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Experimental Study of the Effect of Condenser Tubes Distribution for Domestic Refrigerator

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Abstract

The performance of a condenser in a domestic refrigerator system without wires and a condenser with a novel design consisted of number of loops as elliptical shape is investigated experimentally in this work. The experiment was conducted with a refrigerator designed to work with HFC134a, under no load and with loads of (1.5,3 and 12 liters of water). In particular, the effects of shape change of the condenser were very important in heat transfer enhancement and reduce of the frictional loss as a result of reducing the pressure drop in the condenser. The results shown that compressor work decreases with elliptical condenser about (8.6% to 11.3%), and then the power consumption decreases also. The performance of household refrigerator with an elliptical condenser without fins was better than that of the conventional condenser without fins. Therefore, the elliptical condenser can be used instead of the conventional air cooled condenser in a domestic refrigeration system.

Keywords: *Household Refrigerator, No Wires Tube Conventional Condenser, Elliptical Condenser, Heat Transfer*

1. Introduction

A refrigerator condenser is one of the main operational components that make up the cooling system on a standard refrigerator. Wire on tube heat exchanger has been used in refrigerating and air-conditioning systems for many decades. Conventional condenser consists of a steel tube bended into a single-passage serpentine shape, with wires spot welded perpendicular on both sides. Condensers may be assembled with tubes in a vertical or horizontal position and the air movement can be forced or natural. The thermal performances of various kinds of wire on tube heat exchanger have been reported by many research works. The report of Witzell and Fontaine [1] studied condenser, got a correction for condenser, and concluded that any additional of wire on the external surface of condenser did not increase the rate of heat transfer from condenser. Kirshbaum and Chato [2] modified program developed previously to optimize condenser size with respect to surface area. Also developed a new method of modeling, pipe bends incorporating a new pressure drop correlation. Lee et al. [3] presented experiments to obtain the correlation on the air-side heat transfer coefficient of a single layer wire-on-tube heat exchanger. Wilson et al. [4] investigated experimentally the effect of tube profile change from round to flat shape on condensation heat transfer coefficient. Melo et al. [5] studied experimentally the effects of the gaps between the refrigerator and the back, side and bottom walls of the test section. The results proved that the condenser performance is strongly affected by its position in relation to the adjacent surfaces. Choi et al. [6] introduced the new design wire woven heat exchanger using small tube diameter. Ahmed and Hayder [7] introduced the present modeling of wire and tube condensers that commonly used in a vapour compression cycle based on domestic refrigeration. The modeling results showed the effect of mass flow rate, pressure, refrigerant temperature and ambient temperature on the performance of condenser. Gupta et al. [8] used a method such as tilting of the condenser tube with respect to the horizontal and calculating the heat transfer rate and the amount of heat transfer increased by providing some angle of inclination from the horizontal. They observed with use of convergent divergent construction of the condenser can enhance the heat transfer rate. Sahu et al. [9] presented an experimental analysis of domestic refrigeration system by using wire-on-tube condenser with different spacing of wire also with different operating parameters like heat transfer rate, condenser pressure and condenser temperature.

However, all of the previous work used wire -on- tube heat exchanger, solid metal wire as an extended surface.

An improvement in the efficiency of household refrigeration systems contributes significantly to a reduction in the world consumption of energy and also to a reduction in the global warming. Improving heat transfer effectiveness or/and controlling pressure losses requires novel techniques to develop systems of progressively higher heat transfer performance.

In the present paper, condenser tube is arranged in elliptical shape without fins with natural air movement will be considered. There is working fluid such as refrigerant flowing inside the tube, while the ambient air is directed across the outside surface of the tube panel and compared with conventional no wires tube condenser. The thermal characteristics of a newly-designed and the no wire tube heat exchanger have been investigated.

2. Analysis

The considered heat exchanger consists of a tube bent into a serpentine shape with wires symmetrically welded to both sides in a direction normal to the tubes were cut and removed from the condenser, as shown in figure (1a). From the heat transfer point of view, the exchanger is assumed to be made up of a multiplicity of horizontal tubes. First, the pipe bend pressure drop occurs in conventional condenser causing the frictional pressure drop.

