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Effect of using Double Loop Elliptical Condenser on the Performance of Vapor Compression Refrigeration System (VCRS)

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ABSTRACT

The condenser design plays a very important role in the performance of vapor compression refrigeration cycle. The main objective of this paper is to find the coefficient of performance of vapor compression refrigeration system using conventional condenser and then verifying the effect of performance experimentally by modifying the conventional shaped condenser to double loop elliptical shaped (DLE).Comparison between (DLE) condenser and conventional one is also done by keeping all parameters constant. The results showed that (DLE) condenser gives better performance than the conventional one and gives lower Pressure ratio and then lower Electrical power, higher refrigeration effect and higher coefficient of performance (COP) by about (4.2%),(1.7%),(1.6%) and (3.6%) respectively.

KEYWORDS: Vapor compression refrigeration system, COP, Pressure Ratio, condenser.

INTRODUCTION

The refrigeration cycle is a mean of removing heat from a place where it is not wanted and rejecting it to a place where it is not objectionable. The wire-and-tube condenser is an important component in the refrigeration cycle, where heat of the refrigerant is removed and rejected. Condensers are thus heat exchangers designed to get rid of the heat absorbed by the refrigerant in the evaporator and the heat of compression added by the compressor. One of the commonly used condensers in domestic refrigerators is wire-and-tube condenser. Wire-and-tube condenser consists of a single steel tube, bent into serpentine parallel passes. Solid steel wires are attached to the tube that serve as extended surfaces. The solid wires are brazed on opposite sides of the tubes as shown in Figure 1(a). Usually superheated refrigerant discharged from the compressor is cooled to the condensing temperature and then it condenses to liquid. Subject to availability of additional heat exchanger by condenser surface the refrigerant may leave the condenser in a subcooled state. The heat transfer takes place from the outer surfaces of the wires and tubes to the external environment by free or forced convection.

The effect of varying the condenser fins spacing on vapor compression refrigeration system performance was analyzed by S. SharmasVali *et al* [1]. Several condensers having different fins spacing are taken. It is found that heat rejection depends on the spacing between the fins of the condenser and the performance of the refrigeration system decreases as the fins spacing increases and it is maximum at 2mm . Theoretical calculations and experimental study were carried out by SaratBabu and Prof. N. HariBabu [2] to optimize condenser length for domestic refrigerator of 165 liters capacity .After studying different lengths other than existing length of condenser ,It was found that the optimum length of coil is (7.01m) which gave better performance of refrigerator

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.VivekSahu *et al* [3] investigated experimentally the domestic refrigeration system by using wire-on-tube condenser with different spacing of wire .The results showed that the discharge pressure of 3mm fins spacing was the highest with average value of 4.7% and 10.2% higher than those of 6mm fins spacing and 9mm fins spacing respectively.Santosh Kumar [4] modify the conventional shaped condenser to spiral shaped condenser and with varying pitch.The performance of system was valuated .It was found that the optimum COP is obtained at 2 inch pitch of the coil for the spiral shaped condenser which shows an increase of 18.8% when compared to the conventional copper condenser .Chandrashekhar M. Bagade and S. A. Borikar [5] focused on the condenser design as the key factor to improve the COP of domestic refrigerator .They were interested in improving COP of refrigeration system, without affecting compressor work. Sub cooling is one of the factors that can improve the COP of refrigeration system. It was found there were numbers of condenser design available for domestic refrigerator to enhance its COP. But it was noted that helical coil tube condenser gives better heat transfer rate, maximum mass flow rate, and minimum frictional losses with minimum coil length.

