Optimum Length of a Condenser for Domestic Vapor Compression refrigeration System

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Abstract: The performance of Vapor compression refrigeration system (VCRS) depends on the performance of all its components like compressor, condenser, expansion value and evaporator. The current paper is involved in analysis of the effect of condenser length on the performance of on VCRS.

Condenser is a heat exchanger where heat transfer takes place between the super heated refrigerant received from the compressor and the cooling medium of the condenser. The condenser removes the heat from refrigerant which received in two stages. Heat is received by the refrigerant in the evaporator and also heat is added by the compressor during compression. The refrigerant is first cooled to saturation and then condensed to liquid state. In Domestic refrigerator the condenser coil is used to discharge the heat from the refrigerant after operating the compression to the atmosphere. In this present work a condenser coil with different lengths are tested.

In the present work condenser with variable length ((9.45m, 9.75m, 10.06m) has been used for this investigation by keeping the diameter as constant and compared with existing condenser of 9.14m length. The results shown that 9.75m length condenser coil gives optimum performance than the remaining which gives higher COP, higher heat rejection, refrigeration effect and lower power consumption..

Keywords:Condenser, COP, Refrigeration, Heat rejection

I. INTRODUCTION:

1.1 Refrigeration:

"Refrigeration is the science of providing and maintaining temperature below that of surrounding (ambient) temperature". The term 'maintain' implies, the continuous extraction or removal of heat from a body which is already at lower temperature than its surroundings.

Removal of heat from a body at lower temperature is possible only with the aid of external agency according to the Second Law of Thermodynamics.

Vapor Compression Refrigeration system is an improved type of air refrigeration system. The ability of certain liquids to absorb enormous quantities of heat as they vaporize is the basis of this system. Compared to melting solids (say ice) to obtain refrigeration effect, vaporizing liquid refrigerant has more advantages. To mention a few, the refrigerating effect can be started or stopped at will, the rate of cooling can be predetermined, the vaporizing temperatures can be governed by controlling the pressure at which the liquid vaporizes. Moreover, the vapor can be readily collected and condensed back into liquid state so that same liquid can be re-circulated over and over again to obtain refrigeration effect. Thus the vapor compression system employs a liquid refrigerant which evaporates and condenses readily. The System is a closed one since the refrigerant never leaves the system.

The coefficient of performance of a refrigeration system is the ratio of refrigerating effect to the compression work; therefore the coefficient of performance can be increased by increasing the refrigerating effect or by decreasing the compression work.

II.SELECTION OF CONDENSER FOR A VCR SYSTEM

2.1 Condenser

Condenser is that component which is placed next to compressor in a vapor compression refrigeration system. It is a heat exchanger that affects heat transfer between refrigerant gas, vapor or super saturated vapor coming from compressor and cooling medium such as air or water. It removes heat absorbed by refrigerant in the evaporator and the heat of compression added in the compressor and condenses it back to liquid. The condenser abstracts the latent heat from high pressure refrigerant at the same pressure and constant temperature. For this purpose the condenser employs a cooling medium such as air or water.

III.EXPERIMENTAL SETUP

In vapor compression refrigerating system basically there are two heat exchangers. One is to absorb the heat which is done by evaporator and another is to remove heat absorbed by refrigerant in the evaporator and the heat of compression added in the compressor and condenses it back to liquid which is done by condenser.

This project focuses on heat rejection in the condenser this is only possible either by providing a fan or by extending the surfaces. The extended surfaces are called fins. The rate of heat rejection in the condenser depends upon the number of fins attached to the condenser. In the present domestic refrigerator copper material fins are used. The performance of the condenser will also help to increase COP of the system as the sub cooling region incurred at the exit of the condenser. The performance of the condenser is also investigated by existing and modification condenser. In general domestic refrigerators have no fans at the condenser and hence extended surfaces like fins play a very vital role in the rejection of heat.

