

Manufacturing A Refrigerator with Heat Recovery Unit

Mustafa Mohammed Kadhim

Department of Dairy Technology, College of Food Sciences, Al-Qasim Green University

engmustafa_mo@yahoo.com

Abstract

This study aims to exploit the rejected heating energy from condenser and benefit from it to reheat the foods and other materials. It can also be employed to improve the coefficient of performance of a refrigerator at the same time by using approximately the same consumption electrical energy used to operate the compressor and refrigerator in general. This idea has been implemented by manufacturing of a refrigerator with using additional part has the same metal and condenser pipe diameters but its surface area does not exceed 40% from total surface area of the condenser and its design as an insulated cabinet from all sides to prevent heat leakage through it and located between the compressor and the condenser. Small electrical fan has been added inside this cabinet to provide a suitable air circulation and a homogenous temperature distribution inside the cabinet space. It is expected that the super heating energy of refrigerant (R134a) which comes out of the compressor would be removed inside this cabinet and this insist to condensate the refrigerant (cooling fluid) with a rate higher than that used in the normal refrigerator only. Three magnetic valves have been used in order to control the refrigerant flow in state of operation the refrigerator only or to gather with heating cabinet. To measure the temperatures at each process of the simple vapor compression refrigeration cycle, nine temperature sensors at input and output of each compressor, condenser and an evaporator in additional to input of cabinet and inside it and on evaporator surface have been provided. Five pressure gages have been used to measure the value of pressure and compare it for the two states of operation. The consumption of electrical energy can be calculated by adding an ammeter and a voltmeter and compare between the consumption energy of both states. The obtained results show that there is an improvement in the coefficient of performance in state of operation the refrigerator with heat recovery cabinet by 20% more than that of the operation of refrigerator only. This improvement is due to the reduction in the condenser exit temperature by 4 to 6 C°, and the super heat removing process in reheating cabinet. The temperature of the cabinet reaches to 60 C° which is a sufficient for the food heating. A small amount of refrigerant pressure reduction due to these additions, and its effect on the preformance of the refrigerator may be not considerable.

Key words: Refrigerator, Heat recovery cabinet, Refrigeration cycle, Coefficient of performance

الخلاصة

يهدف هذا البحث الى استثمار الطاقة الحرارية المفقودة من المكثف والاستفادة منها لغرض تسخين الأغذية والمواد الأخرى وكذلك تحسين معامل أداء التلاجة في نفس الوقت باستخدام تقريباً نفس الطاقة الكهربائية المستهلكة لتشغيل الضاغط والتلاجة بصورة عامة. تم تنفيذ هذه الفكرة من خلال تصنيع تلاجية مع إضافة جزء إظافي يقع ما بين الضاغط والمكثف و مكون من نفس معدن المكثف وله نفس قطر الأنابيب وبمساحة سطحية تبلغ حوالي 40% من المساحة الكلية للمكثف، كما أنه صُمم على شكل حاوية معزولة حرارياً لمنع فقدان الحرارة الى الخارج. تم تزويد هذه الحاوية بمروحة كهربائية صغيرة لتدوير الهواء داخلها وتوزيع الحرارة بشكل متجانس. لسيطرة على جريان مائع التبريد R134a تم أستعمال ثلاثة صمامات مغناطيسية لتشغيل التلاجة وحدها أو مع كابينة التسخين، ولقياس درجة الحرارة عند كل نقطة في دورة التبريد تم إضافة تسع متحسسات لقياس درجة الحرارة عند مدخل ومخرج كل من الضاغط والمكثف والمبخر وكذلك كابينة التسخين، كما تم إضافة خمسة مقاييس للضغط للمقارنة بين حالتين التشغيل. الطاقة الكهربائية المستهلكة تُقاس من خلال أستخدام مقياس التيار والفولتية. بينت النتائج المستحصلة الى ان هنالك تحسن في معامل الأداء بنسبة 20% في حالة أستخدام كابينة التسخين، حيث ان هذا التحسن ناتج عن إنخفاض درجة حرارة مائع التبريد الخارج من المكثف بمقدار 4 إلى 6 م° وكذلك إزالة حرارة التحميص داخل كابينة التسخين التي تبلغ درجة الحرارة داخلها حوالي 60 م°. تم ملاحظ نقصان قليل في ضغط مائع التبريد وهذا لا يؤثر على أداء التلاجة.

الكلمات المفتاحية: التلاجة، كابينة التسخين، دورة التبريد، معامل الأداء .

1. Introduction

Air conditioning apparatuses have been become one of the most important requirements of the daily life, especially in the zones which have hot weather in order to provide the best conditions for the people. Moreover They are widely used in cooling and saving foods and in the different industrial applications.

The development in all fields of life made the designers, air conditioning and refrigeration apparatuses manufacturers take into consideration two essential factors: the first factor is energy conservation and how to save on it and how to use it in other fields additional to the cooling and refrigeration processes such as heating as example, the second factor is economic benefit for work to obtain high performance with less cost.

As air conditioning and refrigeration systems have been used widely in our daily life , therefore, it is necessary to take into account these systems and the suitable methods to avoid energy consumption.

The energy consumed in operating the cooling apparatuses represents large part of the total consumption energy in houses and other locations which depend in their air condition on cooling apparatuses. The percentage of the consumption energy for this purpose reached to 63% from the overall consumption of the houses energy, therefore, many studies attempted to investigate the methods of reduction and benefit from this consumption energy on cooling purpose and using it in the best form. One of these studies is proposed by (SADC,1999) which discussed the heat recovery by using the cooling cycle as heat pump arrangement with closed cycle behavior in which the fresh out door air flowed through pipes of condenser coil has been heated and provided to a certain room. Then the remained heat in the returned air has been used in evaporating the refrigerant through the evaporator coil before air expelling and then the principle of energy conservation is applied in cooling cycle. (Thomas, 2003) explained the possibility of heat recovery from the condenser cooling water in water refrigeration chiller units and benefit from it to heat or reheat the internal domestic water in hospitals by using dedicated heat recovery chiller (DHRC) which contain heat exchanger in which heat transfers between condenser water and required domestic water. In additional to heat exchanger the system also includes water collector vessel and circulation pumps. This study explains coefficient of performance improvement of refrigeration units when the heat recovery exchanger is operated with a high percentage. This study also deals with the reduction in energy consumption of compressor unit. After a few years (SADC, 2006)used Ethylene glycol fluid as a refrigerant in a closed cycle which contains two heat exchangers: one of them has been used to absorb heat from the outside air and cooling it and the other one has been used to absorb heat from exhaust air before exit to external surround. Heat transfer efficiency was not less than 60% and circulation pump has been used between these heat exchangers. In other hand heat recovery unit has been used by (Michael, 2008) to recover the super heat from the refrigerant R22 in split air conditioner unit and use it to heat the required air for other purposes. This study explains the possibility of keeping 15% - 18% of the required energy to water heating. In 2011, [Ali Abdul Whaab Ismiae] discusses the possibility of heat recovery from the superheated vapour (R22) in the discharge of compressor of the simple vapor compression refrigeration cycle for a purpose of using it in heating process, i.e. operating as heat pump.