Rajesh Joshi, Dr. A.I. Khandwawala [6] determine the heat transfer coefficient for two phase flow in the condenser of a domestic refrigerator using R134a as refrigerant, an experimental setup has been developed containing different condensers having different inside tube diameters varying in the range of 6.25mm to 12mm and the mass flow rate of refrigerant is varied in the range of 0.002kg/s to 0.02 kg/s. the results indicated that For a specified mass flow rate of refrigerant; as the pipe diameter increases, the Reynolds number decreases and For a specified pipe diameter; the Reynolds number increases with increase in mass flow rate. . the results also indicated that The heat transfer coefficient increases with increase in mass flow rate for a specified value of pipe diameter and The heat transfer coefficient decreases with increase in pipe diameter for a specified value of mass flow rate.Lima, R. S. and Seixlack, A.L [7] presented a numerical model to simulate the unsteady refrigerant fluid flow in wire-and-tube condensers, the kind widely used in vapor compression cycle based domestic refrigerator. The model considered the refrigerant flow inside the tubes divided in a superheated vapor flow, two-phase flow region and a subcooled liquid region. The refrigerant flow is considered as one-dimensional and the homogeneous flow model is employed for the two-phase flow region. The fundamental equations governing the flow through a wire-on-tube condenser are derived from the mass conservation, momentum and energy conservation laws. The model allowed prediction, in steady and unsteady states, of the refrigerant mass flow rate, pressure, quality, refrigerant and wall temperatures distributions along the tube, as a function of the heat exchanger geometry and operating conditions. Comparisons between the results obtained by Hermes and Melo (2008) and those obtained in this work showed good agreement with respect to condenser capacity, outlet temperature and outlet quality. Influence of surrounding space on heat transfer effectiveness of refrigerator's condenser was carried out by V. Dagilis and I. Hofmanas [8]. Experimental investigations showed that the external heat transfer coefficient could arise by 14% in case when the convection is fully free and by 7-9% if the space is enlarged by 0.3 m.T. MahaboobBasha *et al* [9] investigated experimentally of condenser length on the performance of Vapor compression refrigeration system. 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.

As can be seen from the literature, the improvement efficiency of Vaporcompression refrigeration system become the main issue of researches. Therefore, the present work investigates experimentally the effect of using different shape of condenser (double loop elliptical) in domestic refrigerator on the performance of the refrigeration cycles.

2. Experimental setup:

The domestic refrigerator of (352 L) capacity, double door, manufactured by LG ElAraby was used. The experiment includes two types of condenser.The first one is the conventional shaped and the second is double loop elliptical (DLE) as shown in figure (1) .The temperature of the refrigerant inlet/outlet of each component of the refrigerator was measured with thermometer. Thermometer sensors were interfaced with an arduino which is an open-source prototyping platform based on easy-to-use hardware and software via a PC through the GPIB cable for data storage. Temperature is necessary to find out the enthalpy in and out of each component of the system to investigate the performance.

The inlet and outlet pressure of refrigerant for each of the component is also necessary to find out their enthalpy at corresponding state. The pressure gauges were fitted at the inlet and outlet of the compressor and expansion valve as shown in Figure (2). The pressure gauge is fitted with the T-joint and then brazed with the tube to measure the pressure at desired position as mentioned before. The range of the pressure gauge is (0 to 500) Psi for high pressure refrigerant side and (-30 inch Hg) to (250 psi) for low pressure refrigerant side. A service port is installed at the inlet of expansion valve and compressor for charging and recovering the refrigerant. The location of the service port is shown in Figure (2) as well. The evacuation has also been carried out through this service port.

