PPU College of Engineering and Technology
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Mechanical Engineering Department

Graduation Project

Solar Adsorption Ice Maker

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Palestine Polytechnic University

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According to the directions of the project supervisor and by the agreement of all examination committee members, this project is presented to the Departments of Mechanical Engineering, for partial fulfillment Bachelor of engineering degree requirements.

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Abstract

Our project is building, designing, and testing an ice maker machine; this machine uses the solar energy (radiation from the sun).

The desired out come from building this machine is to freeze the water at 0°C to produce 0.8 kg ice, ice maker machine is a device contains chemical materials like (methanol + activated carbon), without any effect on nature. This project can be used in the poor areas which are not able to use the electricity to have the refrigerating effect; by this technology we will solve problems in these areas.

CHAPTER 1

Introduction

1.1 Introduction

As the world becomes more self aware of changing climate conditions caused by global warming; it's vital to reassess our dependence on the burning of the fossil fuels to gain energy. The alternatives for gaining this energy can be found in the sources of renewable energy such as solar energy and wind etc.

In particular, the solar energy alternatives is now being more closely examined in an attempt to utilize this as a source of energy for both domestic and commercial; and users such as refrigerators and air conditioners.

In recent years, increasing attention is being given to the use of the waste heat and solar energy in energizing refrigerating systems. Solar powered refrigeration and air conditioning have been very alternative during the last twenty years, since the availability of sunshine and the need of refrigeration both reach maximum levels in the same season.

Refrigeration and air conditioning are necessary for modern life, and are major consumers of energy. This project will focus on using solar energy in freezing water.

One of the most effective forms of solar refrigeration in the production of ice, as ice can accumulate much latent, thus the size of the ice maker can be made small.

1.2 Project objectives

1. To build an ice maker machine that will be used in ice making.
2. To introduce new technology to the local market.

1.3 Previous studies

1. Heat Transfer Enhancement and Energy Conservation

By Tchernev[1]. Solid adsorption refrigeration makes use of the unique features of certain-refrigerant pairs to complete refrigeration cycles for cooling or heat pump purposes. Zeolite and Activated Carbon were used as absorbent in many systems. In early 1980's, Tchernev carried out an investigation of adsorption refrigeration with the Zeolite and water pair. Also, Pons and Genier worked on solid adsorption pair of Zeolite and water, to produce refrigerating effect achieving coefficient of performance of only about 0.1.

2**.** Experimental study on adsorbent of activated carbon with refrigerant of methanol and ethanol for solar ice maker. Renewable Energy

By M. Li, H. B. Huang, R. Z. Wang[2]. Later, in 1987, they demonstrated that Activated Carbon and Methanol can be served as a suitable pair for a solar powered, solid-adsorption ice maker, Critoph had studied the performance limitation of adsorption cycle for solar cooling and concluded that, in general, Activated Carbon-Methanol combination was preferable for solar cooling which given the best coefficient of performance achievable in a single-stage cycle.

3. By Steven Vanek[3]. In 1996, the American scientist Steven Vanek designs an ice maker which operates in solar energy. This design use the couple cooling gases Ammonia-Calcium Chloride, this system consist of collector, which concentrate the sun light on pipe in the center of the collector and expansion valve, condenser, evaporator and ice box.

In this project solar adsorption cycle with Activated Carbon- Methanol will be used to produce ice.

1.4 Timing table

In order to finish the project in the specific time it was decided to organize the time for project by making a plan table which includes the number of weeks, and the tasks which should be done in each week as shown in Table (1.1):

Table (1.1) the first semester time plan

Task/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Collecting information about project	▨	▨	▨												
reading			▨	▨	▨										
introduction						▨	▨	▨							
Cycle components							▨	▨	▨						
Design									▨	▨	▨	▨			
Project documentation				▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	

The following table is time plane of second semester:

Table (1.2) the second semester time plan

Task/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Design of project	■	■	■	■	■										
Building the project			■	■	■	■	■	■	■	■	■	■	■	■	
Obtained refrigerant and adsorbent									■	■	■	■			
Calculation and experiment											■	■	■	■	■
Conclusion and recommendation													■	■	
Project documentation				■	■	■	■	■	■	■	■	■	■	■	■

CHAPTER2

Conceptual Designs and Functional Specification

2.1 Introduction

The ice maker machine is divided into parts and components in which they are connected with each other. These parts have different types and shapes with different properties. The design must compromise between these properties to achieve the required shape and performance without affecting safety.

Before building any machine, a set of parameters must be considered, they are divided into two groups: the first one is related to machine itself such as: safety, cost, design, volume occupied by the machine, and special components such as movable collector. The second one is related to the refrigeration cycle which works by using methanol and activated carbon.

2.2 Conceptual designs

It is desired to design and produce a chemic-mechanical machine with refrigeration cycle that uses methanol and activated carbon to change the phase of water from liquid to ice phase.

2.3 Operation and analysis of the adsorption cycle

The operation principle of the solid adsorption refrigeration system utilizing solar heat is shown in Fig. (2.1) .The system is composed of a container of adsorbents, which serves as a solar collector, a condenser and an evaporator which acts as a refrigerator. A combination of adsorbent and adsorbate is confined in a collector is supplied with activated carbon (A.C) which is adsorbed with methanol. During the day-time the activated carbon along with the methanol is heated in the collector. Methanol evaporates from the activated carbon and then is cooled in the condenser (liquid methanol) and stored in the evaporator as shown in Fig. (2.2)[4].

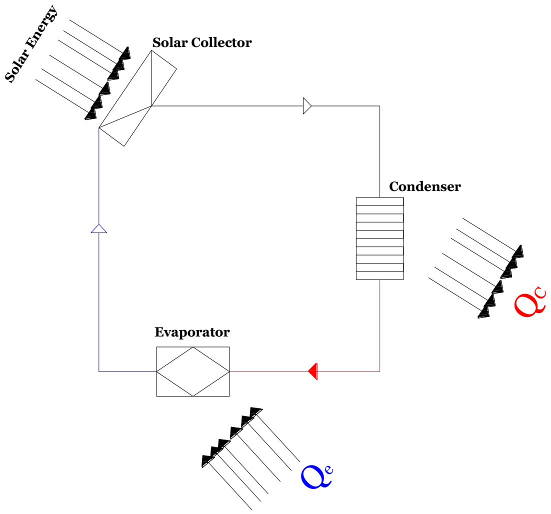


Figure (2.1) Refrigeration system

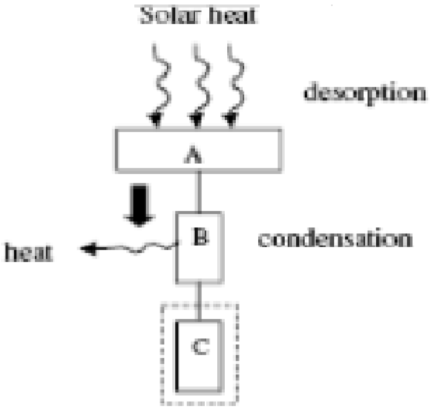


Figure (2.2) Day time (heat-desorption)

Figure (2.2): Operation principle of solid adsorption refrigeration system utilizing solar heat A: adsorption bed (solar collector); B: condenser; C: evaporator.

During the night-time, the collector is cooled by ambient air and the temperature of the activated carbon reaches a minimum as shown in Fig. (2.3). in this period, methanol begins to evaporate by adsorbing heat from the water to be cooled and is adsorbed by the activated carbon. As the evaporation of the methanol continues, the water temperature decreases until it reaches if possible 0°C, where ice starts to be formed.

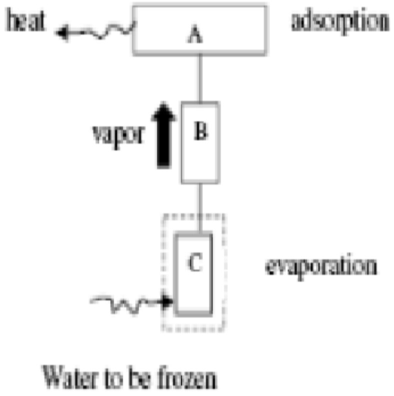


Figure (2.3) Night-time (evaporation-adsorption)

The principle of the solid adsorption cooler is explained using a Clapeyron diagram (lnP versus -1/T), Fig. (2.4) shows the idealized process undergone by (AC + methanol) in achieving the refrigeration effect. The cycle begins at a point A where the adsorbent is at a low temperature (T_{ads}) and low pressure P_e (evaporator pressure). During the daylight, AB represents the heating of A.C along with methanol. The progressive heating of the adsorbent from B to C causes some adsorbate to be desorbed and its vapor to be condensed at the condenser pressure P_c. When the adsorbent reaches its maximum temperature T_C, desorption ceases (T_{dns}). Then the liquid methanol is transferred into the evaporator. During night, the decrease in temperature from C to D induces the decrease in pressure from P_c to P_e. Then the adsorption and evaporation occur while the adsorbent is cooled from D to A. During this cooling period heat is withdrawn both to decrease the temperature of the adsorbent and to withdraw adsorption heat [4].

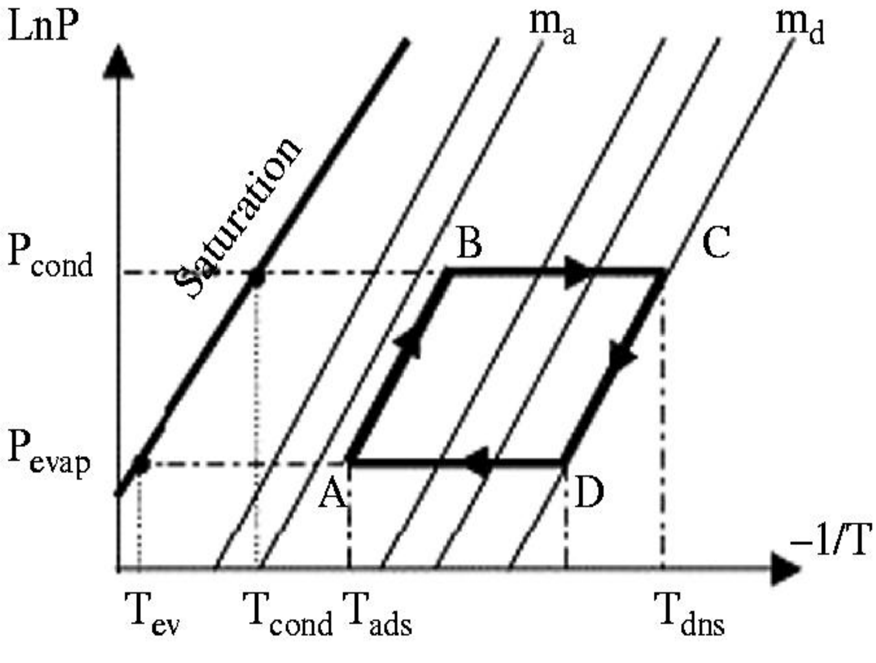


Figure (2.4)Clapeyron diagram (ln P versus -1/T) of ideal adsorption cycle.[4]

From the Clapeyron diagram, the total energy gained by the system during the heating period Q_T will be the sum of the energy Q_{AB} used to raise the temperature of the (A.C+ methanol) from point A to B and the energy Q_{BC} used for progressive heating of the A.C to point C and desorption of methanol.

2.4 Adsorption process

2.4.1 Introduction

Adsorption is the use of solids for removing substances from gases and liquids, this phenomenon is based on the preferential partitioning of substances from the gaseous or liquid phase onto the surface of a solid substrate. This process is reversible as shown in Fig. (2.5).