Generally the simple vapor compression refrigeration cycle consists of the following basic parts: compressor, condenser, expansion valve or capillary tube and evaporator. The condenser and evaporator are heat exchangers of different forms. In evaporator heat transfers from foods and other materials to the cooling fluid while in condenser the heating energy transfers from cooling fluid to the air surrounding it. To do both processes in evaporator and condenser there is work should be done in compressor or electrical energy consumed to operate the compressor.

Note that there is a continuous loss in the heat energy through the condenser to the external surrounding. Therefore, the idea of this research aims to exploit the rejected heating energy from condenser and benefit from it to reheat the foods and other materials and improving the coefficient of performance of refrigerator at the same time by using approximately the same consumption electrical energy to operate the compressor and refrigerator in general. This idea has been implemented by manufacturing of refrigerator with heat recovery unit for food heating, and this refrigerator is charged by refrigerant R134a as it is shown in the figure (1).



Fig. (1): Refrigerator with Heat Recovery System and Main Sensors

2. Simple Vapor Compression Refrigeration Cycle

To understand the way of adding a heat recovery cabinet and its effect on the compression refrigeration cycle, it is necessary to investigate the simple vapor compression refrigeration cycle in details (Stoecker, 1982).

Refrigeration cycle with compression refrigeration system consists of four essential parts which are respectively evaporator, compressor, condenser and expansion valve as shown in figures (2 and 3), and this cycle operates at saturated conditions for refrigerant which is charged in the refrigeration cycle. This cycle is a theoretical cycle assumed that refrigerant vapor exits from evaporator as a dry saturated vapor and enters to the compressor at a saturated temperature of the evaporator pressure. The condensate

refrigerant leaves the condenser at a saturated state and is saturated liquid at a saturated temperature of the condenser pressure. The compressor do to draw refrigerant vapor which is in dry saturated state from evaporator and compressed it from the evaporator pressure to the condenser pressure. In this state external work has been added to the refrigerant vapor with constant entropy. The refrigerant vapor exits from compressor as super heated vapor at a high temperature and enters to condenser to lose super heat and converts to saturated vapor with a constant pressure and then loses the latent heat to convert it to saturated liquid with a constant pressure also. The connected pipe from compressor to condenser is called the discharge line and the connected pipe from evaporator to compressor is called the suction line. The refrigerant exits from condenser as a saturated liquid and enters to the device of expansion which is a capillary tube in small refrigeration units and expansion valve for large refrigeration units. Expansion device job is to reduce the pressure and the temperature of the refrigerant. The refrigerant exits from the expansion device as a mixture of liquid and vapor (wet vapor). This wet vapor enters the evaporator to absorb an amount of heat from the evaporated space (the latent heat of evaporation) to convert it to a dry saturated vapor with a constant pressure and a constant temperature and exits to suction line oriented to the compressor. The above basic processes are the origin for each actual refrigeration cycle has mechanical compression process to refrigerant vapor by compressor.

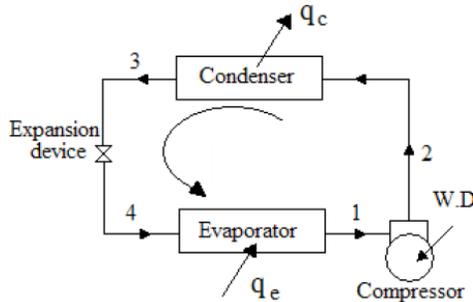


Fig. (2): Diagram of Simple Vapor Compression Refrigeration Cycle

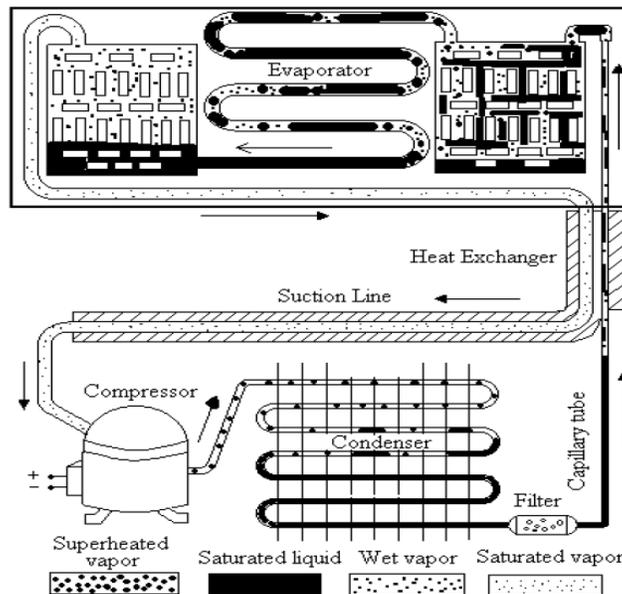


Fig.(3): Layout of Simple Vapor Compression Refrigeration Machine

The simple vapor compression refrigeration cycle is used as a reference to compare the actual cycles with it in order to measure the improvement range of coefficient of performance at different operation conditions, and therefore, we will study the simple vapor compression refrigeration cycle in details. Figures (4) and (5) explain the schematic diagrams of the simple vapor compression refrigeration cycle and represent on pressure - enthalpy ($p - h$) Diagram and temperature - entropy ($T - S$) Diagram to simplify the study it and implement thermodynamic analysis and heating balance on it.

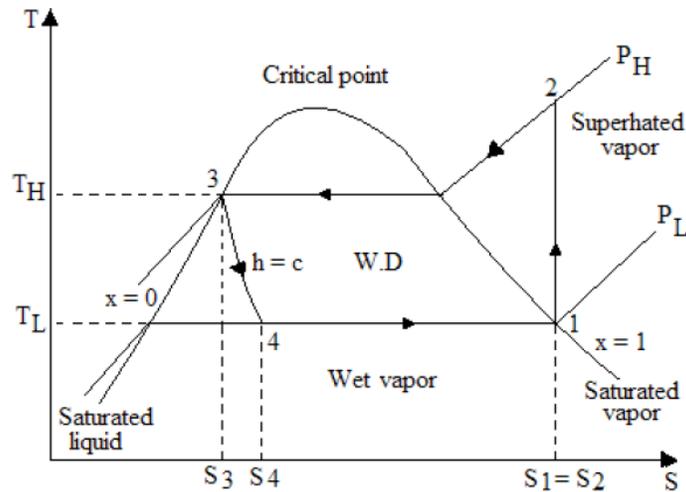


Fig. (4): $T - S$ Diagram for Simple Vapor Compression Refrigeration Cycle

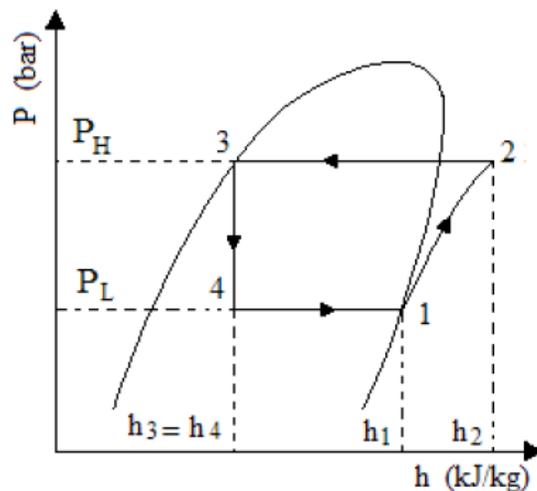


Fig. (5): $p - h$ Diagram for Simple Vapor Compression Refrigeration Cycle

3. Thermodynamic Analysis and heating Balance of Simple Refrigeration Cycle

Simple refrigeration cycle consist of the following four processes (Yuns, 2006) as shown in figures (4) and (5) which are ($T - S$) and ($p - h$) diagrams.

