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Coefficient of Performance Enhancement of Refrigeration Cycles

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ABSTRACT
Refrigerator is one of the home appliance utilizing mechanical vapor compression cycle in its process. Performance of the systems become the main issue and many researches are still ongoing to evaluate and improve the efficiency of any used system. Therefore, this paper presents an experimental investigation of the performance of the refrigeration cycles. A small rrefrigerator is used as the test rig. The Coefficient of Performance (COP) is studied by using different condenser designs and under varying evaporator loads. Three condenser designs are used in present work. These condensers are regular condenser of domestic refrigerator, condenser with copper plain tubes (Cond.1) and condenser with copper tubes welded with stainless steel flat plate (Cond.2). pressures and temperatures measurements of each point in the refrigeration cycle are collected in order to evaluate the refrigerator performance. The results showed that the average COP of Cond.1 and Cond.2 are increased up to 20 % and 14% respectively more than regular condenser design under no load. The evaporator load effects on the machine performance, where the COP of the machine increases with the increase of the evaporator load.
Keywords: Refrigerator – COP – Condenser - Enhancement.

I. INTRODUCTION.

A refrigerator is an electrical appliance used in many households for keeping foods cool enough so that they won't spoil. There are other types of refrigerators that do not operate using electricity, such as gas- or oil-powered refrigerators. Some domestic refrigerators are single units, and others are combined with a freezer. The best temperature setting inside the refrigerator is often between 38 and 40 degrees Fahrenheit, or 3.3 and 4.4 degrees Celsius. If the temperature is set below 32 degrees Fahrenheit or 0 degrees Celsius, the refrigerator will freeze the food [1].

Figure 1 shows different types of the cooling systems. The Coefficient of Performance (COP) of vapor compression refrigeration is higher than other available techniques. It should be noted, however, that the absorption technique can also be directly operated by heat instead of electricity which in certain applications is a benefit for this technique.

The process of refrigeration occurs in a system which comprises of a compressor, a condenser, a capillary tube and an evaporator arranged as depicted schematically in Figure 2.

Vapor compression Refrigeration
COP ≈ 1 – 3

Absorption Refrigeration
COP ≈ 0.2 – 0.3

Thermoelectric Refrigeration
COP ≈ 0.1 – 0.2

Figure 1. Different cooling systems and their COP ranges [14].

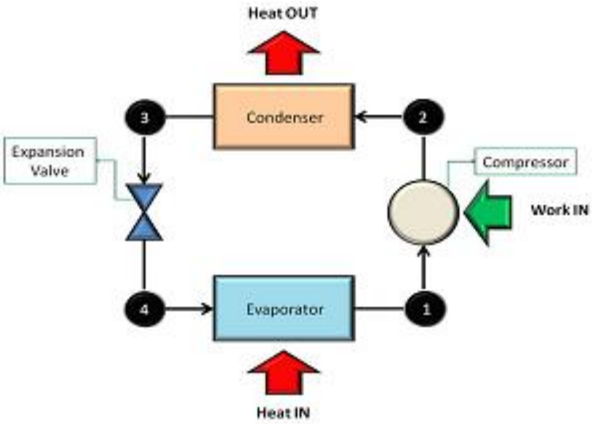

Figure 2: Schematic diagram of a vapor compression refrigeration system [14].

Condensers and evaporators are basically heat exchangers in which the refrigerant undergoes a phase change. Next to compressors, proper design and selection of condensers and evaporators is very important for satisfactory performance of any refrigeration system. Since both condensers and evaporators are essentially heat exchangers, they have many things in common as far as the design of these components are concerned. However, differences exist as far as the heat transfer phenomena are concerned. In condensers the refrigerant vapor condenses by rejecting heat to an external fluid, which acts as a heat sink.

