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EXPERIMENTATION AND PERFORMANCE EVALUATION OF HEAT RECOVERY FROM DOMESTIC REFRIGERATOR

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ABSTRACT

A refrigerator is a device, which is used to maintain a body at a temperature, below that of surrounding. In order to maintain lower temperature continuously, refrigerator must operate on a cycle. Hence, heat must be made to flow from a body at lower temperature to the surroundings, which are at higher temperature. As we have moved into twenty first century, the rise is related with global warming and its effects on the universe. We all are struggling with the environment change, and our desire is energy recycling for the minimum energy waste. We all are trying to recover the waste energy, by recycling and reducing the carbon footprints. Our main aim to increase energy efficiency of refrigerator by waste heat recovery, at the same time, the waste heat can be used in other domestic utility like heating water in winter season and other purposes (cleaning cloths, equipment, utensils). Heat recovered from water cooled condenser is 4.15 times more than the air cooled condenser and in terms of percentage; we recover the heat energy 315.5 % more than the air cooled condenser. In this experiment, the heat recovered using two condensers is up to 123.61 Watts, and it can be improved by optimizing the size of insulated box and using proper insulation material.

KEYWORDS: *Heat Recovery, Vapour Compression System, Insulation Box, Condenser, Throttle Valve*

Article History

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INTRODUCTION

A refrigerator is a device, which is used to maintain a body at a temperature below that of surrounding. In order to maintain lower temperature continuously, refrigerator must operate on a cycle. Hence, heat must be made to flow from a body at lower temperature to the surroundings, which are at higher temperature. It is not possible for heat to flow from lower temperature body to higher temperature body, without any external work. It works on the reverse Carnot cycle. That is called ideal refrigeration cycle or vapors compression cycle. The refrigerator works on the principle of passing of cold fluid continuously throughout the item, which is too being cooled. As we have moved into the twenty first century, the rise in temperature is related with global warming and its effects on the universe. We all are struggling with the environment change and our desire is energy recycling for the minimum energy waste. We all are trying to recover the waste energy by recycling and reducing the carbon footprints. We can increase energy efficiency of refrigerator, by waste heat recovery, at the same time; the waste heat can be used in other domestic utility like heating water in winter season and other purposes (cleaning cloths, equipment, utensils).

VAPOUR COMPRESSION CYCLE

Vapor compression cycle is a refrigeration cycle, which consists of four processes

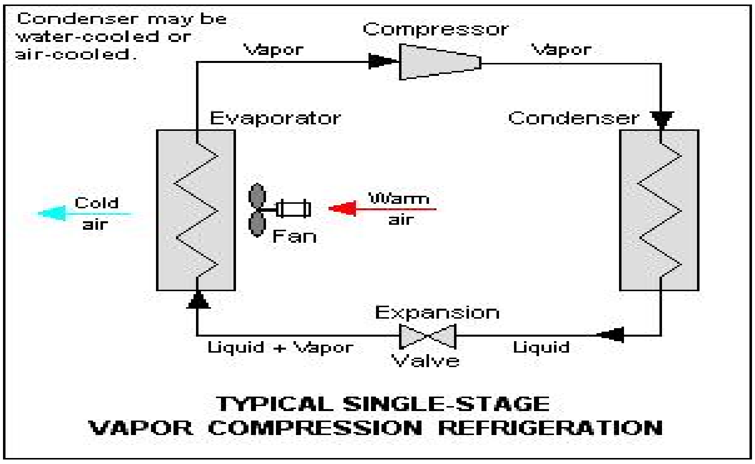


Figure 1

- A compressor, in which, reversible adiabatic compression
- A Condenser, Heat rejection at constant pressure
- Throttling process or isenthalpic process, pressure reducing process in throttling valve
- Heat absorption at constant pressure in evaporator

Here, we use two condensers, which are air cooled & water cooled condenser. In air cooled condenser, heat is removed by air using either natural or forced convection. The condensers are made of steel, copper or aluminum tube, provided with fins to increase air side heat transfer coefficient. The air flows outside the tube and the refrigerant flows inside the tube, in which a condenser is kept inside the insulated box, filled with water

OBJECTIVE

- Design of a domestic refrigerator using air cooled and water cooled condensers.
- Experimentally demonstrate heat recovery, by using two condensers system.

