Demonstration and Performance Analysis of Waste Heat Recovery of Refrigeration System.

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Abstract: *Vapor compression refrigeration system is most commonly, domestic as well as large scale method of producing refrigeration effect. Due to greater coefficient of performance these systems takes the eyes on most of the refrigeration arena in either domestic or industrial. These systems provided quick refrigeration effect and heat rejection is carried out by the chemical properties of refrigerant. The aggregate of rejected heat from such systems is very much high and this heat is scraped into atmosphere as a waste. The rejected heat could be used to operate any other low-grade heat required system. It is a suitable way of utilization of such waste heat hence improve the coefficient of performance of a vapor compression refrigeration plant. Thus, the project deals with the trapping that waste heat into water by replacing air cooled condenser with water cooled Heat Exchanger. And comparing our system with larger capacity system as case study.*

Keywords- *Waste heat recovery, COP, Water Cooled Heat Exchanger, Refrigerant R134a.*

I. INTRODUCTION

The domestic refrigeration is the most common domestic kitchen appliance, which normally includes a thermally insulated inner compartment and in turn when it functions, exchanges heat from inside of the compartment to the exterior environment to ensure that the interior of the thermally well insulated compartment is cooled to the temperature below the environmental temperature of the room or area. In normal refrigeration system condenser convicts heat into environment which is scrap and waste this heat can be used in our daily purposes by introducing heat exchanger in it. The present work deals with the optimization of modified vapor compression refrigeration system by waste heat recovery from condenser using water cooled heat exchanger. This technique not only makes use of the waste heat but also enhances the achievement of the refrigeration system and increases its COP.

There are many devices for recovery of wate heat, but shell and tube heat exchanger is best suited heat for capacity of our prototype.

II. LITERATURE REVIEW

N. B. Chaudhari et al. [1] presented an experimental set up for the waste heat recovery through condenser. The experimental setup consisted of a VCC system and a water-cooled heat exchanger was used. The experimental result shows that as the mass flow rate of cooling water increases, heat recovered from the cooling water and COP of the system increases. Further, they proved that COP of water-cooled condenser is greater than that of air-cooled condenser.

Momin et al. [2] retrieved waste heat coming from the condenser of the home refrigerator to enhance the overall performance of the system. Retrieval of heat is done by thermo siphon. From the experimentation, it was found out that Page 1after the heat retrieving process from the condenser of the refrigerator, its overall COP got raised when compared to conventional refrigerator.

Sreejith K. et al. [3] experimentally analysed the effects of water-cooled condenser in a household refrigerator. They used R134a as the refrigerant. The functionality of air-cooled and water cooled condenser was examined for many load situations. The solutions display that the refrigerator functionality got elevated when water-cooled condenser was used in place of air-cooled condenser on all load situations.

S. N. Vedil et al. [4] studies theoretical approach to recover the waste heat liberated from vapour compression cycle, which is used to run vapour absorption cycle. The required heat is given by the solar energy. The work evaluated the performance of cooling cycle.

Prashant S. Pathak [5] tried to make a cabinet to recover waste heat from condenser from refrigeration system by storing a heat in an insulated cabinet. Rejected heat is used for keeping food hot, heating water which may be used for different purposes.

III. METHODOLOGY

A. Problem Definition: The waste heat liberated to the atmosphere from condenser is goes waste. This heat can be used for some other house hold application.

B. Literature Survey: The thorough literature survey was made on the different methods of wate heat recovery. It found that there are many devices for recovering heat.

C. Research Gap: In conventional refrigeration systems, air cooled condensers were used which liberates waste heat to atmosphere. More compressor power is required for air cooled condensers and hence low COP is obtained.

D. Experimentation: Here, in this experiment the conventional air-cooled condenser is replaced by a modified water-cooled condenser for the waste heat recovery purpose.

E. Result and Analysis: The results obtained are noted in tabular form and compared graphically. Also, we referred case study relevant to our project.