In this study, the new design by taking the elliptical condenser instead of no-wire tube condenser has been presented. When the compressor provides the vapor of refrigerant with high pressure and temperature to the condenser, the vapor of refrigerant starts up and down with a first loop from the outer to the inner and continues rotating moving in the rest of the loops and finally delivers the flow to the capillary tube. However, for a better understanding of the work on the new model of condenser, see the figure (1b).

Heat transfer rate at evaporator or refrigeration capacity, Qe is given by:

$$Q_E = m\ (h1 - h4) \qquad \ldots(1)$$

Where, m is the refrigerant mass flow rate in kg/s, h1 and h4 are the specific enthalpies (kJ/kg) at the exit and inlet to the evaporator, respectively. (h1−h4) is known as specific refrigeration effect or simply refrigeration effect, which is equal to the heat transferred at the evaporator per kilogram of refrigerant.

Power input to the compressor or work of compression WC is given by:

$$W_C = m\ (h2 - h1) \qquad \ldots(2)$$

Where, h2 and h1 are the specific enthalpies (kJ/kg) at the exit and inlet to the compressor, respectively. (h2 − h1) is known as specific work of compression, which is equal to the work input to the compressor per kilogram of refrigerant.

Heat transfer rate at condenser, QC is given by:

$$Q_C = m(h2 - h3) \qquad \ldots(3)$$

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

For the isenthalpic expansion process, h=Const. is given by:

$$h3 = h4 \qquad \ldots(4)$$

The exit condition of the expansion device lies in the two-phase region, hence applying the definition of quality (or dryness fraction), we can write:

$$h4 = (1 - x4)\ hf,e + (x4*hg,e) = hf + (x4*hfg) \qquad \ldots(5)$$

For mass flow rate, [m] is given by: Measurement of the electrical energy input, E allows the mass flow rate to be determined from the simple relationship:

$$E - H = (h_{out} - h_{in}) * m \qquad \ldots(6)$$

Where h are the enthalpy values, per unit mass of the refrigerant. These values are known from the temperature and pressure measurements through the inlet and outlet of the compressor. The heat loss H, expressed as a percentage of E, is between 5 and 7% for most compressor types.

The coefficient of performance, [C.O.P] is given by:

$$C.O.P = Q_E / W_C \qquad \ldots(7)$$

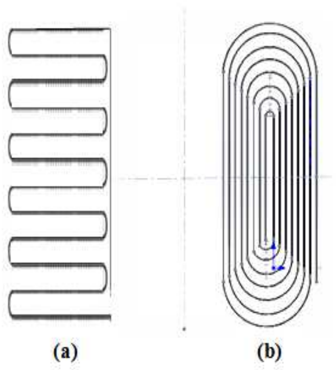


Fig. 1(a). Schematic of No-Wire Tube Type (b) Elliptical Type Condenser.

3. Experimental Setup

The system was manufactured as elliptical shape condenser instead of conventional condenser without wires. The experimental setup of the test unit and apparatus is shown in Figure 2. The refrigerator specifications are given in Table 1.

Table 1,
Refrigerator Specifications.

Model -TETN1600	Concord
Voltage, current and frequency	220V , 0.8A and 50Hz
Gross capacity	190L
Compressor type	Hermetic, HYE69YG, Hi Tech, 1PH, R134a HUAYI Compressor Co.LTD.
Refrigerant	HFC134a
Charged mass	140g
No of door	2
Condenser Types	No Wire Tube Condenser and Elliptical Condenser
Tube material	Steel
Length of tube for both type	19.25m
Diameter of the tube	4mm
Distance between the tube (pitch)	35mm