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In order to know the performance characteristics of the vapor compression refrigerating system the temperature and pressure gauges are installed at each entry and exit of the component. Experiments are conducted on condenser having fins.

Different types of tools are also used like snips to cut the fins to required sizes, tube cutter to cut the tubes and tube bender to bend the copper tube to the required angle. Finally the domestic refrigerator is fabricated as for the requirement of the project. All the values of pressures and temperatures are tabulated.

The figure 1 shows the experimental setup of the refrigerator. In order to know the performance characteristics of the vapor compression refrigeration system the temperature and pressure gauges are installed at each entry and exit of the components. Experiments are conducted on condenser with coil spacing of the condenser on a refrigerator of capacity 170liters. All the values of pressures and temperatures are tabulated.

Domestic refrigerator selected for the project has the following specifications:

Refrigerant used: R-134a
Capacity of The Refrigerator: 170 liters
Compressor capacity: 0.16 H.P.

Condenser Sizes

Diameter	-	6.35 mm

Evaporator

Length	-	7.62 m
Diameter	-	6.4 mm

Capillary

Length	-	2.428 m
Diameter	-	0.8 mm

Condenser length of existing system is 9.14m and in the present work condenser lengths of 9.45m, 9.75m and 10.06m are tested to analyze its effect on the performance of refrigeration system.

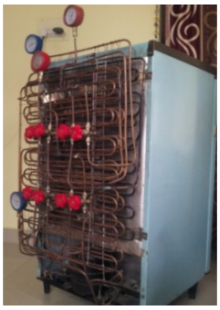

Fig 1 Proposed System with condenser coil lengths of 9.14m, 9.45m, 9.75m & 10.06m.

IV.EXPERIMENTAL PROCEDURE

The following procedure is adopted for experimental setup of the vapor compression refrigeration system

1. The domestic refrigerator is selected, working on vapor compression refrigeration system.
2. Pressure and temperature gauges are installed at each entry and exit of the components.
3. Flushing of the system is done by pressurized nitrogen gas.
4. R 134a refrigerant is charged in to the vapor compression refrigeration system by the following process:
   The systematic line diagram for charging is shown in the fig 2. it is necessary to remove the air from the refrigeration unit before charging. First the valve V_2 is closed and pressure gauge P_2, vacuum gauge V are fitted as shown in the fig. the valve V_5 is also closed and valves V_1, V_4, V_6 and V_3 are opened and the motor is started thus the air from the condenser receiver and evaporator is sucked through the valve V_1 and it is discharged in to atmosphere through the valve V_6 after compressing it in the compressor the vacuum gauge V indicates sufficiently low vacuum when most of the air is removed in the system. The vacuum reading should be at least 74 to 75 cm of Hg. If the vacuum is retained per above an hour it may be concluded that the system is free from the air. After removing the air the compressor is stopped and valves V_1 and V_6 are closed, the valves V_5, V_2 and V_7 of the refrigerant cylinder are opened and then the compressor is started whenever the sufficient quantity of refrigerant is taken in to the system which will be noted in the pressure gauges. The compressor is stopped. The valves V_7 and V_5 are closed and valve V_1 is opened the refrigerant cylinder is disconnected from the system the pressure gauge is used to note the pressure during the charging the system.

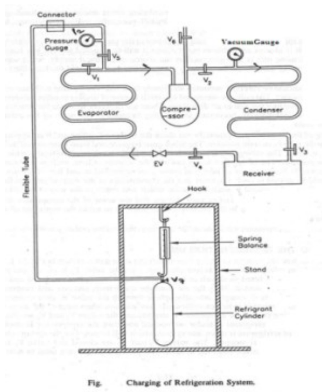

Fig.2 charging of refrigeration system

5. Leakage tests are done by using soap solution, In order to further test the condenser and evaporator pressure and check purging daily for 12 hours and found that there is no leakages which required the absolutely the present investigation to carry out further experiment.
6. Switch on the refrigerator and observation is required for 1 hour and take the pressure and temperature readings at each section.
7. The performance of the existing system is investigated, with the help of temperature and pressure gauge readings.