IV. EXPERIMENTAL SETUP

The important design parameter for a heat recovery device is selecting the type of the heat exchanger for the specified application. In this project, a shell and helical tube type heat exchanger is used. As copper is a highly conductive metal, it was selected as the tube material for the heat exchanger. The inner tube diameter was selected as ¼ inch (6.35mm) according to existing system. The length of the heat exchanger tube was taken as 3m. The helical coiled tubes are much more efficient than the straight tubes. when they are been used for heat transfer applications. So helical coil heat exchanger was been decided to be used and designed. The construction of the heat exchanger involved fitting helical coil inside heat exchanger chamber of size 300*450. The tube was bent by rolling process and the desired construction of heat exchanger was obtained. During this process, care has been taken so as to preserve the circular cross section of the coil. Insulation of foam sheets is given to the chamber to avoid heat loss. After the construction of the heat exchanger, it was fitted to the refrigerator. The heat exchanger acted as a condenser for the refrigerator, one end of which brazing was carried to the discharge line of the compressor and the other end was brazed to the expansion valve. For the experiment we have used compressor having capacity 1/6 inch.

Instruments used for measurements: -

1. K type thermocouples for temp. measurement at different points.
   Model- PM-10,
   Temperature range: -50˚C to 110˚C.
2. Water flow meter: - Accuracy- 4%,
   Model-lzs-15, Measure level: 10-500l/h.
3. Pressure Gauges: -
   Model Number- SLBWORKSNEW-232042976268,
   Make- SLB works.

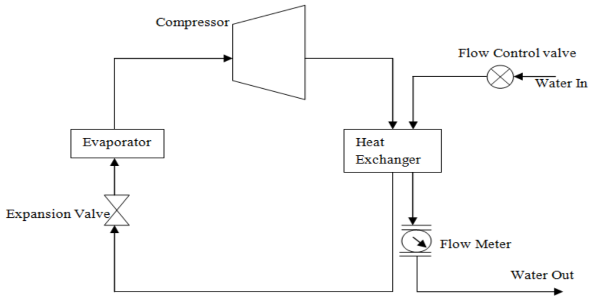

Fig.1 Schematic Diagram of Heat Recovery System

Fig.2 Experimental setup

V. TECHNICAL SPECIFICATION

1. Compressor Power: - 1/6 HP
2. Refrigerant: - R134a (110gm)
3. Copper coil Diameter: - ¼ inch
4. Capillary tube Diameter: - 3mm

Length: - 10feet
5. Heat Exchanger size: - 300*450mm
6. Insulation material: - Foam sheet
7. Evaporator side pressure- 0.25 bar
8. Condenser side pressure- 10.70 bar

VI. EXPERIMENTATION AND CALCULATION

A. Calculation of theoretical COP: -

From P-H chart,

h_1= 396 Kj/kg, h_2= 448 Kj/kg, h_3= h_4= 243 Kj/kg

$(COP)_{th} = (h_1-h_4)/(h_2-h_1)$

= (396-243)/ (448-396)

= 2.9423

Refrigerating Effect = h_1-h_4= 153 Kj/kg

Compressor power = $(1/6)_{th}$= 746*(1/6) = 124.33 ≈ 124 Watts

COP=Q_1/W. D

Q_1 = 2.9423*12 = 364.84 Watts

Q_2 = W.D + Q = 124+276.5762 = 488.84 Kj/kg

Mass flow rate of refrigerant,

$m_r = Q_2$/R. E

= 488.84/153

= 3.1950 * 10^-3 kg/s

Heat available at the condenser for rejection,

$Q_{available} = m_r . (h_2-h_3)$

= 3.1950 * 10^-3 (448-243)

$Q_{available}$= 654.97 Watts.

B. Calculation of Actual COP:

For air cooled condenser,

Work supplied to compressor,

W_c = 187.50 Watts

Considering losses, R.E = 130 Kj/kg

Refrigeration Capacity = 2.4220 * 10^{-3} *130*10^3

= 314.86 Watts

$(COP)_{act}$ = 314.86/187.50

$(COP)_{act}$= 1.6792

For water cooled (Shell and Helical tube type of heat exchanger)

Wc = 146 Watts

$(COP)_{act}$ = 314.86/146

(COP)act= 2.1565

C. Dimensions of Helical Coil tube

Diameter of the inner tube di = 5.25mm

Diameter of the outer tube do= 6.25mm

Number of turns on the tube N= 6

Pitch of the spiral tube P= 40mm

Outside diameter of the coil D= 150mm

D. Observations

The observations are made for a period of one hour with a time interval of 15 min. Temperature at different points is noted and actual COP is calculated accordingly. These readings are taken for refrigerant R134a.