Domestic refrigerator-freezers (RFs) consume a large amount of energy, which accounts for approximately 6% of the electrical energy produced worldwide [2].Refrigerator freezer is a major household appliance designed for preserving foods through refrigerating and freezing. The mechanical system used for this aim is a vapor compression refrigeration system, which usually consists of a compressor, a condenser, an evaporator, and an expansion device. With increasing market demand for saving energy in household appliances, research and development of an energy efficient refrigeration system has attracted many investigators [3, 4].

Afonso and Matos [5] presented the investigation related to improvement of refrigerator by decreasing heat inflow from the side of condenser. It was demonstrated that the coverage decreases the temperature in the inside of the refrigerator by approximately 2 K. Such a simple improvement could sufficiently decrease the power consumption. Surrounding space around condenser of household refrigerator has sufficient influence on heat transfer efficiency. Saidur et al [6] proposed study related to surrounding temperature impact on power consumption of the refrigerator in order determine the influence. Room temperature was changed from 14°C to 32°C, about 60-70% of power consumed by the refrigerator is energy for covering heat inflow due to temperature difference as well as energy for increased power requirement due to higher pressure of condensation. Energy losses because of the system cycling and hydraulic losses are not high. About 30% of energy losses are related to friction and electrical losses of the compressor. Hence the most important factor is the quality and quantity of the insulation of the refrigerator.

Sahu et al [7],presented an experimental analysis of domestic refrigeration system by using wire-on-tube condenser with different spacing of wire, they found that the operating parameters like heat transfer rate, condenser pressure and condenser temperature, refrigerating effect was increased by using wire-on-tube condenser comparatively power consumption remains the same as with air cooled condenser in a domestic refrigeration system. Therefore wire-on-tube condenser can replace the ordinary air cooled condenser in a domestic refrigeration system.Dagilis and Hofmanas [8], presented an experimental and numerical study to investigate the influence of surrounding space on heat transfer effectiveness of refrigerator's condenser. Experimental investigation was carried out with condenser at real conditions when it operates in refrigerating system. The results demonstrate that condenser space impacts the heat transfer by up to 14%. Moreover, the results allowed doing a novel solution for more effective heat transfer, i.e. the creation of small artificial air flow upwards by the natural direction. Thus the combined convection case was getting, which is in good accordance with the conventional construction of the condenser.

Melo et al [9], investigated experimentally the performance of wire and tube condensers which widely used in small refrigeration appliances under various operating conditions. In particular the effects of the gaps between the refrigerator and the back, side and bottom walls of the test section were analyzed. The results prove that the condenser performance is strongly affected by its position in relation to the adjacent surfaces.Ahmadul Ameen et al [10], make a numerical model of a wire-on-tube condenser under varying operating conditions of free convection using finite element methods, they also investigatedexperimentally the performance of two wire-on-tube condensers in a retrofitted domestic refrigerator using refrigerant R-134a and then compare these results with a simulation modeling.

Kedzierski [11] quantified experimentally the change in the heat transfer and pressure drop associated with titling a compact brazed plate heat exchanger from the intended vertical position. The result obtained that both the evaporator and condenser pressure drops were influenced by flow distribution changes as the heat exchanger were rotated.Momin et al [12]presented an experimental study to recover waste heat from condenser unit of a household refrigerator to improve the performance of the system. The heat recovery from the household refrigerator was by thermosiphon. Recovery of heat from the condenser reduces the heat load to surrounding and it make surrounding comfortable.

Collicott et al [13] presented an experimental study to calculate heat transfer factor by free convection and shape factor for wire-and-tube condenser. It was found that the diameter of tube or wire proportional to space between the tube or wire. Taib et al [14] presented the development process of refrigeration,reliable test rig and performance analysis of a domestic refrigerator. The indicator of COP was about 2.75 and refrigeration capacity was ranging from 150 to 205 W.

Lee et al [15] developed the air side empirical heat transfer correlations for forced-convection for wire-and-tube condensers. Yu et al [16] discussed the improved condenser design for air cooled chillers. The condenser component contains an algorithm to determine the number and speed of the condenser fans staged at any given set point of condensing temperature. An increase in chiller COP of 5.6–113.4% can be achieved from the new condenser design and condenser fan operation.