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8. The refrigerant is discharged out and condenser is located at the inlet of the capillary tube.
9. Temperature and pressure gauge readings are taken and the performance is investigated.
10. The readings are tabulated for condenser coil diameter 6.35mm, 7.93mm, and 9.52mm.
11. The following tests are conducted and calculations are shown below.

V.PERFORMANCE CALCULATIONS

The temperature and pressure readings are noted down and from pressure-enthalpy chart for R-134a, enthalpy values at state points 1,2,3,4 and are tabulated as follows shown in table 1.

Parameter	Condenser coil length(m)			
	9.14	9.45	9.75	10.1
Compressor Suction Temperature T_1(°C)	32	34	34	31
Compressor Discharge Temperature T2(°C)	65	68	67	65
Condensing Temperature T3(°C)	51	48	39	48
Evaporator Temperature T4(°C)	-10	-10	-10	-10
Compressor suction pressure P1(bar)	3.2	3.2	3.1	2.7
Compressor discharge pressure P2(bar)	12	12.1	12.2	12.5
Condenser pressure P3 (bar)	12	11.8	11.7	11.2
Evaporator pressure P4(bar)	3.2	3.2	3.2	2.5
Enthalpy,h1 (kJ/kg)	425	428	427	427
Enthalpy,h2 (kJ/kg)	459	462	461	464
Enthalpy,h3 (kJ/kg)	263	262	255	262
Enthalpy,h4 (kJ/kg)	263	262	255	262

Table 1: Temperature, pressure and enthalpy readings.

VI.RESULTS AND DISCUSSION

Calculation of Performance Parameters

Calculation is carried as follows for existing condenser length of 9.14m.

1. Net Refrigerating Effect (NRE) = h_1-h_4 = 425-263 = 162kJ/kg
2. Mass flow rate to obtain one TR, kg/min. m_r = 210/NRE = 210/162 = 1.29 kg/min.
3. Work of Compression = h_2-h_1 = 459-425 = 34 kJ/kg
4. Heat Equivalent of work of compression per TR m_r x (h_2-h_1) = 1.29 x 34 = 43.86 kJ/min
5. Theoretical power of compressor = 43.86/60 = 0.73 kW
6. Coefficient of Performance (COP) = h_1-h_4 / h_2-h_1 = 162/34 = **4.76**
7. Heat rejected in condenser = h_2-h_3 = 459-263 = 196 kJ/kg
8. Heat Rejection per TR = (210/NRE) x (h_2-h_3) = 1.29 x 196 = 252.84 kJ/min
9. Heat Rejection Ratio = 312/210 = 1.20
10. Compression Pressure Ratio = $\frac{Dishcarge\ Pressure}{Suction\ Pressure} = \frac{P_d}{P_s}$ = **12/0.32 = 3.75**

Similarly calculation is carried for remaining three condenser lengths of 9.45m, 9.75m and 10.06m which are tabulated as follows shown in table 2.

S.No	PARAMETERS	Condenser Coil length(m)			
		9.14	9.45	9.75	10.1
1	(COP)	4.76	4.88	5.05	4.45
2	Net refrigerating effect , kJ/kg	162	166	172	165
3	Work of Compression, kJ/kg	34	34	34	37
4	Compressor Power, kW	0.73	0.71	0.69	0.78
5	Mass flow rate to obtain one TR, kg/min	1.29	1.26	1.22	1.27
6	Heat Equivalent of work of compression per TR, kJ/kg	43.9	42.8	41.5	47
7	Heat rejected in condenser , kJ/kg	196	200	206	202
8	Heat Rejection per TR, kJ/min	253	252	251	257
9	Heat Rejection Ratio	1.2	1.2	1.19	1.22
10	Compression Pressure Ratio	3.75	3.78	3.93	4.62

Table 2: Performance parameters using different condenser lengths

Graph 1 shows the effect of condenser coil length on net refrigeration effect. It is observed from the graph that at first refrigeration effect increases with increase of condenser length up to 9.75m and decreases beyond that. The maximum refrigeration effect of 172Kj/Kg is obtained for condenser length of 9.75m.