Compression by mechanical compressor with constant entropy in process 1 - 2, process of condensation and heat rejection with constant pressure inside the condenser in

process 2 – 3, and heat rejection to external field (water or air), and expansion process from the condenser pressure to the evaporator pressure with constant enthalpy in process 3 – 4 by using capillary tube or expansion valve. Evaporation process and heat absorption with constant pressure in process 4 – 1 inside the evaporator and convert the refrigerant from wet vapor state to dry saturated vapor state and heat absorption from evaporator space . thermodynamic analysis and heating balance for previous processes agree with steady state flow energy equation because:

1. Refrigerant mass which flow in period unit is constant for cycle processes.
2. Refrigerant state is constant and steady with time in different parts of cycle.
3. Heat transfer and work from or to the process is constant with time in cycle parts.

To explain the steady state flow energy equation it should be known that in several engineering applications the refrigerant or active fluid (media) in cycle enter to the system and exit with constant rate. For example; in the car air mixture with fuel enters and burns and then generates a kinetic energy in the car. After this process exhaust gases exit and at the same time the car continues to operate in a steady state. If we think that the car engine is as open system as shown in figure (6), the active media enters from point 1 with a known (significant) pressure, specific volume and temperature, and then the thermal energy has been added to produce the internal combustion or chemical interaction to product the work as kinetic energy form. The active media exits from point 2 with a significant pressure, specific volume and temperature different in its magnitude at point1. If the energy conservation law has been applied which state that the total sum of the income energies to any system is equal to the total sum of the outcome (exit) energies from this system. At point 1 the multiply product of pressure and specific volume (P_1V_1) for cooling fluid (refrigerant) and also internal energy which represent the input temperature of the refrigerant (U_1) and potential energy due to gravity force of the earth which is represented by the height (gz_1) and refrigerant kinetic energy ($v_1^2 / 2$) and other different energies for the refrigerant equal to the total sum of these energies at point 2 in additional to thermal energy q input to the system and the work W output from it.

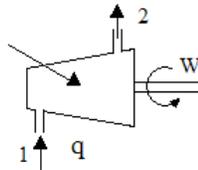


Fig. (6): Steady State Flow Energy of the System

3.1. Steady State Flow Energy Equation

The steady state flow energy equation can be written with respect to the unit mass as follow:

$$u_1 + p_1v_1 + \frac{V_1^2}{2} + gz_1 + q = u_2 + p_2v_2 + \frac{V_2^2}{2} + gz_2 + W \quad \dots \dots \dots (1)$$

Where:

$$h = u + pv, \text{ we get}$$

$$h_1 + \frac{V_1^2}{2} + gz_1 + q = h_2 + \frac{V_2^2}{2} + gz_2 + W$$

$$q - W = (h_2 - h_1) + \left(\frac{V_2^2 - V_1^2}{2} \right) + g(z_2 - z_1) \quad \dots \dots \dots (2)$$

The left side of the last equation consists of two parts, the first part is the amount of added heat to the process, and the second part is the amount of the output work from the process. The right side of this equation consists of three parts: the first part is the change in the internal energy and the stream work (enthalpy change), the second part is the change of kinetic energy between the input and the output of the system, and the third part is the change in potential energy.

3.2. Process of Evaporation and Heat Absorption in the Evaporator

Process 4 – 1 is the evaporation process of the refrigerant with a constant pressure and temperature which is called isobaric process or isothermal process. In this process the refrigerant enters to the evaporator at point 4 as a mixture of the saturated liquid and the dry saturated vapor. The actual refrigeration is produced by the amount of the saturated liquid in the mixture which absorbs the latent heat and it converts to dry saturated vapor at point 1. The required latent heat to evaporate the refrigerant is absorbed from the space in the evaporator which is foods, gas liquors or other products.

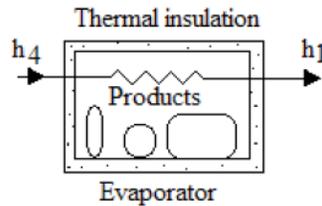


Fig. (7): Heat Balance of Various Type of Evaporators

The used evaporators in refrigeration industry are generally heat exchangers which consist of thermal insulation box as shown in figure (8) to reduce heat loss or heat leakage from the external surrounding which has a higher temperature to inside evaporator which has less temperature. The evaporators are divided to two essential types according to the purpose of using. Some evaporators are used to save foods and solid products and other evaporators are used to the liquids refrigeration like water, dairy products or juices.

The principle of work of these evaporators depends on heat transfer from the foods inside the evaporator to the refrigerant by the natural convection due to different in density and air temperature inside evaporator space, or by forced convection by using electrical fan to produce air circulation inside the evaporator. The heat amount which is absorbed by refrigerant due to it's flow through the evaporator and specific enthalpy change for it from wet vapor state at point 4 to dry saturated vapor state at point 1 with constant flow rate of refrigerant (\dot{m}) and symbol (Q_e) which is evaporator capacity and is calculated by apply the equation of steady state flow energy with neglect the potential energy of gravitation and kinetic energy because there is not find change in height between the input and output of evaporator as well as input speed equals to output speed of the refrigerant, and heat transfer happens with constant pressure and there is no work done in this process [Yuns A. Cengel, 2006].

$$Q_e = \dot{m}(h_1 - h_4) \dots \dots \dots (3)$$

3.3. Condensation Process and Heat Rejection in Condenser

The used condensers in refrigeration applications are heat exchangers which use air or water to cooling it. The super heated vapor exits from compressor at high temperature enters to the condenser to loss super heat and reduces the temperature to the saturated temperature of the condensation pressure, and the refrigerant begins to condensate by losing the latent heat to convert to the saturated liquid at the condenser exit. In the condensers cooled by air or water the rejected heat from the refrigerant equal to the income (gained) heat of water or air flowed on condenser surface. The air cooled condensers have two types, the first type is cooled by the forced convection of air and in which the air current is provided by using fan operates by electrical motor and this air carries the rejected heat from the condenser type A in figure (8).