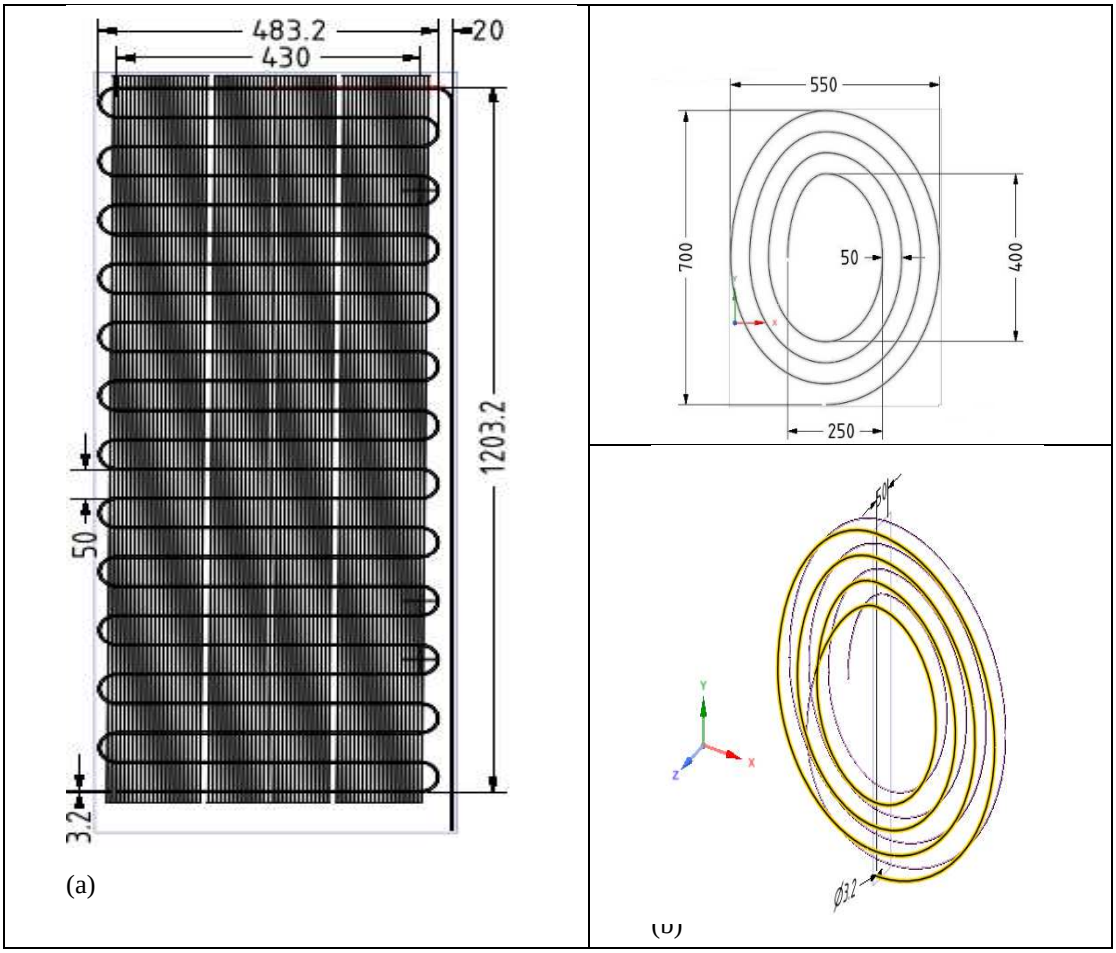


Fig. 1: Schematicof condensers, (a) conventional condenser, (b) (DLE) condenser

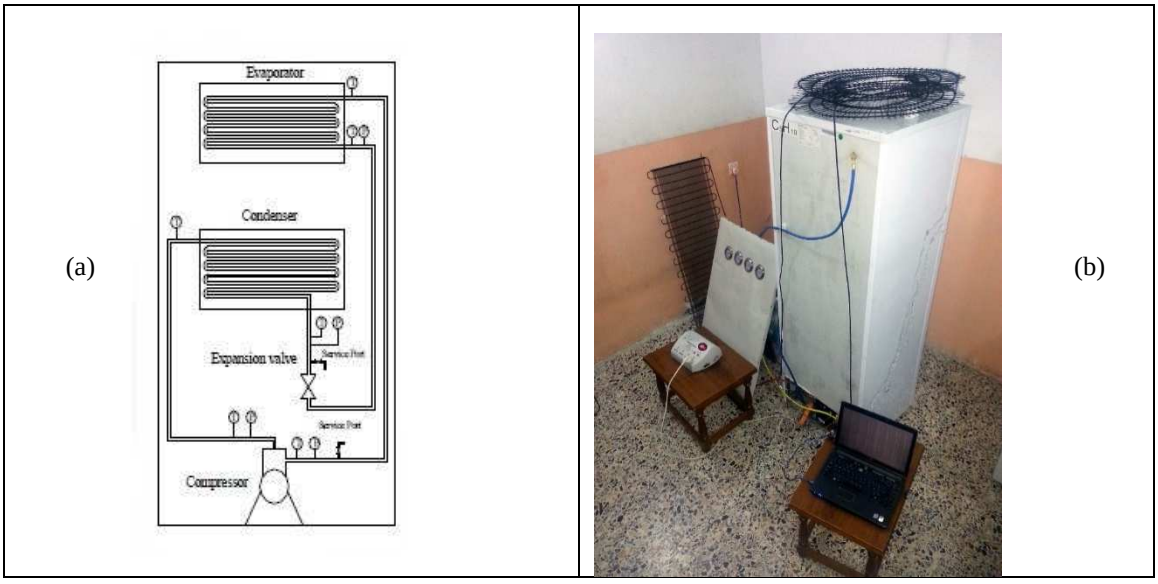


Fig. 2: (a) Schematic of Temp. and pressure measured points, (b) TestUnit and Apparatus.

2.1. Test unit:

The experiments was carried out using a domestic refrigerator with a specially manufactured condenser which consist of two loops each of them having elliptical shape and designed towork with (R-134a) refrigerant as shown in figure (3).The refrigerator is fitted with the thermometers and pressure gauges. The specification of the refrigerator and condenser are shownin Table (1).

Fig. 3: Domestic Refrigerator used as test unit.

Table 1: (a) specifications of the refrigerator, (b) Design parameters and geometrical data of current wire-and-tube condenser.

Specifications	Values
Refrigerant	HFC134a
Charged mass(g)	180
Compressor type	Hermetic
Gross capacity(liter)	352
Power Rating (W)	155
Current rating (A)	1.4
Voltage (V)	220
Frequency (Hz)	50
No of door	2

(a)

Tube material	Steel
Tube inner diameter, dt,i (mm)	3.2
Tube outer diameter, dt,o (mm)	4.9
Tube pitch, pt (mm)	50
Number of tube	25
Tube length (mm)	430
Wire diameter, dw (mm)	1.5
Wire pitch, pw (mm)	6.5
Number of wires (pairs)	110
Total high of condenser (m)	1.20

(b)

2.2. Test procedure:

The system was evacuated with the help of vacuumpump to remove the moisture. The system was chargedwith the help of charging system. The data logger wasset to scan the data from the temperature sensors at an interval of 5 minutes for 2 hours. Besides that, the pressure gauges were fitted on a wood panel. The data was collected manually every five minutes and at the same time when the temperature of each point was recorded. Thepressures and temperatureswere used to determine the enthalpy of the refrigerant. Cool Packsoftware was used to find the enthalpy ofthe refrigerant. All equipment and test unit was placedinside an environment control chamber. The temperature inside thechamber was maintained