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Research Article

Experimental Study of Waste Heat Recovery through Refrigeration System

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Abstract

Energy crisis all over the world compelled us to take necessary steps to reduce energy consumption. Heat is energy, so energy saving is one of the key matters from view point of use of refrigerants and for the protection of global environment This waste heat will affect the environmental conditions because as heat in the environment will increases it will cause global warming and also not good for our ozone layer too. By saving energy we balance the demand & supply of electricity. So it is necessary that a significant and concrete effort should be made for conserving energy through waste heat recovery system. We have tried to make a cabinet to recover waste heat from condenser from refrigeration system by storing a heat in an insulated cabinet. As domestic refrigerators reject large heat inside room which make us uncomfortable in summer due to temperature rise inside the room. So it is now essential to reject this heat outside the room or utilize it for different purposes. Rejected heat is used for keeping food hot, heating water which may be used for different purposes. It is valuable alternative approach to improve overall efficiency and reuse the waste heat. The study has shown that such a system is technically feasible and economically viable. This system is nothing but a cabin that we are going to install over the head of the simple evaporator cabin, this cabin will be an arrangement of coils that will store heat which is get eliminated in the atmosphere. These coils are a hot coil of condenser which is wound under the mild steel cabin and will braze with the filter and the evaporator coil which is insulated and fitted in evaporator cabin. It can serve the purpose of cooking (oven), geysers etc. This system rejected less heat to the environment so it is safer in environmental aspects and store large amount of heat in the cabin.

Keywords: *Waste Heat Recovery, Vapour Compression System, Refrigerator, Air Cooled Condenser, Saving Energy.*

1. Introduction

Whenever a temperature gradient exists within a system, or whenever two systems at different temperatures are brought into contact, energy is transferred. The process by which the energy transport takes place is known as heat transfer. All heat transfer processes involve the exchange and/or conversion of energy. They must, therefore, obey the first as well as the second law of thermodynamics. Heat transfer is a basic and very important topic that deals with energy and has long been an essential part of mechanical engineering curricula all over the world. Heat transfer processes are encountered in a large number of engineering applications such as heat recovery systems. It is essential for mechanical engineers to understand the principles of thermodynamics and heat transfer and be able to use right equation that govern the amount of energy being transferred.

The aim of this study is to design, construct and evaluate dual refrigeration system by manufacturing an experimental apparatus of heat recovery system from the condenser. Although studies have been done before on dual refrigeration systems, more research could be done to further enhance the results obtained by experimenting using different sets of working pair's material and testing them in different conditions and shape and sizes. For example, in experimentation with waste heat recovery system (WHRS) in refrigeration unit, Kaushik and Singh in 2015 have found that 40% of condenser heat can be recovered through the Canopus heat exchanger for typical set of operating conditions in a dual refrigeration system. (P. Elumalai, R. Vijayan, K. Ramasamy and M. Premkumar, *et al*, 2015).

To generate ice, the evaporator temperature must be< 0 ^{o}c. The above system could generate a COP of about 1.2 to 1.4 and in this study the aim of maintaining the COP more than or equal to 1. The main aim is to increase the COP of system by utilizing energy. When the condenser heat is utilized, COP of system will boost up (S. C. Walawade, B.R. Barve, P. R. Kulkarni, *et al*, 2014).

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While eating food in colleges/office every buddy need water cold and Tiffin hot, but we are not gating it. In offices we usually use microwave for heating food, for that we are using electricity i.e. heat energy, similarly for cooling water we are using refrigerator of water cooler in that case we are wasting heat energy from condenser. For both microwave and condenser we are paying electricity. We also have to find what temperature can be generating in the condenser and evaporator so that which foods can be warmed or cooled in the system. This study proves to utilize a combined system rather than a single system, where cooling and heating could be produced continuously in places far away from conventional grid. Most rural and urban area may benefit from this system in years to come.

2. Objective

The objective of this project is to utilize an alternative eco-friendly refrigerant for producing a temperature usually encountered in a conventional refrigerator. By manufacturing such type of dual refrigerator adds new dimension to the world of refrigeration and oven. This dual refrigerator waste heat recovery system gives some amount of relief to the electricity consumption by making it independent on same electric power supply to the compressor and utilize that power to get in cooling as well as heating or keep the food or water warm.

3. Energy Conservation in Refrigerator

A household refrigerator is a common household appliance that consists of a thermally insulated compartment and which when works, transfers heat from the inside of the compartment to its external environment so that the inside of the thermally insulated compartment is cooled to a temperature below the ambient temperature of the room. In most cases, household refrigerator uses air-cooled condenser. Tetrafluoroethane (HFC134a) refrigerant was now widely used in most of the domestic refrigerators and automobile air- conditioners and are using POE oil as the conventional lubricant. Generally, heat from the condenser side is dissipated to room air. If this heat is not utilized, it simply becomes waste heat (K. Sreejith, T. R. Sreesastha Ram, V. J. Mossas, M. J. Nidhin, E.S. Nithil, *et al* 2016).

Refrigerator has become an essential commodity rather than need. Very few of us are aware about the fact that lot of heat is wasted to ambient by the condenser of refrigerator. If this energy can be utilized effectively then it will be an added advantage of commodity our project aims towards the same goal.

Refrigerator in simple language is removal of heat from the place where it is objectionable and dissipation of heat to the place where it is not objectionable. The working process of the refrigerator is explained as below. The systematic diagram of the refrigerator a nd its various parts is as shown below:

Compressor

The compressor is the heart of the refrigerator. The input power that is electricity is used to run the compressor.The compressor compresses the refrigerant (R-12 or R 22) which is in the gaseous form to increase its pressure and temperature. The capacity(tons) of the refrigerator decides the power input to the compressor.

Condenser

The main purpose of condenser is to transfer the heat generated in refrigerant during the compression process. The temperature of the refrigerant entering in condenser is about 400-600c depending input power of compressor. The atmospheric temperature is about 250-300c. Due to such large temperature difference heat transfer takes place from condenser to atmosphere. That means this heat is wasted to atmosphere.

Expansion tube /valve

A capillary tube (small bore copper tube) is used to reduce pressure of refrigerant from condenser to evaporator pressure.

