Experimental Study Of Direct Contact Evaporation Refrigeration System Using R-12

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Abstract:

This paper presents experimental study of refrigeration by using a direct contact evaporation process. The process was performed by using a direct contact evaporator, which is a reservoir containing a water column. The water column was cooled by injecting a refrigerant, R12, directly into the water. The refrigerant absorbed the heat required for evaporation from the water, causing the water to cool, or freeze, in proportion to the heat transferred between the two fluids. The experimental results showed that the process resulted in a decrease in water temperature to a lower limit of temperature (12 ^{0}C, and may be reach a freezing point in perfect cases). The decrease in water temperature along the evaporator and the performance coefficient of the evaporator are used as criteria to evaluate the refrigeration system. By using the heat balance concept between the heat removed from water and the electrical work COP was 4.86. Also by assuming an isentropic process for the experimental conditions, the theoretical COP was 7.7.

R12دراسة عملية لمنظومة تثليج تعمل بالتبخير بالتماس المباشر بأستخدام مائع التثليج

الملخص:

تضمن العمل الحالي إجراء دراسة عملية لظاهرة التثليج بالتماس المباشر،تم ذلك باستخدام مبخر الاتصال المباشر(المبادل الحراري) الذي هو عبارة عن خزان يحتوي عمود ماء ويتم تبريد الماء بواسطة حقن مائع التثليج مباشرة إلى الماء. تؤدي عملية التماس المباشر إلى تبخر مائع التثليج بعد امتصاصه الحرارة اللازمة للتبخر من الماء مما يؤدي إلى تبريد الماء أو تجميده بالاعتماد على كمية الحرارة المتبادلة بين المائعين.سجلت النتائج العملية انخفاض في درجة حرارة الماء إلى درجات منخفضة ١٢ درجة مؤية (قد تصل إلى درجة الانجماد وتشكيل الثلج في الحالة المثالية). مائع التثليج الذي استخدم في الدراسة الحالية (R12). وقد تم اعتماد مقدار الانخفاض في درجة حرارة الماء المجهز على طول ارتفاع المبخر و معامل الأداء كمعيار لتقييم أداءالمنظومة المحلية التصنيع. اثبتت الدراسة ان بأستخدام مبدأ الموازنة الحرارية بين الحرارة المزالة من الماء و الطاقة الكهربائية المستهلكة وجد ان معامل الاداء للمنظومة ٤,٨٦. بألاضافة الى ذلك وجد ان معامل الاداء النظري للمنظومة كان ٧,٧ في حالة فرض ان الشروط العملية كانت في حالة عزل حراري جيد (عملية ثابتة الانتروبي).

1-Introduction:

In tropical countries, including Iraq, electricity is mainly used in the air conditioning system due to high ambient temperature and humidity. For this reason, the ice thermal energy storage has been introduced as a tool for electrical energy management in cooling process. Where the energy is produced in the night and used for conditioning process throughout the daytime [1]. In Chiang Mai-Thailand, ice thermal energy storage with direct contact evaporator has been studied by applying to an office located in Chiang Mai University, the simulation also indicates that the demand-limited storage design system is the most appropriate storage option for the selected office, where the system can shift 39.3% of peak electricity demand from on-peak period to off- period. So that, there was 33.8% of electric bill is saved compared to those of the conventional system [2].

Many researchers reported that the effectiveness of direct contact heat transfer between refrigerant and water was close to 100% [3-4]. Kiatsiriroat et al. [5] studied an ice thermal energy storage having an injection of R12 refrigerant into the water to exchange heat directly. Water temperature decreases to the freezing point and ice is formed, the ice was used for creating chilled water for an air-conditioning purpose. his system has a capacity of approximately 2 tons of refrigeration. It was found that the performance of the system depends on two factors, the compressor speed and the mass flow rate of the refrigerant. The coefficient of performance was about 3·4–3·6. In 2003 Kiatsiriroat et al. [6] studied the heat transfer characteristics of a direct contact evaporator by injection refrigerant (R12 & R22) into water. The water temperature was reduced to the freezing point, and ice could be formed. They used a lump model to predict the water temperature, and it is found that this model can predict the water temperature quite well. They developed correlation that relates the dimensionless parameters, such as Stanton number, Stephan number, Prandtl number and pressure ratio.