Fatemeh et al [17] highlighted that a 23.6 % energy consumption reduction of refrigerator by hot wall condenser removal, 19.3 % R134a refrigerant charge amount reduction of refrigerator cycle, reduction of the production cost by eliminating of nearly 10 m of pipe.

As can be seen from the literature, there are not enough studies on the effect of changing condenser design to enhance the COP of the refrigeration cycles. So, the purpose of the presentwork is an experimental study on different condenser designs to enhance COP of the refrigeration cycles.

II. THEORY AND DATA REDUCTION

It is known that the refrigeration is defined as the process of removal of heat from a region or state or a substance to reduce and maintain its low temperature and transferring that heat to another region, state or substance at higher temperature. The thermodynamic processes that employed in the domestic refrigerator is based on a vapor compression cycle are illustrated on T-s, P-h diagrams as shown in Figure 3.

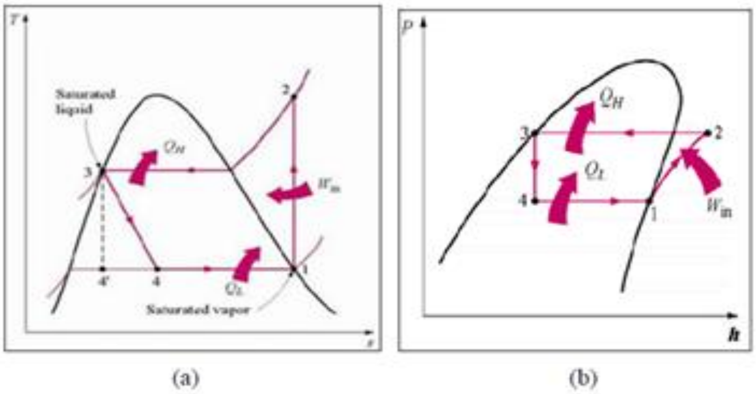

Figure 3: (a) T-s and (b) P-hdiagrams for ideal vapor compression refrigeration cycle [18].

Process line from 1 to 2 represents compressor power. Compressor power isdefined as the power needed to do the compression process in watts. The compressor power is determined by multiplying enthalpy change across the compressor to the mass flow rate, thus,

$$\dot{W}_c = \dot{m}_r (h_2 - h_1) \qquad (1)$$

Meanwhile, process from point 2 to 3 represents heat rejection throughcondenser, the refrigeration capacity can be obtained using equation below:

$$\dot{Q}_c = \dot{m}_r (h_2 - h_3) \qquad (2)$$

Process from point 3 to point 4 shows throttling process through the capillary tube and the process line 4 to 1, represents the heat absorption process in the evaporator. The refrigeration capacity can be obtained using equation below:

$$\dot{Q}_e = \dot{m}_r (h_1 - h_4) \quad (3)$$

The coefficient of performance (COP) is a measure of efficiency of the refrigerator. The COP of a domestic refrigerator is the ratio of the refrigeration capacity to the power supplied to the compressor and it can be expressed by:

$$COP = \frac{\dot{Q}_e}{\dot{W}_c} = \frac{\dot{m}(h_1 - h_4)}{\dot{m}(h_2 - h_1)} \quad (4)$$

The value of enthalpy h is determined by using Refrigerant Properties Database based on temperature and pressure measurements.

III. EXPERIMENTAL SET UP

Experimentsare conducted conventionally by taking all of data manually as seen in Fig 4. The all five points of thermocouplewire (Type PT 100) are located in five positions in the refrigerator:

- Beforecompressor.
- Before condenser.
- After condenser
- After capillary tube
- Insidefreezer.

All pointsare shown in Fig 5.The experiment includes three types of condenser:

a. Regular condenser of domestic refrigeration(Cond 0) Fig. 6 a
b. New design of condenser with plain tubes(Cond 1) Fig 6 b.
c. New design of condenser with plain tubesand flat plat (Cond 2) Fig 6 c.