Evaporator

His part is placed at the freezer compartment. The working is same as the condenser. The refrigerant boiling in the evaporator tubes takes latent heat from surrounding and in turn cools the space

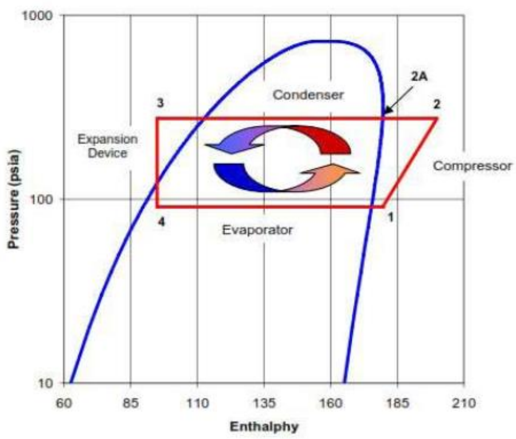

Fig.1 p-h Chart

By retro fitting a waste heat recovery system this waste heat can be recovered and can be utilised for water heating purpose. The hot water thereby produced can be used for several residential and commercial usages. The hot water can also be stored in a tank for later use. The modified system results in energy saving due to non-usage of electricity for heating the water and cost saving by combining both utilities (refrigeration and heating) in one system. The hot water which was obtained from the water-cooled condenser can be utilised for household applications like cleaning, dish washing, laundry, bathing etc. This heat is used to keep snacks and food warm, to heat the water which can be further used in health care centers, schools and industrial processes, to wash the cans in dairy by hot condensate, to dry clothes, grains etc. thereby saving significant amount of energy

In the days of power crisis much more importance should be given to power saving and energy conservation. Efforts being concentrated on finding the new resource of energy or method of saving energy. For example in automobile catalytic converter, in the same sequence we had developed the method to utilize the waste heat in domestic refrigerator. Our aim is have refrigerator and heating oven side by side without spending additional energy.

4. Literature Review

Developed a system that can recover heat from the condenser of the refrigerator. In this work air-cooled conventional condenser is replaced by another heat exchanger to heat water. The results show that water at a temperature of 60ºC was produced by the system. This paper also analyzed the economic importance of the waste heat recovery system from the energy saving point of view (Romdhane ben slama, *et al*, 2009).

Presented a case study on Super Heat Recovery Water and It can be concluded that the system, while operating under full load condition gives a better COP as compared to no load condition. Hence if the system continuously operates under full load, the COP can be improved. The heat absorbed by water has been observed to be highest during full load. The heat recovery technique, which can be applied to a refrigeration system, provides a compound air-cooling and water-cooling. The use of heat recovery system illustrates the improvement in COP and also the reduction in power consumption. The temperature difference obtained between the water inlet and outlet exceeds 10 0C. Thus a more optimum and efficient system can be built to give better results. The heat recovery module can thus be used in various refrigeration applications as well as in air conditioning (Shinde, V. Dhanal, *et al*, 2014).

Modified a domestic 190 liter refrigerator to recover the waste heat by installing a water tank containing the condenser coils of refrigerator. Experiment showed that maximum temperature increment was up to 40 degree centigrade. But major drawback with this type of arrangement was that it had no mobility and cannot be used for domestic purposes (Y. A. Patil and H. M. Dange, *et al*, 2013).

Discussed Heat Recovery System from the Condenser of a Refrigerator. The quantity of heat to be recovered from the condenser of a domestic refrigerator was theoretically calculated. It is in the range 375 Watt to 407 Watt. The quantity of heat recovered from the condenser of a domestic refrigerator I is found experimentally and found as 202 Watt to 410. This depends on the flow rate of water circulated. In this case the water flow rate range is wide. Therefore, there is a wide variation in the results. (N. B. Chaudhari, P. N. Chaudhar, *et al*, 2015).

Presents an attempt is made to recover the waste heat from 165 L refrigerator used for domestic purpose. As indicated in this paper, recovered heat can be utilized as food and snacks warmer, water heater, grain dryer. In the proposed system, the basic requirement is to utilize more and more energy (waste heat). For that purpose some calculations are made regarding size and length of condenser and then WHRS is designed. But after different discussions and calculations for heat transfer rates we approached to the final design of insulated cabin with compact construction and with reasonable cost. So as to extract more and more heat, we have mounted two sections of air cooled condenser one at bottom and one at top side of the insulated cabin. This whole assembly is placed on the top of the refrigerator. The main advantage of this design is that we can get maximum heat with minimum losses (S.C. Walawade, *et al*, 2014).

Recovered waste heat from condenser unit of a household refrigerator to improve the performance of the system by using a thermo siphon. It was found that after recovering heat from the condenser of the conventional refrigerator, its performance was improved than conventional refrigerator. The following experimental facility has been created. Highly insulated hot oven box and heater vessel with 5 litre capacity is installed in the compressor outlet. The control of water inlet to the heater vessel is done by float valve attached inside the chamber. The high pressure high temperature vapour refrigerant is made to pass through the copper tube which is coiled inside the hot oven and heater chamber. The copper tube is highly insulated outside the oven and heater with asbestos rope. Oven box is also fully insulated with foam or fiber wool to prevent loss of heat to atmosphere. By this the heat of the refrigerant is emitted only inside the hot oven and heater chamber and the waste heat is recovered and utilized for useful purpose (P. Elumalai, *et al*, 2015).

The experiment has shown that such a system is technically feasible and economically viable. This system rejected less heat to the environment so it is safer in environmental aspects. This is a system having the refrigerator that is running at normal running condition. And an insulate cabin over it that contains the copper coils and hot water sink. That cabin is a main part of the setup. Exhaust hot gas (134a) from the compressor is make pass through the quarter inches copper coil, which coil is fitted in the cabin and after being cool the gas is again returned to the compressor. This cooling is done directly by water in the form of water sprinkles from the water container that is at the top of the cabin, and that hot water is dropped and collected in the hot water sink and that sink have an exit nipple so we can get the water outside the cabin as per requirement (Lakshya Soni, Pawan Kumar & Rahul Goyal, *et al*, 2016).

