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Waste Heat Recovery System by Using Water Chamber in Between Compressor and Condenser

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Abstract*: Designing of research working-model combined with optimal utilization of waste heat by means of installing water-chamber amongst compressor and condenser. Vapour compression refrigeration system is most typically and domestic and as well large-scale approach to generating refrigerating effect. On the process, it rejects large of heat which is dumped to environment as waste product. The discarded heat could be utilized to operate any sort of low grade heat desired refrigerating device. The retrieved hot water could be utilized for domestic motive like heating water, laundering, bathing moreover to large scale industrial motive like processing, fabricating, diluting, incorporating water into product or else for sterilization and pasteurization essentials. This paper proposes and attain optimum utilization of waste heat recovery from VCR system that has nominal constructional, renovation and operating cost, substantially useful for domestic intent. The maximum Temperature recovered through water chamber is about 54.5□ in forced circulation condition, 51.1□ in with water condition and 42□ in case of without water. The maximum temperature observed is in forced water circulation condition when compared with without water and with water condition and achieved improvement in COP of about 68.83%. Conclusively, it will become alternative for water heater and so fulfils all the applications of hot water, which furthermore, could tackle the demand of LPG gas and electricity, thus, safer in environmental aspects.
***Keywords*: Refrigeration, Waste heat recovery, Energy saving, COP improvement, VCRS Cycle**

I. INTRODUCTION

Vapour compression refrigeration system is most typically and domestic and as well large-scale approach to generating refrigerating effect. In the fast-developing nation like India, the majority of the vapour compression-based refrigeration, air-conditioning and high temperature pumping devices continue to keep operate on halogenated refrigerants credited for their superb thermodynamic and thermo-physical properties aside from the low priced [1].

Heat generally travels downhill, right from a warm body to the cool one, until finally both bodies reach precisely the same temperature. On the process, it rejects large amount of heat which is actually dumped to environment as waste products. The rejected waste heat could possibly be utilized to run any low-grade heat required refrigerating system. The recovered hot water could be put to use for home purpose like heating water, bathing, washing in addition to large scale industrial purpose like fabricating, processing, diluting, incorporating water into product or perhaps for sterilization necessities [2].

Several studies had been performed on refrigeration systems meant for heat recovery, which were analysed in greater detail. Khan and Zubair [3] studied the functioning of the variable speed refrigeration system where the evaporator potential was changed simply by reforming the mass circulation pace on the refrigerant, whereas providing inlet cold temperature of the water as consistent. Slama et.al [4] discussed about the combining of the refrigerator to a cumulus to heat up water, which, the heat yielded towards standard of the condenser of the refrigerating system. Fatouh and Elgendy [5] evaluated the operation features of the vapour compression heat pump intended for concurrent space chilling and so hot water supply. Stalin et.al [6] demonstrated that the temperature of hot water, time needed for obtaining that temperature for the specified volume of water and the lowering of LPG gas by utilizing hot water. Kaushik et.al [7] dealt with the waste heat retrieval on the commercial refrigeration by featuring Canopus heat exchanger. They found that, generally, overall COP of the operational system is normally improved without affecting the actual performance of the system. Walawade et.al [8] studied "Waste heat recovery framework for residential refrigerator". An endeavour has been discovered from condenser of refrigerator to retrieve the heat. Yashwanth M. [9] proposed waste heat retrieval in R & AC System. Using one source from compressor they acquire 3 effective results i.e. warm water, cold water and air conditioning. Maurya & Awasthi [10] studied theoretical methodology towards usage of waste heat of a vapour compression refrigeration system. The discarded heat could possibly be utilized to perform any other low-grade heat needed refrigeration system such as simple ejector. Vedil et.al [11] discussed hypothetical strategy to collect the waste heat separated out of vapour compression cycle, which is used to control vapour absorption cycle. Shinde et.al [12] determined the energy savings concerning better utilization of waste heat from a residential refrigerator. Heat discarded by condenser is of low quality, so this means temperature is low. Varghese et.al [13] illustrated the practical feasibility of the heat recovery system to extract heat which is waste from the condenser exit of the refrigerator and use it for heating. Momin et.al [14] discussed the extraction of waste heat originating from condenser part of the house refrigerator to further improve the entire overall performance of the system. Xing et.al [15] developed model to estimate the efficiency of the cycle by utilizing R404A and R290, after which compared to that of standard cycle. Elumalai et.al [16] discussed about heat retrieval from the condenser on the Vapour Compression Refrigeration (VCR) system by using oven and heating unit that could be installed in middle of compressor and the condenser units. Ambarita et.al [17] discussed about the overall efficiency of garments drying chamber with utilizing the waste heat via split air-conditioner (RAC) had been performed. A drying chamber having a volume of 1m3 had been built and fabricated. Soni [18] developed ways to use waste heat coming from condenser of refrigerator. This system discarded less heat to the natural environment therefore it is safer in environmental attributes. Prasad [19] discussed heat transfer by convection in AC by changing the refrigerants are in accordance with CFD and thermal simulation. Roy and Mandal [20] carried out analysis by combining two standard systems by using a heat exchanger. Krishna, et. al [21] discussed condenser of the air conditioning unit which was attached with a co-axial copper pipe by means of a spiral coil and is linked to water tank via the pipes to heat up the water to be employed for residential purposes.