METHODOLOGY

In the above system, the fundamental need is to use more and more waste heat or recycling the energy. For the above system, we have done the calculations of insulated box size and also for thermostatic valve, and then a heat recovery system is designed. Here, we get to the last design of insulated box with intensive constructions and with affordable cost, so that we get more heat recovery. We designed the above system in two parts, one is air cooled condenser and other is inside the insulated box, which is water cooled condenser. The insulated box was mounted on the top of refrigerator. In this system, we use the waste heat of condenser of domestic refrigerator, by placing another condenser, which is connected parallel to air cooled condenser, which is kept inside the insulated box placed on the refrigerator.

Assembling of Work

We decided to make a heat recovery system, using waste heat in domestic refrigerator; accordingly, we took a 165 liters capacity second-hand domestic refrigerator in working conditions. The various Parts of domestic refrigerator are as follows:-

- Compressor,
- Modification in condensers, which is Air cooled and water cooled,
- Capillary Tube,
- Evaporator is plate type
- Insulated box of iron sheet
- Thermostatic valve

The insulated Box is made by the different parts.

- The box is made up of inner and outer iron sheet, which is separated by an insulating material, thermocol and after defining dimensions, sheet metal working is performed.
- For Insulation purpose, we use the material is thermocol.
- For the more utilization of heat, a condenser which is parallel connected to air cooled condenser and kept inside the insulated box, and that box is filled with measured quantity of water as shown in Figure. The joining of copper tubes at outlet of compressor and inlet of condenser is done by brazing process.
- The box dimension is 17×13×3.4 $inch^3$

EXPERIMENTAL SET-UP

The experimental set-up consists of number of parts as follows:

Figure 2: Insulated Box

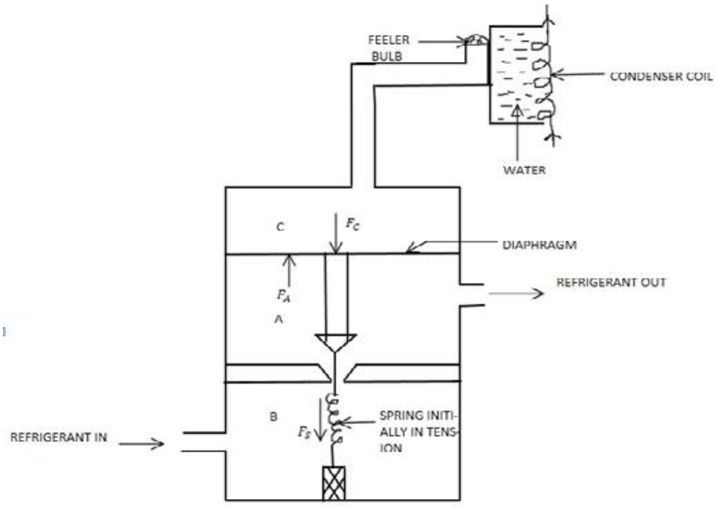


Figure 3: Thermostatic Valve

Thermostatic Valve

A thermostatic valve is an expansion device, usually used in air-conditioning system. In which, the refrigerants are sprayed and atomization of refrigerant take place. Thermostatic valves are those types of valves, which are used for controlling the fluid temperature; it mainly works on the temperature sensing. This is used for opening/closing of the valve by the temperature sensing medium.

Condenser Tube inside the Insulated Box

Specification:

Length: 27 feet OR 324 inch,

Inner diameter: 5.5 mm,

Outer diameter: 6 mm,

Material: copper

Figure 4: Condenser Tube Inside the Insulated Box

EXPERIMENTAL SET UP

- A refrigerator of capacity 165 L was taken for experimentation.
- A box for heating water from waste heat recovery was fabricated and well insulated by inserting thermocol between the sheet metal.
- 27 feet condenser tube of inner diameter 5.5 mm and outer diameter 6 mm was taken, and this condenser tube was bent into 17 turns and that turn is equally spaced by round fins, which was joined by brazing process and that condenser was kept inside the insulated box.
- The condenser, which was kept inside the insulated box, was parallel connected to air cooled condenser (which was back part of refrigerator) from compressor outlet by brazing.
- Similarly, both condensers were parallel connected at condenser outlet.

- Ball valves are connected at the both condensers outlet and inlet for opening and closing the fluid flow through.
- Now, the box was filled with water.
- First of all, both ball valve of water cooled condenser at outlet and inlet was opened and then refrigerator was switched on.