They had designed fabricated and experimentally analysed a waste heat recovery system for domestic refrigerator. They had analysed the system at various load conditions (No load, 40 W load and 100W load). They also carried out the techno-economic analysis by comparing the waste heat recovery system with the conventional geyser. The refrigerator was of 165L capacity, single door, manufactured by Godrej. The system was retrofitted with a Waste Heat Recovery System (WHRS). WHRS is a single tube heat exchanger coiled around and over the air-cooled condenser and compressor and having an inlet for the cooling water and an exit for collecting the hot water. The modified household refrigerator was properly instrumented with digital thermometer, pressure gauges and digital energy meter (Sreejith K, T.R. Sreesastha Ram, V.J. Mossas, M.J. Nidhin, E.S. Nithil, *et al*, 2016)

4. Design

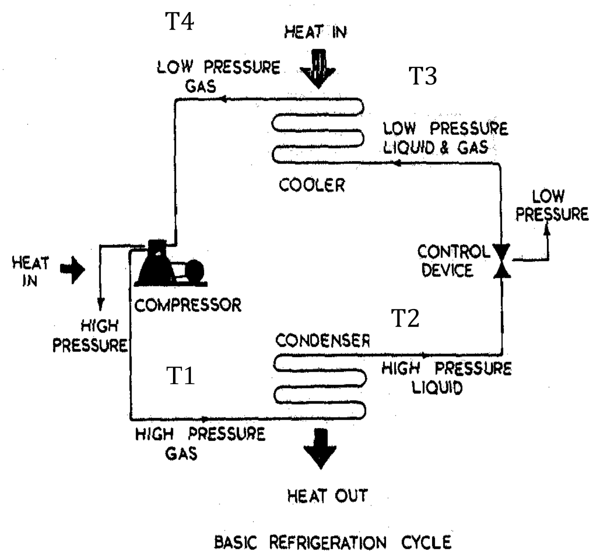

Fig.2 Representation of System Temperature

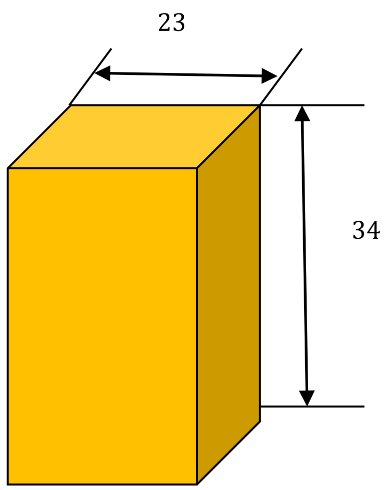

Fig.3 Outer Cabinets Dimension for Condenser & Evaporator

4.1 Selection of compressor

Power of compressor =125watt

20% of compressor power adds due to friction

Actual power of compressor = 1.2 * Power of Compressor

= 1.2 * 125

= 150 (watt)

4.2 Design of Condenser

Notation:

T_1= Temperature at inlet of Condenser tube = 59^0 C

T_2= Temperature at outlet of Condenser tube = 42^0 C

T_{atm} = Temperature of atmosphere = 30^0 C

We know that,

Q = U * A * ΔT

Where U =Overall heat transfer

Then,

ΔT= ((θi - θo)/ (ln (θi / θo)))

θi = T1 - Tatm

= 59-30

= 29 ^{0} C

θo = T2 - Tatm

= 42-30

= 12 ^{0} C

Put θi & θo in above equation, we get,

ΔT= (29-12)/ ln (29/12)

=19.26^0 C

Taking,

U=28 w/m^2 ^{0} C will be the best selection … (From Heat & Mass transfer handbook)

Now we are try to create such a box which have temperature above atmospheric. That means overall heat transfer increases for 10%

U = u * 1.1

= 28*1.1

= 31 w/m^2 ^{0} C

Therefore,

Q = U * A * ΔT

150 = 31*A * 19.26

:. A-contact = 0.2512 m^2

Now,

A-contact = Π * D tube * L tube

Take diameter of tube (quarter inch standard available) = 6.25 mm … (From gas charger & copper tube selection data reference)

0.2512 = Π*6.25* 10^{-3} * L tube

:. L tube =12.79 m

For design purpose,

:. L tube=13 m

Length of the copper tube obtained after calculation is 13m, we have purchased the 50ft length copper tube from the market.

Now Since,

L tube=Perimeter * number of turns

We know,

Box size = 230 x 340

Perimeter = (340 + 230) x 2 =1140 mm

Length of copper tube = perimeter* Number of turns

$13 = 1140 * 10^{-3} *$ Number of turns

:. Number of turns = 11.4

For design purpose,

:. Number of turns = 12

The number of turns obtained is 12 on the 1140mm perimeter box.

4.3 Design of Evaporator

Notation:

T_3 = Temperature at inlet of evaporator = ^{0} c

T_4 = Temperature at outlet of evaporator = ^{0} C

T_{atm} = temperature of atmosphere = ^{0} C

Now,

$$\theta i = T\ atm - T_3$$
$$= 30-(-11.7)$$
$$=41.7^0 C$$
$$\theta o = T\ atm - 3.4$$
$$= 30 - 3.4$$
$$=26.6^0 c$$

Then,

$\Delta T = ((\theta i - \theta o)/ (\ln (\theta i / \theta o)))$

$=41.7-26.6/ (\ln (41.7/26.6))$

$=33.58^0 C$

Therefore,

$Q = U * A * \Delta T$

Taking $U=16\ w/m^2\ {}^0C$ will be the best selection (from Heat &Mass transfer handbook)

Now we are try to create such a box which have temperature above atmospheric .That means overall heat transfer increases for 10%

$U= 16 * 1.1$

$= 18\ w/m^2\ {}^0C$

Therefore,

$Q = U * A * \Delta T$

$150 =18*A*33.58$

:. A contact = 0.2481 m^2

Now,

A contact = Π * D tube * L tube

$0.2481 = \Pi * 6.25* 10^{-3}$ * L tube

:. L tube = 8.53 m

Length of the copper tube obtained after calculation is 8.35m, we have purchased the 40ft length copper tube from the market.

Now Since,

L tube=Perimeter * number of tubes

We know,

Box size = 230 x 340

Perimeter = (340 + 230) x 2 =1140 mm

Length of copper tube = perimeter* Number of turns

$8.53 = 1140 * 10^{-3} *$ Number of turns

From this number of turns obtained,

Number of turns = 7.48

But by taking it round up value we obtained,

Number of turns = 8

By Design Of Condenser And Evaporator We Get The Length And Number Of Turn Of Copper Tube On The Inner Box Of The System. Illustrated in table given bellow:

Table 1 Specification of Length And Turn of Copper Tube From Above Calculation

S.No	Parameter	Evaporator	Condenser
1	Length of the copper tube	8.35m	13m
2	Number of turns	8	12

5. Fabrication And Assembly Work

5.1 Major Equipments and Parts

Since the concept gives brief idea about utilizing waste heat at domestic level, hence we have decided to manufacture two cabinets of capacity 15 liters each.

Parts are same as of domestic refrigerator as follows: Compressor, Capillary Tube, Filter and Evaporator cabin with insulation & Condenser cabin with Insulation. The insulated condenser cabin is a peripheral component which is used for utilizing the waste heat from refrigerator and another cabinet is for cooling effect generation. This insulated cabin is fabricated by using Mild Steel Sheets.