II. EXPERIMENTAL SETUP

A. Methodology and Experimental Facility

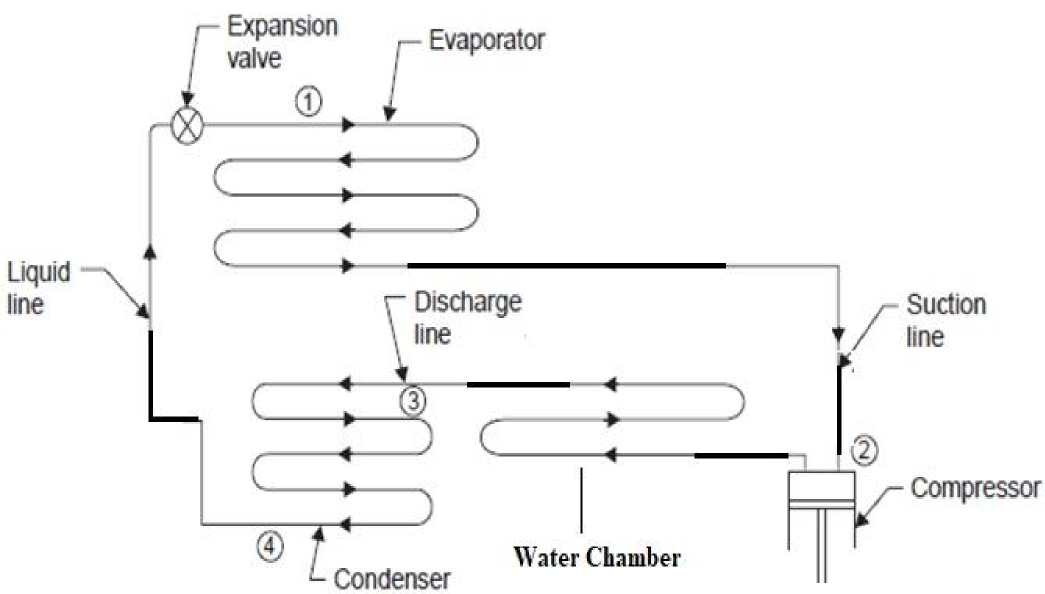

Fig. 1 Vapour Compression Refrigeration System with Water Chamber.

Highly insulated water gallon chamber with 4 litre capacities is introduced in the compressor exit. The high pressure high temperature vapour refrigerant is made to pass through the copper tube which is coiled inside the insulated water gallon chamber. Figure 1 shows the VCRS system with water chamber. The copper tube is highly insulated outside the chamber. By this the heat of the refrigerant is emitted only inside the water chamber and the waste heat is recovered and utilised for useful purpose. The pumping system is employed to circulate the water movement in water chamber intended for forced circulation experimentation and as well, digital thermometer is utilized for more accurate way of measuring of temperature for output and input. The observations were taken in SI unit with temperature in degree centigrade and time in minute and hour. The length for the condenser unit is 30 feet which are bend and formed in net shape so as to decrease the area. The hot chamber and evaporator chamber is made of plastic material which is insulated from inside, hence no heat escape to the surrounding environment. The presence of hole in the chambers is the copper pipe inlet and the hole at the top is the electrical wire inlet so as to pour the pump inside for forced water circulation condition.

B. List of Equipment's

The list of equipment's on which the experimental investigations were carried out is given in table 1.