Table 1 shows the three condensers configurations:

Type of Condenser	Material	Length	Tube diameter
Cond 0	Iron	10.30 m	0.0065 m
Cond 1	Copper	10.30 m	0.0065 m
Cond 2	Copper	10.30 m	0.0065 m

The refrigeration load is changed by using a heater connected with a voltage regulator device inside the refrigerator. Five thermocouples (Type- T) are connected to a temperature read out unit for measuring the temperature with calibration equation [$T_{act} = 0.91\ T_{measured} + 0.0420$], and 5 pressure gauges are connected for measuring pressures of each point with different refrigeration loads of (0, 15, 40, 55, 80, 100 Watts), and recorded every ten minutes during two hours working time for the three cases in order to investigate the performance of the refrigerator.

Figure 4: Experimental test rig used

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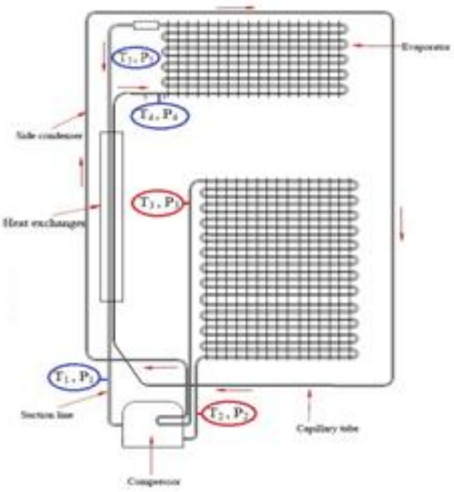

Figure 5: Temperature and pressure measured points.

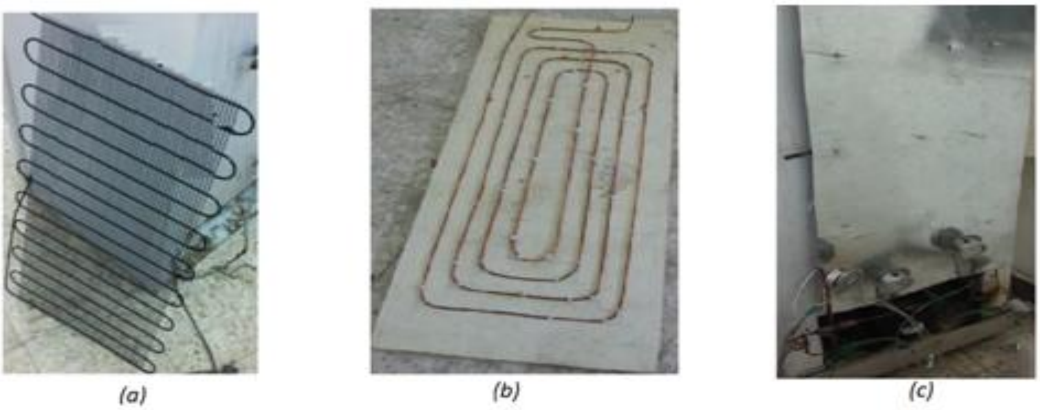

Fig 6: Three condenser type used in present work ,(a) Regular condenser of domestic refrigeration (Cond 0) , (b) Condenser design with plain tubes (condenser 1) and(c) Condenser design with plain tubes and flat plat (condenser 2).

IV. RESULTS AND DISCUSSIONS

Experiments are performed to investigate the effect the condenser design and heat load conditions on the refrigerator coefficient of performance (COP). For that purpose a two condenser designs prepared and compared with the regular condenser of domestic refrigeration.

As shown in Fig 7, during a 120 minute working time with no load inside the evaporator, the heat rejected from the condenser increased gradually to reach a steady state of an average of 130 kJ/kgfor a regular condenser design.