Table 2 Equipment's with Specifications

S. No	Equipment	Type/ Material	Specification/ Capacity
1.	Refrigerator a. Compressor b. Condenser c. Evaporator	Applicable for Domestic Type, Hermetically sealed Copper, Air cooled copper insulated cabin	15 lit 125W,disp.7.2cc/rev 13m,12 turns 8.35m,8 turns
2.	Refrigerant	R134a	1.5 KG
3.	Insu. Cabin a. Outer Box b. Inner box c. Door d. Insulation	Mild Steel Cabin M.S M.S M.S Thermocol	 23cm x 30cm x 34cm 18cm x 27cm x 29cm 26cm x 03cm x 24cm Thickness:3.5cm

5.2 Fabrication of Insulated Cabin

1) Material Used: Mild Steel Sheet.
2) Process used: Sheet metal forming.

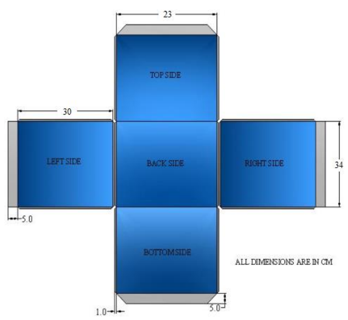

Fig.4 Outer Box of Cabin

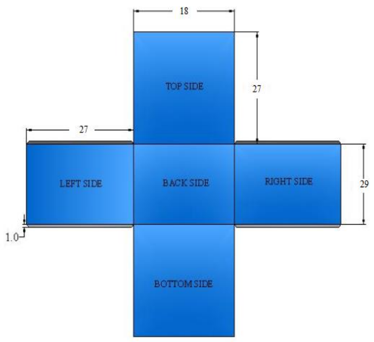

Fig.5 Inner Box of Cabin

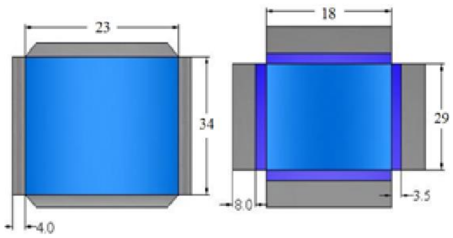

Fig.6 Door of Cabin

5.3 Fabrication of Cabin

Design and Development of Waste Heat Recovery System from Vapour Compression Refrigeration System by forming two cabinets with insulated chamber filled with copper tube of 50ft long.

1) Inner box and outer box of insulated cabin are made up of Mild Steel Sheet. After defining dimensions, sheet metal working is performed. The cabin is painted by silver color.
2) Insulation material, here Thermocol is used for insulation purpose and it is of 3.5cm thickness.
3) After forming all parts of cabin it is assembled in well manner.

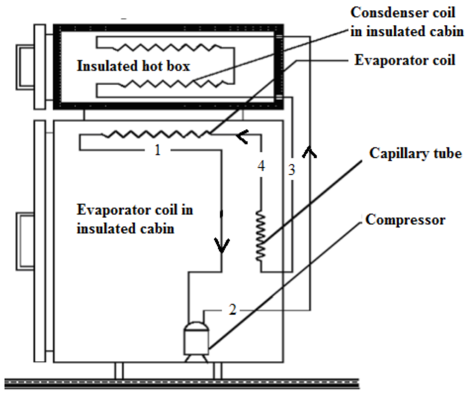

Fig.7 Actual Proposed Waste Heat Recovery System

6. Experiment

Air cooled condenser is used in present domestic refrigerator. In proposed work air cooled condenser replaced by condenser coil inside insulated hot box. New condenser design is essential so following theoretical work is essential (A. M. Vibhute, Avinash M. Patil; 2015):

1) To calculate theoretical condenser effectiveness for as per experimental work with heat recovery.
2) To calculate theoretical coefficient of performance of existing refrigerator and proposed refrigerator.
3) To design condenser of proposed refrigerator for easy maintenance practices.
4) To determine required quantity of refrigerant in proposed refrigerator.
5) To prepare mathematical model for proposed refrigerator with waste heat recovery system.

Coefficient of performance and overall efficiency of both domestic refrigerators with air cooled condenser and with proposed insulated hot box condenser for waste heat recovery is compared, analyzed to determine energy efficient system. To determine heat recovered in insulated hot box of proposed waste heat recovery system of domestic refrigerator. Results of theoretical and experimental work are compared as follows (A. M. Vibhute, Avinash M. Patil; 2015):

1) Compare theoretical and actual condenser effectiveness of existing and proposed condenser.
2) Compare Coefficient of performance of existing domestic refrigerator (air cooled condenser) and proposed domestic refrigerator (with waste heat recovery system).
3) To determine energy efficient refrigerator from comparison of both present and proposed refrigerator.

6.1 Vapour compression system (VCS)

6.1.1 Analysis of Domestic Refrigerator (VCS)

Table 3 Compressor Inlet and Outlet Pressures

S.No	Parameters	Domestic Refrigerator kg/cm²	Proposed Refrigerator kg/cm²
1	Pcd	11.38	13.5137
2	Pci	1.38	1.00

Actual COP of System Based On Experimental data For Refrigerator of 165 liters capacity, given data from Kirloskar Ltd manual follows:

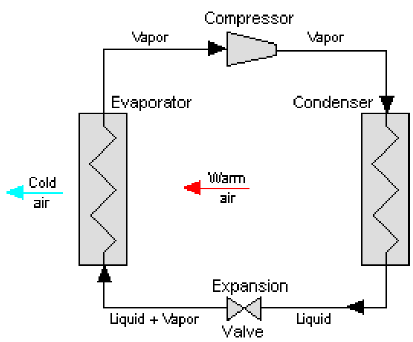

Fig.7 VCC System Systematic Diagram

1) Temperatures
   Compressor suction temperature $T_1 = 29.5\ ^0C$
   Compressor Discharge Temperature $T_2 = 72.2\ ^0C$
   Condensing Temperature $T_3 = 39.4\ ^0C$
   Evaporator Temperature $T_4 = 0.10\ ^0C$
2) Pressure
   Compressor Suction pressure $P_1 = 16.5$ psi
   Compressor Discharge Pressure $p_2 = 165$ psi
   Condensing Pressure $P_3 = 156$ psi
   Evaporator pressure $P_4 = 17$ psi
3) Convert all the pressure in to Bar.
   Conversion pressure Unit -1.psi = 0.069 bar
   P1 = 16.5 x 0.06 = 1.13 bar
   P2 = 165 x 0.069 = 11.38 bar
   P3 = 156 x 0.069 = 10.76 bar
   P4 = 17 x 0.069 = 1.173 bar
4) Current and Voltage
   Current = 1.1 Amps
   Voltage = 230 Volts
   From pressure enthalpy Chart for R-134a, enthalpy values at state points 1, 2, 3, and 4. The state points are fixed using pressure and temperature and each point.