The second type of the condensers is cooled by the free convection of air and in which the refrigerant enters from the higher point of a condenser to lose its heat and exits from the lower point and the rejected heat transfer to the surrounded air through pipes of the condenser and fins which are fixed on it to increase heat transfer rate and then air is heated and reduce it's density and moves to the upper point and locate instead of air layer has low temperature, therefore, this behavior of heat transfer is called free or natural convection as shown in type B in figure (8). While in the condensers cooled by water, the super heated vapor for refrigerant input to the condenser from upper point and condensate on the pipes which contain water inside it and exits from the lower point of the condenser as shown in type C of figure (8) (Stoecker, 1982).

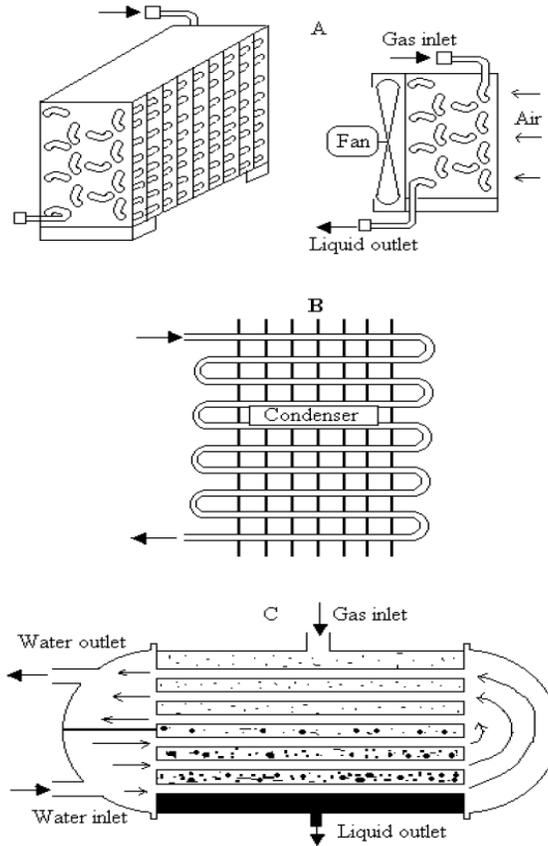


Fig. (8): Various Types of Condenser for Refrigeration Cycles

In all the types of the condensers cooled by air or water the refrigerant enters to the condenser as super heated vapor with a high temperature and enthalpy at state 2 and exit from it as saturated liquid with low temperature and enthalpy at state 3 with a refrigerant flow rate \dot{m} . The rejected heat from the condenser with constant pressure which is condenser capacity Q_c measured by the steady state flow energy equation (2) after neglect the potential energy change and the kinetic energy change because there is not find change of height and refrigerant speed at input and output of the condenser, and heat transfer in the condenser occurs with constant pressure and there is no work done in this process (Yuns, 2006).

$$Q_c = \dot{m}(h_2 - h_3) \dots \dots \dots (4)$$

We should be taken in to consideration that the input temperature of cooling fluid (air or water) which is used to cooling the condenser must be less than the saturating refrigerant temperature at the condenser pressure with difference $5 - 10 \text{ }^\circ\text{C}$ in order to condensate the refrigerant with high efficiency.

3.4. Expansion Process

Expansion process occurs with a constant enthalpy when the refrigerant pressure is reduced and expanded from the high pressure (condenser pressure) to the low pressure (evaporator pressure). This expansion occurs through capillary tube or expansion valve and the refrigerant temperature is reduced from the condenser temperature to the evaporator temperature by the flashing phenomena which is a rapid evaporation for a small part of the liquid to vapor. Process 3 – 4 is expansion by throttling in which the specific enthalpy of the refrigerant is constant at start and end of this process with no heat loss through the pipes and the valves and without preformed work. By apply the general steady state flow energy equation (2) with negligible potential and kinetic energy because there is no change in height and speed of the refrigerant at input and output of the expansion valve, and there is no heat transfer or work done in this process.

$$h_3 = h_4$$

$$\Delta s = s_4 - s_3 \dots \dots \dots (5)$$

The capillary tube is used in the house's refrigerators and in the small refrigeration units, while the expansion valves are used in the large refrigeration units as shown in figure (9). The capillary tubes are copper tubes with diameter $d = 2 \sim 5 \text{ mm}$ and length $L = 3 \sim 5 \text{ m}$. The refrigerant pressure reduction is due to hydraulic losses. When it flows through these tubes the rough metal surface resists the liquid flow and reduce the pressure. There are three types of expansion valves: hand expansion valve, automatic expansion valve and the high quality and efficiency type which is thermostatic expansion valve. The theory of hand expansion valve work depends on the refrigerant flow through a nozzle produce throttling and pressure reduction with constant enthalpy. It is possible to control the levels of high and low pressure and also the refrigerant flow rate by a metal needle which is used to increase or decrease the hole area of the nozzle by the hand. In expansion process with a constant enthalpy the refrigerant exits from expansion valve as mixture of saturated liquid and saturated dry vapor at pressure and temperature of the evaporator. The entropy change during the expansion process caused by heating energy transfer in the refrigerant due to internal friction between refrigerant particles and metal

surfaces. The energy transfer which occurs in the refrigerant does not effect on the enthalpy (Stoecker, 1982).

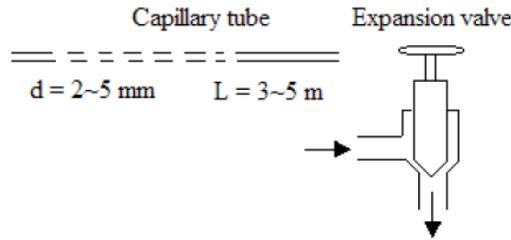


Fig. (9): Hand Expansion Valve and Capillary Tube

3.5. Compression Process

The refrigerant exits from the evaporator in saturated dry vapor state and enters to the compressor of this state without heat transfer or pressure reduction through the suction pipes which connect between the evaporator and the compressor. The compression process 1 – 2 occurs with a constant entropy and the work done is equal to the enthalpy change as shown in the steady state flow energy equation after neglecting the potential and kinetic energy because there is no change in height between the input and the output of the compressor and also the refrigerant speed change is small and can be neglected as compared with the enthalpy change. Heat transfer does not occur in the compression process, and the work done can be calculated as follow (Stoecker, 1982).

$$W = m'(h_2 - h_1) \dots \dots \dots (6)$$

The refrigerant exits from the compressor as superheated vapor, its temperature higher than the saturated temperature of the condenser pressure. The compression process in the compressor occurs by applying work on the refrigerant to increase it's pressure from the evaporator pressure to the condenser pressure and this process is adiabatic and frictionless which means that no heat transfer to or from this process, and the work done on the refrigerant increases the enthalpy to produce heating energy equal to this mechanical work.

The types of the used compressors in different applications for refrigeration purposes are reciprocating compressors, centrifugal compressors and rotary compressors. The rotary compressors are used in house refrigerator and the small refrigeration units, while the centrifugal compressors are used in the small and large refrigeration units.