at 25°C±2. Theexperiment has been conducted on the domesticrefrigerator at no load and closed door conditions. After the test was done, the refrigerator door was kept open toallow the refrigerator temperature to reach the ambient temperature again. Moreover, some random tests were repeated to ensure reproducibility of the data. Then, the test was repeated with load of 6 bottles (2 kg each) of water at 25C placed in the freezer .Next, all test procedure repeated with new condenser configuration to compare its performance with conventional one.

3. Theoretical Analysis:

The pressure–enthalpy diagram prepared for theoretical data is shown in Fig (4).It is known that the actual refrigeration cycle systems have some deviations from the ideal one due to pressure losses of fluid flow and heat transfer exchange between the surroundings. The superheated state of vapor exists at the inlet part of the compressor, the pressure of the liquid at the exit part of the condenser is lower than the pressure at the inlet part of it, there is a pressure drop greater than the ideal one between the condenser and expansion valve, and also a larger pressure drop occurs on the evaporation line.The data reduction of the theoretical results can be analyzed below [10].

The pressure ratio of the cycle is: P.R = Pcond /Pevap (1)

The refrigerating effect (RE) is calculated as follows:RE = h1−h4kJ/kg (2)

Where h1 and h4 are the specific enthalpies(kJ/kg) at the exit and inlet of the evaporator.

Mass flow rate to obtain one TR, kg/min. mr = 210/NRE (3)

Isentropic compression work of the compressor is: Wcomp = h2−h1 kJ/kg (4)

Where h1 and h2 are the specific enthalpies (kJ/kg) at the inlet and exit of the

Heat Equivalent of work of compression per TR= mr x (h2-h1) (5)

Theoretical powerper ton of refrigeration is:(P /TR) = 3.5Wcomp / RE kW/TR (6)

Coefficient of performance (COP) = RE /Wcomp (7)

Heat rejected by condenser =h2-h3 kJ/kg (8)

Where h2 and h3 are the specific enthalpies (kJ/kg) at the inlet and exit of the condenser.