6.1.2 COP of Domestic Refrigerator

h1 = 428.12 KJ/Kg
h2 = 451.98 KJ/Kg
h3 = 214.76 KJ/Kg
h4 = 395.01 KJ/Kg

These enthalpies are noted from the p-h chart of the concerned refrigerant:

1) The refrigerating effect is calculated as,
   Re = h1-h4 kJ/kg = 428.12- 395.01
   Re = 33.11 (kJ/kg) (1)
2) The work done per kg of refrigerant is given by,
   W= h2-h1 kJ/kg = 451.98- 428.12
   W= 23.86 (kJ/kg) (2)
3) The coefficient of performance is given by,
   COP = (Re/W)
   = (h1-h4/ h2-h1)
   = [(428.12- 395.01)/ (451.98- 428.12)]
   COP = 1.38 (3)
4) The coefficient of performance using Carnot cycle is given as,
   COP (Carnot) = (Te/ Tc-Te)
   COP = 7.08 (4)
5) Heat rejected from Condenser
   $= m_{refri} * (h2 - h3)$
   = 237.22 (5)

Table 4 COP of VCC System

S.No	Cycle	COP
1	Carnot Cycle	7.08
2	Bell- Colemn Cycle	4.96
3	Vapour Compression Cycle	1.38

6.2 Proposed Waste Heat Recovery System (WHRS)

Experimental setup consists of 30L working Capicity, Dual Refrigerator Waste Heat Recovery System. The refrigeration system is having a vertival cabinet. A cabinet is madse up of MS Sheet and fitted with a copper coil in an insulatesd cabin. A 2 cabinet has a volume of 15 lit each for testing.

Pressure gauge is fitted at the inlet and outlet of compressor to check the working pressure in the system. A temperature sensor set has been used to monitor various temperature encounteresd in the system. Symboles Usesd for Indicating Temperatures are listed below:

Table 5 indication of symbols

S.No	Symbol (^{0}C)	Component
1	T1	Evaporator temperature at outlet
2	T2	Condenser temperature at inlet
3	T3	Condenser temperature at outlet
4	T4	Evaporation temperature at inlet
5	T5	Condenser box temperature
6	T6	Evaporator box temperature
7	P1	Suction Pressur
8	P2	Discharge Pressure

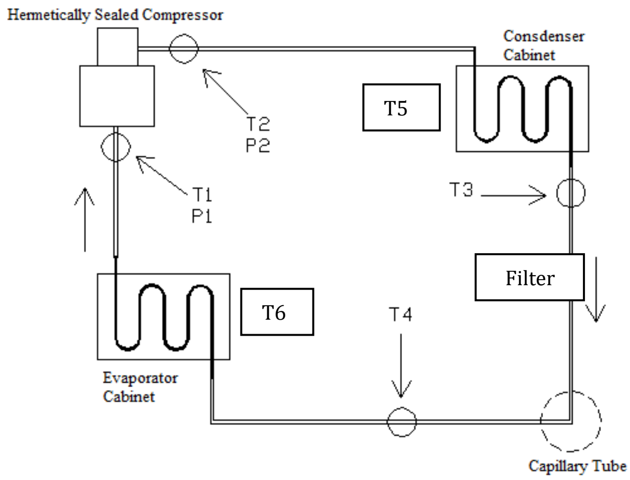

Fig.8 Experimental setup of proposed system

6.2.1 Analysis of Dual Refrigerator (WHRS) for 1st Experiment

For date: 3/05/2017

Time: 10:30 AM - 11:00 AM

Preassure at inlet of compressor: 1 bar

Preassure at outlet of compressor: 13.5137bar

Table 5 Data obtained from 1st Experiment

S. No.	Time	Cond. Temp. (I/P)	Cond. Temp. (O/P)	Evap. Temp. (I/P)	Evap.Temp. (O/P)	Cond. Box temp.	Evap. Box temp.
	(min)	T2 (◦c)	T3 (◦c)	T4 (◦c)	T1 (◦c)	T5 (◦c)	T6 (◦c)
1	0	34	34	34	34	34	34
2	5	43.4	43.1	2	21.3	35.8	31.2
3	10	47.2	44.3	-2.1	20.5	37.2	26.1
4	15	47.7	45	-2.8	19.8	38.6	22.1
5	20	48.4	46.1	-3.3	17.8	39.8	19.5
6	25	49.6	46.8	-3.6	17.4	41.1	16.7
7	30	52.5	50.4	-3.8	17.2	42.5	14.3

Actual COP of System Based on Experimental data for Proposed Dual Refrigerator of 30 liters capacity, this data came after the Experimentation are given bellow:

From pressure enthalpy Chart for R-134a, enthalpy values at state points 1, 2, 3, and 4. The state points are fixed using pressure and temperature and each point.

6.2.2 COP of Dual Refrigerator from 1st Experiment

For 1.2 Reading

h1 = 410.539 KJ/Kg
h2 = 421.298 KJ/Kg
h3 = 261.222 KJ/Kg
h4 = 399.550 KJ/Kg

These enthalpies are noted from the p-h chart of the concerned refrigerant:

1) The refrigerating effect is calculated as,
Re = h1-h4 kJ/kg
Re = 10.989 (kJ/kg) (9)

2) The work done per kg of refrigerant is given by,
W= h2-h1 kJ/kg
W= 10.759 (kJ/kg) (10)

3) The coefficient of performance is given by,
COP = (Re/W)
= (h1-h4/ h2-h1)
COP = 1.02 (11)

4) Heat rejected in Condenser
= m_{refri}* (h2 – h3)
= 160.08 (kJ/kg) (12)

For 1.3 Reading

h1 = 410.100 KJ/Kg
h2 = 422.848 KJ/Kg
h3 = 263.046 KJ/Kg
h4 = 396.611 KJ/Kg

These enthalpies are noted from the p-h chart of the concerned refrigerant:

1) The refrigerating effect is calculated as,
Re = h1-h4 kJ/kg
Re = 13.489 (kJ/kg) (13)

2) The work done per kg of refrigerant is given by,
W= h2-h1 kJ/kg
W= 12.748 (kJ/kg) (14)