3.6. Coefficient of Performance and Relative Efficiency of the Simple Refrigeration Cycle

Coefficient of Performance (C.O.P) is the measurement of the activity of the refrigeration units and it also means the comparison among the different refrigeration units and its systems. The coefficient of performance is calculated by the ratio between the benefit of the refrigeration unit to the external work done on this unit which is electrical energy.

$$COP = \frac{\text{Unit Refrigeration Capacity (Desired Effect)}}{\text{Net Power Input}} = \frac{Q_e}{W}$$

In the simple refrigeration unit heating loss does not occur, therefore, the coefficient of performance (COP) is expressed as follows (Stoecker, 1982):

$$COP = \frac{m(h_1 - h_4)}{m(h_2 - h_1)} = \frac{h_1 - h_4}{h_2 - h_1} \dots \dots \dots (7)$$

The relative efficiency η_R of the refrigeration unit is the ratio between the coefficient of performance of the simple refrigeration cycle to the coefficient of performance of the Carnot cycle which operates at the same conditions of pressures and temperatures:

$$\eta_R = \frac{COP}{COP_{car}} \dots \dots \dots (8)$$

From the previous explanation of the simple vapor compression refrigeration cycle we note that the condenser job through process 2 – 3 is to reject the heat gain of the refrigerant to the surround continuously without benefit from it. To implement the objective of this research which is manufacturing and using the refrigerator as heat pump of recover heat, the following parts have been added to the refrigeration system which is represent the simple vapor compression refrigeration cycle.

4. Heating Cabinet

Heating cabinet has been designed with the following internal dimensions (heating space): width 52 cm, height 20 cm and depth 48 cm, while the external dimensions are width 64 cm, height 32 cm and depth 60 cm. Heating recovery coil has been put inside the heating space of the cabinet which is small coil and has the same pipes diameters and metal of the refrigerator condenser (diameter 4 mm and length 200 cm). The total area of this coil represents 40 % of the total area of the original refrigerator condenser which is the required area to remove the super heat from the superheated vapor of the refrigerant and convert it to saturated liquid. The cabinet structure is thermally insulated by using a glass wool (thermal insulator) with thickness of 3 cm to obtain good insulation (ASHRAE, 1983). Thermal interaction occurs between the super heated vapor and the cabinet air which surrounds the foods by using a small fan which has been connected (constructed) inside the cabinet to increase the activity of the supper heat drawing and benefit from it in food heating as shown in figure (10).



Fig. (10): Heating Cabinet

5. By – Bass Line

Joint of T form has been added and mounted directly on the discharge line of the compressor and mounted on it the required valves to reverse the super heated vapor flow which exits from the compressor in the direction of the reheating coil of the cabinet instead of it's moving in the direction of the condenser.

6. Solenoid Valves (Magnetic Valves)

Three magnetic valves have been added to this system, two of which operate at the same time special for the cabinet operation, and the third valve is special for the refrigerator operation in state of operating it without the cabinet and connected directly by the condenser. The operation of the third valve is opposite to the first and second valves as shown in the figure (11).



Fig. (11): By – Pass Line and Solenoid Valves

7. The Electrical and Examination Circuit of Refrigerator with Heat Recovery System

As it is known the electrical circuit of the refrigerator consists of the electrical motor coils of the compressor which are represented by the running or (operation) coils and the starting coils. The circuit contains also an over load , a relay and a control unit of the required temperature (Thermostat control), as well as groups of electrical wires. The electrical circuit is modified to become more suitable with the object of this study. A special electrical circuit has been implemented in state of using the magnetic valves (solenoid valves) as shown in figure (12). Electrical switch has been added to provide the electrical current to the magnetic valves. The cabinet fan is operated to reheat the foods. The electrical circuit is operated as a heat pump or as a simple refrigeration cycle.

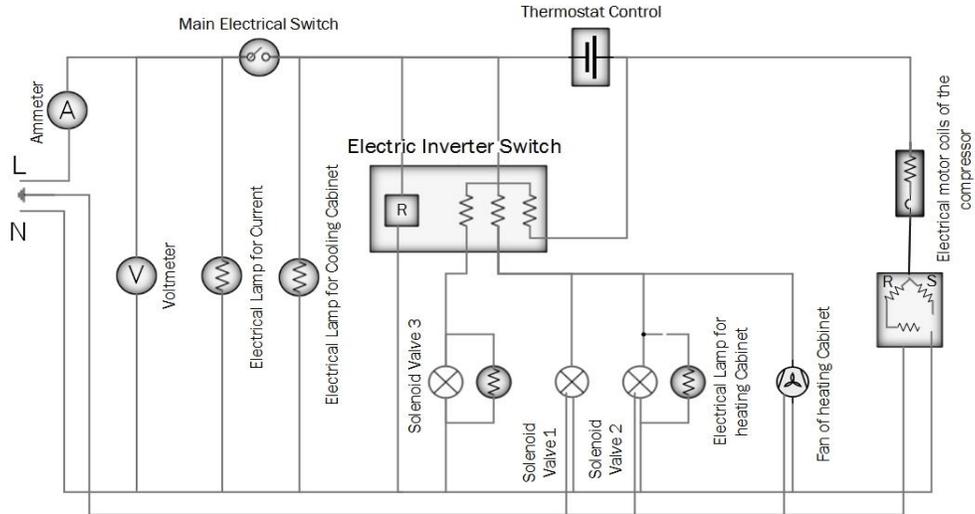


Fig. (12) Electrical Circuit of Refrigerator with Heat Recovery Coil

The examination circuit has been designed to implement the objective of this research. Group of pressure and temperature gauges have been added to measure the pressure and temperature of the refrigerant and air inside the heating and cooling cabinets and their details and locations are explained in figure (13). The mechanical circuit is constructed by using the welding joints and the pipes lines joints. Finally the refrigerator is charged by the refrigerant R134a with magnitude of 90 g.

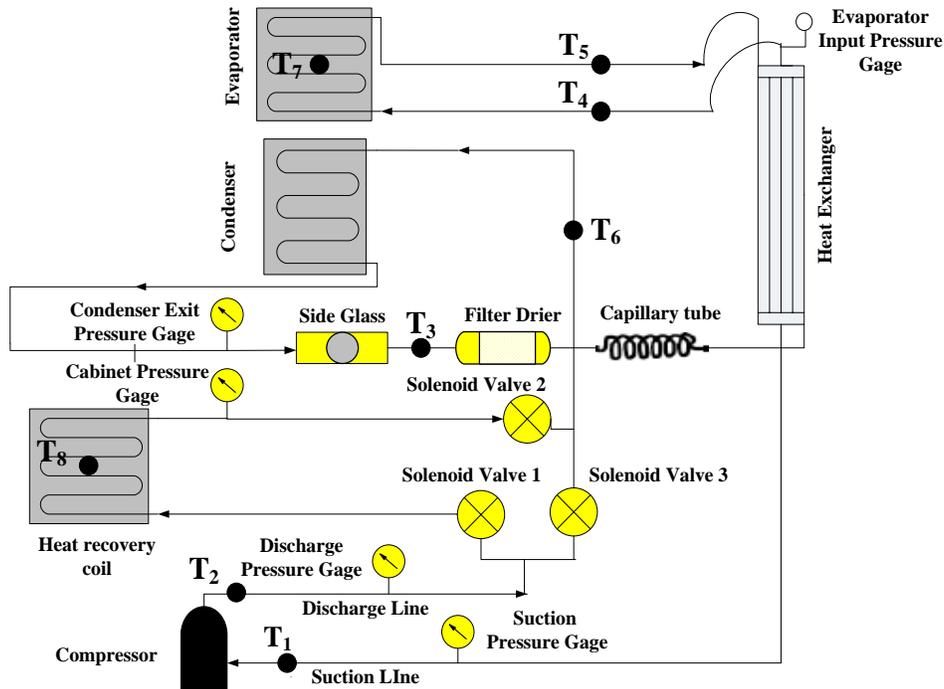


Fig. (13): Mechanical Circuit of Refrigerator with Heat Recovery Coil

8. Results Discussion

Several experiments have been implemented on the manufactured refrigerator in order to explain the effect of the addition of the heat recovery coil on the coefficient of