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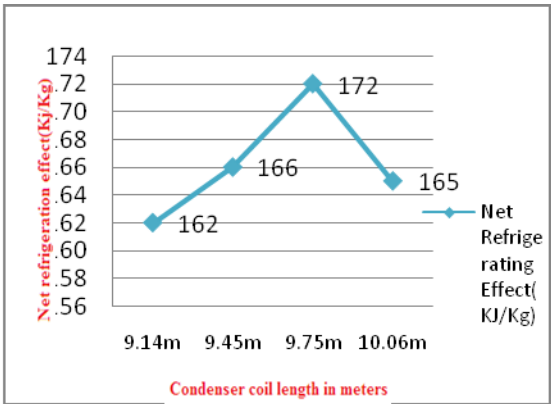
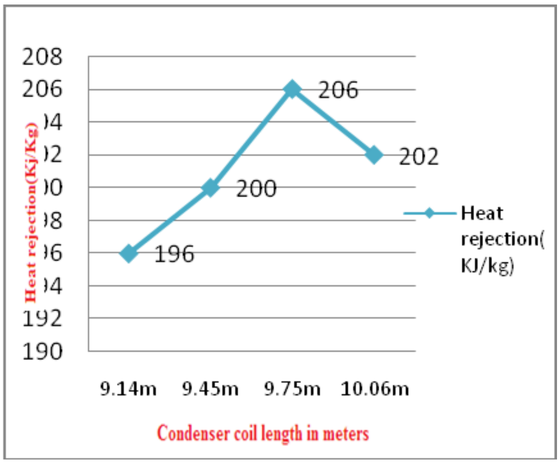


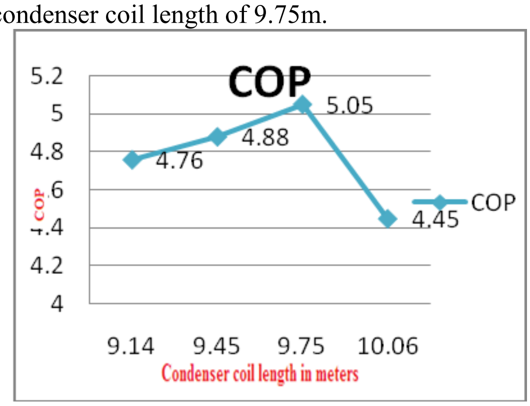
Graph no. 1 Condenser coil length Vs Refrigerating effect

Graph 2 shows the effect of condenser coil length on the heat rejection. It is observed from the results that as condenser length increases heat rejection increases up to 9.75m length of condenser and decreases beyond that. A maximum heat rejection of 206Kj/Kg is found to be obtained at 9.75m condenser length.



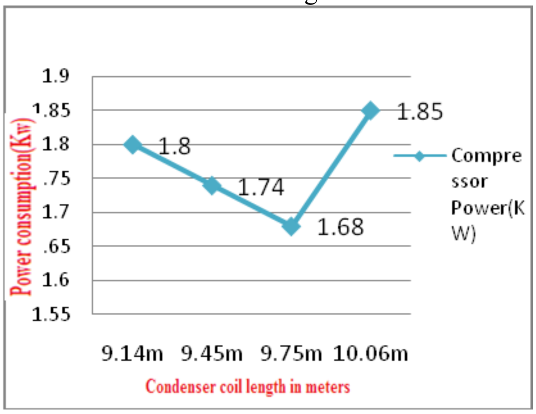
Graph no. 2 Condenser coil length Vs Heat rejection

Graph 3 shows the effect of condenser coil length on COP of the refrigeration system. It is observed from the graph that COP increases for condenser length from 9.14m to 9.75m and decreases beyond that. A maximum COP of 5.05 is obtained for condenser coil length of 9.75m.