Heat Rejection per TR = (210/NRE) x (h2-h3) (9)

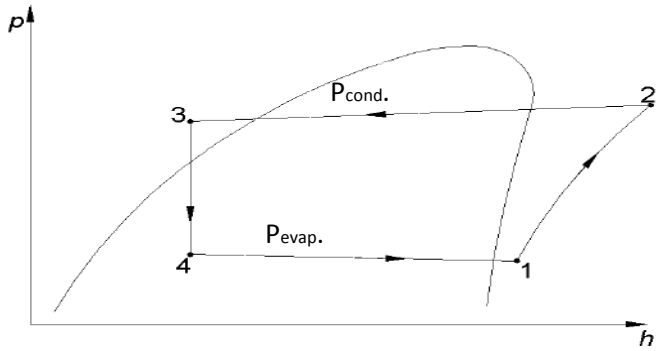


Fig. 4: P-H diagram of actual vapor compression cycle

RESULTS AND DISCUSSION

It can be seen from Figures (5, 6) that (DLE) condenser has a lower discharge pressure (P2) and then lower pressure ratio than conventional condenser and this will lead to improve the performance. This can be attributed to the decrease of frictional loss and easily circulating refrigerant flow in (DLE) condenser.

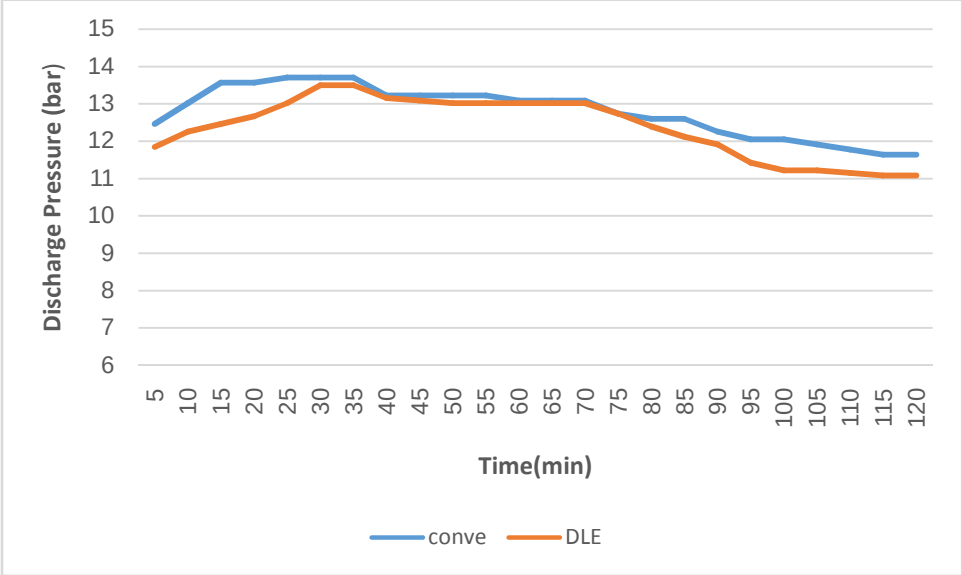


Fig. 5: Comparison discharge pressure vs. time for the conventional and (DLE) condensers