performance (C.O.P.). The refrigerator has been operated without the heat recovery coil continuously for one hour, and the readings have been recorded every 10 minutes without stopping in the compressor operation to show the refrigerator performance during the long operation (Ali, 2011). The readings of the examination refrigerator have been recorded in the laboratory with normal thermal conditions (temperature is 25 ~ 27 °C and good ventilation state), and then the refrigerator has been operated at the same thermal conditions with the heat recovery coil and these readings are showed in tables (1) and (2).

Table (1): Refrigerator Operation Only

Time min	Pressure (Bar)					Temperature (C°)							
	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Suction Line T ₁	Discharge Line T ₂	Condenser Input T ₆	Condenser Exit T ₃	Evaporator Input T ₄	Evaporator Exit T ₅	Evaporator Surface T ₇	Cooling Cabinet
10	12.3	-	12	0.9	0.4	18	59	51	44	-4	11	-9	28
20	12.3	-	12	0.9	0.4	16	66	56	45	-6	5	-17	21
30	12.2	-	12	0.8	0.4	14.5	71	59	46	-9	3	-19	17
40	12.2	-	12	0.8	0.3	13	76	62	46	-10	2	-20	15
50	12.2	-	12	0.8	0.3	12	80	65	47	-11	1	-20	12
60	12.2	-	12	0.7	0.3	12	84	67	48	-11	1	-21	10

Table(2): Refrigerator Operation with Heat Recovery Cabinet

Time min	Pressure (Bar)					Temperature (C°)									
	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Suction Line T ₁	Discharge Line T ₂	Condenser Input T ₆	Condenser Exit T ₃	Evaporator Input T ₄	Evaporator Exit T ₅	Evaporator Surface T ₇	Cooling Cabinet	Heating Cabinet T ₈	Heating Cabinet
10	10	10	9.8	0.8	0.3	17	57	47	39	-9	8	-9	28	49	40
20	10.5	10.4	10.3	0.8	0.3	15	64	48.5	41	-11	4	-18	21	56	46
30	11	10.9	10.7	0.8	0.4	13.5	70	49.5	42	-12.5	2	-20	15	62	50
40	11.3	11.1	11	0.9	0.4	11	74	50	43	-13	1	-21	13	66	53
50	11.5	11.3	11.2	0.9	0.4	10	77	50.5	43.5	-12.5	-0.5	-22	11	70	56
60	11.7	11.3	11.2	0.9	0.4	9.5	80	51	44	-13	-1	-22.5	9.5	74	59.5

The essential factors (parameters) of the research can be discussed from the above practicable readings as follow:

8.1. Refrigerant Temperature

It can be noted that the refrigerant temperature which leaves the condenser T_3 when the refrigerator is operated as the refrigeration cycle with the heat recovery system is reduced by the value of 4 C° to 6 C° less than their values in the refrigerator operation state as the refrigeration cycle only. This means that when the refrigerant flow has been reversed in direction of the heat recovery coil led to increase the value of the refrigerant cooling (sub cooling liquid) in the condenser and before enters to the heat exchanger which consists of the capillary tube of the liquid line and the suction line of the compressor. This increasing in the refrigeration is rather high in the houses refrigerators which depend on the natural air refrigeration (cooling) (Roy, 2002; Hand Book of Refrigeration,1977). This leads to increase the amount of the absorbed heat in the evaporator coil which increases the refrigeration effect of the cycle as shown in the figure (14).

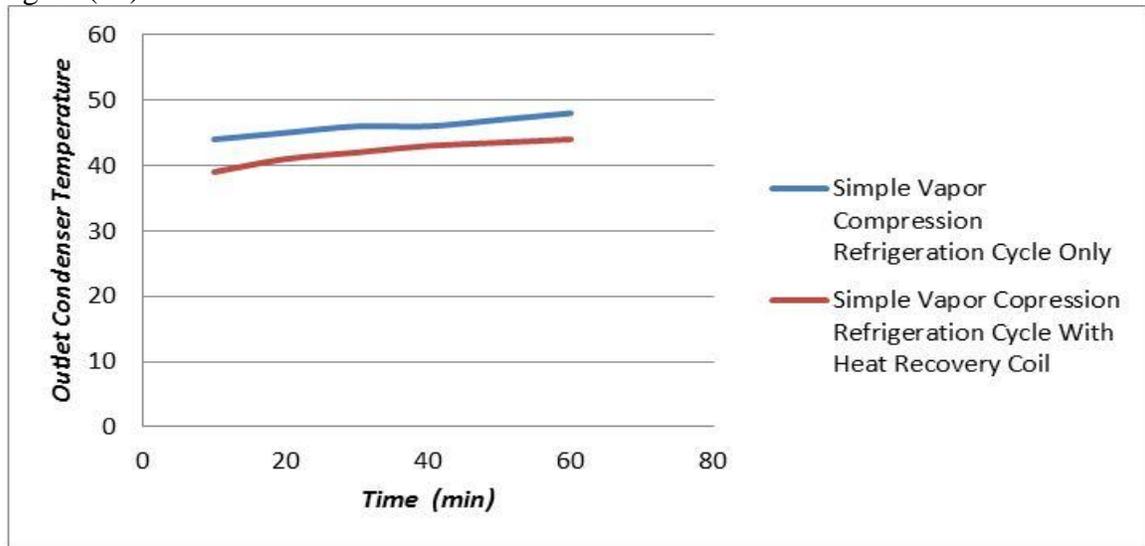


Fig. (14): Outlet Condenser Temperature for Simple Vapor Compression Refrigeration Cycle With or Without Heat Recovery Coil

8.2. Heat Recovery Cabinet

From table (2) can be noted that the air temperature inside the reheating cabinet is approximately not less than 40 C° after 10 minutes of operation to reach 60 C° after one hour of operation with the increasing rate approximately reach to 4 C° every 10 minutes of operation.

This temperature can be increased with the continuous operation over one hour or at increasing the degree of vapor super heat which is incoming from the compressor during the operation of the refrigeration cycle, as well as , that the air circulation inside the heating cabinet by using the fan will make the temperature inside the cabinet always high, and then the benefit ability from it in food reheating or saving it in hot state at less (ASHRAE, 1981).