Thongwik et al. [7], studied the heat transfer characteristics during ice formation of a direct contact heat transfer between carbon dioxide and water. In this work, the low temperature carbon dioxide, approximately -15 to -60°C, is injected into water at 28°C and exchanges heat directly. The flow rate of carbon dioxide is varied between 0.003-0.017 kg/s while the volume of water is between 1-3 L. They found that the effectiveness of the direct contact heat transfer between carbon dioxide and water is closed to 100%. Moreover, the lumped model can be used for predicting the temperature of water and the mass of ice formation quite well.

The ice slurry production technique was proposed by using water mixture (water/oil/Tween-60) instead of pure water. Thongwik et al. [8], investigated the heat transfer characteristic of ice slurry formation by using a direct contact heat transfer technique between carbon dioxide and water mixture. The low temperature carbon dioxide, approximately -15 °C to -60°C, was injected into the water mixture. The initial temperature and the volume of water mixtures were 28°C and 1-3 liter, respectively, while the flow rate of carbon dioxide was varied between 0.003-0.017 kg/s. It was found that the suitable water mixture composition for producing ice slurry was water/oil/Tween-60 = 100/6/1 by volume. Moreover, the lumped model could be used for predicting the temperature of water mixture and the mass of ice slurry within ±10% variation.

The present study aims to design a simplified cooling system to study of direct contact icing phenomenon by experimental way and to measure the change of water temperature with the time in the direct contact evaporator as a result to injection icing fluid directly. In addition to calculate the coefficient of performance of this system.

2- Experimental Apparatus:

The technical specifications of the water cooling system depend on the required water inlet and exit temperatures, and the volumetric flow rate of water required by the consumer. These specifications are used to determine the capacity of the cooling coil (the evaporator), which is then used to size the remaining parts in the cooling system. The experimental setup consists of:

1. Evaporator (direct contact)
2. Drying unit
3. Compressor
4. Condenser
5. Expansion valve
6. The refrigerant
7. The bowl receiver gases

The water is cooled by injecting refrigerant into the pot gases through the expansion valve to reduce pressure and temperature. This underscores the importance of the valve is not only controlling the cooling rate, but also pressure and temperature of the refrigerant. The cooling will be in two stages: the first stage is to inject refrigerant , and the second stage is lowering the water temperature to the freezing point by transferring heat to the coolant, which turns to steam and flows out of the storage container to the compressor, and then to the condenser. Before the refrigerant goes to the compressor, it must dried by passing through drying unit. The basic function of the drying unit is to remove moisture from the two-phase steam to protect the compressor from damage. Fig.[1] shows a schematic diagram of the system.