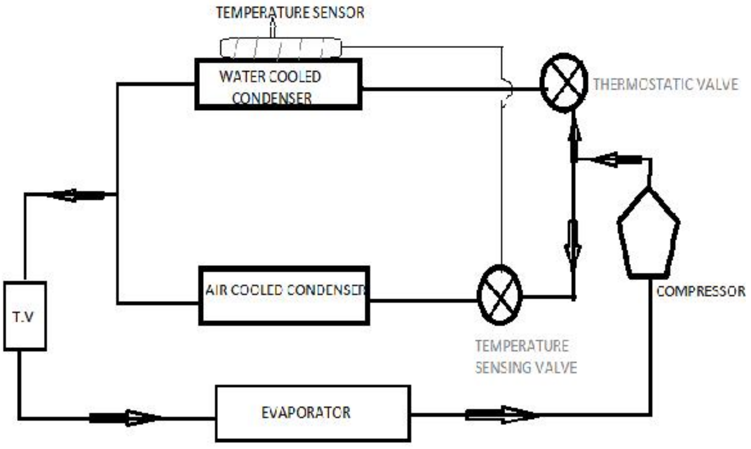


Figure 5: Heat Recovery in Domestic Refrigerator Using Two Condensers

Figure 6: Front View of Experimental Set-Up

Figure 7: Back View of Experimental Setup

OBSERVATIONS AND CALCULATION

Refrigerator cooling capacity = 76 Kcal/hr = 76 × 4.187 × 1000 / 3600 = 88.392 W

Power required running the compressor = 1/8 HP = 1/8 × 746 = 93.25 W

Now, for the same temperature difference and per kg mass flow of refrigerant

Heat recover from air cooled condenser = $m \times C_{pa} \times \Delta T$

And heat recover from water cooled condenser = $m \times C_{pw} \times \Delta T$

Where C_{pa} is heat capacity of air = 1.006 KJ/Kg-K and C_{pw} is heat capacity of water = 4.18 KJ/Kg-K

So, we see from above equation, heat recover from water cooled condenser is 4.15 times more than the air cooled condenser, and in terms of percentage, we recover the heat energy 315.5 % more than the air cooled condenser.

Table 1: Experimental Data of Water Cooled Condenser and Cop of Domestic Refrigerator

Condenser Temperature (°C)	Cop
30.95	4.62
31.35	4.57
31.75	4.51
32.20	4.46
32.75	4.39
33.35	4.31
33.90	4.25
34.14	4.22
34.50	4.18
34.95	4.12
35.25	4.09

Table 2: Experimental Data of Water Temperature with Time

Time (Minute)	Water Temperature (°C)
t= 7	31.35
t= 12	32.00
t= 17	32.55
t= 23	33.20
t= 29	33.95
t= 35	34.60
t= 41	35.20
t= 47	35.80
t= 53	36.30
t= 59	36.80
t= 65	37.01

Table 3: Experimental Data of Energy Consumption with Time of Domestic Compressor

Time (Minute)	Energy Consumption with Air Cooled Condenser (kwh)	Energy Consumption with Water Cooled Condenser (kwh)
T= 0	4.00	4.00
T= 30	4.07	4.04
T= 60	4.15	4.075
T= 90	4.225	4.175
T=120	4.295	4.255

CALCULATION ANALYSIS OF DOMESTIC REFRIGERATOR

Refrigerant--R134a

Condenser Temp.	36°C
Evaporator Temp.	-16°C

From refrigeration table of R134a, we have

Condenser Pressure	9.1171 bar
Evaporator Pressure	1.5721 bar

From p-h diagram of refrigerant-R134a, we have

h_1 =389.11KJ/kg-k, s_1=1.7383 KJ/kg-k, v_1=.1256m^3/kg, s_2=1.7129+1.088ln$\frac{T_2}{36+273}$=s_1=1.7383

T_2=316.30 K= 43.3°C, h_2=425.7224KJ/kg

From pressure enthalpy plot of R-134a, we have T_2=43.3°C

Compressor Specification:

Let Compressor rpm N=1400 rpm. Volumetric efficiency=65%

Let Power of Motor=50Watts, Assuming 100% compressor efficiency, we have

50=$\dot{m}(h_2 - h_1)$= $\dot{m}$(425.7224-389.11)*100, $\dot{m} = .00136566\ {kg}/{s}$, Now, let V=displacement Volume of Compressor then,, $\dot{m} = \frac{V*\eta_V}{v_1} * \frac{N}{60} {kg}/{s}$ =$\frac{V*.65}{.1256} * \frac{1400}{60} {kg}/{s}$ =.00136566 ${kg}/{s}$, V=$1.1309 * 10^{-5}, m^3 = 11309.4657\ mm^3$, Let $\frac{Stroke}{Bore} = \frac{L}{D} = 1.2$, L=1.2D, V=$\frac{\pi*D^2}{4} * L = \frac{\pi*D^2}{4} * 1.2D$, D=$\sqrt[3]{\frac{4*11309.4657}{\pi*1.2}} = 22.89mm \approx 23mm$, L=1.2D=27.50mm

Heat rejected by the condenser=

$$\dot{m}(h_2 - h_1) = .00136566(425.7224 - 250.41)kw = .23942kw = 239.42watts$$

Refrigeration capacity=

$$\dot{m}(h_1 - h_4) = .00131566(389.11 - 250.41)kw = .18942kw = 189.42watts$$

Calculation of Extra Power Required for the Compressor

Assuming refrigerant to be incompressible for instance,

$$\frac{P_1}{\rho} + \frac{V_1^2}{2} = \frac{P_2}{\rho} + \frac{V_2^2}{2}; \frac{P_1}{\rho} - \frac{P_2}{\rho} = \frac{V_2^2}{2} - \frac{V_1^2}{2}; \frac{\Delta P}{\rho} = \frac{V_2^2}{2} - \frac{V_1^2}{2}; \Delta P = \rho * (\frac{V_2^2}{2} - \frac{V_1^2}{2}); \Delta P = \rho * \frac{V_1^2}{2}(\frac{V_2^2}{V_1^2} - 1)$$

Let, $A_1 = 4.15mm^2$; $A_2 = 2.06mm^2$; $\dot{m} = .00136566\ {kg}/{s}$

Again taking enthalpy, $h_1 = h_2 + \frac{V_2^2}{2} - \frac{V_1^2}{2}$; $\Delta h = \frac{V_2^2}{2} - \frac{V_1^2}{2} = \frac{V_2^2}{2}(1 - \frac{A_2^2}{A_1^2})$; $\dot{m} = \frac{A_2*V_2}{v_2} = .00136566 = \frac{2.06*10^{-6}*V_2}{v_2}$; v_2=specific heat at 9.1172 bar and 43.3°C; v_2=.0244 ${m^3}/{kg}$ (from refrigeration table); v_2=$\frac{0.0013656*0.0244}{2.06*10^{-6}}$=16.17${m}/{s}$; $\Delta\ = \frac{16.17^2}{2}(1 - \frac{16.17^2}{4.15^2})$=98.5215 ${J}/{Kg}$

Extra power required for the compressor

$W_{additional} = \dot{m} * \Delta$□=. 00136566 *98.5215 watts=.134 watts.

Actual compressor power required= (50+.134) watts=50.134 watts.

Volumetric efficiency of compressor gets altered i.e. decreases and to compensate for this compressor rpm must be increased for a constant mass flow rate although the effect is quite small.

Calculation of Water Temperature Various with Time

We Take Godrej Refrigerator of 165 L, Refrigerator effect =88.392

Condenser temperature ‘T_3’ = -12^{0}C, Evaporator temp. ‘T_4’ =1/8H.P. = 93.25 Watts.

From P-H Diagram we take the value of enthalpy at condenser outlet and evaporator outlet. So,

hg_1 = 391.46 kj/kg, hf_3 = 259.41kj/kg, Now Refrigeration effect = m (h_1-h_4) ; 88.392 = m (391.46-259.41)$\times10^3$ = 6.6937$\times10^{-4}$Kg/sec. = 2.41 Kg/hr. = 0.67 gm/sec.

Also, Enthalpy at Compressor outlet:

$h_2 = (391.46 + \frac{93.25}{6.6937\times10^{-4}})$ = 530.77 kj/kg

So, Heat rejected out of the condenser =m (h_2-h_{3f}) =6.6937(530.77-259.41)×100 =181.64 watts

Let initial temperature of water is 30^0c, Inner diameter of Condenser tube = 5.5 mm, Outer diameter of Condenser tube = 6 mm, Condenser tube inner diameter = 5.5 mm, mass flow rate = 6.6937×10^{-4}kg/sec

From p-h diagram Reynolds no at saturation = 12249.635 which is greater than 2200 so flow is turbulent.