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S.NO.	EQUIPMENT	TYPE/MATERIAL	SPECIFICATION
1	Refrigerator	Domestic Type	165 L, 365 Btu/hr
	1.compressor	Reciprocating Type	Model LG MA42LPJG
		Hermitically Sealed	1/8 HP, 160 Watt
			RPM- 2850
	2.Condenser	Copper, Sealed	30 Feet Length
	3.Evaporator	Copper, Air cooled Plate type	
2	Refrigerant	R-134A	100 Gram
3	Chamber	Hot chamber	Blue
		Cold Chamber	Yellow

Table 1 List of Equipment's

C. Experimental working model

Vapour compression refrigeration system model consists of two water highly insulated water gallon chamber of different colour (for difference purpose). The usage for the hot and cold chamber is same as that of used in domestic water storing. The colour of the equipment is used different for each, to distinguish between them. The yellow chamber is depicted as evaporator and blue as hot water chamber for our waste heat extraction. In similar way two pressure gauge shows discharge pressure and suction pressure which are in red colour and blue coloured respectively. Camera-ready Figure 2 shows the working model of VCRS (front view).

Fig. 2 Working VCRS working model (Front view)

D. Hot and Cold Chambers

Highly insulated water gallon chamber of 4 litre is used for the purpose hot water extraction shown in blue colour. the copper pipe coiled inside the chamber for maximum contact to water for maximum heat absorption. The hot chamber is fitted in between the compressor and condenser. The high pressurised high temperature vapour flow from compressor to water chamber, then to condenser. Camera-ready Figure 3 shows the hot chamber (blue colour).

Fig. 3 During the experiment- both chambers with no water

The ice is formed in the Evaporator and hot chamber being empty. The digital thermometer wire can be seen frosted. The ice formation is quick and result we can get is cold water whereas the hot chamber being hot, if poured water, the demand for hot water could be achieved. The camera-ready figure 4 shows the after-experiment condition with no water at hot chamber.

Fig. 4 After the experiment- without no water at Hot chamber

E. Modification in Recovery Setup

1) Highly insulated chamber with 4 litres capacity is installed in the compressor outlet.
2) The high pressure high temperature vapour refrigerant is made to pass through the copper tube which is coiled inside the chamber.
3) The copper piping is certainly well insulated outside of the chamber.
4) The heat of the refrigerant is emitted only inside the chamber and waste heat is recovered and utilized for useful purpose.

III. EXPERIMENTAL INVESTIGATION

Experiment is plotted on temperature vs time graph for evaporator and hot water chamber which include without water condition, with water and forced circulation condition. The experiment was taken for about 3 hours in same temperature of about 33 on consecutive 3 days.

The maximum temperature had been extracted in hot water chamber which otherwise could go waste in environment. And the respective pressure also measured for the same interval at same point of time. The following 3 cases had been investigated.

A. *CASE I: Pressure and Temperature for Without Water Condition*

Pressure and Temperature measured for without water condition. The hot chamber placed between compressor outlet and condenser is emptied. The reading is noted and constructed into 20-minute time duration gap, thus it shows the proper variation and comparison between temperature and time. The observations are given in as below table 2.

	WITHOUT WATER										
S.NO.	TIME	01:20	01:40	02:00	02:20	02:40	03:00	03:20	03:40	04:00	04:20
1	PCD	21.4	30.4	30.4	30.4	31.4	31.4	32	32	31.2	31
2	PCS	11	9.4	9.4	9.4	9.6	9.6	9.6	9.5	9.5	9.5
3	TWC	31.4	38.5	38.5	38.5	45.6	41	43.5	43.8	43	42
4	TEVP.	29.1	21.9	21.9	21.9	3.7	1.8	0.3	-1.5	-3.7	-5.5

Table 2 Pressure and temperature for without water

The effect of temperature on time is shown in figure 5, to clearly visualize and compare the effect of temperature on time in water chamber and evaporator in without water condition.

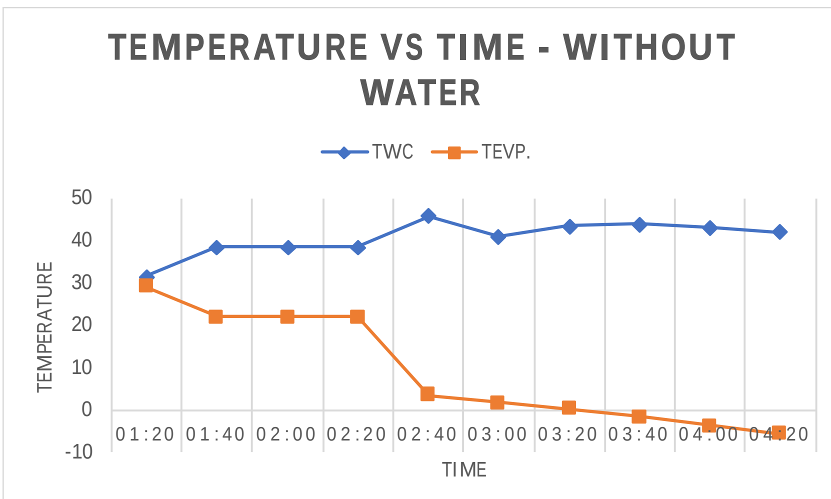

Fig. 5 Comparison between evaporator temp.and water chamber temp. vs time graph- without water