Table 1. Variation in COP of system when air cooled condenser is used with R134a as refrigerant.

Sr. No.	Time (min)	Temperature in Evaporator (^{0}C)	COP
1	00	27	1.38

2	15	23	1.44
3	30	17	1.56
4	45	13	1.61
5	60	11	1.68

Table 2. Variation in COP of system when water cooled (Shell and tube type) HEX is used with R134a as refrigerant.

Sr. No.	Time (min)	Temperature in Evaporator (^{0}C)	COP
1	00	27	1.90
2	15	23	1.96
3	30	17.5	2.04
4	45	14.3	2.10
5	60	11.2	2.15

Now, the readings are noted for different water flow rates of cooling water. The water flow rates are 10, 15, 20, 25 LPH. The effect of flow rates on evaporator temperature, water outlet temperature and compressor power are noted. Below one sample calculation is provided for calculating waste heat recovered.

Shell-in- helical tube type of HEX

For 10 LPH,

Heat recovered = $m_w * c_p * \Delta T$

= (10*4187*(48-30)*1000)/3600

= 209.35 Watts

Similarly, for mass flow rates 15, 20, 25 heat recovered is calculate.

Table 3. Performance of shell and coil type of HEX for different flow rates of water.

Sr. No.	Flow rate of water (LPH)	Comp. Outlet temp. (^{0}C)	Water inlet temp. (^{0}C)	Max. outlet water temp. (^{0}C)	Heat Recovered (Watts)
1	10	66	30	47.4	202.37
2	15	62	30	42.8	223.30
3	20	63	30	41	255.87
4	25	62.9	30	39.2	267.50

VII. RESULTS AND DISCUSSION

Effect of R134a Refrigerant for Air Cooled and Water-Cooled Condensers.

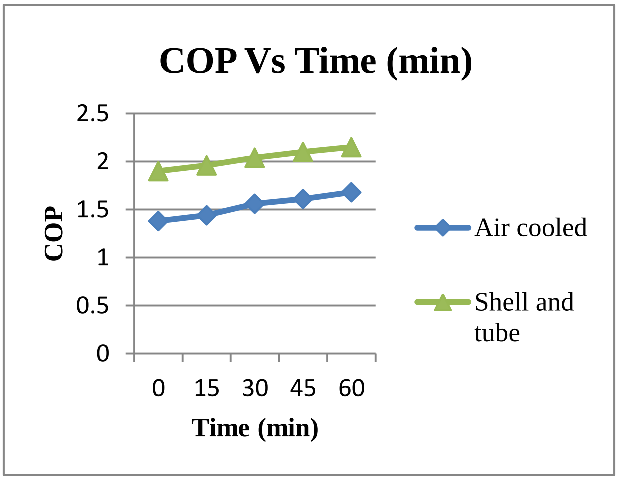

Fig. 3 Variation in COP Vs Time (min) for two types of condensers

Fig. 3 Shows the effect of different heat exchangers on the COP of the refrigeration system. It can be noted that, the COP is increased for water cooled condensers over air cooled condenser due to low compressor power required.

VIII. CFD ANALYSIS

Computational fluid dynamics (CFD) study of the system starts making of the desired geometry and the mesh for modeling the dominion. Generally, geometry is simplified for the CFD studies. Meshing is the discretization of a domain into small volumes where the equations is solved by the help of iterative methods. Modeling begins with the describing of the boundary and

initiated by initial conditions for the dominion and leads to modeling of the entire system. Finally, it is followed by the analysis of the results, discussions and conclusions.

Boundary conditions:

Refrigerant inlet temperature- 51 ^{0}C

Water inlet temperature- 30 ^{0}C

Mass flow rates of cooling water- 10, 15, 20, 25 LPH

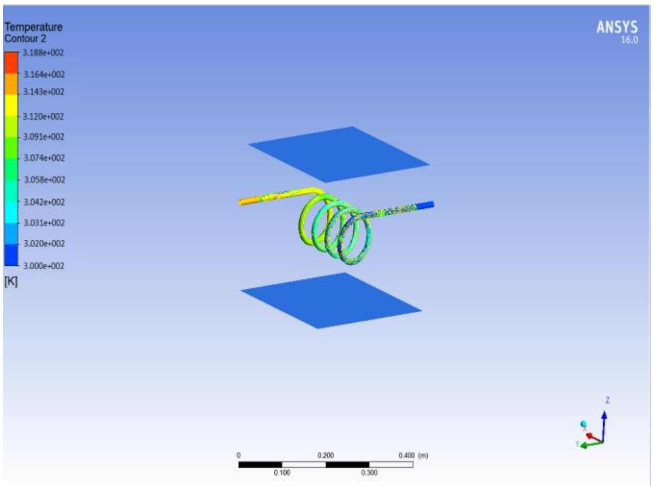

Fig. 4 Temperature distribution for 10 LPH water flow rate

Table 4. Comparison of CFD and experimental results: -

Sr. No.	Flow rate of water (LPH)	Max. outlet water temp. (^{0}C)		Heat Recovered (Watts)	
		CFD	Experimental	CFD	Experimental
1	10	48.5	48.4	215.16	214.00
2	15	45.2	43.2	265.17	230
3	20	43.3	41.3	307.04	262.85
4	25	40.6	39.9	290.76	287.85

Comparison with Experimental Results: -

Figure mention below shows the variation in maximum outlet temperature of cooling water and maximum heat recovered at different water flow rates for CFD and experimental readings. It can be clearly seen from the graph that the CFD results are closely matching with the experimental output. The lower values of experimental readings are due to the radiation losses and limitations of measuring instruments.

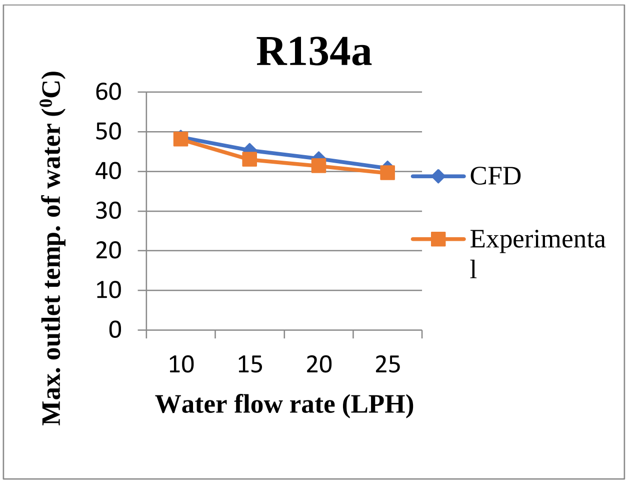

Fig. 5 Max. outlet temperature of water (^{0}C) Vs water flow rates (LPH) for CFD and experimental output.

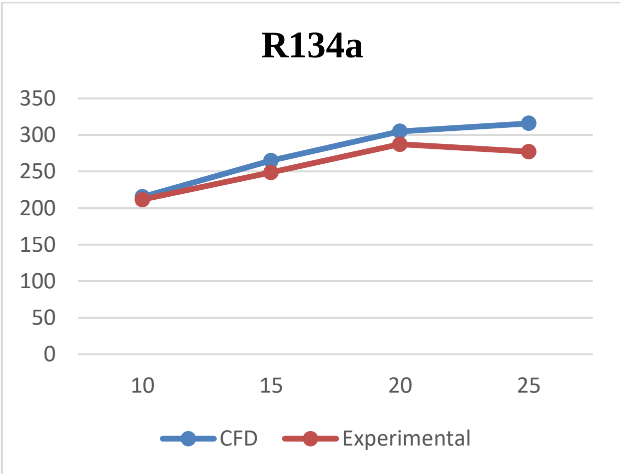

Fig. 6 Max. heat recovered (Watts) Vs water flow rates (LPH) for CFD and experimental output.

IX. CASE STUDY

A Case Study of Waste Heat Recovery from Water Chiller equipped with Screw Compressor was carried out under the guidance of authorized person which we have visited and noted down the require parameters for calculation.

Case study on water chiller:

1. Industry person: - Mr. Ravindra Rajole.
2. Case study on: - Water chiller equipped with Screw compressor.
3. Location of plant: - Magarpatta city, Hadapsar, Pune, Maharashtra PIN: 411013.