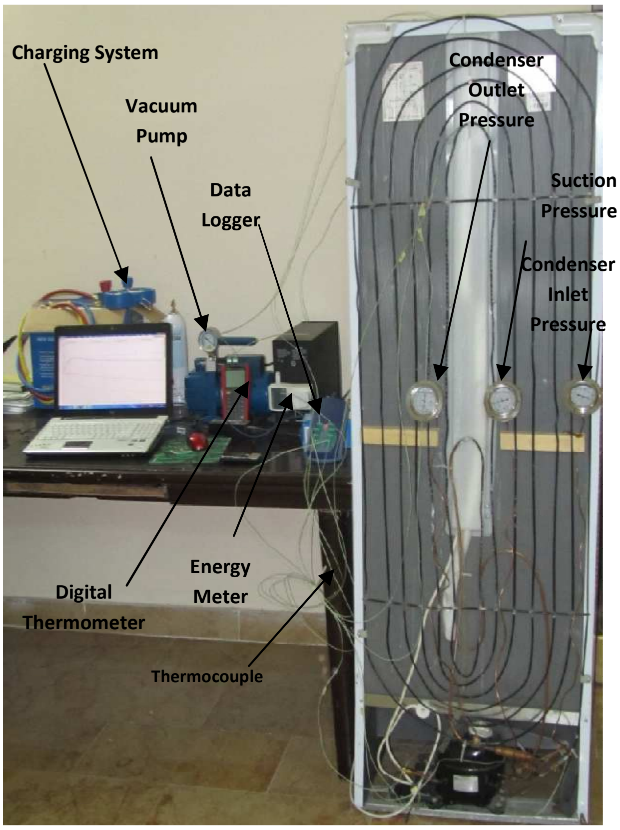


Fig. 2. Experimental Setup of the Investigation Unit and Apparatus.

3.1. Experimental Procedure

Schematic diagram of the experimental apparatus is shown in Figure (3a and b). The domestic refrigerator consists of an evaporator, elliptical air-cooled condenser and hermetically sealed reciprocating compressor.

The refrigerator was instrumented with one low pressure gauge (LPG) type P&M located at the inlet of the compressor for measuring the suction pressure reads from -30cm Hg to 18 kg/cm^2. High pressure gauge (HPG) reads from 0 to 35kg/cm2, two located at compressor and condenser outlet. Eight K-type calibrating thermocouples of 2m length (each) were used for local surface temperatures and connected to data logger. The TC-08 from Pico, England with 8 channels thermocouples measurements units, which can measure and record temperatures ranging from –270°C to +1820°C. PicoLog is a powerful and flexible data acquisition program designed for collecting, analyzing, and displaying data over long or short periods of time. As per the refrigerator manufacturer recommendation, quantity of the required charge for HFC134a is

140g. In the experiment, refrigerant charge is 10% higher due to the presence of instruments and connecting lines. An experimental system was evacuated with the help of a vacuum pump to remove the moisture and charged with the aid of the charging system. During the experiment, the ambient temperature was 29 ± 2^{o}C. The experimental procedures were repeated, and the readings from the various modes were taken. Service port was installed at the compressor inlet for charging and discharging the refrigerant. The experiment was conducted on the domestic refrigerator at four load conditions namely, (no load, 1.5, 3 and 12 litter of water put in the freezer compartment). At each load condition, the temperature and pressure at salient points were noted down for one second interval, recorded by the data logger connected to the laptop. The experiment was done until steady state conditions were attained in most the temperatures down. The energy consumption of the system was measured by using Plug-In Mains Power and Energy Monitor (Model 2000MU includes 7 precision digital meter) and the LCD display shows all meter readings which include Volt, Current, Watt, Frequency, Power Factor, and Volt ampere (VA), it starts to accumulate kilowatt hour (KWH) and its duration time (hour) after power on. The typical accuracy for voltage is in the range of 190V-250V; and for current is in the range of 0.2A-15A. The input volt to the compressor is regulating by Fridge Stabilizer upto 300 Ltrs. (165-280 V) (2 Amp.). The performance of the refrigerator with conventional condenser without fins and of the elliptical condenser is evaluated then the test results of two types were compared