B. *CASE II: Pressure and Temperature for With Water Condition*

Pressure and Temperature measured for with water condition. The pressure variation at the discharge and suction is also measured simultaneously with the temperature variation for the same duration of time. The observations are given in as below table 3.

	WITH WATER										
S.NO.	TIME	01:20	01:40	02:00	02:20	02:40	03:00	03:20	03:40	04:00	04:20
1	PCD	21.3	28.3	29.4	30	30.5	31	31	31	31	31
2	PCS	11.2	9	9.2	9.4	9.5	9.5	9.5	9.5	9.5	9.5
3	TWC	30.1	35.6	40.6	44.2	46.7	48.6	49.6	50.2	50.8	51.1
4	TEVP.	29.7	15.5	6.5	3.8	4.1	4.1	2	1.4	0.1	-0.9

Table 3 Pressure and temperature for with water

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The Effect of temperature on time is shown in figure 6, to clearly visualize and compare the effect of temperature on time both in water chamber and evaporator for with water condition.

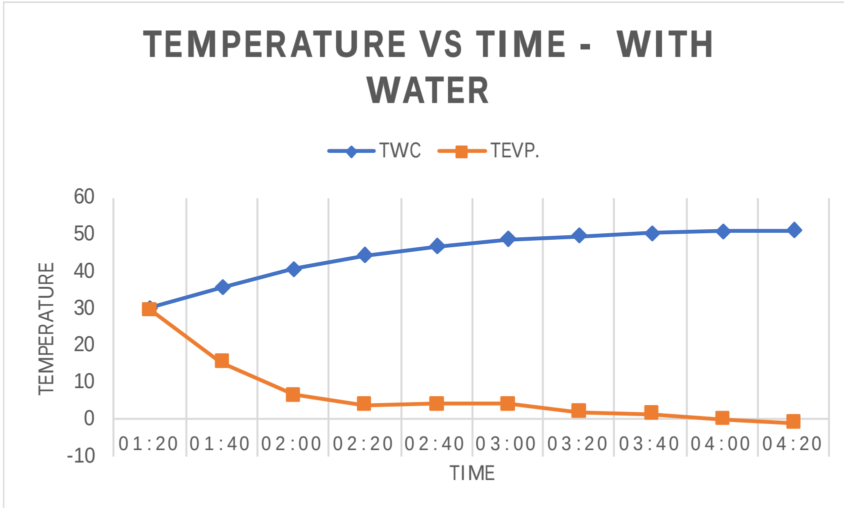

Fig. 6 Comparison between evaporator temp. and water chamber temp. vs time graph- with water

C. CASE III: Pressure and Temperature for Forced Circulation

Pressure and Temperature measured for forced circulation condition. The pressure variation at the discharge and suction is also measured simultaneously with the temperature variation for the same duration of time. The observations are given in as below table 4.

	FORCED CIRCULATION										
S.NO.	TIME	01:20	01:40	02:00	02:20	02:40	03:00	03:20	03:40	04:00	04:20
1	PCD	21.2	27.8	28.8	30.2	31	31.6	31.6	32.2	31.2	32.4
2	PCS	11.2	9	9.2	9.4	9.5	9.5	9.5	9.5	9.5	9.5
3	TWC	30.2	34.5	39.2	44	47.3	49.5	51.1	52.3	53.6	54.5
4	TEVP.	30.1	23.8	15.9	3.8	3.2	2.1	1.1	0.1	-1.6	-2.7

Table 4 Pressure and temperature for forced circulation

The effect of temperature on time is shown in figure 7, to clearly visualize and compare the effect of temperature on time both in water chamber and evaporator for forced water circulation condition.