2.4.2 Adsorption phases

- Heating and pressurization.
- Heating and desorption with condensation.
- Cooling and depressurization.
- Cooling and adsorption with evaporation.

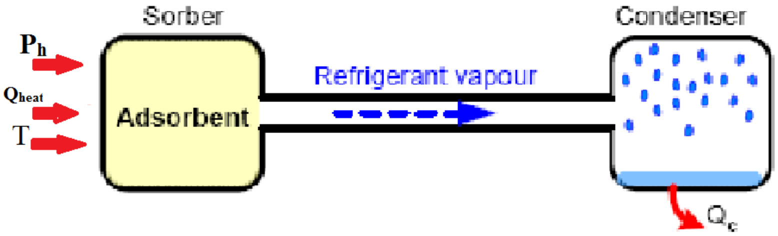


Figure (2.5a) Adsorption phase at Day

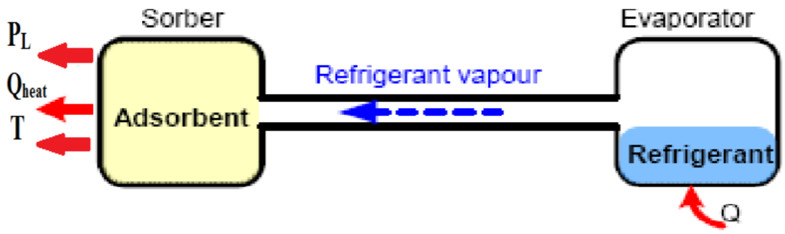


Figure (2.5b) Adsorption phases at Night

2.4.2.1 Heating and pressurization:

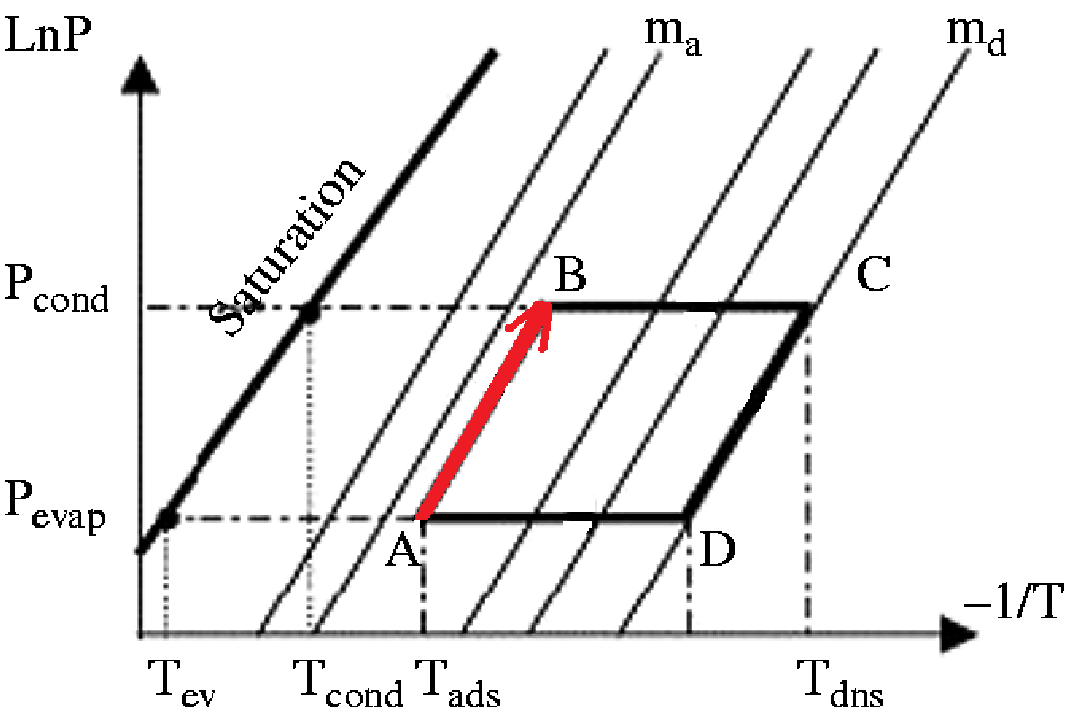


Figure (2.6) Heating and pressurization

When the cycle process begins the methanol will be adsorbed in activated carbon and because of the increase of temperature the methanol will leave activated carbon particles, heating and pressurization process occurs in the pipe, in this process the adsorbent temperature increases, which induces a pressure increase from the evaporation pressure up to condensation pressure, this period is equivalent to the compression phase in vapor compression refrigeration cycles [from A to B] as shown in Fig. (2.6).

2.4.2.2 Heating and desorption with condensation:

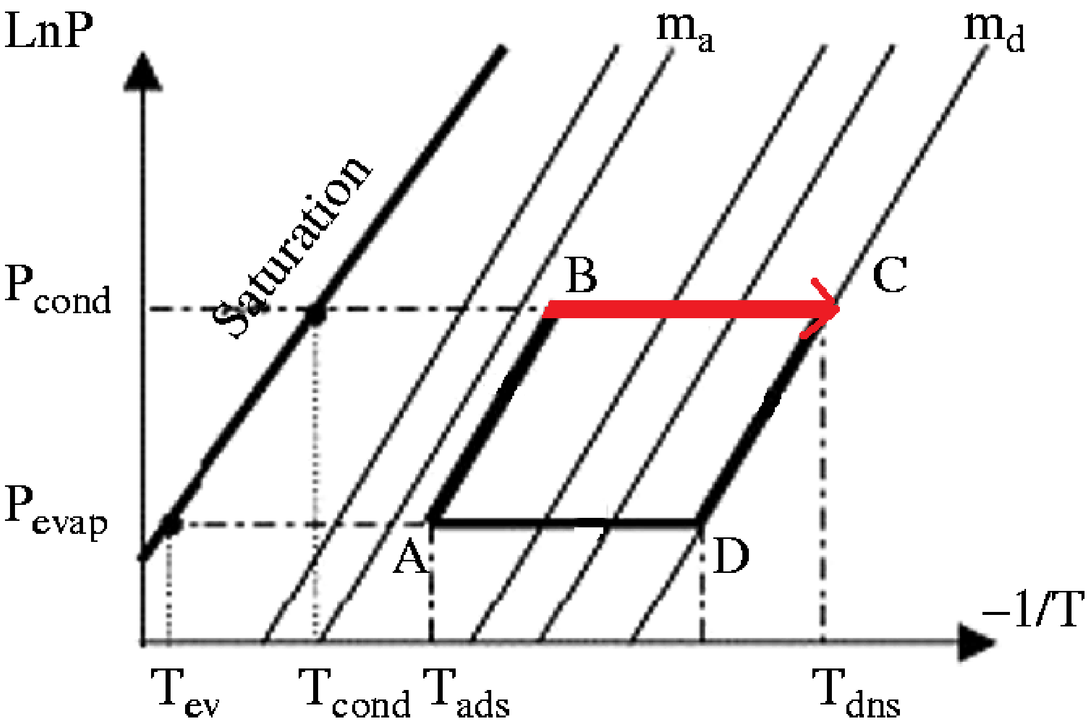


Figure (2.7) Heating and desorption with condensation

This phase occurs in pipe and condenser, during this period adsorber continues receiving heat while being connected to the condenser, which now superimposes its pressure.

The adsorbent temperature continues increasing, which induces desorption of vapor, this desorbed vapor is liquefied in the condenser as shown in Fig. (2.7).

The condensation heat is released to the second heat sink at intermediate temperature; this period is equivalent to the condensation phase in compression cycles.

2.4.2.3 Cooling and depressurization:

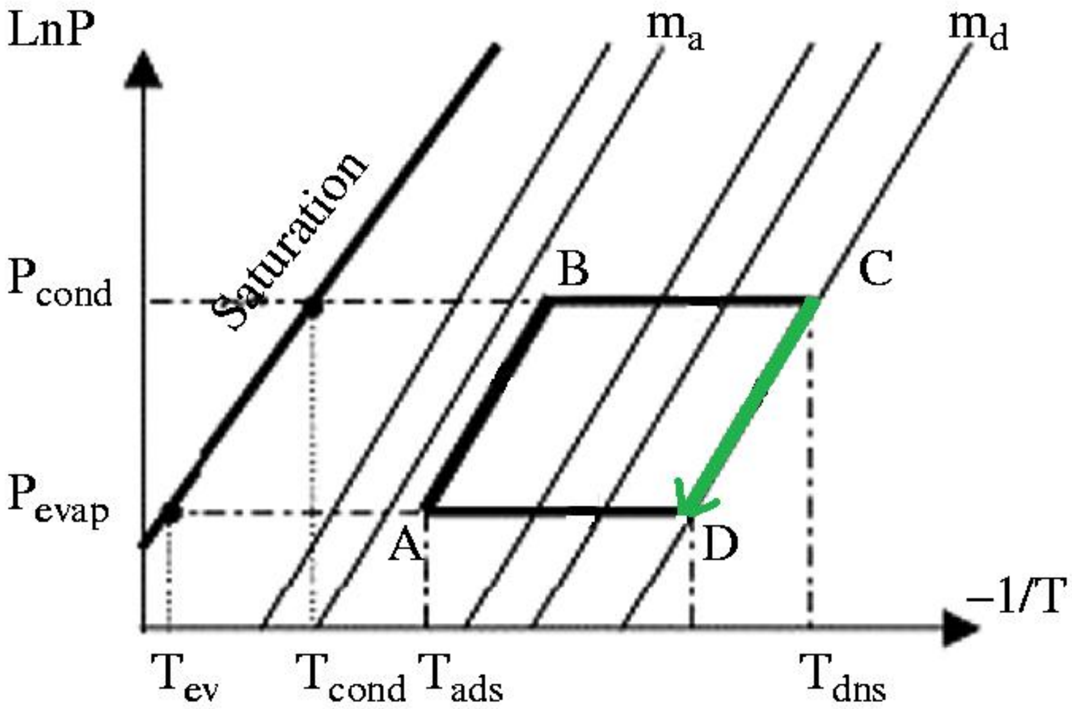


Figure (2.8) Cooling and depressurization

In this period, the adsorber releases heat while being covered from the sun. The adsorbent temperature decreases, which induce the pressure decrease from the condensation pressure down to the evaporation pressure, this period is equivalent to the expansion phase in compression cycles as shown in Fig. (2.8).