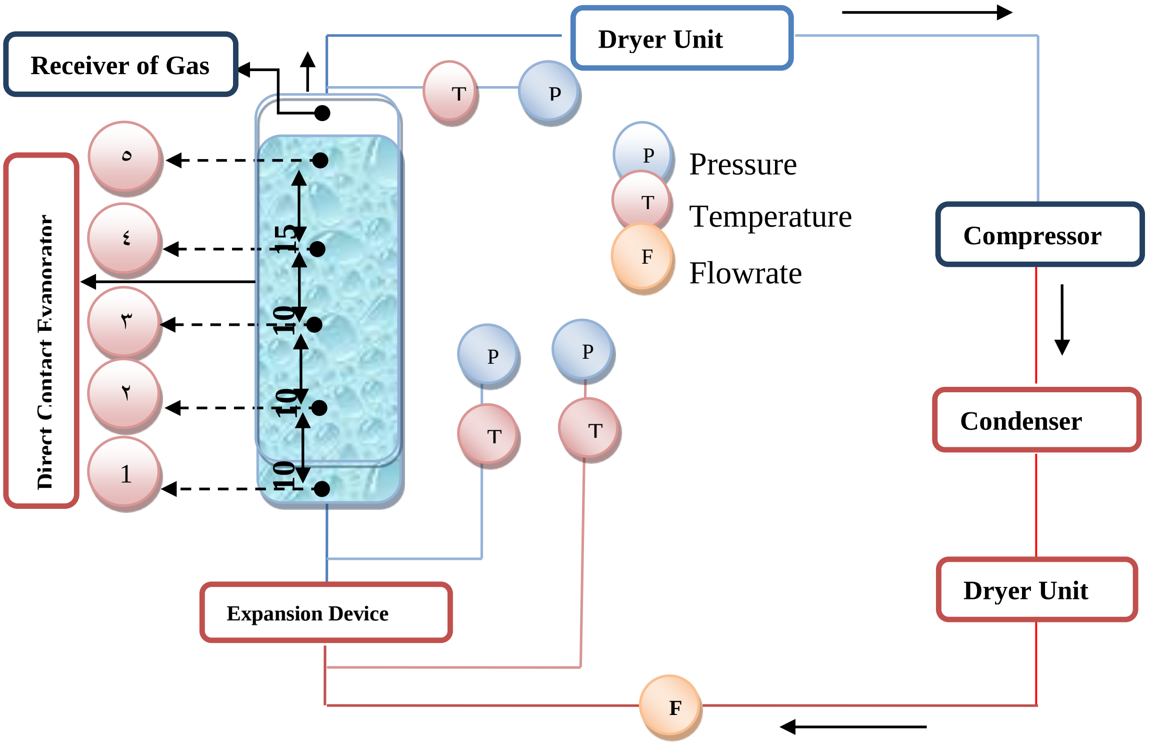

Figure 1 Schematic diagram of the experimental apparatus

2-1 The Direct Contact Evaporator:

The direct contact evaporator is a storage tank with a 30 cm diameter and a height of 110 cm. The water storage tank is made of stainless steel 304, which is highly corrosion-resistant and non-toxic. Fig.2 shows the principle of the direct contact evaporator. The cold refrigerant is injected into the water within the storage tank to extract heat from the water through direct conduction. The water temperature decreases, and ice is formed when freezing point is reached. In this study we study we not reach the freezing point so the ice not formed. The refrigerant vapor leaves the storage tank through the top of the vessel.

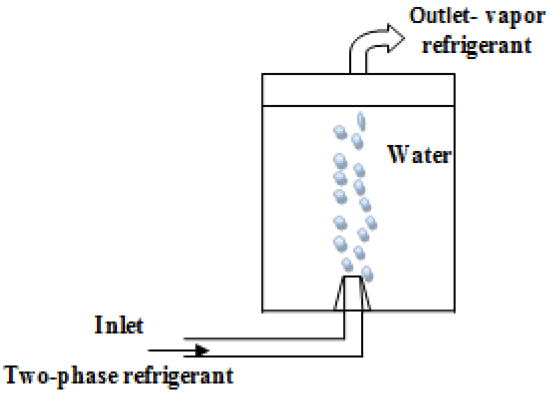

Figure 2- Direct Contact Evaporator

2-2 Dryer Unit

The dryer unit that is used in this apparatus is a standard dryer (it looks and operates the same as a refrigerator dryer). Two dryer units are used in this apparatus. The first one is placed before the compressor to ensure that no moisture (water droplets stuck from cooling fluid) may enter. The other dryer unit is placed directly after the condenser to guarantee the absence of gas in the refrigerant, which turned into a liquid, after leaving the condenser.

2-3 Compressor

The compressor used in this apparatus is a standard reciprocating hermetic compressor, which works on single phase 220 volt AC current, and operates at approximately 250 Watts.

2-4 Condenser

The air-cooled condenser consists of several columns of 6.35mm diameter copper tubes.

2-5 Capillary Tube

A standard capillary tube is used, which is made from copper with a 1.22mm internal diameter and a length of 2.44m.

2-6 Refrigerant

In the current study we used R12 as the refrigerant fluid. The table in Appendix (1) describes the characteristics of this fluid. The mass of R12 that used in this experiment is approximately 225 grams.

3- Apparatus Manufacturing

The simple materials used to manufacture the device that were found in the local market, include: Air compressor, refrigerator compressor, refrigerator pipes, gauges for temperature and pressure, refrigerator condenser, dryer, refrigerant (R12) (in the present study there is no loss in refrigerant quantity because our experiment done as a closed cycle), expansion valve, and some other necessary accessories to complete the system. Appendix (2) describes the fabrication process and also the final shape of the system used in the experiment. The temperature was measured by using temperature gauges (thermocouples), with a digital thermometer, at five points along the evaporator (shown in Figure 1), and the pressure was measured by using a Bourdon Gauge at three points. Appendix (2) illustrates the manufacturing procedure. If ice forming (as a fine particles mixed with water), the evaporator storage tank must be provide by two valves one (in the bottom) for enter fresh water and the other (in top) to exit the mixed water (contain fine particles of ice mixed with water), and using special technical [3-6] in order to separate the ice from water.