A/C Screw Chiller Health & Performance Report

Customer:- MAGARPATTACITY CLIENT NAME:---- Date:-30/01/2021
Unit Model :- ACFX105-5S Tower:-4 Chiller no :-3
Refrigerant: R22

SR.NO	Parameter	Unit	Test Data C
1	CHW Inlet temp	°F	51.4
2	CHW Outlet temp	°F	44
3	Evaporator delta temp	psig	7.4
4	CHW Inlet press	psig	70
5	CHW Outlet press	psig	65
6	Ambient temp DBT	°F	97
7	Voltage R-Y	V	402
8	Y-B	V	403
9	R-B	V	405
10	Voltage Average	V	403.33
11	Volage Unbalanced	%	0.25
12	Compressor Current R	A	171
13	Y	A	172
14	B	A	165
15	Curreny Average	A	169.33
16	Current unblanced	%	4.13
17	KWH Consumption	KW	106.47
18	Total KWH Consumption	KW	106.47
19	Suction Pressure	psig	64
20	Discharge Pressure	psig	253
21	Discharge line Temp	°F	159
22	Compressor loading Capacity	%	100
23	Chilled Water Flow Rate	usgpm	245.6
24	Total TR	TR	75.72
25	I.KW/TR	KW/TR	1.41
26	Total CFM	CFM	70380

Fig. 7 Specification of plant.

Calculations:

Data: Compressor work (Wc) = 106.47 KW

$Q1 = 266.31$ KW

$Q2 = 266.31 + 106.47 = 372.78$ KW

Heat Rejected in condenser is 372.78 KW.

We know that,

Heat rejected in condenser Qrej = Heat absorb by air across condenser Qabs

$Q_{rej} = \dot{m}\ air \times Cp\ air \times \Delta T\ air$

We have,

$\rho\ air = 1.225\ Kg/m^3$

$\dot{V}\ air = 70380\ CFM = 33.21\ m^3/s$

$\dot{m}\ air = \rho\ air \times \dot{V}\ air$

$\dot{m}\ air = 1.225 \times 33.21$

$\dot{m}\ air = 40.682\ Kg/s$

Take Cp of air as 1 Kj/Kg K

Put values in above equation,

$372.78 = 40.682 \times 1 \times \Delta T\ air$

$\Delta T\ air = 9.16\ °C$

Take temperature of inlet air as 28°C.

$To = Ti + \Delta T$

$= 28 + 9.16$

$= 37.16 \approx 38°C$

Temperature of air at outlet is 38°C.

Comparison between Prototype project (Domestic refrigerator) and Case study (Water Chiller):

Table 5. Comparison of Prototype project and Case Study

DESCRIPTION	PROTOTYPE (Domestic Refrigerator)	CASE STUDY (Water Chiller)
Capacity (In TR)	0.12 Ton	75.75 Ton
Compressor	Hermitically Sealed Compressor	Screw Compressor
Discharge Pressure	10.2 bar	17.44 bar
Suction Pressure	0.2 bar	4.41 bar
Available Heat Recovery	0.6 KW	372 KW
ΔT Available	(10 to 15 °C)	(10°C)
Type of Condenser (HE)	Shell and Helical Tube Heat Exchanger	Air Cooled Condenser
Coefficient of Performance	2.94	1.41 (I.KW/TR)
Refrigerant	R134a	R22

Conclusion of Case Study:

1. If we go on increasing ΔT we have to reduce the water flow to the condenser, for that condenser size will increase.

2. If we want to reduce condenser size then we have to increase water flow rate, but in that case we will get less temperature difference.

3. That's why considering cost perspective in big refrigeration systems like water chiller plants the ΔT is kept fixed it means Water flow to condenser is also kept fixed.

X. CONCLUSIONS

In this work, a modified vapor compression refrigeration system was modelled by and performance parameters are predicted by plotting graphs. Following conclusions are

made on practical study of modified VCR system performance
1. The COP of water-cooled condenser system is greater than COP of air-cooled condenser system.
2. Problem of increase in surrounding temperature in case of air-cooled condenser is eliminated by trapping that heat into the water by the use of water-cooled Heat Exchanger.
3. When we use system at full load condition, It has been observed that COP of system increases by using water cooled condenser over air cooled condenser due to reduced compressor work.
4. As the mass flow rate of cooling water increases the rate of heat recovery also increases. At the same time with increase in the mass flow rate outlet temperature of water decreases.

XI. ACKNOWLEDGMENT

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