Figure8 shows a variation of COP with time at no load inside the evaporator. It is shown from this figure that the COPdecreases with time then reach a steady state values after 90 minutes.Lokhande et al [19] graphed the COP variation vs time for a domestic refrigerator while a heat load inside its evaporator. The graph of Lokhande shows a trend matching with the currents study

The comparison of the results between the three condensers at no load inside evaporator is shown in Figs. 9 and 10. These Figs. show that the Cond. 1 gives the values of Q_c and then COP more than Cond.2 and in turn more than regular condenser (Cond. 0). This can be attributed to the higher heat conduction from the tubes and the free movement of air around the tubes of Cond. 1 more than that of Cond. 2 and Cond. 0 which lead to increase the heat transfer to the air.

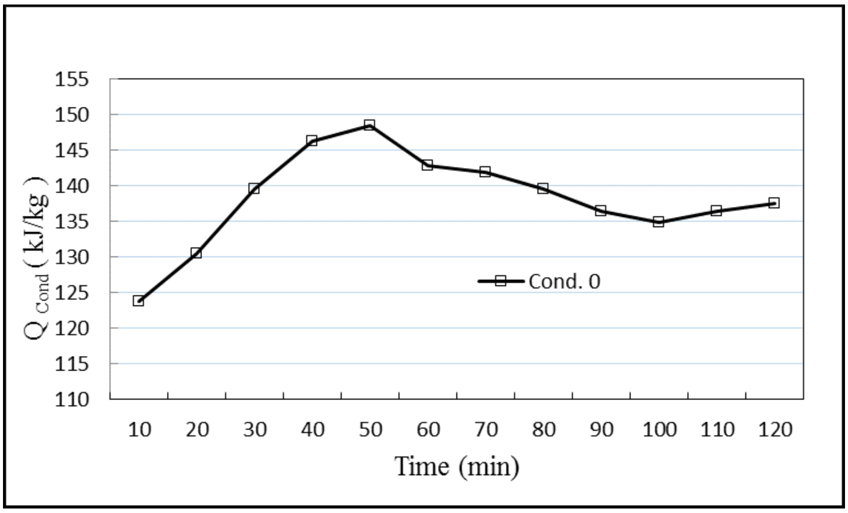

Fig.7 Variation of $Q_c$with Time for regular condenser (Cond. 0) with no load inside evaporator

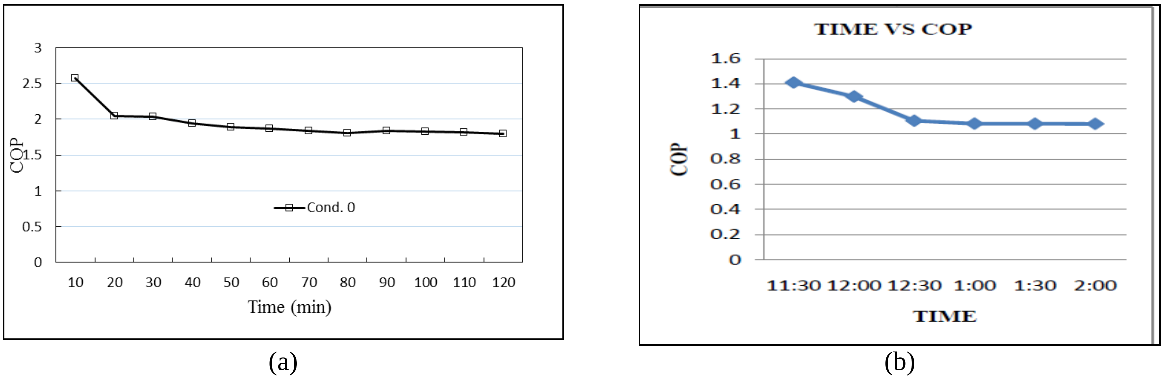

Fig.8 Variation of COP with Time for regular condenser design with no load inside evaporator. (a) Present study (b) Lokhande study

Fig 11 shows a comparison of the percentage increase of COP for the two condensers (Cond.1 and Cond.2) at no load inside evaporator. It can be seen that the first one (cond.1) gives improvementforthe COP more than the second one (Cond.2). This result can be attributed to the fact that the heat transfer from the tubes of the Cond.1 is more than that of the Cond.2 which covered by stainless steel sheet where the movement of air around the tubes is restricted by this plate.This mean that the covering the condenser tubes with a stainless steel plate (Cond.2) gives low COP because it resists the natural convection heat transfer process between the tubes surface and its surrounding.