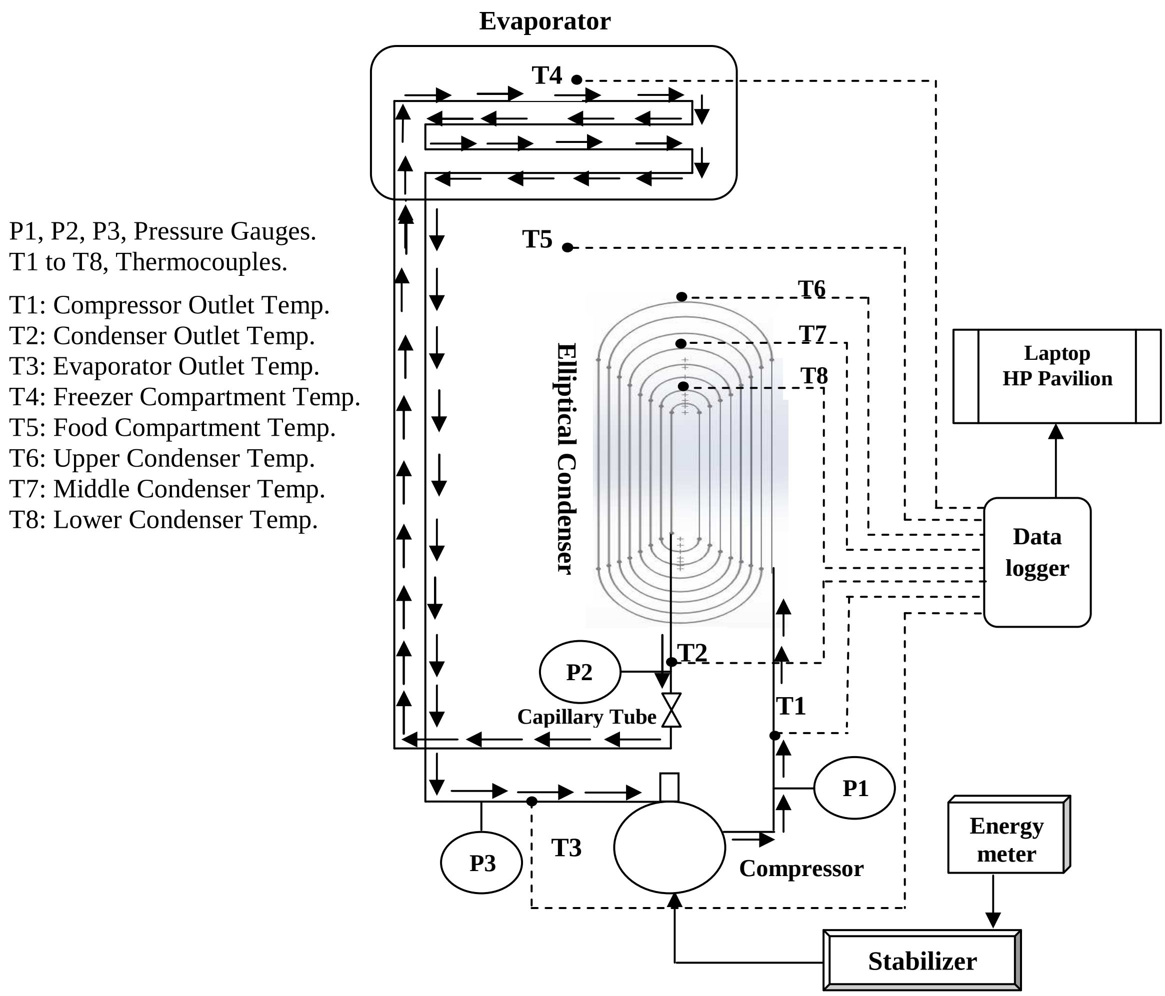


Fig. 3a. Schematic Diagram of the Investigation Unit and Apparatus.

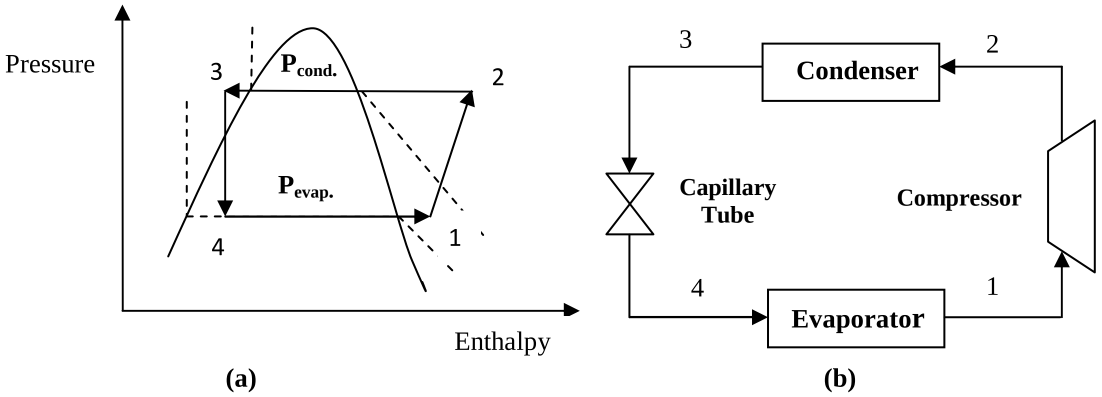


Fig. 3b.(a) Shows the process path on a pressure–enthalpy (*P*– *h*) diagram, and (b)shows a schematic diagram of the process equipment.