2.4.2.4 Cooling and adsorption with evaporation:

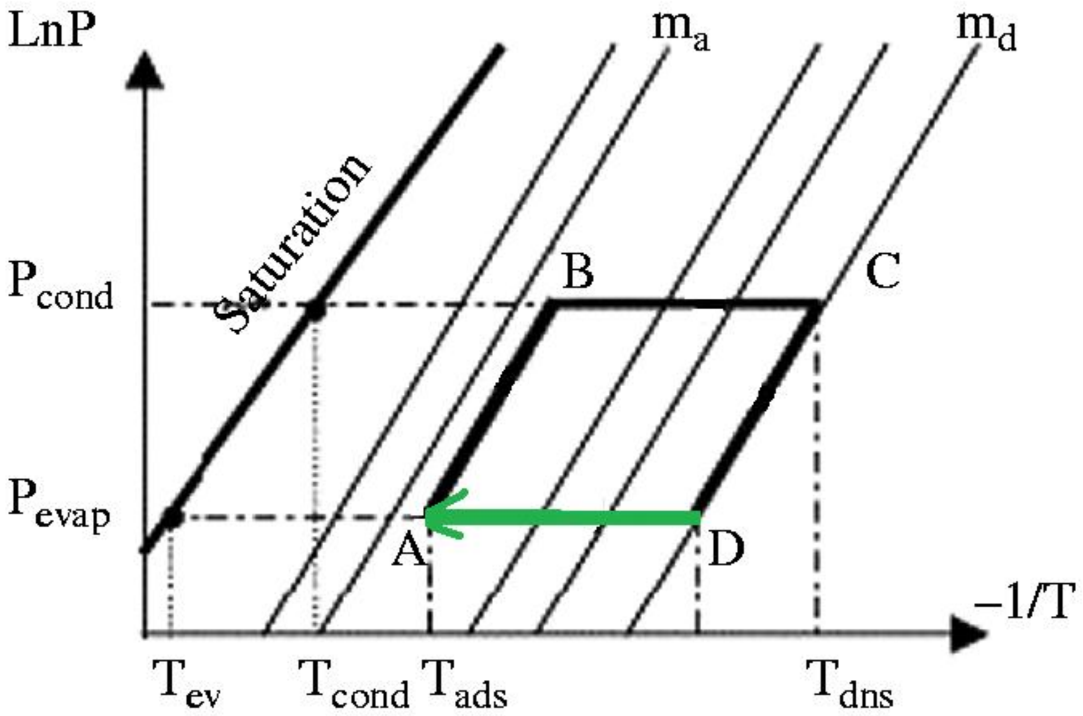


Figure (2.9) Cooling and adsorption with evaporation

This phase occurs in ice box and tube, during this period the adsorber continues releasing heat while being connected to the evaporator, which now superimposes its pressure. The adsorbent temperature continues decreasing, which induces adsorption of vapor. This adsorbed vapor is evaporated in the evaporator, the evaporation heat is supplied by the heat source at low temperature, and this period is equivalent to the evaporation phase in compression cycles as shown in Fig. (2.9).

2.5 Refrigerant and adsorbent

2.5.1 Refrigerant (Methanol)

It is also known as methyl alcohol, wood alcohol is a chemical compound with formula CH3OH it is toxic drinking 10 ml will cause blindness, and as little as 100 ml will cause death. It is the simplest alcohol, light, volatile, colorless and flammable. At room temperature it is a polar liquid and is used as antifreeze, solvent, and as denaturant for ethanol.

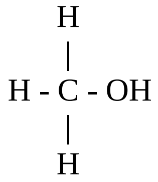
Methanol is produced naturally in the anaerobic metabolism of many varieties of bacteria, and is ubiquitous in the environment. As a result, there is a small fraction of methanol vapor in the atmosphere. Over the course of several days, atmospheric methanol is oxidized by oxygen with the help of sunlight to carbon dioxide and water.

Thermal and physical properties of methanol:

The chemical identity and physical/chemical properties of methanol are summarized in Table (2.1)

Table (2.1) Chemical identity and chemical/physical properties of methanol [5]

Characteristic/Property	Data
Molecular Formula	CH4O

Chemical Structure	 $\mathrm{H-\overset{\overset{H}{\vert}}{\underset{\underset{H}{\vert}}{C}}-OH}$
Physical State	colorless liquid
Molecular Weight	32.04 g mol^{-1}
Melting Point	-97.8^{o}C
Boiling Point	64.7^{o}C at 760 mm Hg
Water Solubility	Miscible
Liquid Density	0.7918 g/cm^{3}
Vapor Density	0.204 g/cm^{3}
Vapor Pressure	13.02 kPa
Reactivity	Flammable; may explode when exposed to flame
Conversion Factors	1 ppm = 1.33 mg/m^{3} 1 mg/m^{3} = 0.76 ppm
Dynamic viscosity	$5.9*10^{-4}$ Pa

- **Applications of methanol:**

The largest use of methanol by far is in making other chemicals. About 40% of methanol is converted to formaldehyde, and from there into products as diverse as plastics, plywood, paints, explosives, and permanent press textiles. Derivatives of methanol include dim ethyl ether, which has replaced chlorofluorocarbons as an aerosol spray propellant, and acetic acid. Dim ethyl ether or "DME" also can be blended with liquefied petroleum gas (LPG) for home heating and cooking, and can be used as a diesel replacement transportation fuel. Methanol is also used as a solvent, and as antifreeze in pipelines and windshield washer fluid.

2.5.2 Adsorbent (Activated carbon)

It is also called activated charcoal or activated coal, is a form of carbon that has been processed to make it extremely porous and thus to have a very large surface area available for adsorption or chemical reactions.

- **Applications of activated carbon:**

There is much usage for activated carbon, like:

Adsorption refrigeration, gas purification, gold purification, metal extraction, water purification, medicine, sewage treatment, air filters in gas masks, and many other application.

Carbon adsorption has numerous applications in removing pollutants from air or water streams both in the field and in industrial processes such as, spill cleanup, groundwater remediation, drinking water filtration and air purification volatile organic compounds capture from painting, dry cleaning, gasoline dispensing operations.

2.6 Adsorption cycle Components

2.6.1 Adsorbent Bed (collector)

Adsorbent bed is the most important part of the solar cooler, it is the heart of solid adsorption refrigeration system, and the characteristics of the adsorbent bed are the most obvious factors which directly affect solid adsorption systems. For the flat-plate solar cooler, the collector is often designed into an integrated shape to enhance heat transfer, on the top of the adsorbent bed, a glass cover is necessary to form a "greenhouse" for the adsorbent bed, the sketch of the cross section of the adsorbent bed shown in Fig. (2. 10).

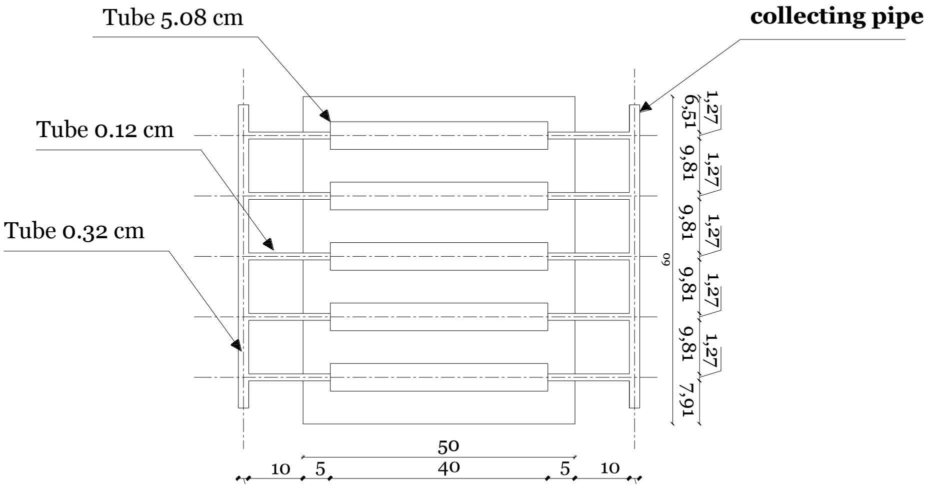


Figure (2.10) Section of the adsorbent bed

2.6.2 Condenser

During the process of desorption of methanol, a good designed condenser is needed to reject the desorption heat by helical copper tubes condenser immersed in a water, its position below the collector, the sketch of the cross section of the condenser shown in figure (2.11).

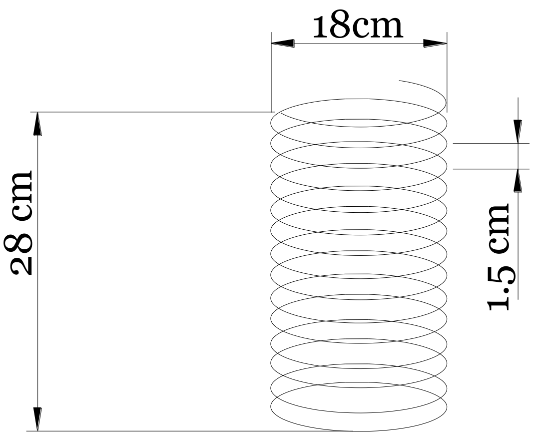


Figure (2.11) Helical condenser

2.6.3 Evaporator

The evaporator must have sufficient volume to collect the entire condensed methanol in order to enhance the heat transfer effect. The evaporator is partially immersed in a water, which is made of stainless steel, and both the evaporator and water are placed in insulated box covered with insulation as shown in Fig. (2.12).

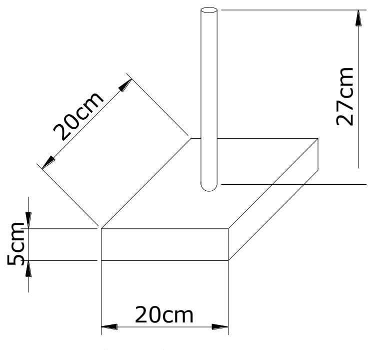


Figure (2.12) Evaporator

2.6.4 Ice box

Ice box is a box made from stainless steel, where the evaporator located inside it and also where the ice is formed as shown in Fig. (2.13)

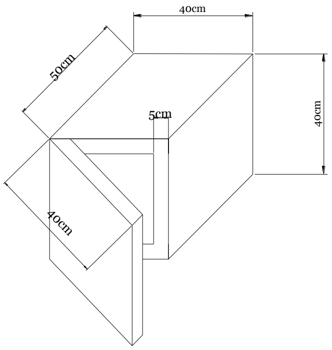


Figure (2.13) Ice box

Chaptre 3

Thermal theory and modeling of components

3.1 Introduction

This chapter deals with the system components, specifically mechanical components; collector, condenser, evaporator, and ice box shown in Fig. (3.1). Also thermal equations for each component are stated, and energy balance is made using Fourier equation and Newton's law.

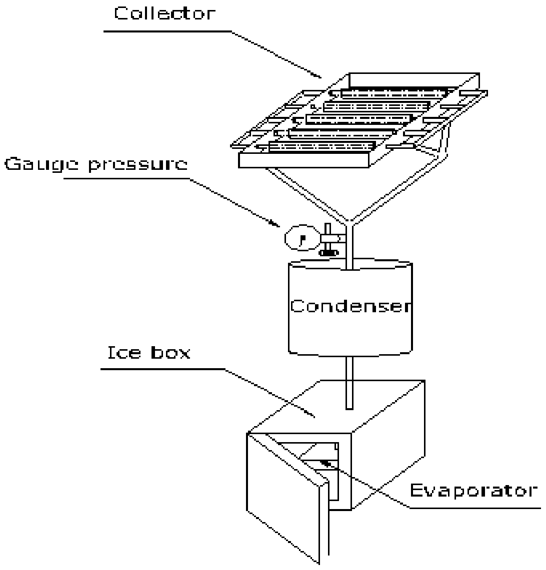


Figure (3.1) schematic of adsorption system

3.2 Thermal energy balance for evaporator

3.2.1 General description of evaporator

The evaporator is one of the four basic and necessary hardware components of the refrigeration system show Fig. (2.12). In the evaporator, the refrigerant is evaporated by the heat transferred from the heat source. During evaporation, the temperature of a pure refrigerant is constant, as long as the pressure does not change. The temperature of the refrigerant must be below that of the heat source. This low refrigerant temperature is attained as a result of the reduction in pressure caused by adsorption process (chemical reaction) started

3.2.2 Thermal energy balance

The description of the thermal theory and modeling of evaporetor will start here with the energy conservation equation. Each component will be identified and then decomposed into its heat transfer rate subcomponents.