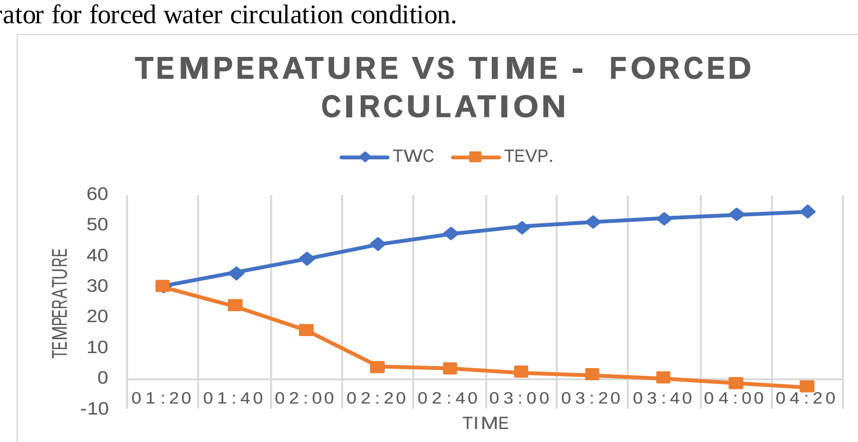

Fig. 7 Comparison between evaporator temp. and water chamber temp. vs time graph- forced circulation.

IV. EXPERIMENTAL INVESTIGATION

A. *Temperature Comparison*

1) Temperature in hot chamber was measured for all the 3 situations i.e. without water, with water and forced circulation case. And graph had been plotted respectively. The comparison provides the insight to distinguish from between cluster of choices. Table 5 shows the water chamber temperature comparison.

		WITHOUT WATER	WITH WATER	FORCED CIRCULATION
S.NO.	TIME	Twc	Twc	Twc
1	01:20	31.4	30.1	30.2
2	01:40	38.5	35.6	34.5
3	02:00	38.5	40.6	39.2
4	02:20	38.5	44.2	44
5	02:40	45.6	46.7	47.3
6	03:00	41	48.6	49.5
7	03:20	43.5	49.6	51.1
8	03:40	43.8	50.2	52.3
9	04:00	43	50.8	53.6
10	04:20	42	51.1	54.5

Table 5 Water Chamber temperature comparison

The Graphical representation is given in figure 8 between temperature and time to clearly visualize and compare the effect of temperature on time in water chamber in without water, with water and forced water circulation condition. The maximum temperature attained is in forced water circulation condition of about 54.5□.

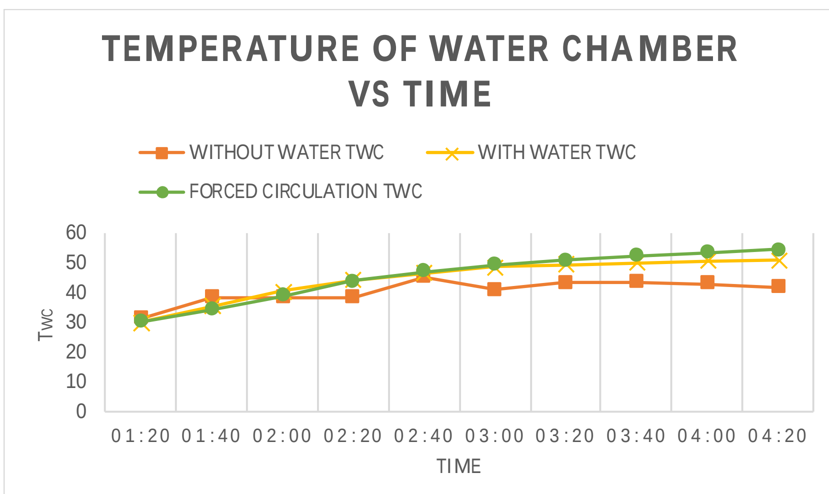

Fig. 8 Temp. of water chamber vs Time graph

2) Temperature in evaporator chamber was measured for all the 3 situations i.e. without water, with water and forced circulation case. And graph had been plotted respectively. Table 6 shows the evaporator temperature comparison.

		WITHOUT WATER	WITH WATER	FORCED CIRCULATION
S.NO.	TIME	Tevp.	Tevp.	Tevp.
1	01:20	29.1	29.7	30.1
2	01:40	21.9	15.5	23.8
3	02:00	21.9	6.5	15.9
4	02:20	21.9	3.8	3.8
5	02:40	3.7	4.1	3.2
6	03:00	1.8	4.1	2.1
7	03:20	0.3	2	1.1
8	03:40	-1.5	1.4	0.1
9	04:00	-3.7	0.1	-1.6
10	04:20	-5.5	-0.9	-2.7

Table 6 Evaporator temperature comparison

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The Graphical representation is given in figure 9 between temperature and time to clearly visualize and compare the effect of temperature on time in Evaporator in without water, with water and forced water circulation condition. The maximum refrigerating temperature attained is in without water condition of about -5.5□.