3) The coefficient of performance is given by,
COP = (Re/W)
= (h1-h4/ h2-h1)
COP = 1.05 (15)

4) Heat rejected in Condenser
= m_{refri}* (h2 – h3)
= 159.802 (KJ/kg) (16)

For 1.4 Reading

h1 = 409.722 KJ/Kg
h2 = 423.043 KJ/Kg
h3 = 264.110 KJ/Kg
h4 = 396.672 KJ/Kg

These enthalpies are noted from the p-h chart of the concerned refrigerant:

5) The refrigerating effect is calculated as,
Re = h1-h4 kJ/kg
Re =13.05 (kJ/kg) (17)

6) The work done per kg of refrigerant is given by,
W= h2-h1 kJ/kg
W=13.321 (kJ/kg) (18)

7) The coefficient of performance is given by,
COP = (Re/W)
= (h1-h4/ h2-h1)
COP = 0.97 (19)

8) Heat rejected at Condenser
= m_{refri}* (h2 – h3)
= 158.933 (kJ/kg) (20)

For 1.5 Reading

h1 = 408.63 KJ/Kg
h2 = 423.312 KJ/Kg
h3 = 265.794 KJ/Kg
h4 = 396.37 KJ/Kg

These enthalpies are noted from the p-h chart of the concerned refrigerant:

9) The refrigerating effect is calculated as,
Re = h1-h4 kJ/kg

Re = 12.26 (kJ/kg) (21)

10) The work done per kg of refrigerant is given by,
W= h2-h1 kJ/kg
W=14.68 (kJ/kg) (22)

11) The coefficient of performance is given by,
COP = (Re/W)
= (h1-h4/ h2-h1)
COP = 0.83 (23)

12) Heat rejected in Condenser
= m_{refri}* (h2 – h3)
= 157.518 (kJ/kg) (24)

For 1.6 Reading

h1 = 408.410 KJ/Kg
h2 =423.768 KJ/Kg
h3 = 266.872 KJ/Kg
h4 = 396.190 KJ/Kg

These enthalpies are noted from the p-h chart of the concerned refrigerant:

13) The refrigerating effect is calculated as,
Re = h1-h4 kJ/kg
Re =12.22 (kJ/kg) (24)

14) The work done per kg of refrigerant is given by,
W= h2-h1 kJ/kg
W=15.358 (kJ/kg) (25)

15) The coefficient of performance is given by,
COP = (Re/W)
= (h1-h4/ h2-h1)
COP = 0.79 (26)

16) Heat rejected in Condenser
= m_{refri}* (h2 – h3)
= 156.896 (kJ/kg) (27)

For 1.7 Reading

h1 = 408.300 KJ/Kg
h2 =424.785 KJ/Kg
h3 = 273.461 KJ/Kg
h4 = 396.070 KJ/Kg

These enthalpies are noted from the p-h chart of the concerned refrigerant:

17) The refrigerating effect is calculated as,
Re = h1-h4 kJ/kg
Re = 12.230 (kJ/kg) (28)

18) The work done per kg of refrigerant is given by,
W= h2-h1 kJ/kg
W= 16.485 (kJ/kg) (29)

19) The coefficient of performance is given by,
COP = (Re/W)
= (h1-h4/ h2-h1)
COP = 0.74 (30)

20) Heat rejected in Condenser
= m_{refri}* (h2 – h3)
= 152.324 (KJ/Kg) (31)

6.2.3 Analysis of Dual Refrigerator (WHRS) for 2nd Experiment

For date: 4/05/2017
Time: 12:30 AM - 1:00 AM
Preassure at inlet of compressor: 1 bar
Preassure at outlet of compressor: 13.5137bar

Table 4 Data obtained from2nd Experiment

S. No.	Time	Cond. Temp. (I/P)	Cond. Temp. (O/P)	Evap. Temp. (I/P)	Evap. Temp. (O/P)	Cond. Box temp.	Evap . Box temp.
	(min)	T2 (◦c)	T3 (◦c)	T4 (◦c)	T1 (◦c)	T5 (◦c)	T6 (◦c)
1	0	33	33	33	33	33	33
2	5	41.4	37.8	2.2	30.6	35.7	30.6
3	10	44.1	40.2	-1.3	24.3	38.2	27.2
4	15	48.3	43.2	-2.3	22.2	40.3	19.8
5	20	49.5	44.9	-4.1	21.5	42.4	16.2
6	25	51.6	46.2	-6.9	20.9	44.6	14.6
7	30	54.2	47.6	-7.7	20.6	46.8	12.2

Actual COP of System Based on Experimental data for Proposed Dual Refrigerator of 30 liters capacity, this data came after the Experimentation are given bellow: From pressure enthalpy Chart for R-134a, enthalpy values at state points 1, 2, 3, and 4. The state points are fixed using pressure and temperature and each point.

6.2.4 COP of Dual Refrigerator from 2nd Experiment

For 2.2 Reading

h1 = 415.120 KJ/Kg
h2 = 420.442 KJ/Kg
h3 = 253.254 KJ/Kg
h4 = 399.668 KJ/Kg

These enthalpies are noted from the p-h chart of the concerned refrigerant:

21) The refrigerating effect is calculated as,
Re = h1-h4 kJ/kg
Re = 15.452 (kJ/kg) (36)

22) The work done per kg of refrigerant is given by,
W= h2-h1 kJ/kg
W= 5.322 (kJ/kg) (37)

23) The coefficient of performance is given by,
COP = (Re/W)
= (h1-h4/ h2-h1)
COP = 2.90 (38)

24) Heat rejected in Condenser
= m_{refri}* (h2 – h3)
= 167.188 (KJ/kg) (39)

For 2.3 Reading

h1 = 412.139 KJ/Kg
h2 = 421.592 KJ/Kg
h3 = 256.842 KJ/Kg
h4 = 398.130 KJ/Kg

These enthalpies are noted from the p-h chart of the concerned refrigerant:

25) The refrigerating effect is calculated as,
Re = h1-h4 kJ/kg
Re = 14.009 (kJ/kg) (40)

26) The work done per kg of refrigerant is given by,
W= h2-h1 kJ/kg
W= 9.453 (kJ/kg) (41)

27) The coefficient of performance is given by,
COP = (Re/W)
= (h1-h4/ h2-h1)
COP = 1.48 (42)

28) Heat rejected Condenser
= m_{refri}* (h2 – h3)
=164.750 (KJ/kg) (43)