The energy balance for the evaporetor is:

$$Q_e = \dot{\mathrm{m}} * \mathrm{Cp} * (\mathrm{T_w} - \mathrm{T_d}) \tag{3.1}$$

Where:

Q_e: The amount of heat through the evaporator [W].

$\dot{\mathrm{m}}$: The amount of ice [kg/day].

Cp: Specific heat capacity of water [kJ/kg.ºC].

T_w: The water temperature [ºC].

T_d: The desired temperature [^oC].

$Q_e = 0.8 * 4.18 * (25 - 0)$

$Q_e = 90\ W$

$$Cop = \frac{Q_e}{Q_H} \quad (3.2)$$

Where:

Cop : Coefficient of performance.

Q_H: The amount of heat from collector [W].

$$Q_H = \frac{90}{0.5}$$

$Q_H = 180\ W$

$$Q_e = \mathrm{h} * \mathrm{A} * \left(\mathrm{T}_{\mathrm{B/S}} - \mathrm{T}_{\mathrm{e}}\right) \quad (3.3)$$

Where:

Q_e : The amount of heat from evaporator [W].

h: enthalpy of methanol [kJ/kg].

A: evaporator surface area [m^2].

$T_{B/S}$: Desired temperature inside ice box [^oC].

T_e : Evaporator temperature [^oC].

$Q_e = 726 * \mathrm{A} * (0-(-3))$

A= 0.04 m^2

To calculate the mass flow rate of methanol:

$$Q_e = \dot{\mathrm{m}} * \mathrm{Cp} * (\mathrm{T_w} - \mathrm{T_d}) \tag{3.4}$$

$\dot{\mathrm{m}}$: The mass flow rate of methanol [kg/s].

Cp: Specific heat capacity of methanol [kJ/kg.ºC].

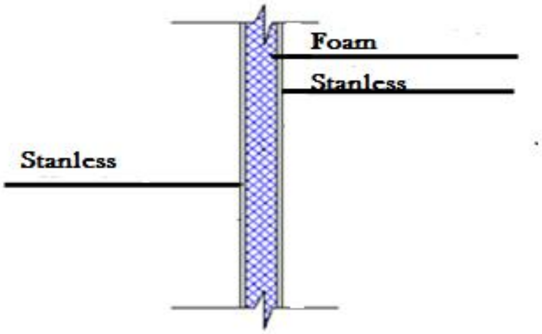
$90 = \dot{\mathrm{m}} * 45 * (3)$

$\dot{\mathrm{m}}$= 0.67 kg/s

3.3 Thermal energy balance for ice box

3.3.1 General Description of ice box

Ice box is the refrigeration space, the wall of this box is made from stainless steel, Fiber glass and foams, insulation material is used to prevent heat transfer in and out of the box, in order to maintain the required temperature, show Fig. (3.2).



Figure(3.2) Wall construction

3.3.2 Thermal energy balance

In conduction mode of heat transfer systems are in physical contact and heat is transferred from one molecule to the adjacent one. Thus the agitation of the hotter molecule is transferred to the cooler molecule. It was observed by Fourier that the conduction heat flux q/A in a given direction is directly proportional to temperature difference in the direction of heat flow ΔT and invrsely proportional to the distance in the same direction Δx.[10]

Thus:

$$\frac{\dot{q}}{A} \propto \frac{\Delta T}{\Delta x} \qquad (3.5)$$

For very small changes in ΔT and Δx and changing the relationship Eq.(3.5) to an equlatity, the Fourier's equation of conduction is as follows:

$$\frac{\dot{q}}{A} = -k\frac{dT}{dx} \qquad (3.6)$$

Where:

k : Thermal condctivity of the material through which conduction takes place.[W/m.^{o}C] from table (3.1)

Table (3.1) Thermal conductivity of some construction materials. [10]

Material	Thickness (cm)	Thermal conductivity [W/m. ℃]
Stainless steel	0.1	15
Foams	5	0.036

Integration of Eq.(3.6), the following result is obtained:

$$\frac{\dot{q}}{A} = \frac{k}{x}(T_1 - T_2) \tag{3.7}$$

Where:

x: distance separating the two surfaces whoes temperatures are T_1 and T_2 where T_1 is greater than T_2.

Where $R_{cond.}$ is the thermal resistance due to conduction.[m^{2}.^{o} C/W], which is defined as follows:

$$R_{cond} = \frac{x}{k} \tag{3.8}$$

The total thermal resistance for the heat transfer from the air on one side of a composite wall of n number of layers to the air on the other side is given as follow:

$$R_{th} = R_o + \sum_{j=1}^{n} (R_{cond})_j + R_i \tag{3.9}$$

Where:

$$\sum_{j=1}^{n}(R_{cond})_j = R_1 + R_2 + \cdots + R_n \qquad (3.10)$$

And n, is the number of homogeneous layers of the composite wall. R_i and R_o are the inside and the outside film thermal resistances of the air filmes [$m^2.^oC/W$] which are listed in tabel(3.2) and (3.3). The overall heat transfer cofficint of the wall is defined as follows:

$$U = \frac{1}{R_{th}} \qquad (3.11)$$

Inside and outside film thermal resistances is defined as follows:

$R_i = 0.12\ \mathrm{m}^2.\ ^\circ\mathrm{C/W}$

$R_o = 0.06\ \mathrm{m}^2.\ ^\circ\mathrm{C/W}$

$R_{th} = 0.12 + \frac{0.001}{15} + \frac{0.05}{0.036} + \frac{0.001}{15} + 0.06$

R_{th}= 1.65 $\mathrm{m}^2.\ ^\circ\mathrm{C/W}$

$U = \frac{1}{1.65}$

U= 0.64 $\mathrm{W/m}^2.\ ^\circ\mathrm{C}$

$Q = UA\Delta T$, ΔT= (T_{out}-T_{in}) (3.12)

Where:

T_{out} : outside box temperture , 37 ℃.

T_{in} : inside box temperture , 0 ℃.

$Q = 0.64 * (0.4 * 0.4) * 37$

Q=3.8 W

Table (3.2) inside film resistance, R_i[10]

Element	Heat Direction	Material Type	R_i m^2.^{o}C/W
Wall	Horizontal	Construction materials	0.12
		Metals	0.31
Ceilings and floors	Upward	Construction materials	0.1
		Metals	0.21
	Downward	Construction materials	0.15

Table (3.3) outside film resistance, R_o[10]

Wind speed		Less than 0.5 m/s	0.5-5 m/s	More than 5 m/s
Element	Material Type	Outside Resistance R_o, m^2.^{o} C/W		
Wall	Construction materials	0.08	0.06	0.03
	Metals	0.1	0.07	0.03
Ceillings	Construction materials	0.07	0.04	0.02
	Metals	0.09	0.05	0.02
Exposed floors	Construction materials	0.09	–	–

3.4 Thermal energy balance for condensor

3.4.1 General description of condensor

During the process of desorption of methanol, a well designed condenser is needed to reject the desorption heat. A helical copper tube condenser immersed in a water tank to transfer the heat between methanol and water shown in Fig. (2.11). It is the part uses to convert vapor to liquid and get it out to the evaporator. We used a helical copper tube condenser immersed in a water tank to transfer the heat between methanol and water.

3.4.2 Condenser design

Designing a helical coil condenser as shown in Fig. (3.3) the equation below can be used to determined the parameters. [14]

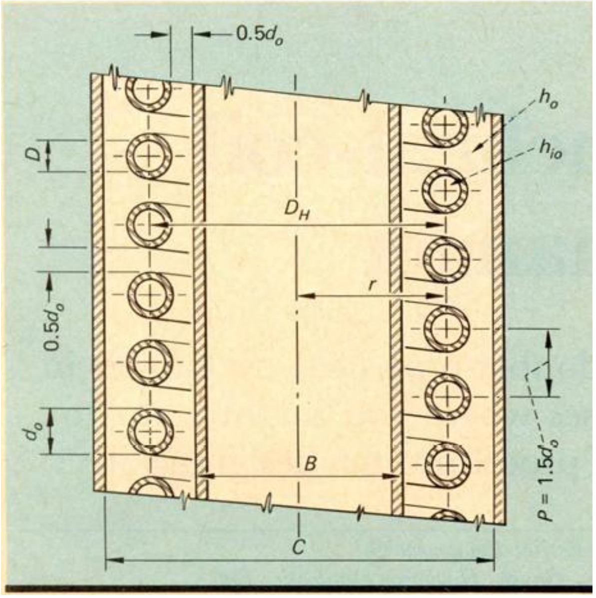


Figure (3.3) Schematic helical coil condenser [14]

$$L = N\sqrt{(2\pi r)^2 + P^2} \tag{3.13}$$

Where:

L: Length of helical coil needed to form N turns [m].

N: Theoretical number of turns of helical coil.

$$P = 1.5 * d_0 \tag{3.14}$$

Where,

d_0 : Outside diameter [m].

$$l = N\sqrt{(2\pi * 0.006)^2 + (1.5 * 0.0012)^2}$$

$$l = 0.04N \text{ [m]}$$

$$V_c = \left(\pi/_4\right){d_0}^2 l \tag{3.15}$$

Where:

V_c : The volume occupied by N turns of coil [m^3].

$$V_c = \left(\pi/_4\right)(0.0012)^2 * 0.04N$$

$$V_c = 5.3 * 10^{-8} N \ [m^3]$$

$$V_a = \left(\pi/_4\right)C^2 PN \tag{3.16}$$

Where:

V_a: The volume of the annulus [m^3].

C: The inner diameter of the tank [m].

$$V_a = \left(\pi/_4\right)(0.34)^2 0.018N$$

$$V_a = 1.63 * 10^{-3} N \ [m^3]$$

$$V_{\mathrm{f}} = V_a - V_c \tag{3.17}$$

Where:

V_{f} : The volume available for the flow of fluid in the annulus $[m^3]$.

$$V_{\mathrm{f}} = 1.63 * 10^{-3} N - 5.3 * 10^{-8} N$$

$$V_{\mathrm{f}} = 1.62 * 10^{-3} N$$

$$D_e = {}^{4V_f}\big/_{\pi d_o l} \tag{3.18}$$

Where:

D_e : The shell side equivalent diameter of the coiled tube $[m]$.

$$D_e = {}^{[4 * 1.62 * 10^{-3} N]}\big/_{[\pi * 0.012 * 0.04N]}$$

$$D_e = 0.18 \ m$$

The mass velocity of the fluid is:

$$u = \frac{\dot{v}}{A} \tag{3.19}$$

u : The methanol velocity [m/s].

$\dot{v}$: Volume flow rate of methanol [m^3/s].

A: Cross section area of coil,$A = \pi r^2$ [m^2].

$A = \pi * (5 * 10^{-3})^2$

A=7.85*10^{-3} m^2

$$\dot{v} = \frac{\dot{m}}{\rho} \tag{3.20}$$

$$\dot{v} = \frac{0.67}{0.8}$$

$\dot{v} = 0.84$ m^3/s

$$u = \frac{0.84}{7.85 * 10^{-3}}$$

u=107 m/s

$$Re = \frac{\rho u D}{\mu} \tag{3.21}$$

μ: Dynamic viscosity [Pa].