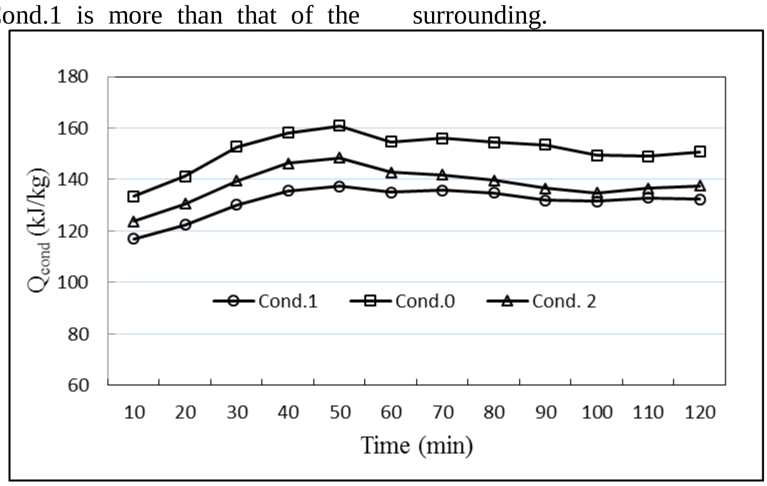

Fig. 9 Comparison of $Q_c$vs. Time for the three condensers with no load inside evaporator

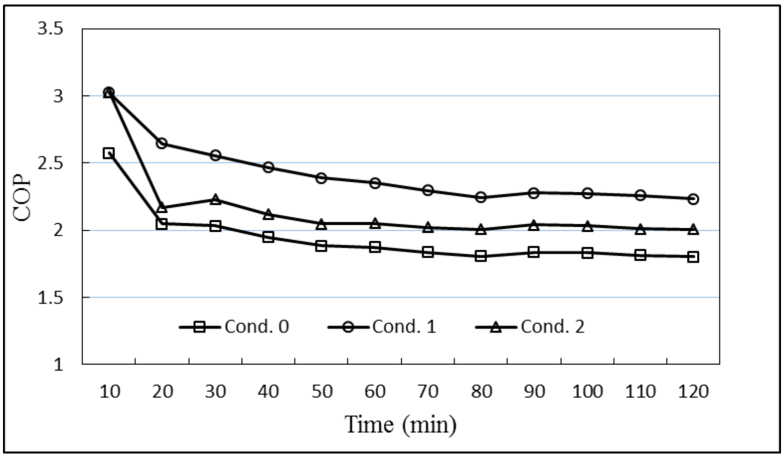

Fig.10Comparison of COP vs. Time for the three condensers with no load inside evaporator

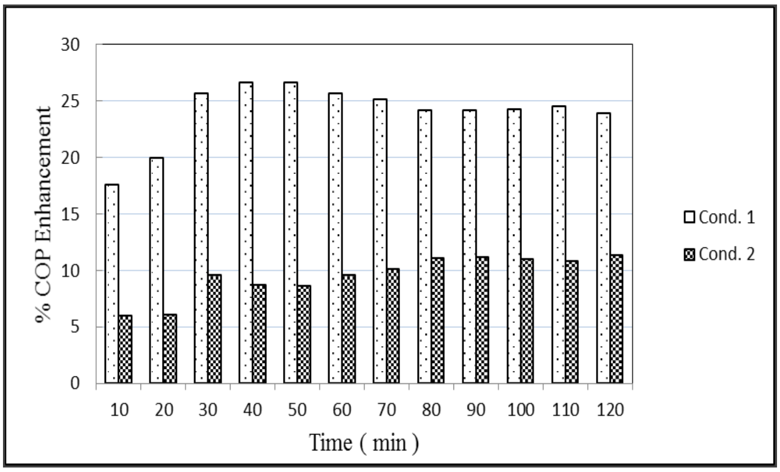

Fig.11 Comparison of the % COP improvementwith thetime for Cond.1 and Cond.2 at no load inside the Evaporator.