Calculation of U_o for condenser:

Heat rejected out of the condenser = U_o A(LMTD)

Assuming water temperature to be constant similar to and air cooled condenser so, U_o = 59.44 w/m^2k

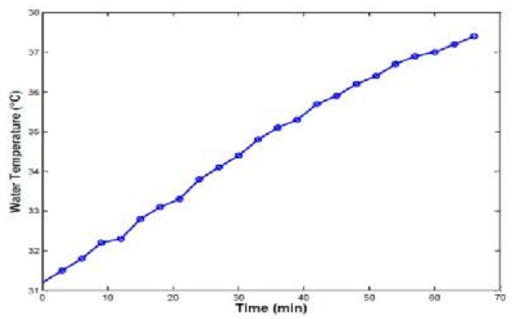
Actual value of U_o is taken some what is less since LMTD will decreases with time.

U_o = 55 w/m^2k So, Heat recovered up to T = 35^0c, Q = 123.611 watt

RESULTS AND DISCUSSION

In the above experimental set-up, following results have been found-

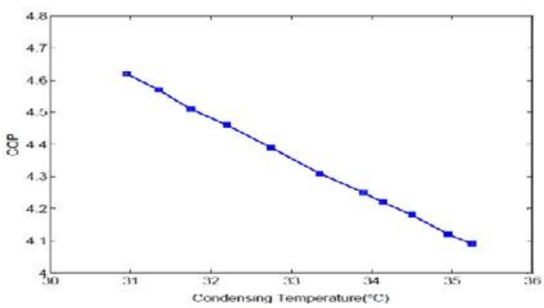
Variations in Temperature of Water



Graph between water temperature Vs time (when the water cooled condenser are open)

Figure 8

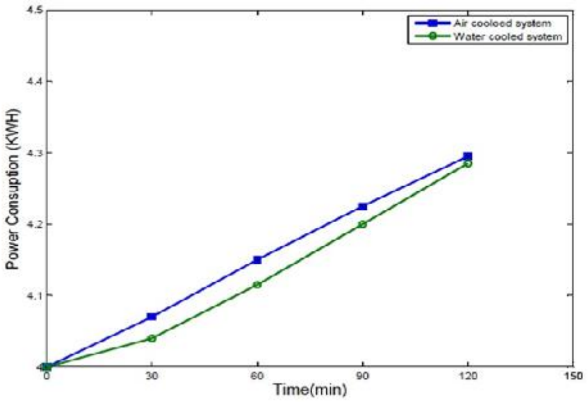
Variations in Cop of Refrigerator



Graph between water cooled condenser temperatures Vs Cop of refrigerator

Figure 9

Variation of Energy Consumption



Graph between energy consumption with Air cooled and Water cooled Condenser of Refrigerator Vs Time

Figure 10

Amount of Heat Recovery

Heat recovered by domestic Refrigerator using two condensers is about 124 watt up to 35^0c. Also, this can be improved by

- Optimizing the size of insulated box and by mixture of Refrigerant used.
- By proper insulation of Box.
- By increasing the surface area of condenser tube which is kept inside the insulated box

The Variation of 'COP' of Refrigerator with Condenser Temperature

Initially, the COP of compressor is maximum for water cooled condenser. But as time passes, the condenser temperature increases and the COP of refrigerator decrease, slightly. But for the same time, refrigerators have low COP with air cooled condenser than the water cooled condenser.

The Variation of Energy Consumption between Air Cooled System & Water Cooled System

Here, with the water cooled condenser the energy consumption is less than the water cooled condenser. So, we also saved the energy, and in other hand, we get heat recovery from domestic refrigerator. This heat recover can be used in the number of domestic and industrial uses. In minimum fabrication maintenances and running cost, this system is much useful for domestic purpose. It is a valuable alternative approach, to improve overall efficiency and reuse the waste heat.

CONCLUSIONS

Future Scope

Waste heat recovery, by using dual condenser system was analyzed in the work. Also, thermostatic valve was designed for the same purpose. Future scope in this area draws attention towards analysis of the same system employed with multi evaporator system.

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