ρ: Density of methanol [0.8 g/cm^3].

$$Re = \frac{0.8 * 107 * 0.01}{5.9 * 10^{-4}}$$

Re= 1450

$$Pr = \frac{Cp\mu}{k} \tag{3.22}$$

Where:

Pr: prantl number.

k: Thermal conductivity of methanol [w/m.^{o}C].

$$Pr = \frac{45 * 5.9 * 10^{-4}}{0.204}$$

Pr= 0.13

$$\mathrm{h_i} = \frac{\mathrm{j_H} * \mathrm{k} * (Pr)^{\frac{1}{3}}}{\mathrm{D}} \tag{3.23}$$

Where:

$\mathrm{j_H}$: Colburn factor for heat transfer , from Fig.(3.4) for (Re= 1450) is 25.

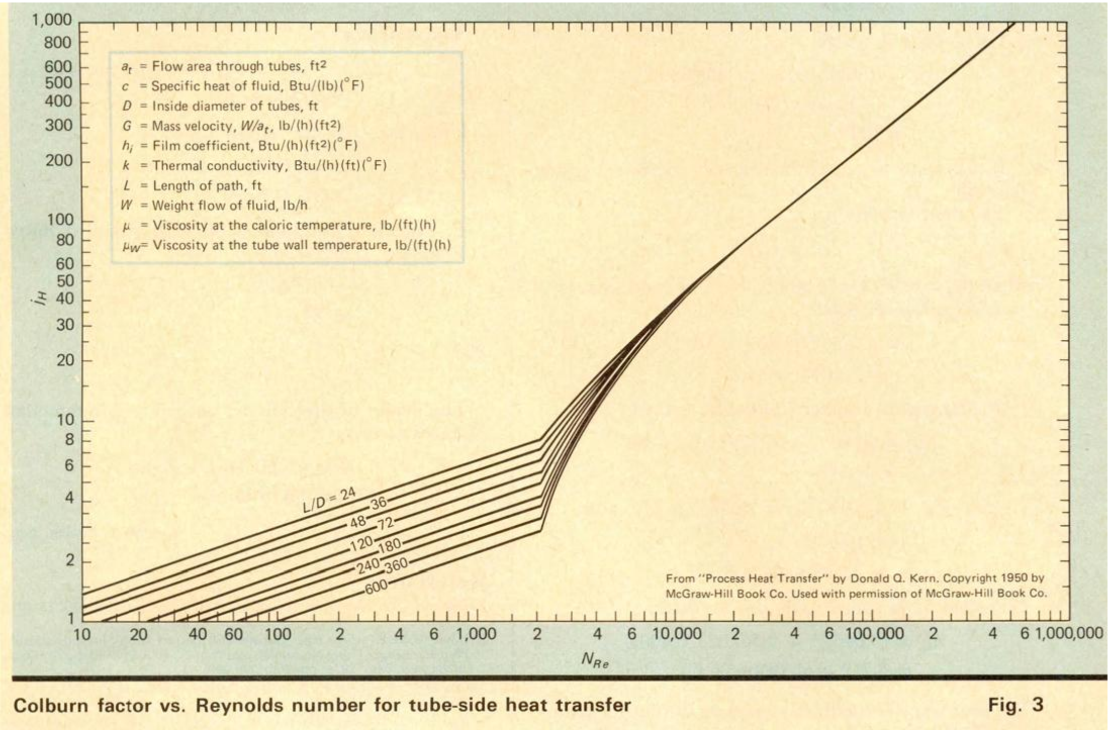
$$\mathrm{h_i} = \frac{25 * 0.204 * (0.13)^{\frac{1}{3}}}{0.01} \tag{3.24}$$

$\mathrm{h_i}$= 260 w/m^2.^{o}C

$$h_o = h_i \left(\frac{D}{d_o}\right) \tag{3.25}$$

$$h_o = 260 \left(\frac{10}{12}\right)$$

$h_o = 216$ w/m^2.^{o}C



From "Process Heat Transfer" by Donald Q. Kern. Copyright 1950 by McGraw-Hill Book Co. Used with permission of McGraw-Hill Book Co.

Colburn factor vs. Reynolds number for tube-side heat transfer **Fig. 3**

Figure (3.4) Colburn factor [14]

3.4.3 Thermal energy balance

The description of the thermal theory and modeling of condensor will start here with the energy conservation equation. Each component will be identified and then decomposed into its heat transfer rate subcomponents.

The energy balance for the condensor is

$$Q_{cond} = \dot{m} Cp \Delta T \tag{3.26}$$

Where:

Q_{cond}: The amount of heat from condser [W].

$Q_{cond} = 0.67 * 45 * (64 - 25)$

Q_{cond}=1175.8 W

To determine the value of U there are many parameters that should be determined before reaching U value, starting with the flow rate of refrigerant, radiuses, then the heat transfer coefficient, and all calculation done at the entrance of the condenser, so the methanol properties were determined according to the state at entrance of the condenser.

$$U = \frac{1}{\frac{1}{h_i}+\frac{r_i\,ln\left({r_o}/{r_i}\right)}{k}+\frac{r_i}{r_o}+\frac{1}{h_o}} \qquad (3.27)$$

$$U = \frac{1}{\frac{1}{260}+\frac{5\,ln\left({6}/{5}\right)}{401}+\frac{5}{6}+\frac{1}{216}}$$

$U = 1.23$ W/m^2.^{o}C

To find the heat transfer area for the coil:

$$Q = UA\Delta T \qquad (3.28)$$

$1.1758 = 1.18 * A * 39$

A=0.024 m^2

Determine the number of turns of coil. Since $A = \pi d_o L$, and L is expressed in terms of N, the number of turns of coil needed can be calculated by:

$$N = \frac{A}{\pi d_o \left(\frac{L}{N}\right)} \tag{3.29}$$

$$N = \frac{0.024}{\pi 0.0012 \left(\frac{0.04N}{N}\right)}$$

N =15 turn

The find the height of coil:

H=N*P+d_o (3.30)

Where:

H: the coil height [m].

H= (15*0.018)+0.012

H= 28.2 cm

3.5 Thermal energy balance for solar collectors

3.5.1 General description of solar collectors

The flat-plate collector consists adsorbers bed, glass cover, insulation, and collector pipes shown in Fig. (3.5a), (3.5b). The adsorbent bed is usually made of stainless steel and then selective coating covered on top surface of the steel plate box to enhance receiving solar flux radiation. The cover glasses are used to reduce convection and radiation losses from the adsorber. The collector pipe is usually made from copper and also have small hollow to let the methanol vapor defuse the activated carbon.

The amount of solar irradiation reaching the top of the outside glazing will depend on the location, orientation, and tilt of the collector. The amount of useful energy collected will also depend on the optical properties (transmissivity and reflectivity), the properties of the adsorber bed (adsorptivity and emissivity), and losses by conduction, convection, and reradiation.

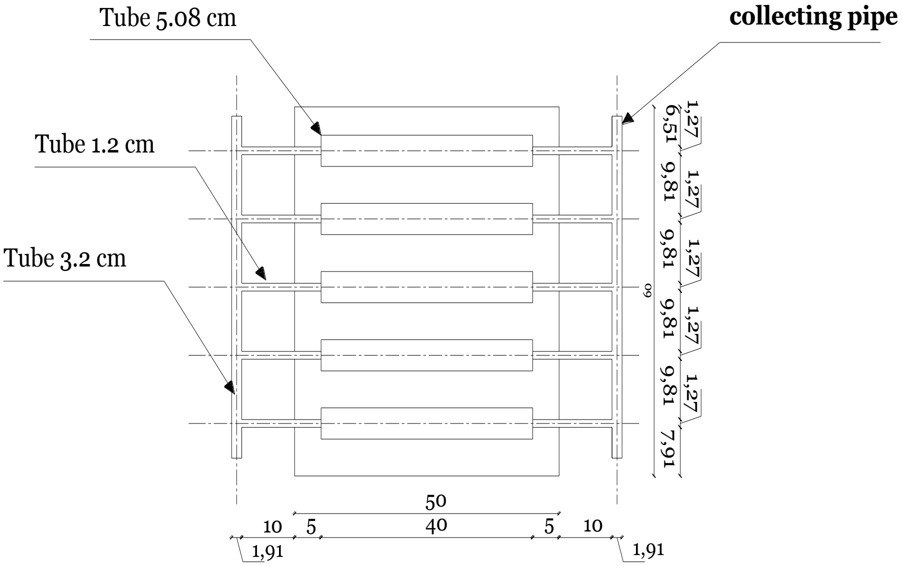


Figure (3.5a) Flat-plate collector

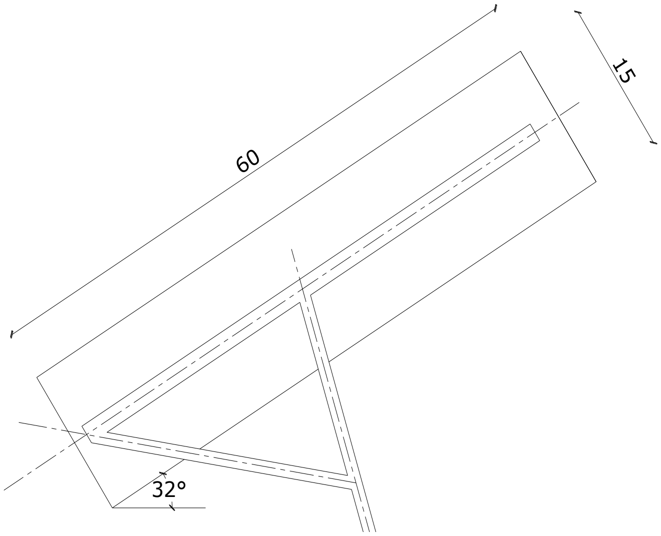


Figure (3.5b) Flat-plate collector (side section)

3.5.2 Potential of solar energy in Palestine

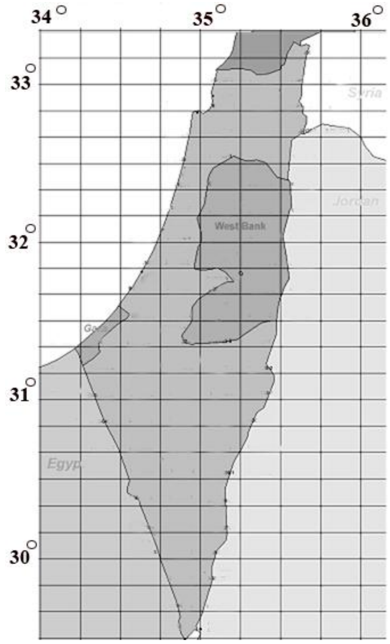


Figure (3.6) Palestine potential

Palestine has high solar energy potential; it has about 3000 sunshine hours per year and high annual average of solar radiation amounting to 5.4 kWh/m^2 on horizontal surface, which classified as a high solar energy potential. The lowest solar energy average is in December, it amounts to 2.63 kWh/ m^2 - day. The solar radiation on horizontal surface varies from 2.63 kWh/m^2-day in December to 8.4 kWh/m^2-day in June because it is located between 29^o-33^{o}N and 34^o-36^o as shown Fig (3.6). [8]

3.5.3 Total solar irradiation:

The usual objective in many solar calculations is to determine the solar irradiation of a given surface, i.e., the energy rate per unit area striking the surface. The key equation for this calculation is

$$I_i = I_{DN} \cos\theta + I_{d\theta} + I_r \tag{3.31}$$

Where:

I_i = Total solar irradiation of a surface, W/m^2

I_{DN} = Direct radiation from sun, W/m^2

$I_{d\theta}$ = Diffuse radiation from sky, W/m^2

I_r = Short wave radiation reflected from other surfaces, W/m^2

θ = Angle of incidence, degrees, Fig. (3.7).