8.3. Super heat Removing Zone

The refrigeration cycle and (P – H) diagram of the refrigerator with or without the reheat cabinet are explained in figures (15) and (16) which explain that when the

additional valves are used in the cycle, the heat recovery process or superheat removing process will be limited between point 6 and 8, and which in assumption is removed heat out the condenser in state of operation the refrigerator only, but benefit from it to heating the foods in the heat recovery coil.

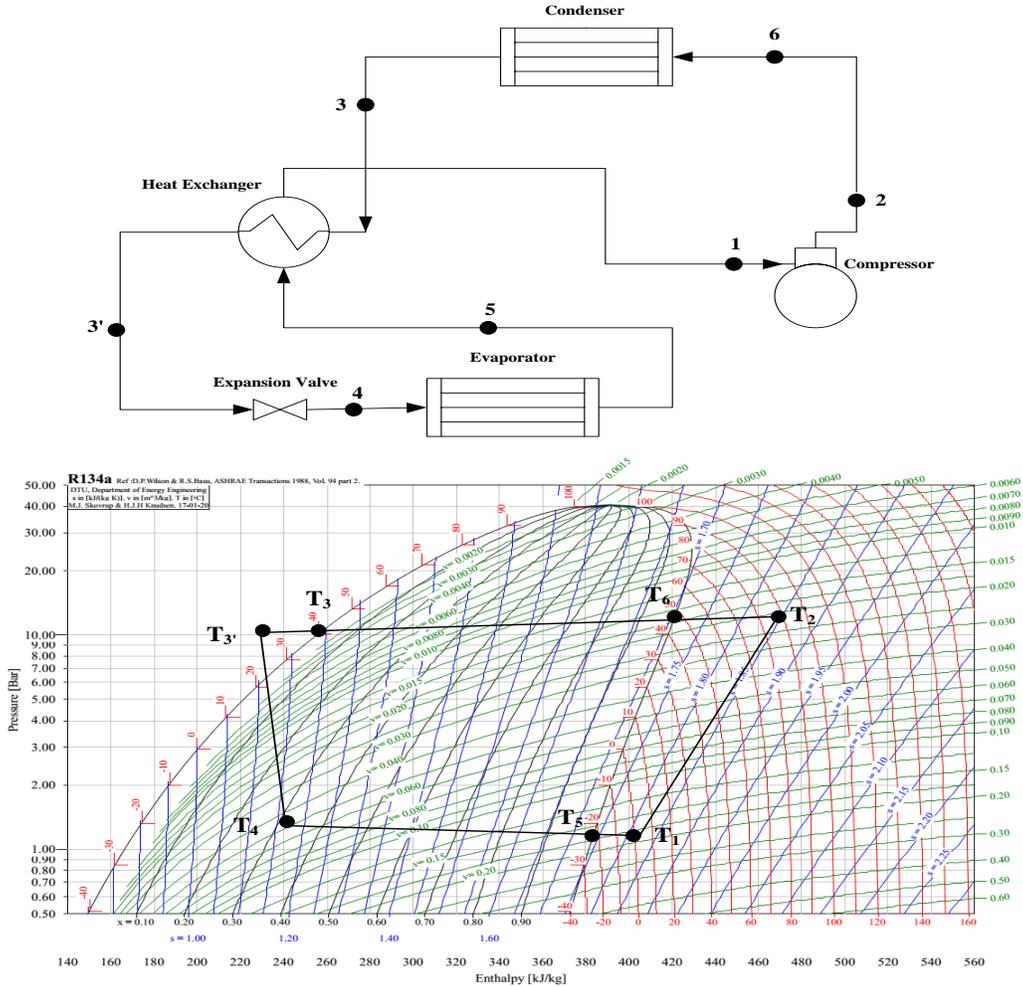


Fig. (15): Simple Vapor Compression Refrigeration Cycle Only

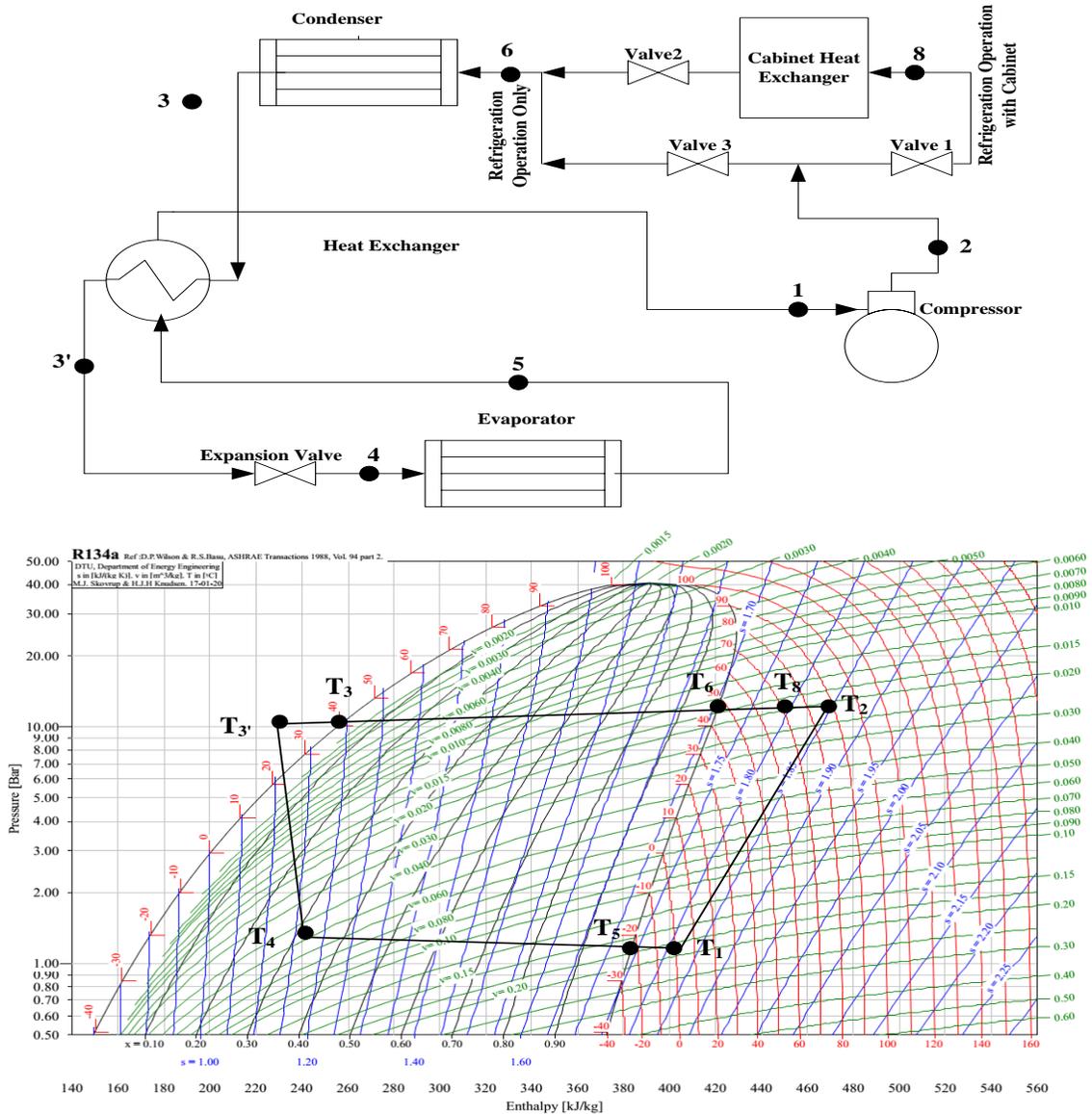


Fig. (16) : Simple Vapor Compression Refrigeration Cycle With Heat Recovery Coil

8.4. Coefficient of Performance (C.O.P.)

The coefficient of performance is calculated in both operation conditions from the equation (7) which depends on the enthalpy change of the refrigerant and is found from (P – H) diagram of the refrigerant R134a. All values of the coefficient of performance of the readings for both operation state have been inserted in figure (17), and note that there is an improve in the coefficient of performance when the refrigerant flow is reversed in the direction of the heat recovery cabinet with a percentage reach to 20 % more than it's values when the refrigerator is operated only.

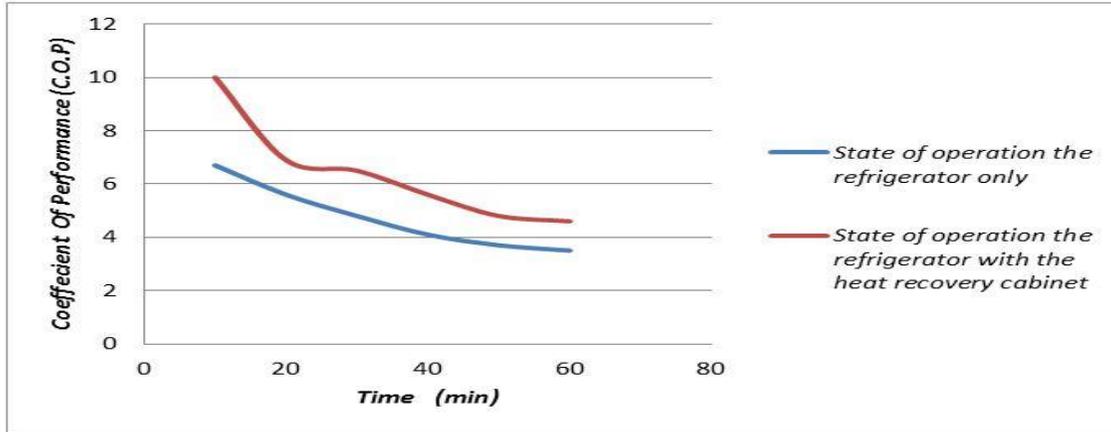


Fig. (17): Coefficient of performance of the refrigerator with or with out cabinet

8.5. Pressure Reduction

The value of the refrigerant pressure reduction due to the addition of the magnetic valves and the heat recovery coil has been calculated. Generally the rates of pressure difference between both state of operation are small and can be neglected because the pipe diameter of the heat recovery coil is the same pipe diameter of the condenser, and due to small distance between valves location or between the heat recovery coil and the main parts of the refrigeration cycle, thus the addition lengths are small. Then the rates of pressure reduction are constant and suitable with the designed rates of the refrigeration cycle in the refrigerators industry (Althouse, 1988 ; Wang, 2001).

8.6. The Energy Consumption

The intensity of the electrical current and the voltage are calculated during the operation of the refrigerator only or with the heat recovery cabinet by using ammeter and voltmeter, then the consumed power can be calculated from the following equation (William, 1995).

$$P = I.V \dots \dots (9)$$

Where : P is the consumed electrical power (W), I is the drawn electrical current (Amper) and V is the drawn voltage (volt). It can be shown from table (3) that the electrical power is approximately constant in the both state of operation and the difference does not exceed 25 W and this value is the fan and the magnetic valves consumption which are very small in comparison with the refrigerator consumption.

Table (3): The Energy Consumption

Time (min)	Frequency (Hz)	Voltage (volt)	Refrigerator Only		Refrigerator With Heat Recovery Cabinet	
			Current (A)	Power (W)	Current (A)	Power (W)
10	50	220	0.889	195.58	0.891	196.02
20	50	220	0.881	193.82	0.886	194.92
30	50	220	0.879	193.38	0.882	194.04
40	50	220	0.878	193.16	0.880	193.60
50	50	220	0.878	193.16	0.880	193.60