4- Experimental Results

The vapor-compression refrigeration cycle has four components as shown in Figure 3. These are the evaporator, the compressor, the condenser, and the expansion (or throttle) valve. The most widely used refrigeration cycle is the vapor-compression refrigeration cycle. In an ideal vapor-compression refrigeration cycle, the refrigerant enters the compressor as a saturated vapor and is cooled to the saturated liquid state in the condenser. It is then throttled to the evaporator pressure and vaporized as it absorbs heat from the refrigerated space. The following equation describes the coefficient of performance of the system (COP) [8,11,12] as the evaporator heat (Q_{Evap}) divided by the compressor work ($W_{Comp.}$), both measured in kJ. The experimental coefficient of performance is calculated by dividing the amount of heat that removed from the water to the electric work consumed in the compressor, as follows;

$$Q_{cooling} = \dot{m}\, c_p [T_{t=0} - T_{t=1.8\,hour}] \qquad (1)$$

Where:

$Q_{cooling}$= The amount of heat removed from water.

$\dot{m}$= mass of water in the evaporator.

$T_{t=1.8\,hr}$ = the average water temperature (for 5 point) at t= 110 min.

$$Q_{cooling} = 77.75 * 4.2 * [28 - 14.6] \qquad = 1215.56\ W$$

Compressor Work= I V = 250 W

Where; I and V are current and voltage required to operate the compressor.

So, the coefficient of performance (COP) for the system calculated as follow;

$$COP = \frac{Q_{cooling}}{W_{Compressor}} \qquad (2)$$

$$COP = \frac{1215.56}{250} = 4.86$$

The theoretical COP for the system is calculated as follow (by applying measured values of pressure and temperature from system) ;

$$C.O.P = Q_{Evap}/W_{Comp} \qquad (3)$$

The heat of evaporation and compressor work can be described as the mass of the refrigerant (m_r) multiplied by the change in enthalpy of the refrigerant during the relevant process. This is shown below by equations 4 and 5:

$$Q_{Evap} = m_r(h_1 - h_4) \quad (4)$$

$$W_{Comp.} = m_r(h_2 - h_1) \quad (5)$$

Where:

h_1= Enthalpy of saturated steam[kJ/kg]

h_2 = Enthalpy of superheated steam [kJ/kg]

h_3 = Enthalpy of saturated liquid [kJ/kg]

h_4= Enthalpy of Wet steam [kJ/kg]

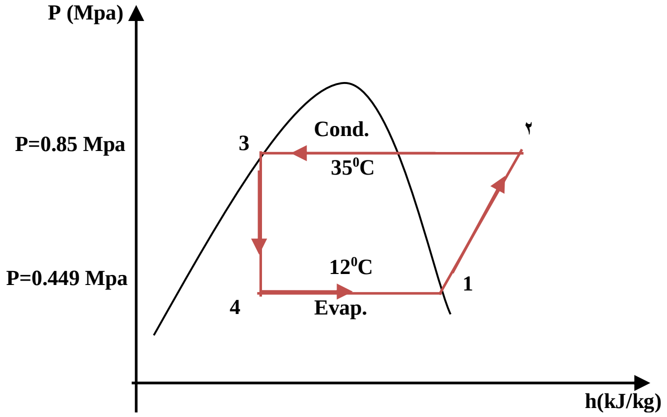

Figure 3 A simplified schemes for the enthalpy change with the pressure of the system.

Therefore the Coefficient of Performance can be simplified to the following equation, by substituting Equations 4 and 5 into Equation 3:

$$C.O.P = \frac{(h1-h4)}{(h2-h1)} \quad (6)$$

The enthalpy at states 3 and 4 are the same due to the assumption that the experimental conditions across the expansion device (capillary tubes) result in an isentropic process. Based on these results, the C.O.P for designed apparatus is calculated to be:

$$\mathrm{C.O.P} = \frac{(355 - 239.5)}{(370 - 355)} = 7.7$$

After turning on the compressor and reaching a stable state on the pressure gauge, the temperature of the column of water was measured in the storage tank at five different points shown in Table [1].