The first term $(I_{DN} \cos\theta)$, is the contribution of direct normal radiation to total irradiation. On a clear, cloudless day, it constitutes about 85 percent of the total solar radiation incident on a surface. However, on cloudy days the percentage of diffuse and reflected radiation components is higher. The objective of solar radiation calculations is to estimate the direct, diffuse and reflected radiations incident on a given surface. These radiations and the angle of incidence are affected by solar geometry.

Note:

- ❖ The maximum direction radiation at the earth's surface is 1000 W/m^2.[9]

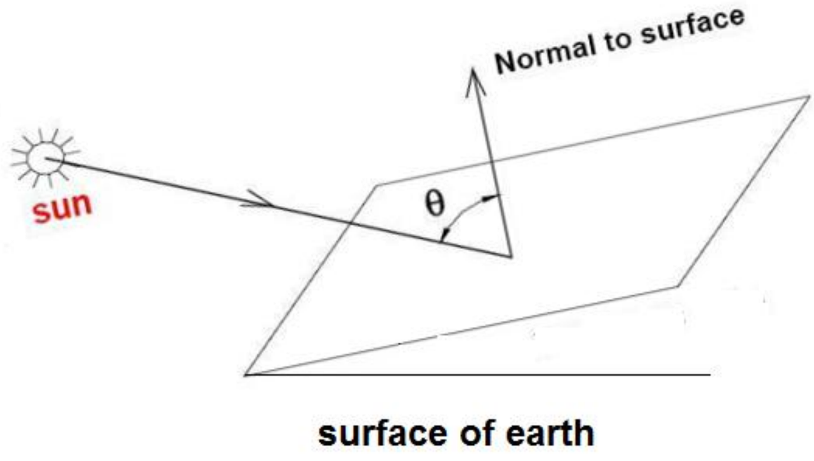


Figure (3.7) Angle of incidence

3.5.4 Solar geometry:

The angle of incidence θ depends upon:

i. Location on earth

ii. Time of the day, and

iii. Day of the year

The above three parameters are defined in terms of latitude, hour angle and declination, respectively as shown in Fig. (3.8).

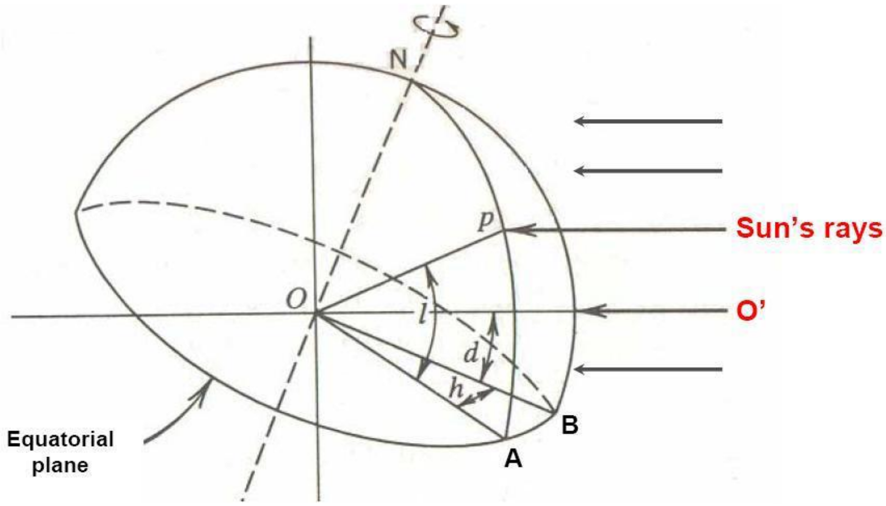


Figure (3.8) Definition of latitude (L), declination (d) and hour angles (h)

With reference to Fig. (3.8), the various solar angles are defined as follows:

Latitude,l**:** It is the angle between the lines joining O and P and the projection of OP on the equatorial plane, i.e.:

$$l = \text{angle (POA)}$$

Hour angle, h**:** It is the angle between the projection of OP on the equatorial plane i.e., the line OA and the projection of the line joining the center of the earth to the center of the sun, i.e., the line OB. Therefore:

$$h = \text{angle (AOB)}$$

Declination, *d:* The declination is the angle between the line joining the center of the earth and sun and its projection on the equatorial plane, the angle between line OO' and line OB:

$$d = \text{angle (O'OB)}$$

3.5.5 Collector angle (β):

In Palestine the solar collector is tilted by an angle of 32^o for the largest solar gain.

The tilted angle β is fixed seasonally as follows:

β =L+10 =32 +10 =42 during winter period.

β =L=32 during spring and autumn period.

β = L-10 =32-10=22 during summer period

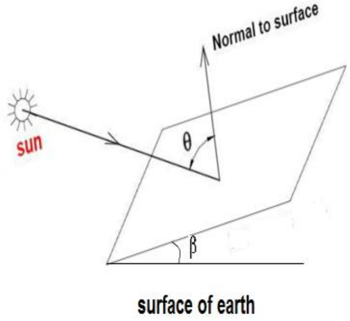


Figure (3.9) Collector angle

3.5.6 Thermal energy balance

The description of the thermal theory and modeling of solar collectors will start here with the energy conservation equation. Each component will be identified and then decomposed into its heat transfer rate subcomponents.

The energy balance for the adsorber bed given by:

$$Q_H = \eta * s * A \tag{3.32}$$

Where:

A: Surface area for heat transfer.[m^2].

s: Normal radiation at the earth's surface [W/m^2].

η: collector efficincy .

From Eqn (3.2), Q_H=180 W.

$Q_H = \eta * s * A$

A= 180/(0.6*1000)

A= 0.3 m^2

Table (3.4) Typical valus of U .[9]

Type of glazing	**U**, W/m^2.k
Unglazing	13-15
Single	6-7
Double	3-4

For the purpose of selecting collector, disgen often use a graph of collector efficincy, as shown in Fig.(3.10). The efficiency is a function of the optical and thermal properties of the cover plate and the adsorber and also the term $((t_{ai}-t_\infty)/I_i)$. As the temperature t_{ai} increases, the losses increase and the efficincy drops. Similarly, at low ambint teperatures the efficiency is low because of high losses. As the solar irradiation on the cover plate I_i increases, the efficincy increases because the loss from the collector $U(t_{ai} - t_\infty)$ is fairly constant for given adsorber and ambient temperatures and becomes a smaller fraction as I_i increases.[9]

Fig. (3.10) also shows the effects of the cover plates. A collector with no cover plate or with a single cover plate is more efficient at low $(t_{ai} - t_\infty)$, where convective losses are small. A double-glazed collector is better at higher $(t_{ai} - t_\infty)$, where the convective losses would have been significantly larger then the additional transmision loss through the second cover plate.[9]

The adsorptivity and emissivity of a surface may vary with the wavelength of the incident radiation. Surface coatings for the adsorber bed can be selected in such a way that the surface is highly adsorbing at the short wavelength of solar radition $(\alpha \approx 0.9)$ but has a low emissivity $(\epsilon = 0.5)$ at the longer wavelengths characteristic of a surface radiating at 100 to 200^{o}C. Such surfaces are referred to as selective surfaces. The performance of single-glazed collector can be upgraded by using a selective coating for the adsorber surface without adding second cover plate, as shown by the curve for collector D in Fig.(3.10).[9]

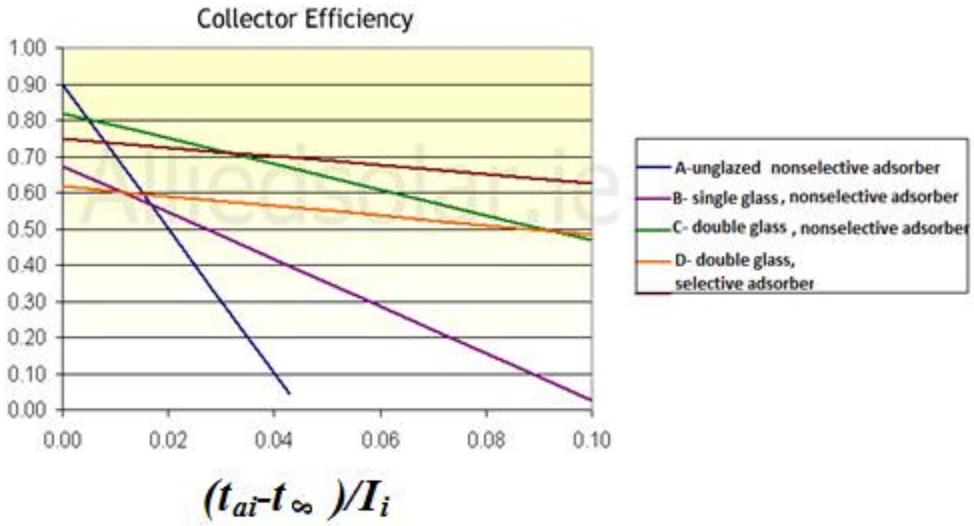


Figure (3.10) Collector efficient of typical Flat-plate collector

$$\frac{t_{ai} - t_\infty}{Ii} \qquad (3.33)$$

Where:

t_{ai}: Temperature of inlet fluid to adsorber [^{o}C]

t_∞: Temperature of surrounding [^{o}C]

$$\frac{64 - 37}{1000}$$

=0.027

From Fig. (3.10) η(for $\frac{t_{ai} - t_\infty}{Ii} = 0.02$) is 60%

In order to find the pressure in the evaporator and the condenser see the following chart

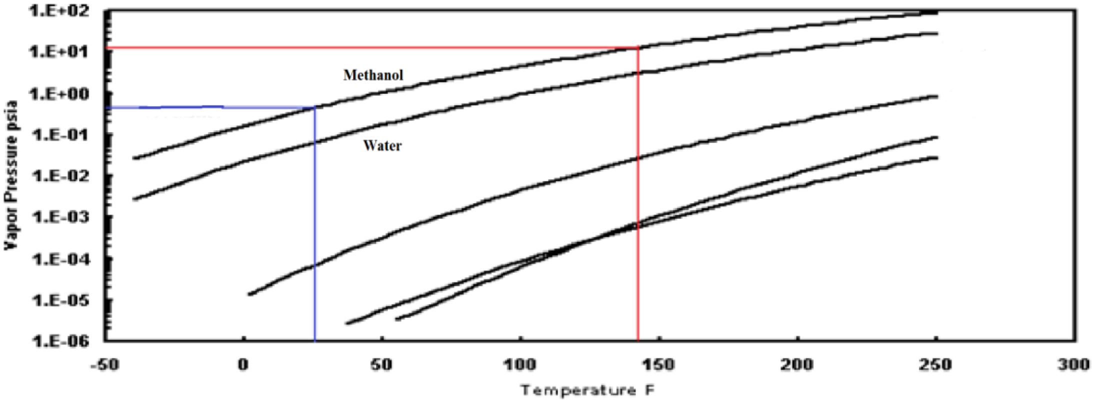


Figure (3.11) Comparison of Calculated Solvent Vapor Pressure as a Function of Temperature.[15]

From F.g.(3.11): P_{cond} = 10 psi , P_{evap}= 0.4 psi

Chaptre 4

Design and Pipe Selection

4.1 Introduction

Pipes are used to carry fluids at high pressure and deliver it to all cycle components in order to complete the refrigeration process to get ice, The selection of pipes should be suitable for its purpose, it must be able to resist the wear, rust, and the changing in temperature and pressure in the fluid which flows inside it.[11]

4.2 Pipe selection

In this project the methanol will be used as a refrigerant, the selected material must not react with methanol should not corrode; so that the steel tube 1006/1010 (SAEJ526) and copper tube will be used in all parts of cycle, the mechanical and Physical-chemical properties of steel and copper tube are shown in Table (4.1), Table (4.2) and Table (4.3).[12]

Standards

- Low carbon electro welded steel tube: 1006/1010 (SAE J526).
- Quality of steel: NBR 5906.
- Internal residue: ASTM A254/84 e NBR 14666.
- Internal moisture: NBR 14667.
- Chemical reactivity: NBR 14668.
- Compatibility with methanol.