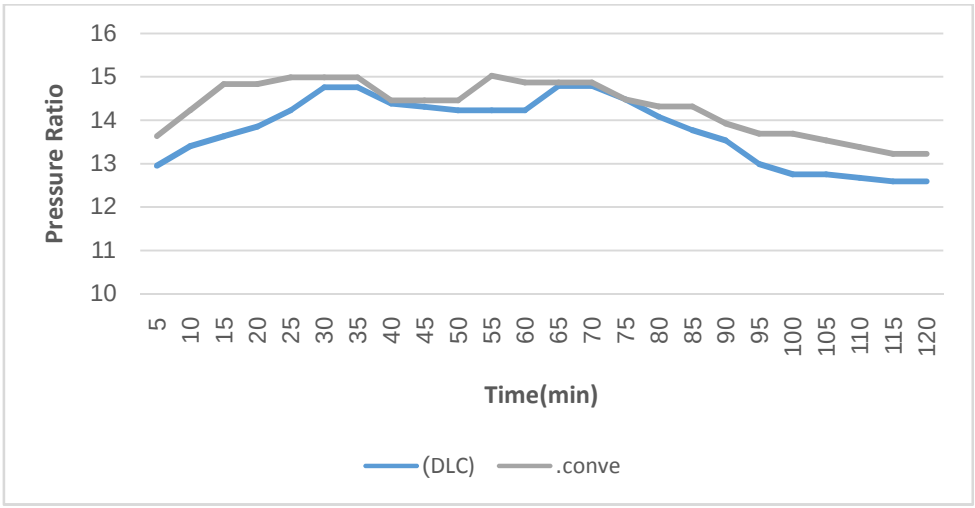


Fig. 6: Comparison Pressure ratio vs. time for the conventional and (DLE) condensers

The change in power per ton of refrigeration with time represented in Figure (7). The refrigeration power decreases as the discharge pressure or (condensing temperature) decreases. Therefore, the (DLE) condenser gives lower power consumption than conventional condenser.

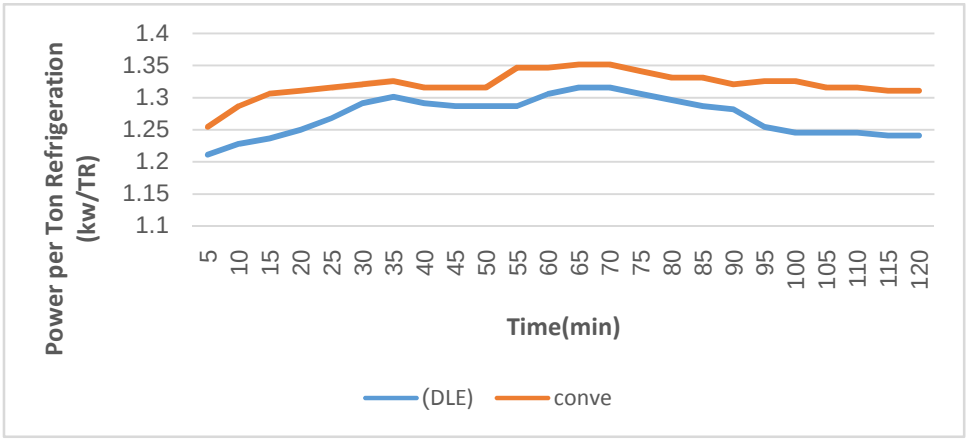


Fig. 7: Comparison of power per ton of refrigeration vs. time for the conventional and (DLE) condensers

It seen from figures (8,9) (DLEC) gives higher refrigerating effect and heat rejected .More heat rejected gives more subcooling of refrigerant after condensation. This is further responsible for increment in the refrigerating effect of any refrigeration system.

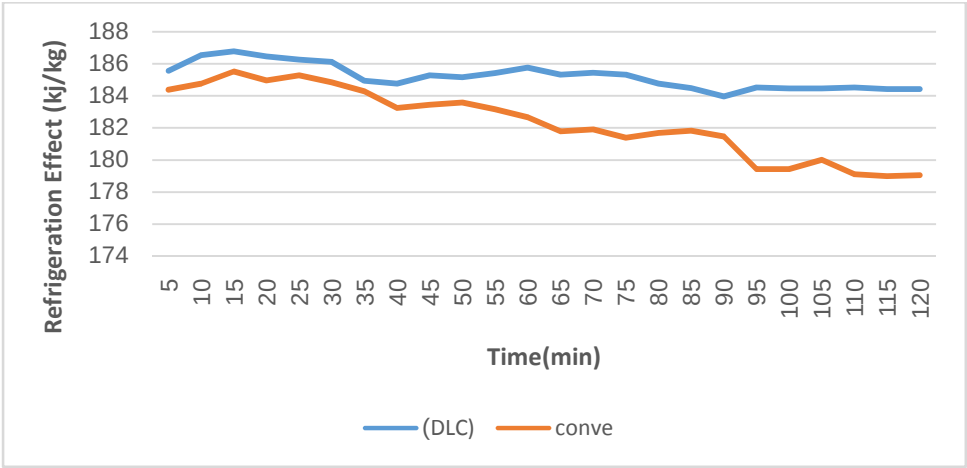


Fig. 8: Comparison of refrigeration effect vs. time for the conventional and (DLE) condensers