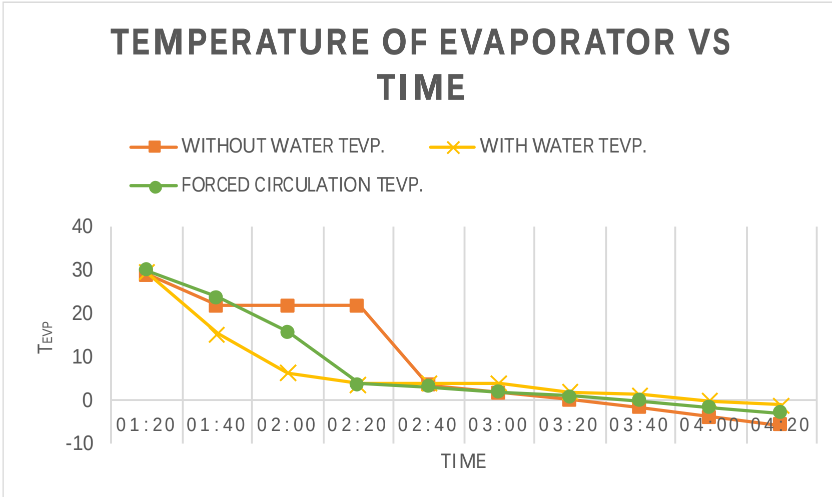

Fig. 9 Temperature of evaporator vs Time Graph

B. Performance Comparison

1) Theoretical co-efficient of overall performance designed for the refrigeration cycle had to be determined for all the three instances. Table 7 shows the COP comparison for refrigeration cycle.

S.NO.			02:40	03:00	03:20	03:40	04:00	04:20
1	WITHOUT WATER	COPREFRIGERATION	6.603819	7.010204	6.326389	5.993377	5.766595	5.631579
2	WITH WATER	COPREFRIGERATION	6.504695	6.226966	5.777311	5.622951	5.386588	5.232692
3	FORCED CIRCULATION	COPREFRIGERATION	6.263039	5.803797	5.482	5.231801	4.916667	4.725524

Table 7 COP comparison for refrigeration cycle

The effect of Refrigeration COP and time is shown in figure 10, to clearly visualize and compare the effect of Refrigerating COP on time in water chamber in without water, with water and forced water circulation condition.

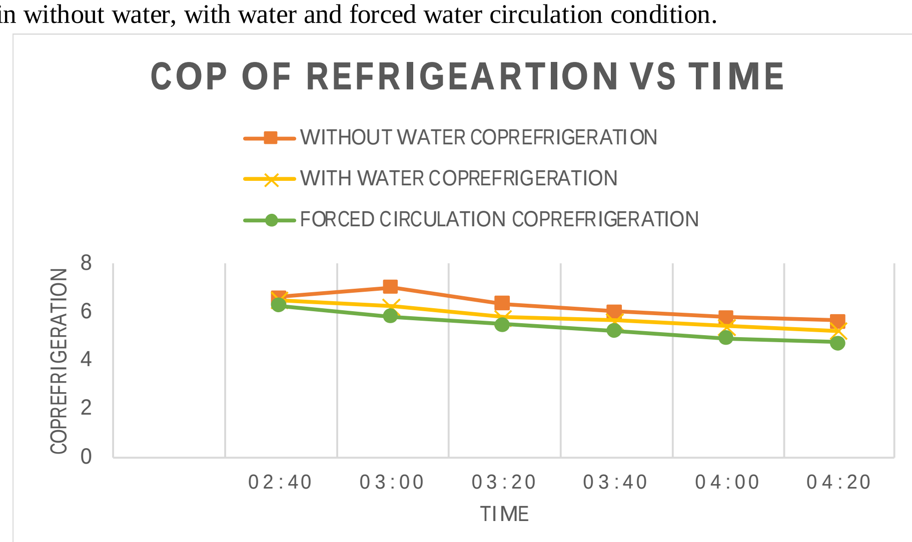

Fig. 10 COP of refrigeration vs time - all three cases comparison

2) Theoretical co-efficient of overall performance designed for the heat pump has to be determined for all the three instances i.e. without water, with water and forced water circulation condition. The COP for heat pump is unity more than the refrigeration. This comes from the formula which details that COP of heat pump is equals to sum of COP of refrigeration and unity. Table 8 shows the COP comparison for refrigeration cycle.