4. Results and Discussions

Figure 4. gives the comparison of the temperature at the inlet and outlet of the condenser for two types of conventional and elliptical condensers with steady state condition. For all load conditions, the outlet temperature from the compressor (T1) was greater for the conventional condenser without fins than elliptical condenser because the condenser inlet pressure was higher for conventional condenser than that for elliptical one. Also the work done by the compressor is decreased with elliptical condenser, and then the power consumption also decreases. This figure shows that the temperature difference about the elliptical condenser is smaller than the conventional one.

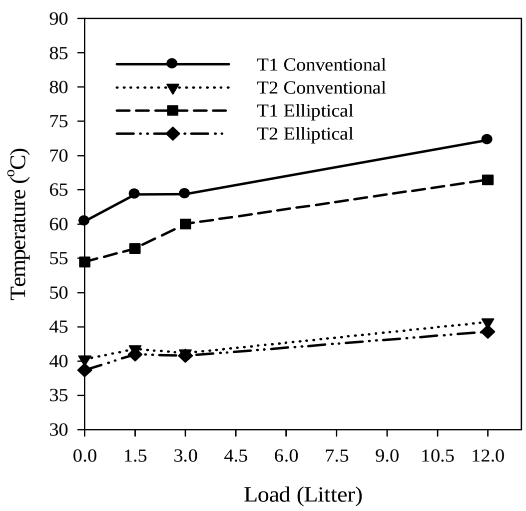


Fig. 4. Variation the Inlet and Outlet Temperature of the Condenser with Load.

Figure 5. shows that for all load conditions, the average temperature of the condenser was greater for the conventional condenser without fins than elliptical condensers at steady state condition. This is due to the pressure drop for conventional condenser was higher than that for the elliptical condenser, then increasing the frictional losses as a result of elbow of the conventional condenser. Also the work done by the compressor increases with conventional condenser without fins, and then the power consumption also increases. These results confirmed that the performance of household refrigerator with elliptical condenser was better than that of the conventional condenser.

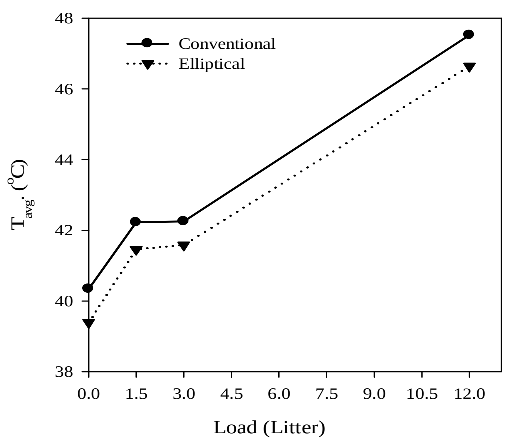
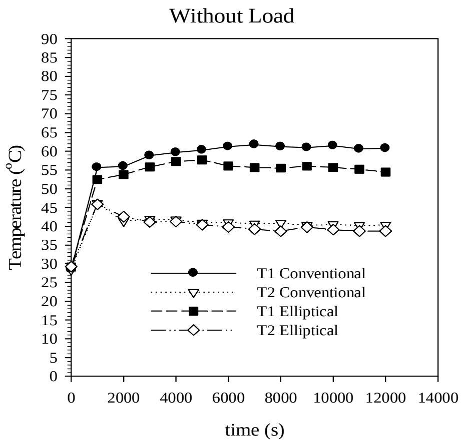


Fig. 5. Variation of the Average Temperature at the Surface of the Condenser (T6,T7 and T8) with Load.