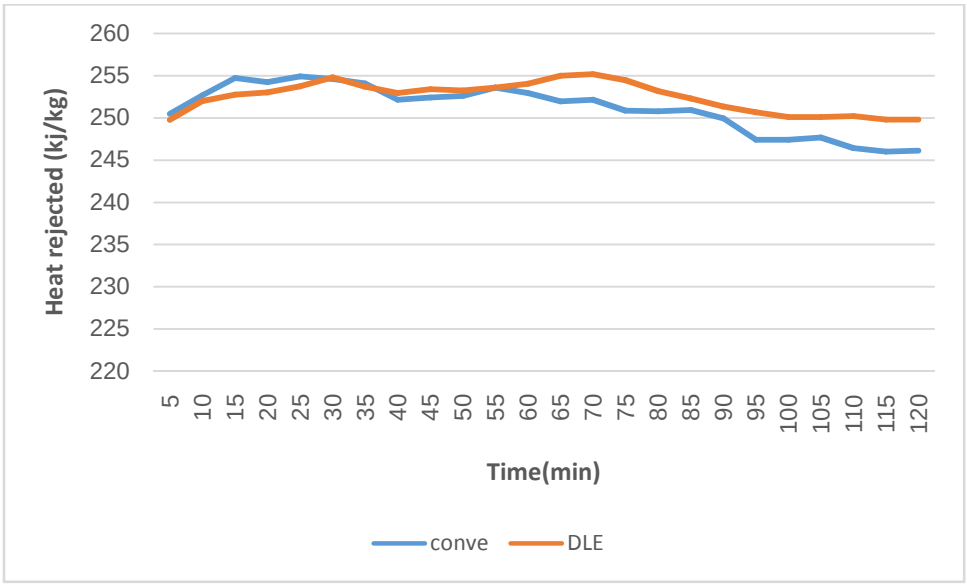
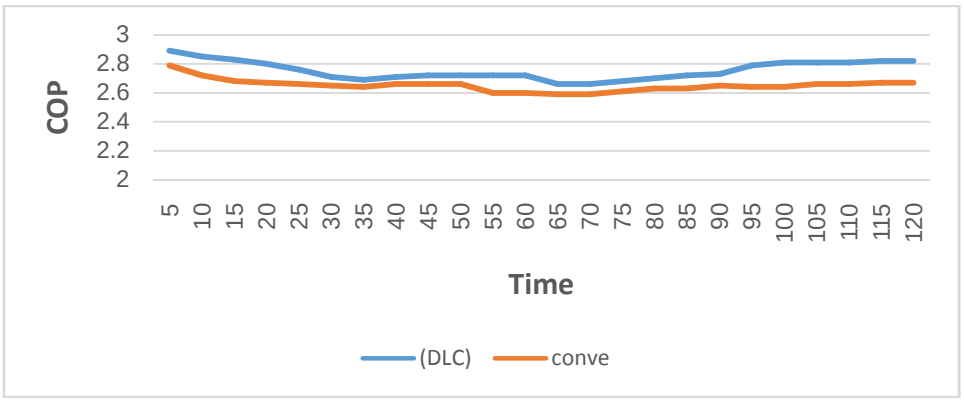
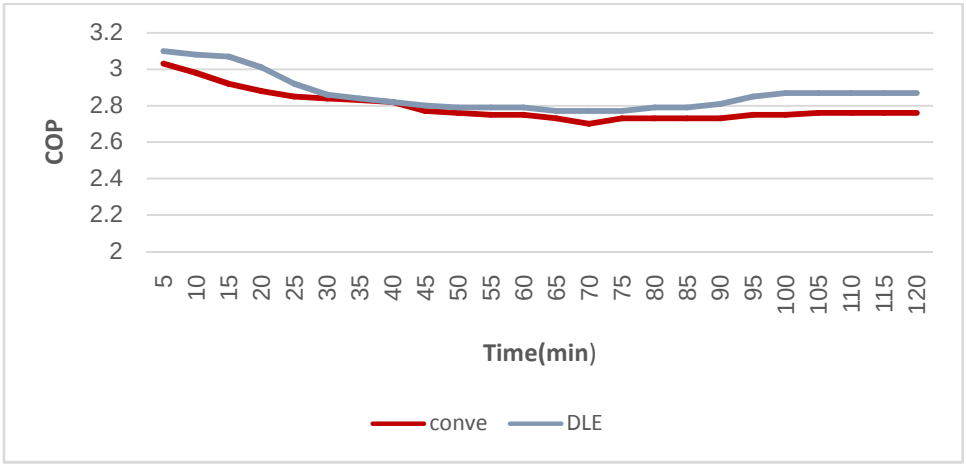