Table 1 Enthalpy, Temperature & Pressure for the system

System Point	Enthalpy (kJ/kg)	Temperature (°C)	Pressure (MPa)
1:Saturated Steam	**335**	**12**	**0.44903**
2:Superheated Steam	**370**	**-**	**-**
3:Saturated Liquid	**239.5**	**35**	**0.85**
4:Wet Steam	**239.5**	**35**	**0.85**

4- Performance parameters and Practical results

The vapor-compression refrigeration cycle has four components as shown in Figure 3 evaporator, compressor, condenser, and expansion (or throttle) valve. The most widely used refrigeration cycle is the vapor-compression refrigeration cycle. In an ideal vapor-compression refrigeration cycle, the refrigerant enters the compressor as a saturated vapor and is cooled to the saturated liquid state in the condenser. It is then throttled to the evaporator pressure and vaporizes as it absorbs heat from the refrigerated space. In this study temperature of water (in the evaporator) measured in different location alonge the evaporator as a sample study to show the decrease in temperature within the direct contact evaporation precess.

5- Discussion

According to the experimental results, it is clear that during the period of operation (approximately 1.6 hour) there was a clear reduction in the temperature of the water, as a result of heat absorption by refrigerant as shown in Figures 4-8. The drop in temperature of the storage tank (evaporator), which is assumed to be an isolated and adiabatic process, is equal to 13° C at most points. This shows the effectiveness of the direct contact evaporator for cooling. It is possible that the decrease in the temperature of the evaporator may increase if the quantity of refrigerant is increased. In addition , this will likely increase the time required to complete the cooling process.

Similar behavior of all five curves that clear in the results indicated that there was no significant effect of the location (of measured temperature) and the measured pressure on the process but the time plays significant role in the process (see table 2). Effect of other factor can be study and me be give different results for the process.

It is noted from the coefficient of performance calculations, that the coefficient of performance of the cycle (COP=7.7) is relatively high compared to traditional cycles, which reach approximately 4 [10-18]. This proves that the process is not only feasible, but also highly efficient.

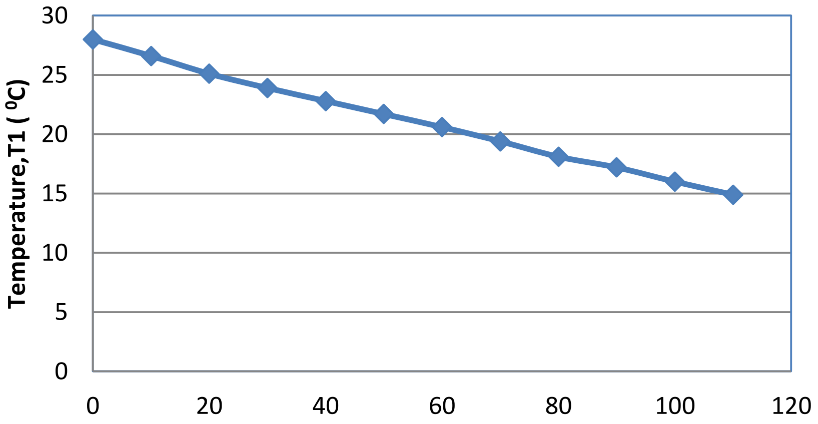

Figure 4. The change of the temperature (T_1) inside the storage tank vs. time in direct contact evaporator

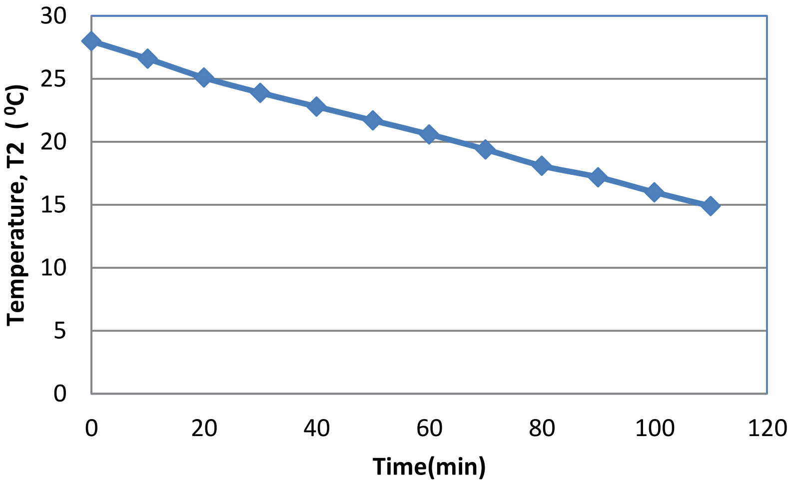

Figure 5.The change of the temperature (T_2) inside the storage tank vs. time in direct contact evaporator.