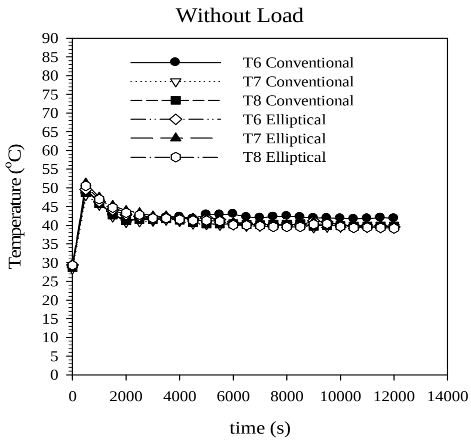
Figure 6. (a,b,c and d) reveals a comparison of the transient temperature at the inlet and outlet of the condenser for conventional and elliptical condensers. For all load conditions, the temperature difference through the elliptical

condenser was less than the conventional condenser without fins. This is contributed to developed turbulences inside the rotating flows in the tube and increasing the velocity of the flow as a result of changing the shape of the condenser to elliptical that resulted in the increase of the dissipation of heat.

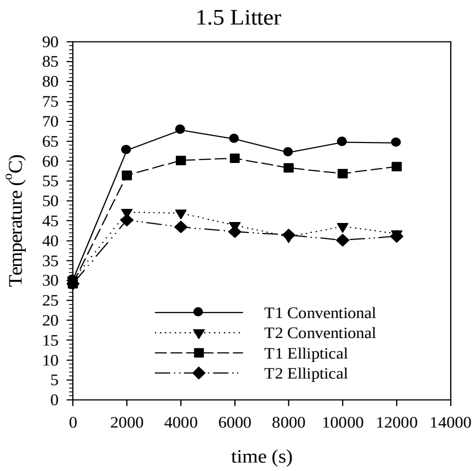
Figure 6. (e,f,g and h) manifests the temperature at the surface of the condenser. For low load conditions, the surface temperature of the condenser at the upper, middle and lower (T6,T7 and T8) was converge for both types. At high load conditions, the surface temperature was nonuniform for the conventional condenser while in elliptical condenser, the temperature at these locations converge where flow characteristics are the same for each region of the condenser. This is ascribed to that the pressure drop through the condenser was low and that means the heat dissipation from the elliptical condenser was uniform.



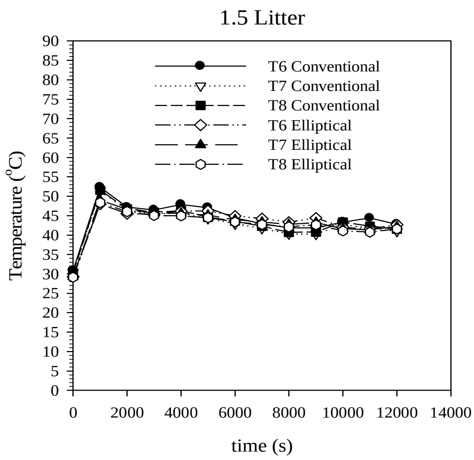
(a)



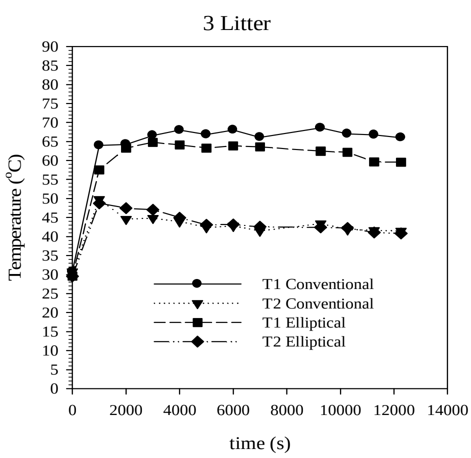
(e)



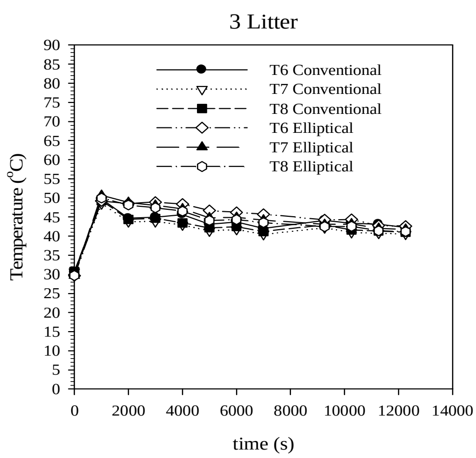
(b)