Table (4.1) Mechanical properties of stainless steel tubes[12]

Feature	**Unit**	**Specification**
Tensile strength	MPa	290 minimum
Yield strength	MPa	170 minimum
Elongation	%	14 minimum
Hardness	HR 15 T	80 maximum
Hydrostatic resistance	Psi	725 minimum
Expansion	%	25 maximum

Table (4.2) Physical-chemical properties of stainless steel tubes [12]

Feature	**Unit**	**Specification**
Insoluble internal residue	mg/m^2	12 maximum
Soluble internal residue	mg/m^2	28 maximum
Total internal residue	mg/m^2	40 maximum
Internal moisture	mg/l	50 maximum
Humid chamber	Hours	240 minimum

Table (4.3) Physical-chemical properties of copper tubes[13]

Name and Symbol	Copper: Cu
State	Solid
Atomic Number	29
Element category	Transition Metal
Standard atomic weight	63.546(3) g·mol^{-1}
Density	8.94 g·cm^{-3}
Melting point	1084.62 °C
Boiling point	2562 °C
Crystal structure	Face-Centered Cubic
Magnetic ordering	Diamagnetic
Electrical resistivity	(20 °C) 16.78 nΩ·m
Thermal conductivity	(300 K) 401 W·m^{-1}·K^{-1}

4.3 Adsorbent bed (collector) design:

The collector is the main part of the system, it works as compressor in refrigeration cycle to make the compression process, it used to collect the solar energy from the sun (sun radiation), and contain the tubes which the activated carbon inside it.

To design the collector, the parameter should be determined as follow:

In Fig. (4.1) shown below the outer shaper of the collector is parallel rectangular (cuboid), and for dimension design the equation as follow can be used:

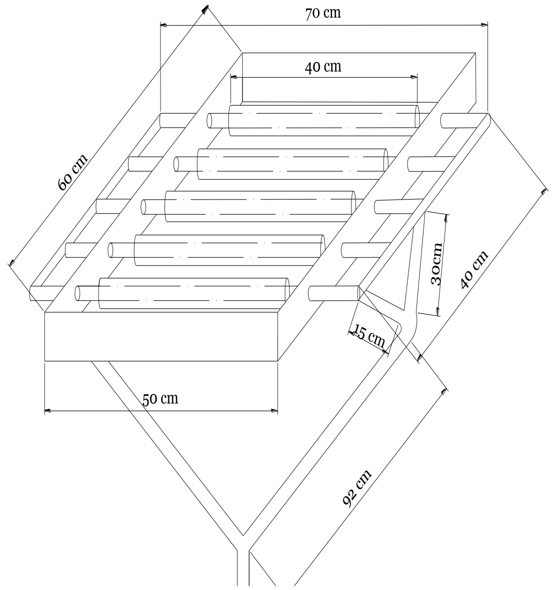


Figure (4.1) collector

$$A_{box} = x * y \tag{4.1}$$

Where:

A_{box} : The area of the box $[m^2]$, 0.3m^2.

x : The width of the box $[m]$, 0.5m.

y : The length of the box $[m]$, 0.6m.

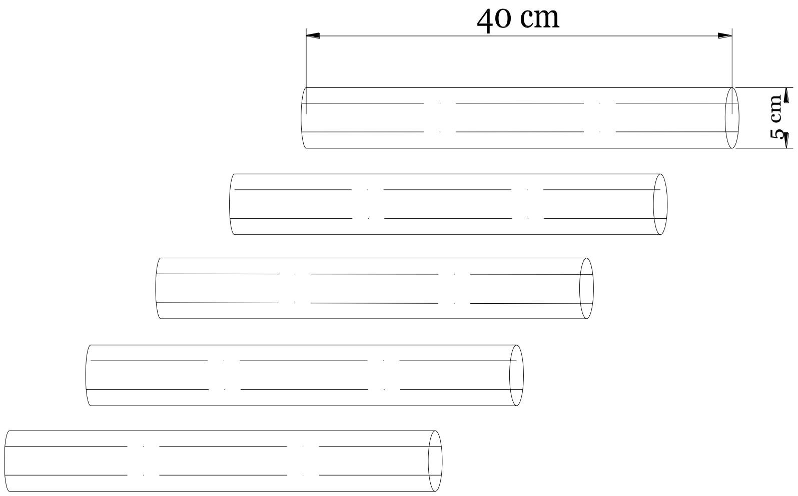


Figure (4.2) pipes contain activated carbon

The length of pipes inside the collector which contain activated carbon is (0.4m) and the diameter is (0.05 m), in Fig (4.2)

To find the number of tubes is

$$L = d_o \times N_t + S \times N_s \quad (4.2)$$

Where:

L: Length of the collector [m], 0.6 m.

d_o: Out diameter of tube[m], 0.05 m.

N_t: Number of tubes

S: Space between tubes[m], 0.04m.

N_s: Number of space, 6.

$0.6 = 0.05 \times N_t + 0.04 \times 6$

N_t= 5

The volume of tubes is:

$$V_{tube} = \pi r^2 l \qquad (4.3)$$

Where:

V_{tube} : Volume of tubes inside the collector [m^3].

r : Radius of the tube [m].

l: Length of the tube [m].

$$V_{tube} = \pi(0.025)^2 * 0.4$$

V_{tube}= 7.85*10^{-4} m^3

In one tube:

$V_{A.c}$=V_{tube} =7.85*10^{-4} m^3

In all tubes (5):

$V_{A.c}$=7.85*10^{-4}*5m^3

$V_{A.c}$=39.25$10^{-4}$$m^3$

The amount of activated carbon that we used:

$$\rho = \frac{m}{V} \qquad (4.4)$$

Where:

ρ: Density of activated carbon [kg/m^3] ,(0.4*10^{-3}kg/m^3).

m: Mass of activated carbon [kg].

V: Volume of activated carbon [m^3],(39.25$*$ $10^{-4}$$m^3$)

$0.4 * 10^{-3} = \frac{\mathrm{m}}{39.2510^{-4}}$

M=1.55 kg.

The amount of methanol that we used:

1kg activated carbon → 0.26kg methanol [8]

So;

$m_{methanol}=1.55*0.26$

$m_{methanol}=0.4kg$

$$\rho = \frac{m}{V}$$

ρ: Density of methanol [g/m^3], (0.8g/cm^3).

m: Mass of methanol [g].

V: Volume of methanol [cm^3],

$$0.8 = \frac{400}{V}$$

V= 500 cm^3 =0.5L

So,

The refrigerant will pass through the inner pipes which are located inside outer pipes these pipes has 5 cm, 1.2 cm diameters with 70 cm length, these pipes connect to two collector pipe. The length of collector pipe is 60 cm, 3.8 cm diameter, as show in Fig. (4.3).

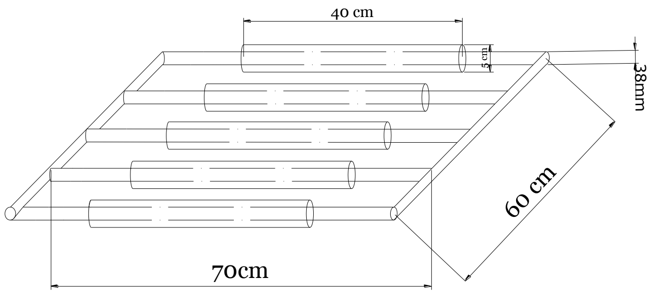


Figure (4.3) pipes

4.4 Condenser design:

As we mention previous in condenser designing we used a copper tubes with specific properties as in table (3.1),

We selected a tube with dimension as:

Diameter = 12 mm

Height = 27 cm

Number of annuls =15 turn

The distance between annuls =1.5 cm

4.5 tank design:

The tank is made from steel; its cylindrical in shape, the condenser is passing through it, this tank full of water in order to condense the methanol, in Fig.(4.4).

$$Q_c = \mathrm{m} * \mathrm{Cp} * (\mathrm{T_w} - \mathrm{T_d}) \qquad (4.5)$$

$1.1758 = \mathrm{m} * 4.18 * 39$

m= 0.03kg

$$\rho = \frac{m}{V} \tag{4.6}$$

$1 = \frac{0.03}{V}$

V= 0.03 m^3

V= 30 L

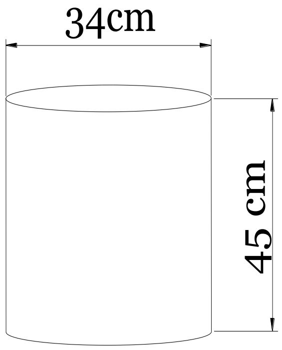


Figure (4.4) tank

4.5 Evaporator design

By knowing the dimension of the ice box and the heat transfer of evaporator, we can determine the parameters of the evaporator by using the following equation:

$$A_{evp} = wl \tag{4.7}$$

Where:

A_{evp}: Cross section Area of evaporator [m^2].

w : Width of evaporator [m], 0.2 m.

l : Length of evaporator [m]. 0.2 m.

$A_{max.evp}$ = 0.2*0.2 = 0.04 m^2.

$$V_{evp} = wlh \tag{4.8}$$

Where:

V_{evp}: Evaporator volume [m^3].

h: The height of evaporator [m], 0.05 m.

$V_{evp} = 0.2 * 0.2 * 0.05$

V_{evp}=2*10^{-3} m^3

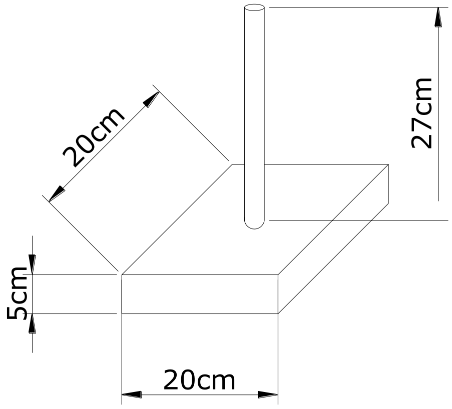


Figure (4.5) evaporator

4.6 Ice box design

The dimension of the evaporator is 20*20*5 cm, so the dimension of ice box is larger than the evaporator.

The inside dimension of ice box 30*30*30 cm, use the insulation (Foam) 5cm thickness, and use the steel cover covered of them.

Outside dimension of box is 40*40*40 cm.