60	50	220	0.878	193.16	0.880	193.60

8.7. The Initial and Operation Cost

When you are doing any change or modification in the refrigeration cycles, you should be aware of effect of this development on the economical cost. In general, the cost is divided into initial cost and operation cost. The initial cost represents the apparatus manufacturing or buy it which is different according to the company of the manufacture, manufacture properties and the refrigerator capacity (ASHRAE, 1999). Thus the idea of refrigerator manufacture has three functions which are freezing, cooling and reheating process in the heat recovery cabinet in stead of two functions (freezing and cooling only) does not mean in necessary rise the initial cost due to the difference between the adopted methods of manufacture in the companies , as well as, to the several variables such as impost and prices change in markets.

The operation cost is represented by the cost of the electrical energy consumption which is provided to the operation, and finally maintenance cost. This study explains that no difference approximately between the consumed electrical power in the both states of operation and the limited time for the cabinet operation or part of this time occurs at the same time of the refrigeration cycle operation, this means in the same period of the compressor work (operation), the process of heat recovery in the cabinet occurs in the same period. Thus the increase in the consumed energy cost is not taken in to consideration.

The maintenance cost is represented by repair costs or exchange damage parts . The suggested additions on the refrigerator such as fan and valves are simple additions and not complex thus do not need to the high maintenance cost, as example the fan motor can be replaced immediately after it's failure or doing the maintenance with out stopping the operation of the refrigerator, and this case is similar to the valves (Automatic, 1997).

9. Conclusions

From this study which is refrigerator manufacture with heat recovery system and the obtained results, we can conclude the following points:

1. The benefit ability from the rejected heat of the compression refrigeration cycle of the refrigerator by super heat recovery to reheat the foods or saving it hot at least, and also the refrigerator operation as heat pump at the same time.
2. The coefficient of performance can be improved when the refrigerator is operated with heat recovery system (heating cabinet).
3. The use of magnetic valves (solenoid valves) does not effect on the coefficient of performance of the refrigeration cycle and the obtained results show that there is an improvement in the coefficient of performance of the refrigeration cycle in state of the cabinet operation with magnetic valves.
4. Generally the pressure reduction is small and approximately not considerable and then does not effect on the performance of the refrigeration cycle of manufactured refrigerator.
5. All the suggested additions are part of the operation cost which are the fan maintenance and the magnetic valves. The consumed electrical energy to operate these additions is small thus it can be manufacture a refrigerator has three functions which are freezing, cooling and heating at the same time.

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