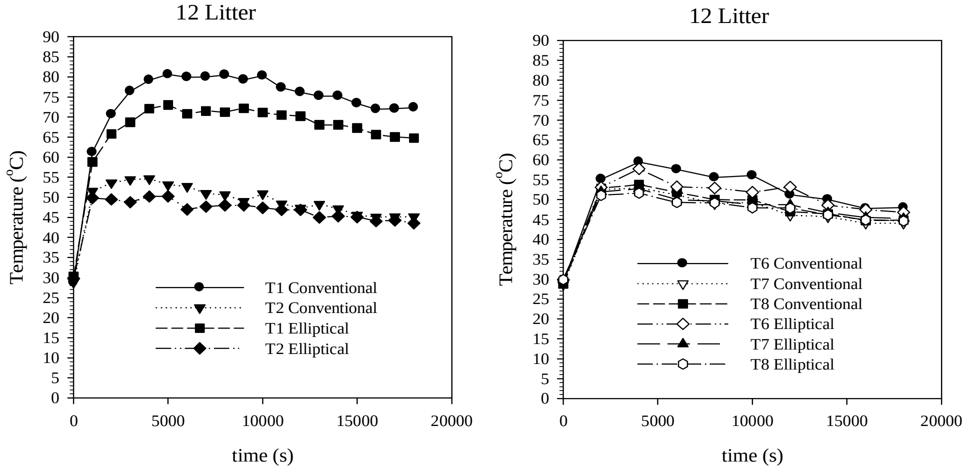
(f)



(c)



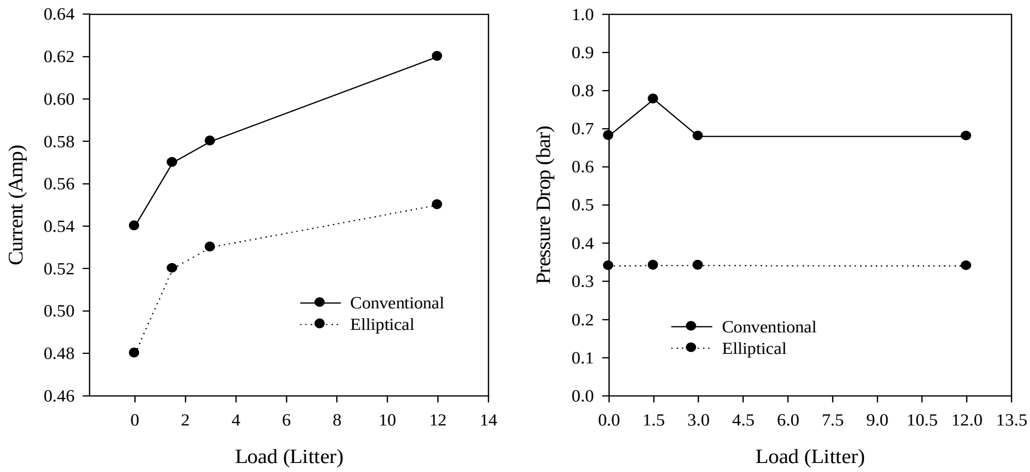
(g)



(d) **(h)**

Fig. 6. (a, b, c and d) the variation of temperature with time for inle and outlet of the condenser and (e, f, g and h) the Variation of the Average Temperature at the Surface of the Condenser (T6,T7 and T8) with all loads.

Figure 7. (a) and (b) illustrates the comparison of the current and pressure for two types of condensers at a steady state condition . For all load conditions, the current was low for the elliptical condenser compared to the conventional condenser without fins. That is owing to the decrease of load on the compressor as a result of easily rotating flow in the elliptical condenser. Also, the pressure drop for elliptical was less than that for the conventional condenser, due to the decrease of frictional losses as a result of improving the shape of condenser, where can rotate the flow without restriction to the flow in the elliptical condenser.



(a) **(b)**

Fig. 7. (a) variation of the current and (b) the pressure drop with all load.