For 2.4 Reading

h1 = 411.018 KJ/Kg
h2 = 423.274 KJ/Kg
h3 = 261.374 KJ/Kg
h4 = 396.977 KJ/Kg

These enthalpies are noted from the p-h chart of the concerned refrigerant:

29) The refrigerating effect is calculated as,
Re = h1-h4 kJ/kg
Re = 14.041 (kJ/kg) (44)

30) The work done per kg of refrigerant is given by,
W= h2-h1 kJ/kg
W= 12.256 (kJ/kg) (45)

31) The coefficient of performance is given by,
COP = (Re/W)
= (h1-h4/ h2-h1)
COP = 1.14 (46)

32) Heat rejected in Condenser
= m_{refri}* (h2 – h3)
= 161.900 (KJ/kg) (47)

For 2.5 Reading

h1 = 410.645 KJ/Kg
h2 = 423.730 KJ/Kg
h3 = 263.958 KJ/Kg
h4 = 395.889 KJ/Kg

These enthalpies are noted from the p-h chart of the concerned refrigerant:

33) The refrigerating effect is calculated as,
Re = h1-h4 kJ/kg
Re = 14.756 (kJ/kg) (48)

34) The work done per kg of refrigerant is given by,
W= h2-h1 kJ/kg
W=13.085 (kJ/kg) (49)

35) The coefficient of performance is given by,
COP = (Re/W)
= (h1-h4/ h2-h1)
COP = 1.12 (50)

36) Heat rejected in Condenser
= m_{refri}* (h2 – h3)
= 159.772 (KJ/kg) (51)

For 2.6 Reading

h1 = 410.325 KJ/Kg
h2 = 424.494 KJ/Kg
h3 = 265.948 KJ/Kg
h4 = 394.181 KJ/Kg

These enthalpies are noted from the p-h chart of the concerned refrigerant:

37) The refrigerating effect is calculated as,
Re = h1-h4 kJ/kg
Re = 16.144 (kJ/kg) (52)

38) The work done per kg of refrigerant is given by,
W= h2-h1 kJ/kg
W= 14.169(kJ/kg) (53)

39) The coefficient of performance is given by,
COP = (Re/W)
= (h1-h4/ h2-h1)
COP = 1.13 (54)

40) Heat rejected in Condenser
= m_{refri}* (h2 – h3)
= 158.546 (KJ/kg) (55)

For 2.7 Reading

h1 =410.160 KJ/Kg
h2 =425.378 KJ/Kg
h3 =268.104 KJ/Kg
h4 =393.693 KJ/Kg

These enthalpies are noted from the p-h chart of the concerned refrigerant:

41) The refrigerating effect is calculated as,
Re = h1-h4 kJ/kg
Re = 16.467 (kJ/kg) (56)

42) The work done per kg of refrigerant is given by,
W= h2-h1 kJ/kg
W= 15.218 (kJ/kg) (57)

43) The coefficient of performance is given by,
COP = (Re/W)
= (h1-h4/ h2-h1)

COP = 1.08 (58)

44) Heat rejected in Condenser

$= m_{refri} * (h2 - h3)$

$= 157.274$ (KJ/kg) (59)

7. Results And Disscussion

The graphs plotted below indicate an increase in the Condenser inner Cabinet temperature with time which can be used as an oven. The temperature rise varies according to type of load applied. The power consumption decreases with an increase in outlet temperature. The COP decreases with an increase in time. Thus as time increases, the COP decreases and remains constant after a certain interval of time and does not go bellow 1 in Experiment 2nd. The overall temperature difference encountered at the end of 30 minutes from room temperature 33^0C in Condenser Cabinet exceeds 14^0C & in Evaporator Cabinet is decress 21^0C. Thus, with an increase in the time interval the water and food temperature can be increased in Condenser & can be decress in Evaporator considerably as per the requirement of the user.

For Experiment 1:

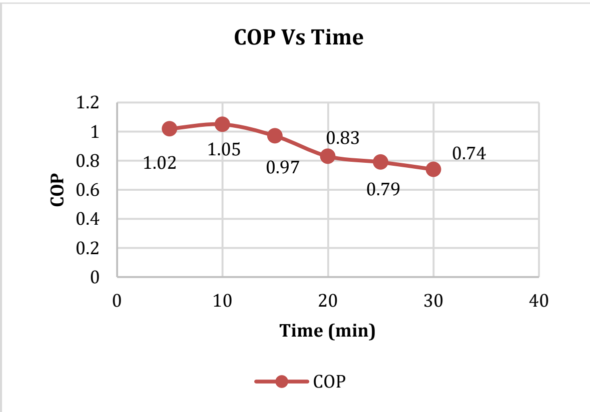

Chart 1 COP Vs Time for Experiment 1st

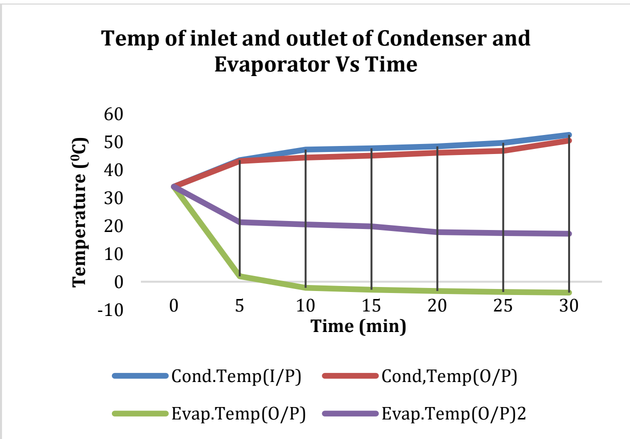

Chart 2 Temp of inlet and outlet of Condenser and Evaporator Vs Time for Experiment 1st