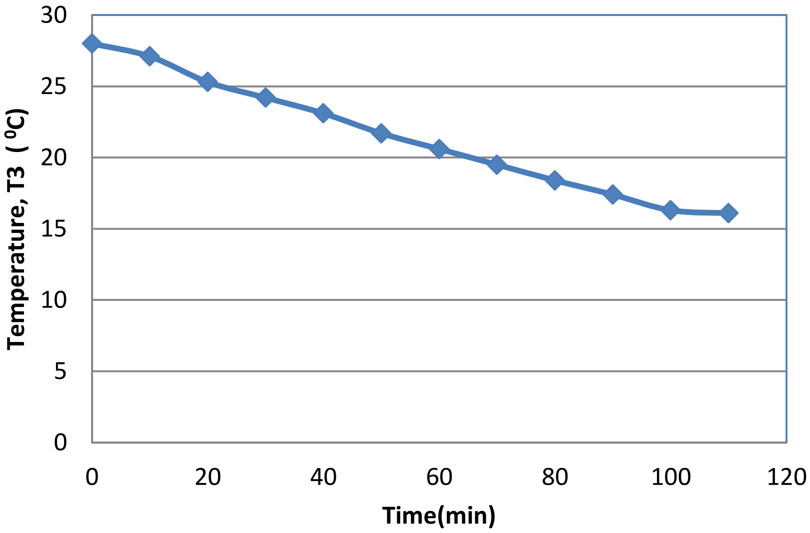

Figure 6.The change of the temperature (T_3) inside the storage tank vs. time in direct contact evaporator.

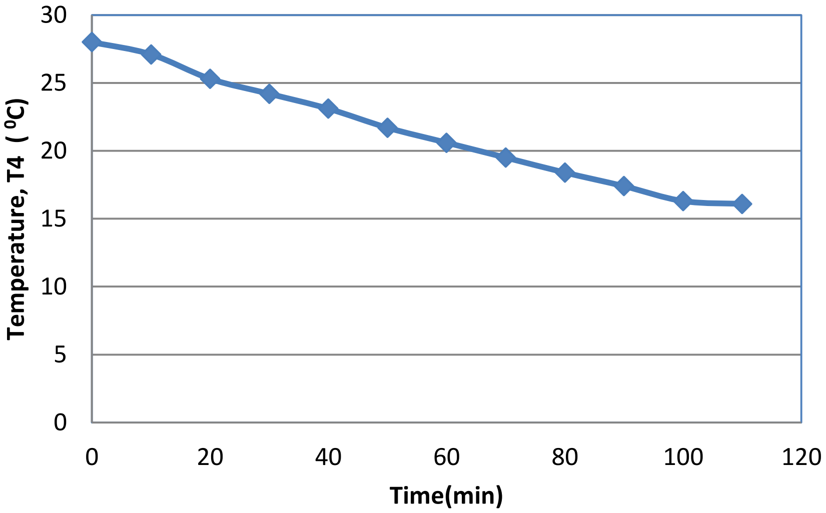

Figure 7. The change of the temperature (T_4) inside the storage tank vs. time in direct contact evaporator.