S.NO			02:40	03:00	03:20	03:40	04:00	04:20
1	WITHOUT WATER	COPHEAT PUMP	7.603819	8.010204	7.326389	6.993377	6.766595	6.631579
2	WITH WATER	COPHEAT PUMP	7.504695	7.226966	6.777311	6.622951	6.386588	6.232692
3	FORCED CIRCULATION	COPHEAT PUMP	7.263039	6.803797	6.482	6.231801	5.916667	5.725524

Table 8 COP comparison for Heat pump

The effect of Heat Pump COP and time is shown in figure 11, to clearly visualize and compare the effect of Heat Pump COP on time in water chamber in without water, with water and forced water circulation condition.

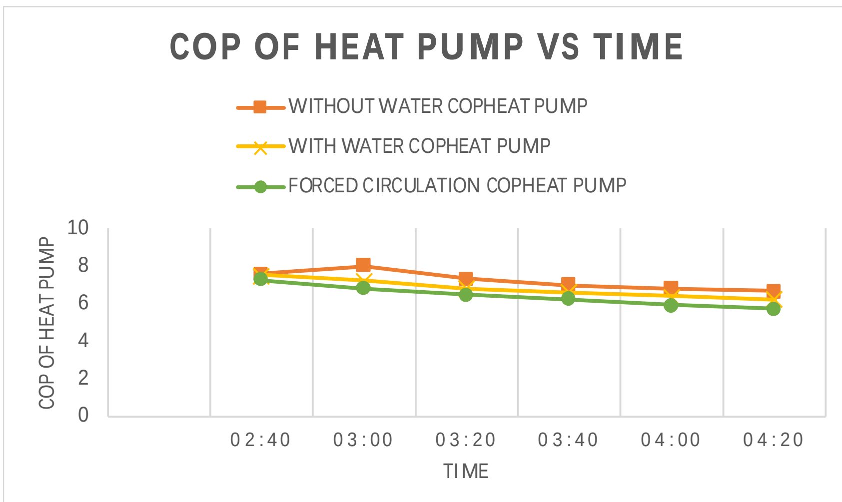

Fig. 11 COP of heat pump vs time - all three cases comparison

V. CALCULATIONS

Actual Cop of System:
For 165 Litre Capacity of Refrigeration,
Refrigerator Cooling Capacity (Amount of Refrigeration Generated or Heat Extracted/removed in Refrigerator)

= 365 Btu/hr
= 92 kcal/hr
= (92 × 4.184 ×1000)/3600
= 107 W

Power Needed for Operating the Compressor (Work Upon Refrigerant)

= 1/8 HP
= 1/8×746
= 93.25 W

COP_{ACTUAL} = (Heat Extracted in Refrigerator)/ (Work done by Compressor)

= 107/93.25
= 1.14

Details of Experimentation:
Initial Temp = 30.2□

Final Temp = 54.5

Time Required for Reading Δt = 180 min

Mass of Water in Chamber = 4 kg

Specific Heat of Water, CP = 4.184 KJ/kg K

Heat Absorbed by Water, Q = $(m \times C_P \times \Delta T)/\Delta t$

= (4 × 4.184 × (54.5-30.2))/ (180 × 60)

= 37.656 J/s

Heat Retrieval Obtained, Q = Heat Soaked up by Water

= 37.656 J/s

Improvement in Cop:

Condensers heat is employed, and it is also component to compressor work. The denominator on formula will certainly decrease in value. Therefore, COP of system will enhance.

$COP_{IMPROVED}$ = (Heat Extracted in Refrigeration)/ (Work done by Compressor - Heat Recovery Achieved)

= 107/ (93.25-37.656)

= 1.92467

Improvement in COP = $(COP_{IMPROVED}-COP_{ACTUAL})/COP_{ACTUAL} \times 100$

= (1.92467-1.14)/1.14×100

= 68.83 %.

VI. RESULTS

As far as from the experiments, calculations and comparisons made, the following results were attained:

A. The maximum Temperature recovered through water chamber is about 54.5 in forced circulation condition, 51.1 in with water condition and 42 in case of without water.

B. The maximum temperature observed is in forced water circulation condition when compared with without water and with water condition.