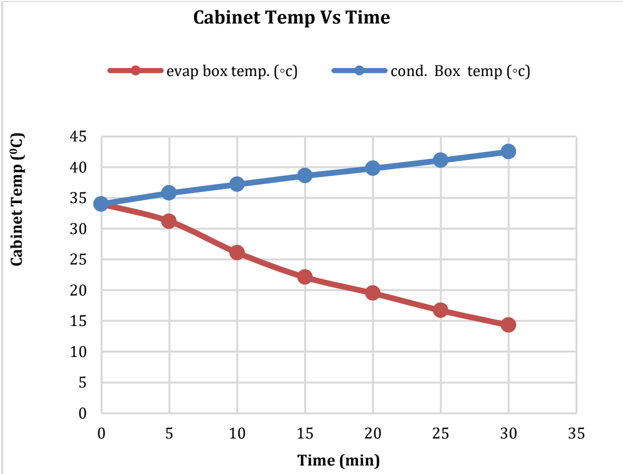

Chart 3 Cabinet Temp of condener and Evaporator Vs Time for Experiment 1st

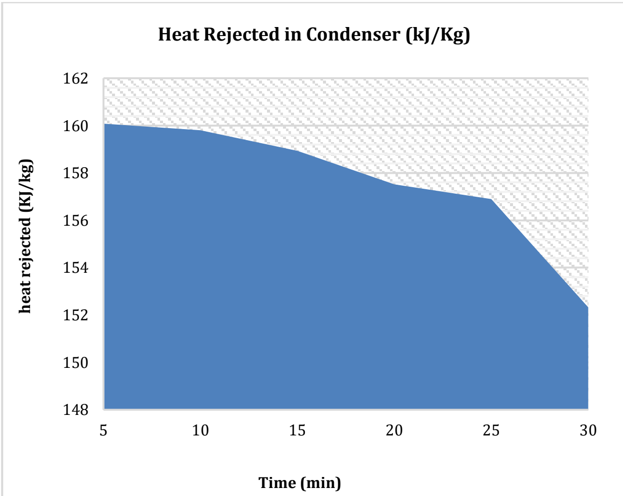

Chart 4 Heat Stored in Condenser Vs Time for Experiment 1st

For Experiment 2:

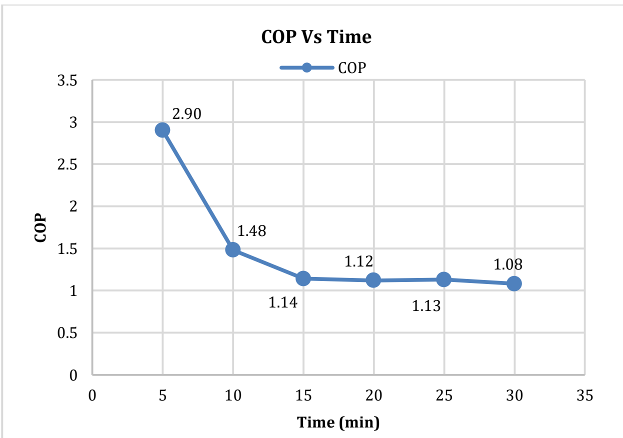

Chart 5 COP Vs Time for Experiment 2nd

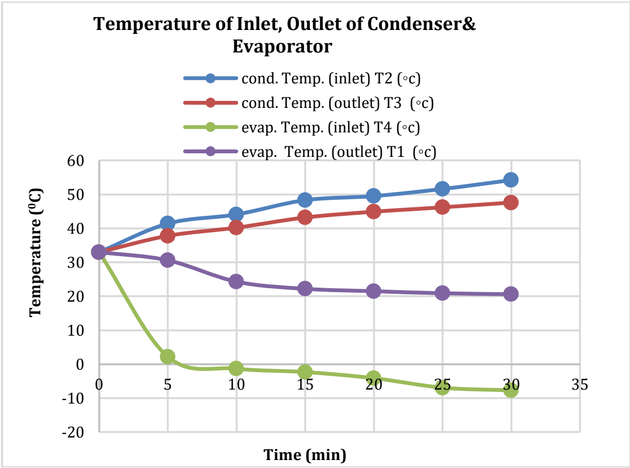

Chart 6 Temp of inlet and outlet of Condenser and Evaporator Vs Time for Experiment 2nd

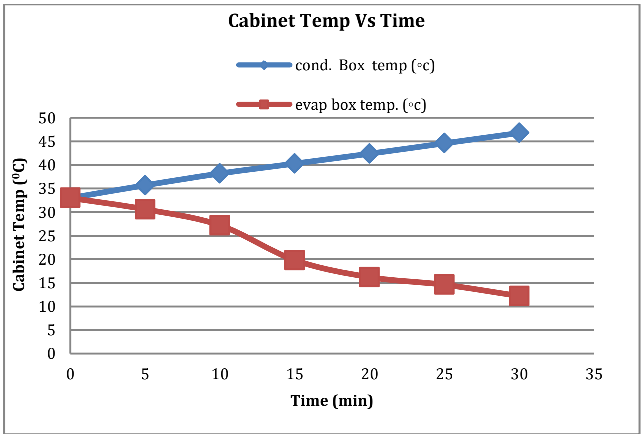

Chart 7 Cabinet Temp of condener and Evaporator Vs Time for Experiment 2nd

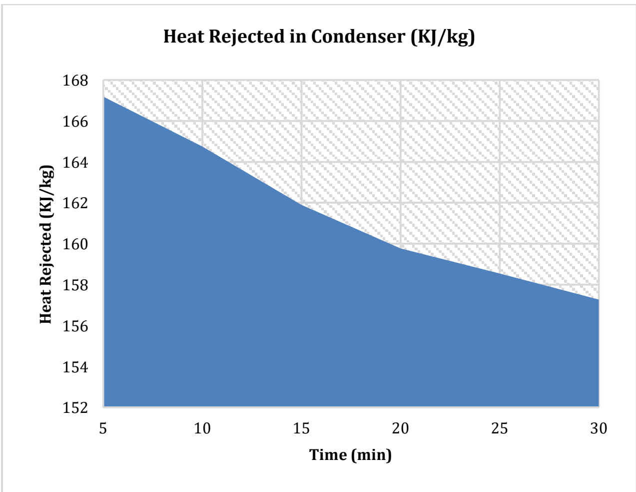

Chart 8 Heat Stored in Condenser Vs Time for Experiment 2nd

Conclusions

The conclusion of this project is that we can make a system which can give two scorce of energy at the same power consumption, i.e heat energy in condenser and cooling energy in evaporator. During 1st Experiment we seen that the COP of system get reduced from 1 to 0.77 due to not utilized for full load condition for heating and cooling water but in 2nd Experiment we seen that the COP reduced but not more then 1 this could be happen due to utilized for heating and cooling water. So we can say that the COP of system can be improved by utilizing waste heat energy to heating water or food stuffs. The overall temperature difference encountered at the end of 30 minutes from room temperature 33^{0}C in Condenser Cabinet exceeds 14^{0}C & in Evaporator Cabinet is decress 21^{0}C and become 46.8^{0}C in Condenser and 12.2^{0}C in Evaporator after 30 minutes. Thus, with an increase in the time interval the water and food temperature can be increased in Condenser & can be decress in Evaporator considerably as per the requirement of the user. If this system made full insulated then we can get better result then the above result.

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