Fig. 9: Comparison of heat rejected vs. time for the conventional and (DLE) condensers

Figure (10-a,b) shows the comparison of the COP both at no load and 12kg water inside the freezer. As a result of the refrigeration effect and the isentropic compression work, the COP increases with a decrease in the condensing pressure due to the increase in the refrigerating effect (RE) and the decrease in the compression work. Therefore, the (DLE) condenser gives higher coefficient of performance than conventional condenser.



(a)



(b)

Fig. 10: Comparison of COP vs. time for the conventional and (DLE) condensers. (a) no load,(b) 12kg water load inside freezer

During the test period,it can be seen form Figure (11) that the lower air temperature inside freezer refers toa higher refrigeration effect gained with using (DLE) condenser.

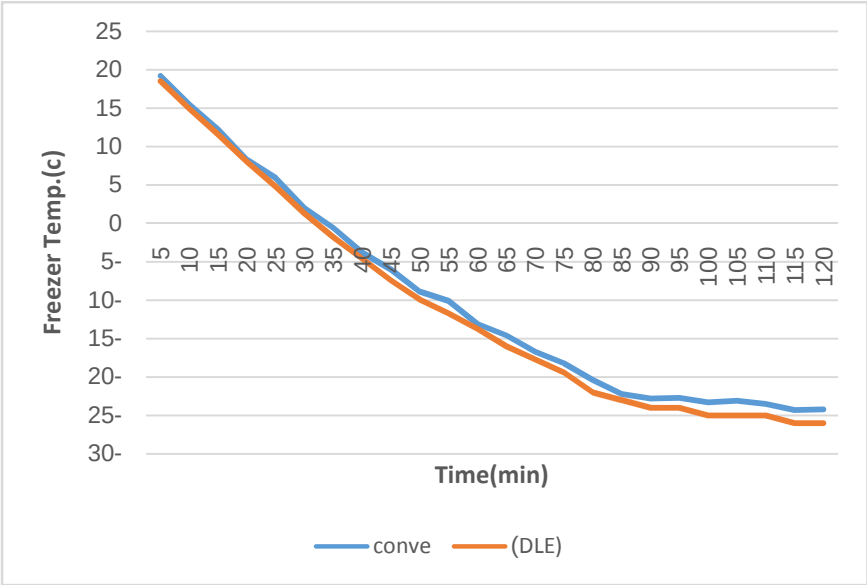


Fig. 11: Comparison air Freezer temp. Vs. time for the conventional and (DLE) condensers

Conclusions:

- The pressure drop through the (DLE) condenser is lower than conventional condenser and that can be attributed to decrease of frictional loss and easily circulating refrigerant flow in (DLE) condenser.
- In case of (DLE) condenser, power consumption of compressor decreases relative to the conventional condenser.
- Referring to Fig. (10)The vapor compression system performance can be enhanced with the help of improving the shape of the condenser to (DLE) condenser.It is seen that the performance of the refrigeration system of domestic refrigerator with (DLE) condenser is better than that of the conventional condenser.

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