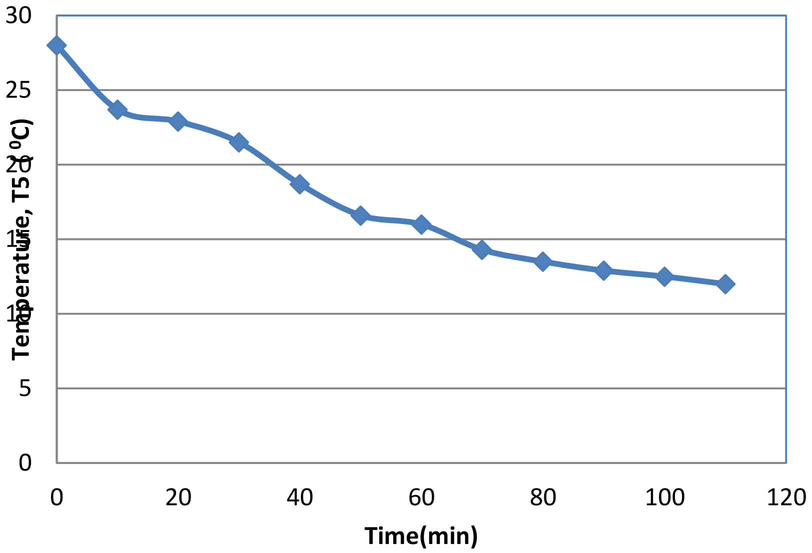

Figure 8. The change of the temperature (T_5) inside the storage tank vs. time in direct contact evaporator.

Table2. Experimental Results of temperature change according to selected points with various times in direct contact Evaporator

NO.	Time (min)	$T_1(^0C)$	$T_2(^0C)$	$T_3(^0C)$	$T_4(^0C)$	$T_5(^0C)$	P(Mpa)
1	0	28	28	28	28	28	1.1
2	10	26.8	26.6	26.8	27.1	23.7	0.85
3	20	25.3	25.1	25.4	25.3	22.9	0.80
4	30	24	23.9	24.2	24.2	21.5	0.75
5	40	22.9	22.8	22.8	23.1	18.7	0.65
6	50	21.8	21.7	21.9	21.7	16.6	0.63
7	60	20.7	20.6	20.7	20.6	16	0.55
8	70	19.3	19.4	19.4	19.5	14.3	0.52
9	80	18.2	18.1	18.3	18.4	13.5	0.50
10	90	17.3	17.2	17.5	17.4	12.9	0.43
11	100	16.1	16	16.3	16.3	12.5	0.40
12	110	15	14.9	15.1	16.1	12	0.40

5- Conclusions & Recommendation

The Direct Contact Evaporation Refrigeration System with injection of refrigerant gives a high heat transfer performance than other conventional system (indirect system), Since there is no large amount of heat loss throught the material pipes (evaporater pipes). This study concern to measure the expermintal teperature of water during a period of time (0- 110 min) as a sample study.

The following recommendations can be useful in a future works:

1- Another refrigant can be use in the system (such R22,…).
2- Using locally isolator material to isalate the different part of the system and study the different in results due to that isolation.
3- Using a special type of a glass evaporator in order to imaging process and study a shape of evaporated droplets.
4- the value of water in evaporatar (water storage tank) and the value of refirgant can be change and study its effect on the results

Acknowledgement

The authors gratefully acknowledge the college of Engineering- Mechanical Engineering department. Sincere thanks is also to many of students from the department who contributed to the completion of this work.

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Appendix [1]

Properties of R12[10]	
Boiling Point °C	-29.79
Freezing Point °C	-158
Critical Temperature °C	112
Critical Pressure(kPa)	4113
Vaporization Latent Heat at 25 °C (kJ/kg K)	165.1
Liquid Specific Heat at 25 °C (kJ/kg K)	0.971
Vapor Specific Heat at1atmosphere and 25 °C (kJ/kg K)	0.607
Ratio CP/CV at 1 atmosphere	1.14
Thermal Conductivity of Liquid at 25 °C (W/m K)	0.071
Thermal Conductivity of Vapor at1 atmosphere	0.0096