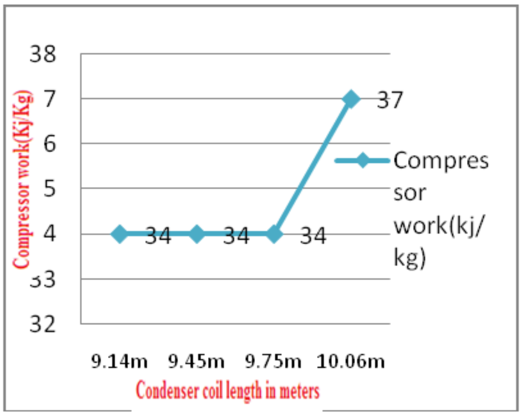
Graph no. 3 Condenser coil length Vs COP

Graph 4 shows the effect of condenser length on power consumption and it is found that power consumption decreases with increase of condenser length up to 9.75m and increases again beyond that. A minimum power consumption of 1.68KW is found at 9.75m condenser length.



Graph no. 4 Condenser coil length Vs power consumption

Graph 5 shows the effect of condenser coil length on compressor work and observed that there is no change in work done by the compressor up to the condenser length of 9.75m and beyond that load on the compressor increased due to more pressure drop in the condenser.



Graph no. 5 Condenser coil length Vs Compressor work

The seasonal COP while showing a major increase when the length is increases from 9.14m to 9.17m, actually shows a slight decrease when the length decreases beyond 9.75m. Continuing to increase the length condenser coil also further increases the heat transfer area. Hence, naturally one might imagine that the seasonal COP would also continue to increase. However as graph 3 have shown this is not the case.

As the length of condenser increases means the depth of the condenser increases and both the refrigerant-side and air-side heat transfer areas increase. However, increasing the length also increases the refrigerant flow path, as well as the air flow path (deeper coil), thus increasing both the refrigerant-side and air-side pressure drops. The increase in the refrigerant-side pressure drop with

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increasing condenser length is observed. Therefore, two competing effects are at work. As the condenser length from 9.14m to 9.17m, the increase in the overall heat transfer area has a larger effect on the seasonal COP than the resultant increase in the pressure drop, hence the seasonal COP increases. Graph 5 displays the compressor work versus the length of condenser coil, and shows that the compressor work is constant(actually decreases very slightly) when length of condenser increases from 9.14m to 9.75m. Again, this is because the increase in the overall heat transfer area has a larger effect on the seasonal COP than the increase in pressure drop. However, when the length increased beyond 9.75m , the resultant increase in the pressure drop has a larger effect on the seasonal COP than the increase in the overall heat transfer area, thus the seasonal COP decreases. Results shows that as the length increased beyond 9.75m, the compressor power actually increases, thus confirming the aforementioned tren**d.**

VII.CONCLUSIONS

From the experimental investigation following conclusions were drawn.

- COP of the VCR system with 9.75m length condenser is 5.74% more than the existing system.
- The Net Refrigeration Effect of the VCR system with 9.75m length condenser is 5.81% more than the existing system.
- The power consumption of the VCR system with 9.75m length condenser is 5.48% less than the existing system.
- Heat rejection in the 9.75m length condenser is 4.85% more than the existing condenser.
- Compared to all other condensers(9.14m, 9.45m & 10.06m) the condenser of length 9.75m gives,
    - The maximum net refrigeration effect
    - Maximum heat rejection
    - Maximum COP and minimum power consumption.
- ✓ Hence it is concluded that the condenser with 9.75m of length is the optimum length and is recommended for domestic refrigerator.

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