C. The improvement in COP is about 68.83%.

VII. CONCLUSION

"Waste heat recovery system" is an excellent tool to conserve available energy. An attempt is made to retrieve the waste heat from 165 L refrigerator utilized for domestic purpose, which in turn later on could be employed in large scale production and as well, removal from private and commercial refrigeration system. It is perceived that by installing water chamber in between compressor and condenser, will utilize the maximum heat emitted to atmosphere for heating the food particles and also for heating the drinking water. By this system the power consumption and LPG consumption in a house for heating food items and water can be reduced. Effective heat retrieval system could be formulated and designed for each and every household and industrial refrigeration system. In the event this could be commenced from individual level then it can sum up and massive influence can be acquired. Therefore, with small addition in expense if we retrieve and as well, using again the waste heat, in that case undoubtedly, we can easily advance towards energy preservation and as well, at the same time accomplish our daily function. In present scenario, just where everybody at home is moving out, this combination of refrigerator and as well, food warmer is surely a boom to efficient house wife.

VIII. ACKNOWLEDGMENT

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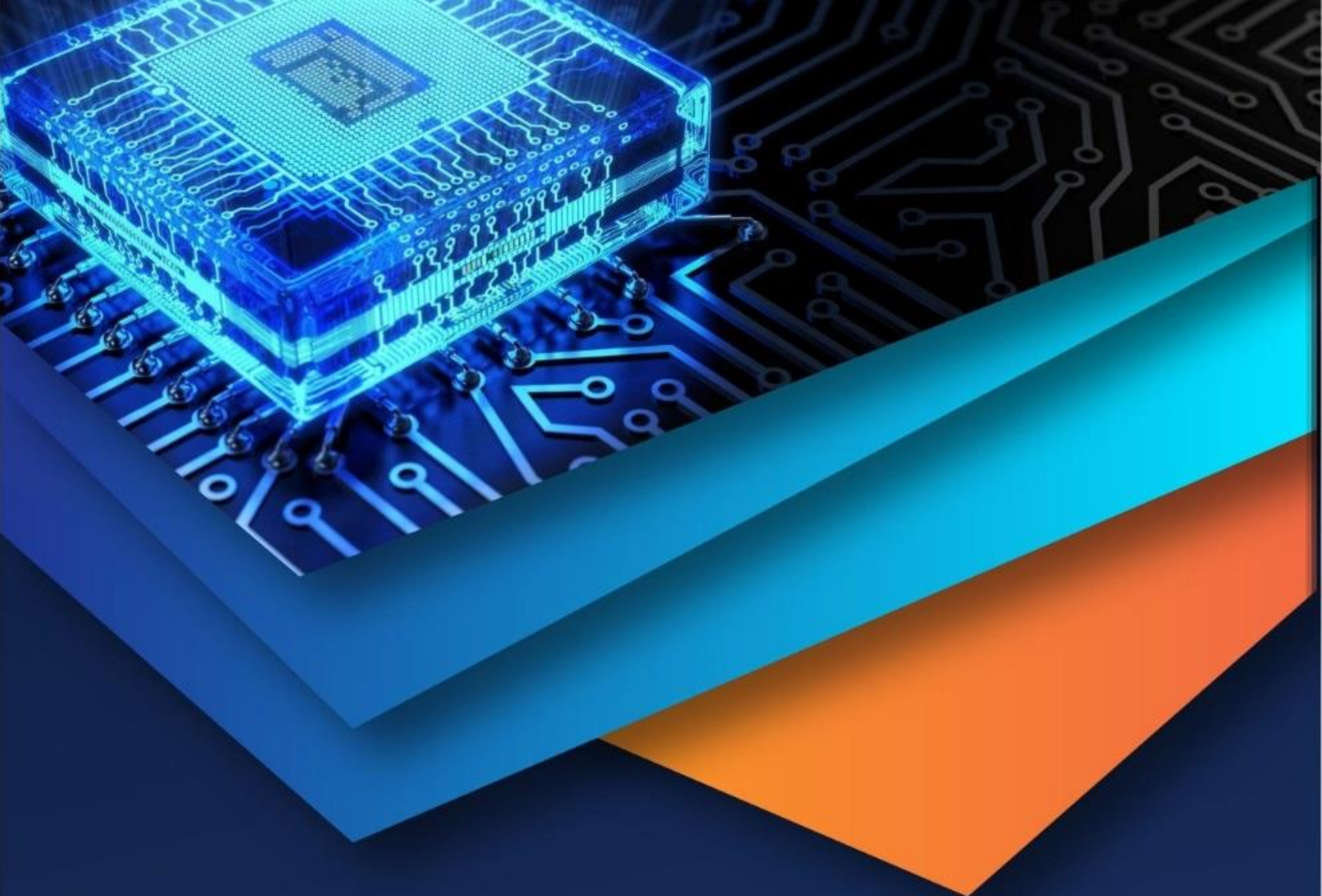

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