The comparison of the results between the three condensers at load 100 Watt inside the evaporator is shown in Figs. 12 and 13. Also, the comparison between the three condensers with variation of load at time 90 minutes is shown in Fig. 14.

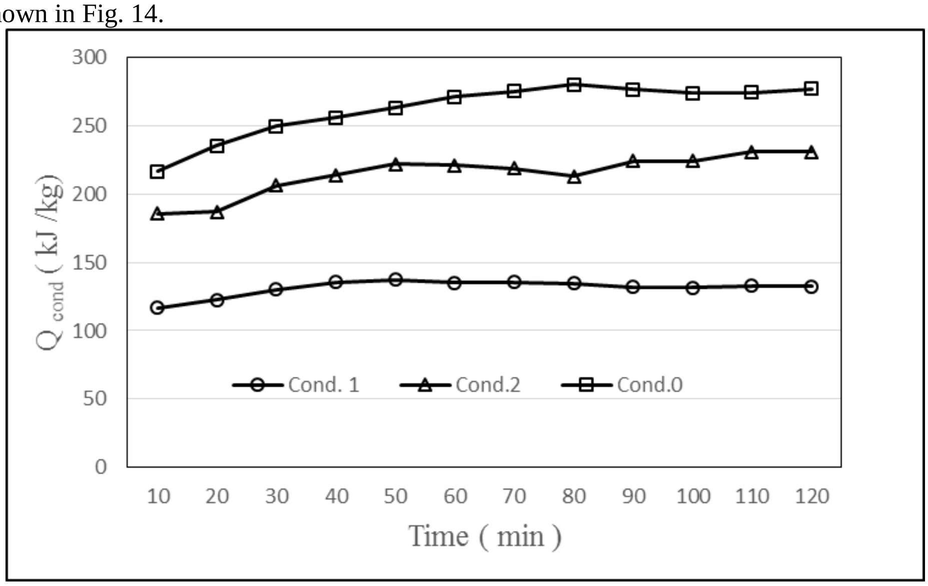

Fig.12 Comparison of Q_{cond} vs. Time for the three condensers at 100 Watt heat load inside the evaporator.

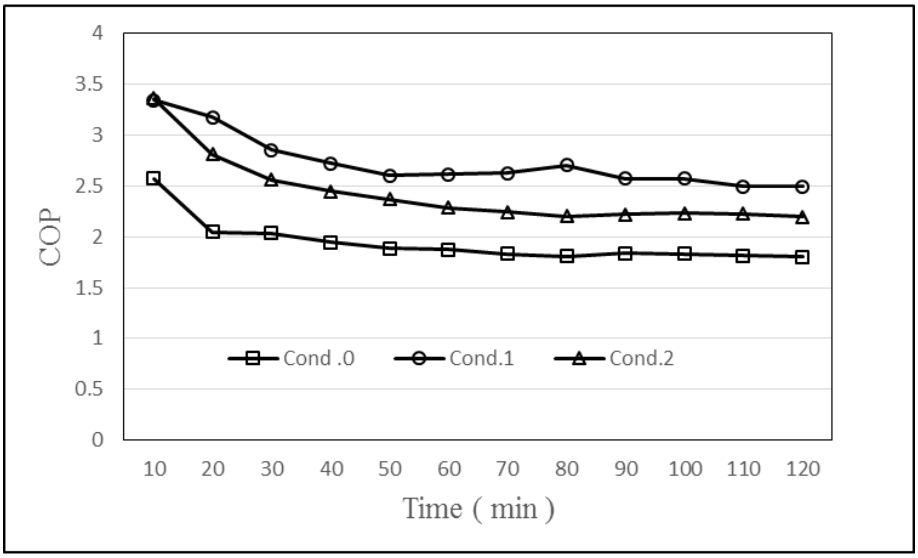

Fig.13Comparison of COP vs. Time for the three condensers at 100 Watt heat load inside the evaporator