Figure 8. (a) and (b) shows that the coefficient of performance was higher for the elliptical condenser compared to the conventional one. Also, the compressor work with elliptical condenser was lower than that of conventional condenser. That is because of easily rotating flows in the elliptical condenser which can reduce the load on the compressor.

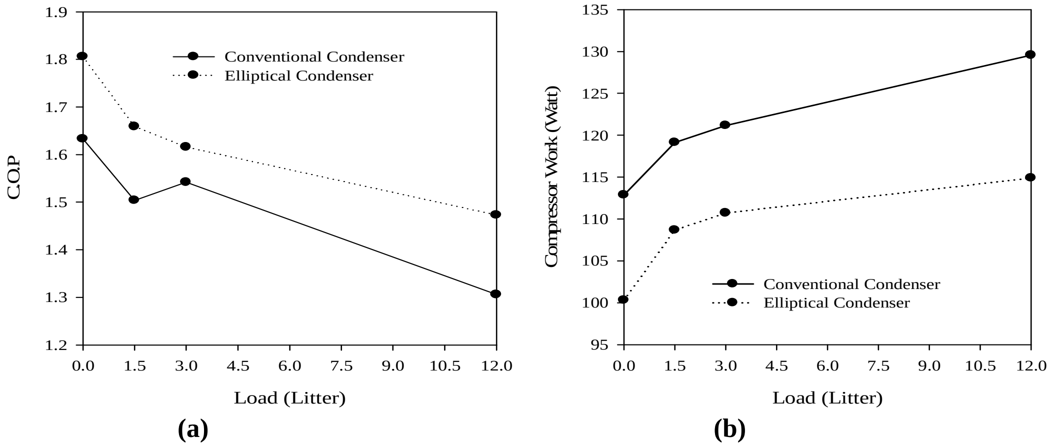


Fig. 8 (a) variation the coefficient of performance and (b) the compressor work with all load.

5. Conclusions

Based on the previous discussion of the obtained results the following conclusions can be extracted.

1- The work done by the compressor decreases about (8.6% to 11.3%) with elliptical condenser and then the power consumption also decreases.

2- 2- The temperature difference between the inlet and outlet of the condenser is smaller for elliptical condenser than the conventional one.

3- Developed turbulences inside the rotating flows in the tube and the increasing of velocity of the flow occurred as a result of changing the shape of the condenser to elliptical that resulted in the increase the dissipation of heat.

4- The pressure drop through the elliptical condenser was about (0.35 bar) while in the conventional one was about (0.68 bar).

5- The heat dissipation from the elliptical condenser was uniform.

6- Decreases of frictional losses caused as a results of improving shape of the condenser, where can rotate the flow without restriction to the flow in the elliptical condenser.

7- The coefficient of performance increases about (4.5% to 11.33%) with elliptical condenser respect to the conventional condenser without fins.

8- The performance of household refrigerator with elliptical condenser was better than that of the conventional condenser without fins.

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دراسة تجريبية على تأثير توزيع انابيب المكثف لثلاجة منزلية

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الخلاصة

اداء المكثف في نظام الثلاجة المنزلية بدون اسلاك ومكثف مع تصميم جديد يتكون من عدد من الحلقات بشكل بيضوي بحث تجريبيا في هذا البحث. التجارب كانت تعمل على ثلاجة مصممة للعمل مع (HFC 134a). وتحت احمال متغيرة (بدون حمل ، ١.٥، ٣ ،١٢ ليتر من الماء). وبشكل خاص تاثير تغيير شكل المكثف مهم جدا في تحسين انتقال الحرارة وتقليل خسائر الاحتكاك بوصفه محصلة لتقليل الهبوط بالضغط في المكثف. توضح النتائج ان الشغل المنجز بوساطة الضاغط يقل مع المكثف البيضوي حوالي (٨.٦% الى ١١.٣%)، وعليه القدرة المستهلكة كذلك تقل. اداء الثلاجة المنزلية مع المكثف البيضوي بدون زعانف افضل من المكثف التقليدي بدون زعانف. لذلك يمكن استخدام المكثف البيضوي بدلا عن المكثفات التقليدية المبردة بالهواء في نظام الثلاجة المنزلية.