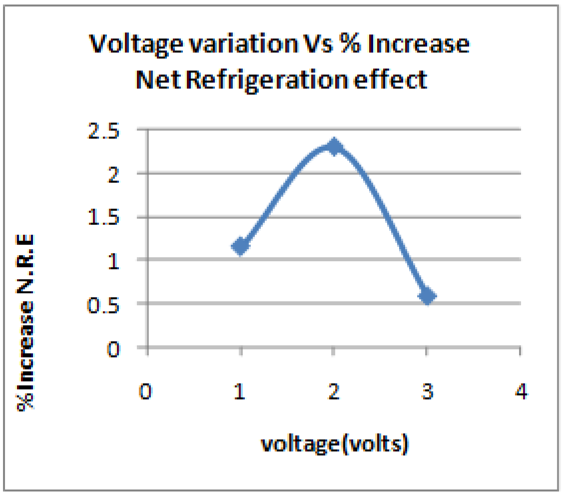

Figure 8 Voltage variation Vs %Increase Net Refrigeration effect

Figure 8 shows the operating voltage of the peltier module increased, the percentage increase in net refrigeration effect is increased and reached a maximum value of 2.298% at a voltage of 4.2V. As the voltage is increased the percentage increase in net refrigeration effect decreased and reached a minimum value of 0.574% at a voltage of 5.6V.

4.5. Pressure rise without diffuser and with diffuser

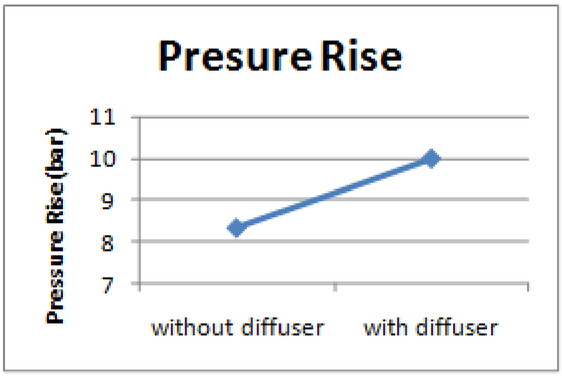

Figure 9 Pressure rise Without Vs With diffuser

From the Figure 9 it is observed that there is an increase in the pressure at condenser inlet when diffuser is incorporated at the condenser inlet. There is an increase of 1.65 bar when diffuser is used.

5. Conclusion

For the experimental analysis conducted on water cooler of capacity 20 litres by incorporating a diffuser at condenser inlet and by sub cooling the refrigerant after the condenser using Peltier Module, following conclusions were drawn. The COP of the refrigeration system is increased by 15.62% when diffuser is inserted into the existing refrigeration system. With sub cooling at 4.2 V operating voltage, the COP is again increased by 2.02 % with respect to refrigeration system with diffuser. Totally, The COP is increased by 17.92% when both diffuser and sub cooling are used in the refrigeration system. The maximum net refrigeration effect is increased by 2.29% with thermo electric sub cooling at the exit of condenser. The reduction in compressor work due to the addition of diffuser at the condenser inlet is 13.63%.

6. References

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7. APPENDIX

7.1. Performance values With Diffuser Angle of 1.5^0 and sub-cooling(voltage at2.8V)

Time	P_s	P_d	Temperature in (^{0}C)					
			T_1	T_2	T_3	$T_{3'}$	T_4	T_5
0	5.0	5.0	33.8	33.8	33.7	33.7	33.8	33.8
15	0.4	9.0	28.5	40.3	35.6	35.5	4.3	1.6
30	0.4	9.0	25.1	42.9	35.8	35.6	3.5	-8.0
45	0.4	9.0	23.6	43.5	35.9	35.6	3.7	-
60	0.4	9.0	21.7	44.6	35.7	35.5	3.2	11.1
75	0.4	9.0	20.9	45.3	35.4	35.2	2.9	-
90	0.4	9.0	20.6	45.5	35.3	34.9	2.1	11.9
105	0.4	9.0	20.1	45.8	35.0	34.3	1.4	-
120	0.4	9.0	19.8	46.1	34.8	33.8	1.2	12.5
135	0.4	9.0	19.8	46.2	34.4	33.4	1.1	-
150	0.4	9.0	19.8	46.2	34.4	33.3		13.1

7.2. Performance values With Diffuser Angle of 1.5o and sub-cooling(voltage at4.2V)

Time	P_s	P_d	Temperature in (^{0}C)					
			T_1	T_2	T_3	T_3'	T_4	T_5
0	5.0	5.0	34.1	34.1	34.1	34.1	34.1	34.0
15	0.4	9.0	29.0	41.2	35.9	35.6	4.1	2.0
30	0.4	9.0	25.3	43.1	35.7	35.7	3.2	-9.1
45	0.4	9.0	23.7	43.7	35.9	35.2	2.6	-11.5
60	0.4	9.0	21.9	44.3	35.3	34.5	1.9	-12.1
75	0.4	9.0	21.1	45.6	34.9	33.8	1.6	-12.9
90	0.4	9.0	20.6	46.1	34.6	33.4	1.4	-14.2
105	0.4	9.0	20.0	46.4	34.5	32.9	1.2	-15.6
120	0.4	9.0	19.8	46.5	34.4	32.7	1.0	-15.9
135	0.4	9.0	19.7	46.6	34.3	32.7	0.8	-16.3
150	0.4	9.0	19.7	46.6	34.3	32.7	0.8	-16.3

7.3. Performance values With Diffuser Angle of 1.5^0 sub-cooling(voltage at 5.6V)

Time	P_s	P_d	Temperature ing (^{0}C)					
			T_1	T_2	T_3	$T_{3'}$	T_4	T_5
0	5.0	5.0	33.6	33.6	33.6	33.6	33.6	33.6
15	0.4	9.0	28.9	41.1	35.1	35.0	5.8	2.3
30	0.4	9.0	25.4	42.9	35.4	35.2	4.1	-8.5
45	0.4	9.0	24.1	43.8	35.9	35.6	2.9	-11.4
60	0.4	9.0	22.0	44.4	35.2	34.8	2.1	-12.2
75	0.4	9.0	21.1	45.7	34.9	33.7	1.8	-13.7
90	0.4	9.0	20.5	45.9	34.6	33.3	1.5	-14.9
105	0.4	9.0	20.0	46.2	34.5	32.9	1.4	-15.8
120	0.4	9.0	19.9	46.5	34.2	32.6	1.3	-15.9
135	0.4	9.0	19.9	46.4	34.1	32.6	1.3	-16.0
150	0.4	9.0	19.9	46.4	34.1	33.6	1.3	-16.0