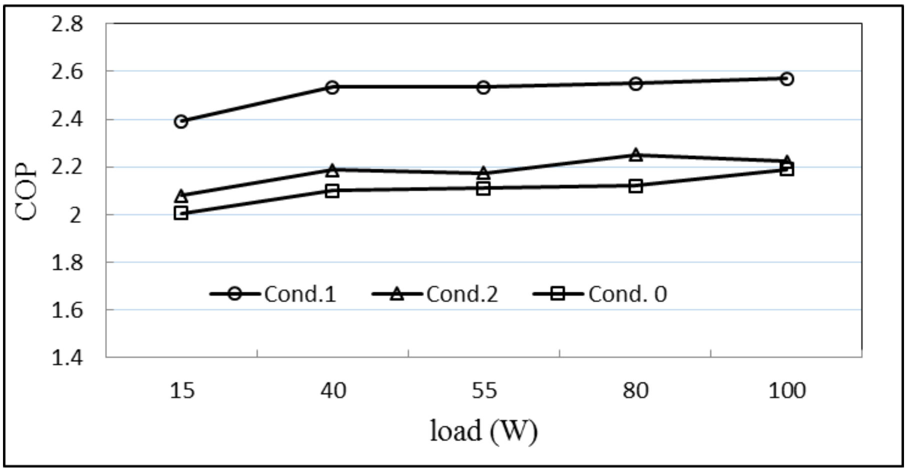

Fig.14 Comparison of the COP variation at different heat loads for different condenser designs after 90 minute working time.

These Figs. show that the Cond.1 gives the higher values of Q_c and then COP more than Cond.2 and in turn more than regular condenser (Cond. 0). This also, can be attributed to the higher heat conduction from the copper tubes of cond.1 and the free movement of air around the tubes of Cond.1 more than that of Cond. 2 and Cond. 0 which lead to increase the heat transfer to the air and this cause the increase of COP.

V. CONCLUSIONS

The experimental investigation of the performance of the refrigeration cycles is presented. A small refrigerator is used as the test rig. The coefficient of performance (COP) is studied by using different condenser designs and under varying evaporator loads. There are three condenser designs are used in present work. These condensers are regular condenser of domestic refrigeration, condenser with copper plain tubes (Cond.1) and condenser with coppers tubes welded with stainless steel flat plate (Cond.2). The pressures and temperatures measurements of each point of the refrigeration cycle are collected in order to evaluate the refrigerator performance.

It was found that:

- The values of the heat rejected from the condenser and COP of the refrigeration cycleincrease gradually with working time until it reaches a steady state conditions after around 90 minutes.
- For two different designs of the condenser (Cond.1 and Cond.2), the Cond.1 of coiled tubes only givesa lower amounts of heat rejection and higher % COP improvement than the Cond.2 of coiled tubes welded with a stainless steel sheet plate.
- For different values of cooling load, the Cond.1 gives the best performance compared to the others two condensers (Cond.0 and Cond.1)

- The evaporator heat load as a parameter shows an effect on the cycle performance, where the heat rejected from the condenser and COP increase with the increase of the evaporator load.

Nomenclatures:

h	Enthalpy (kJ/kg)	$\dot{Q}_e$	Evaporator heat load (kW)
$\dot{m}_r$	Refrigerant mass flow rate (kg/s)	COP	Coefficient of Performance
$\dot{Q}_c$	Condenser heat load (kW)	$\dot{W}$	Compressor Power (kW)

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