Appendix [2]: Steps of apparatus design

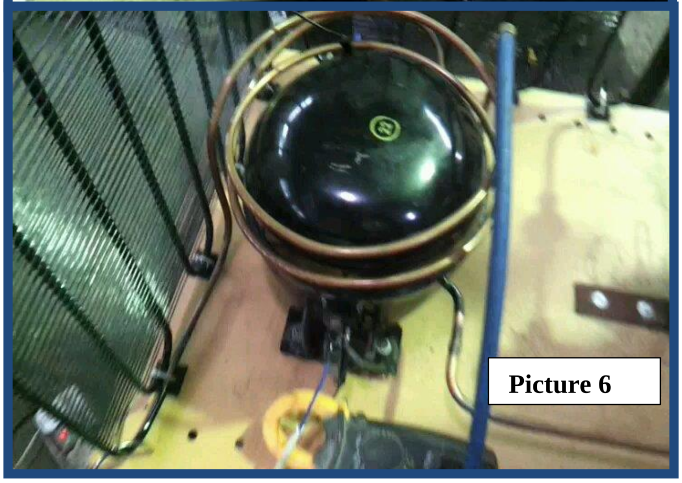

Picture 1


Picture 2


Picture 3


Picture 4

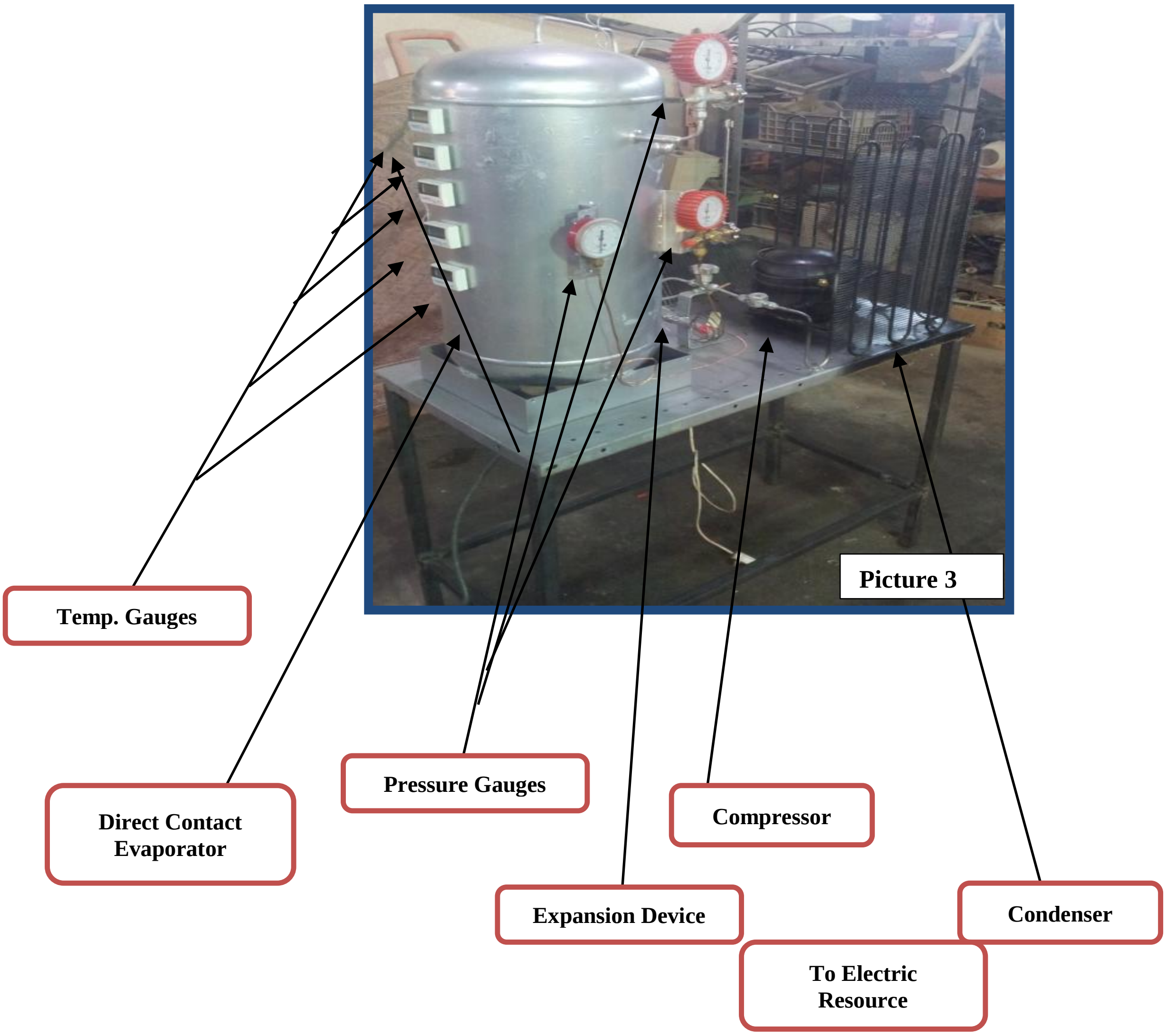

Picture 5


Picture 6

Appendix [3]: The final shape for the apparatus


Picture 1


Picture 2


Picture 3