Show Fig. (4.6)

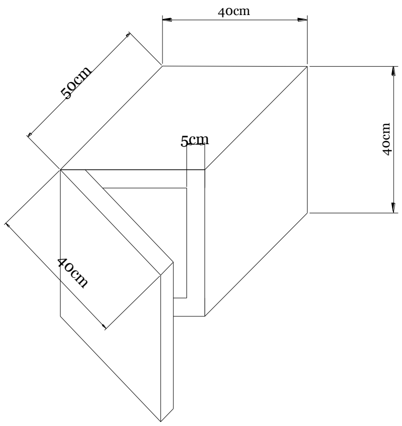


Figure (4.6) ice box

Chaptre 5

Experimental Work, Result and Discussions

5.1 Integration of the Subsystem

The collector, condenser, evaporator were checked for vacuum proof and then were connected with each other using stainless steel pipe of 38 mm, and later with another pipe of 12mm. The whole system was mounted on a frame bracket installed with wheels, so that it can be moved easily when necessary. Only one valve is installed beside condenser, which helps to vacuum the whole system as well as to charge the system with refrigerant. A pressure gauge is installed behind condenser to check for the pressure conditions in the system. Besides, no any other valves or measuring instruments are used in the system. A thermocouple is used for monitoring the temperature only. In order to ensure that the system can work normally, it is essential that the whole system should be vacuum proof. Show Fig. (5.1)

Figure (5.1): Photograph of the system

5.2 The experimental method

After the construction of the system with water condenser, several tests were performed to ensure good sealing, since any kind of air leakage inside the system will lead to failure in the process, since such system work under vacuum. The total pressure may increase due to leaks or desorption of air from activated carbon, then the adsorption of methanol is reduced.

Furthermore, the boiling temperature of the methanol increases and the rate of evaporation decreases, and as a result the cooling effect decreases. The system was completely sealed by special stainless steel welding.

5.3 Methanol Charging and Heating Process

After the system was sealed, it was evacuated side by side with heating to flush out entrapped air and moisture using a vacuum pump until the pressure in the system decreased to 24 in Hg. This was also used to test the system for any leakage. Many attempts were done to overcome the leakage problem, and the system was left for sufficient time for leakage monitoring.

5.4 Result

It will be described and show all results which have took from the ice maker machine after we have designed and built, we will talk about all inputs and outputs in and out of the machine like the energy source quantity we used, and the temperature that reached.

The result is the final level in the project; it's the system outputs which it is the most important thing.

On Monday 6-5-2013 in Hebron city the project testing started again after fixing problem that appeared in the project and the following values of irradiation and collector temperatures was taken by using temperature sensors in order to complete the calculation of the cycle.

Table (5.1) the irradiation and collector temperatures with time

Date Time, GMT+03:00	Tc(out)	Ta	sunn (w/m2)
4/29/2013 7:00	23.593	24.122	44.58333333
4/29/2013 7:05	23.857	24.484	47.08333333
4/29/2013 7:10	24.291	24.919	49.44444444
4/29/2013 7:15	24.629	25.671	51.66666667
4/29/2013 7:20	24.871	25.671	53.88888889
4/29/2013 7:25	25.065	26.207	56.11111111
4/29/2013 7:30	25.234	26.573	58.05555556
4/29/2013 7:35	25.234	26.182	60.13888889
4/29/2013 7:40	25.162	26.329	61.94444444
4/29/2013 7:45	25.162	26.573	64.02777778
4/29/2013 7:50	25.186	27.21	65.69444444
4/29/2013 7:55	25.186	27.21	67.5
4/29/2013 8:00	25.089	27.21	69.44444444
4/29/2013 8:05	24.895	27.604	71.38888889
4/29/2013 8:10	24.677	27.554	73.75
4/29/2013 8:15	24.484	27.579	75.13888889
4/29/2013 8:20	24.46	27.358	76.38888889
4/29/2013 8:25	24.677	27.481	78.19444444
4/29/2013 8:30	25.841	26.72	79.02777778
4/29/2013 8:35	27.382	27.284	81.38888889
4/29/2013 8:40	28.99	27.308	82.08333333
4/29/2013 8:45	30.621	27.505	83.47222222
4/29/2013 8:50	32.355	27.899	85.97222222
4/29/2013 8:55	33.94	27.776	86.52777778
4/29/2013 9:00	35.208	27.776	87.63888889

4/29/2013 9:05	36.227	27.481	89.16666667
4/29/2013 9:10	37.151	26.5	91.66666667
4/29/2013 9:15	37.893	25.817	434.5833333
4/29/2013 9:20	38.7	25.939	455.5555556
4/29/2013 9:25	39.63	26.818	480.6944444
4/29/2013 9:30	40.487	27.186	502.9166667
4/29/2013 9:35	41.181	26.818	523.3333333
4/29/2013 9:40	41.825	27.087	543.4722222
4/29/2013 9:45	42.505	27.456	564.0277778
4/29/2013 9:50	43.163	27.308	579.5833333
4/29/2013 9:55	43.829	27.677	602.6388889
4/29/2013 10:00	44.503	27.554	622.0833333
4/29/2013 10:05	45.092	26.94	640.6944444
4/29/2013 10:10	45.687	27.136	655.4166667
4/29/2013 10:15	46.258	27.604	669.0277778
4/29/2013 10:20	46.866	27.604	686.1111111
4/29/2013 10:25	47.385	27.481	702.9166667
4/29/2013 10:30	47.941	27.186	714.3055556
4/29/2013 10:35	48.504	27.235	732.3611111
4/29/2013 10:40	49.006	27.456	749.4444444
4/29/2013 10:45	49.581	28.147	758.75
4/29/2013 10:50	50.231	28.221	781.1111111
4/29/2013 10:55	50.856	27.998	790.1388889
4/29/2013 11:00	51.454	27.677	806.6666667
4/29/2013 11:05	52.024	27.628	822.6388889
4/29/2013 11:10	52.492	27.038	836.9444444
4/29/2013 11:15	53.001	26.744	850.5555556
4/29/2013 11:20	53.627	26.842	861.8055556
4/29/2013 11:25	54.187	27.407	871.6666667
4/29/2013 11:30	54.716	27.259	884.0277778
4/29/2013 11:35	55.251	27.333	897.3611111
4/29/2013 11:40	55.754	27.407	899.4444444
4/29/2013 11:45	56.263	27.136	916.9444444
4/29/2013 11:50	56.659	27.038	927.7777778
4/29/2013 11:55	57.098	27.407	931.25
4/29/2013 12:00	57.623	27.727	945.8333333

4/29/2013 12:05	58.154	27.136	954.3055556
4/29/2013 12:10	58.734	27.702	954.0277778
4/29/2013 12:15	59.365	28.171	964.0277778
4/29/2013 12:20	59.876	29.015	964.3055556
4/29/2013 12:25	60.568	27.974	982.0833333
4/29/2013 12:30	61.094	27.53	985.1388889
4/29/2013 12:35	61.717	28.345	990.2777778
4/29/2013 12:40	62.213	28.593	990.9722222
4/29/2013 12:45	62.624	28.27	1006.25
4/29/2013 12:50	63.364	29.414	1004.027778
4/29/2013 12:55	63.881	29.04	1010.416667
4/29/2013 13:00	64.357	30.293	1014.583333
4/29/2013 13:05	65.033	29.54	1004.722222
4/29/2013 13:10	65.375	29.015	1007.638889
4/29/2013 13:15	65.77	28.916	1013.333333
4/29/2013 13:20	65.969	29.34	1015
4/29/2013 13:25	66.521	28.642	1019.444444
4/29/2013 13:30	66.673	28.543	1018.333333
4/29/2013 13:35	66.928	28.196	1017.5
4/29/2013 13:40	67.287	29.29	1018.75
4/29/2013 13:45	67.546	28.99	1015.416667
4/29/2013 13:50	68.016	29.615	1008.472222
4/29/2013 13:55	68.599	29.59	1016.25
4/29/2013 14:00	69.082	29.315	1001.666667

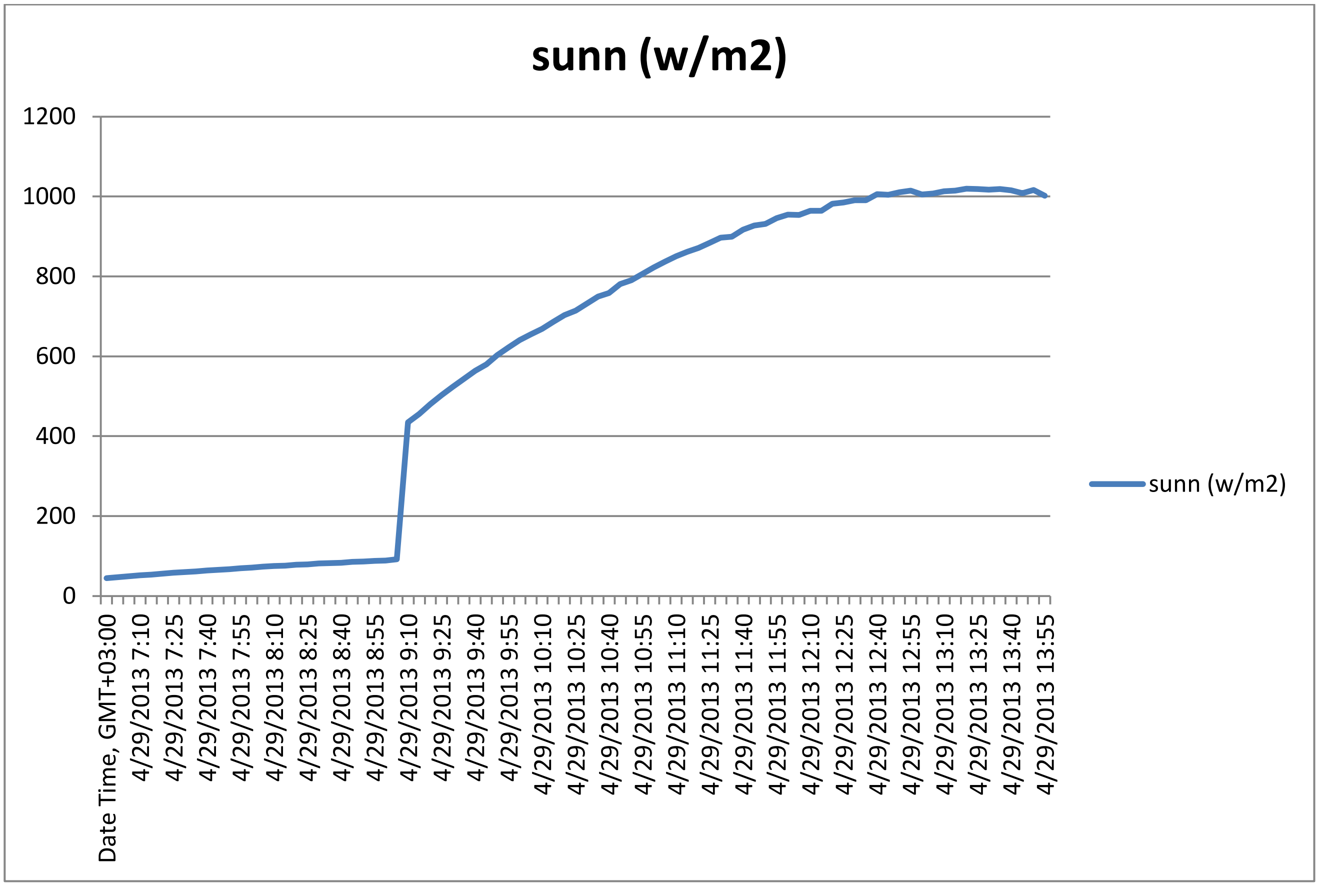


Figure (5.2) the irradiation with time

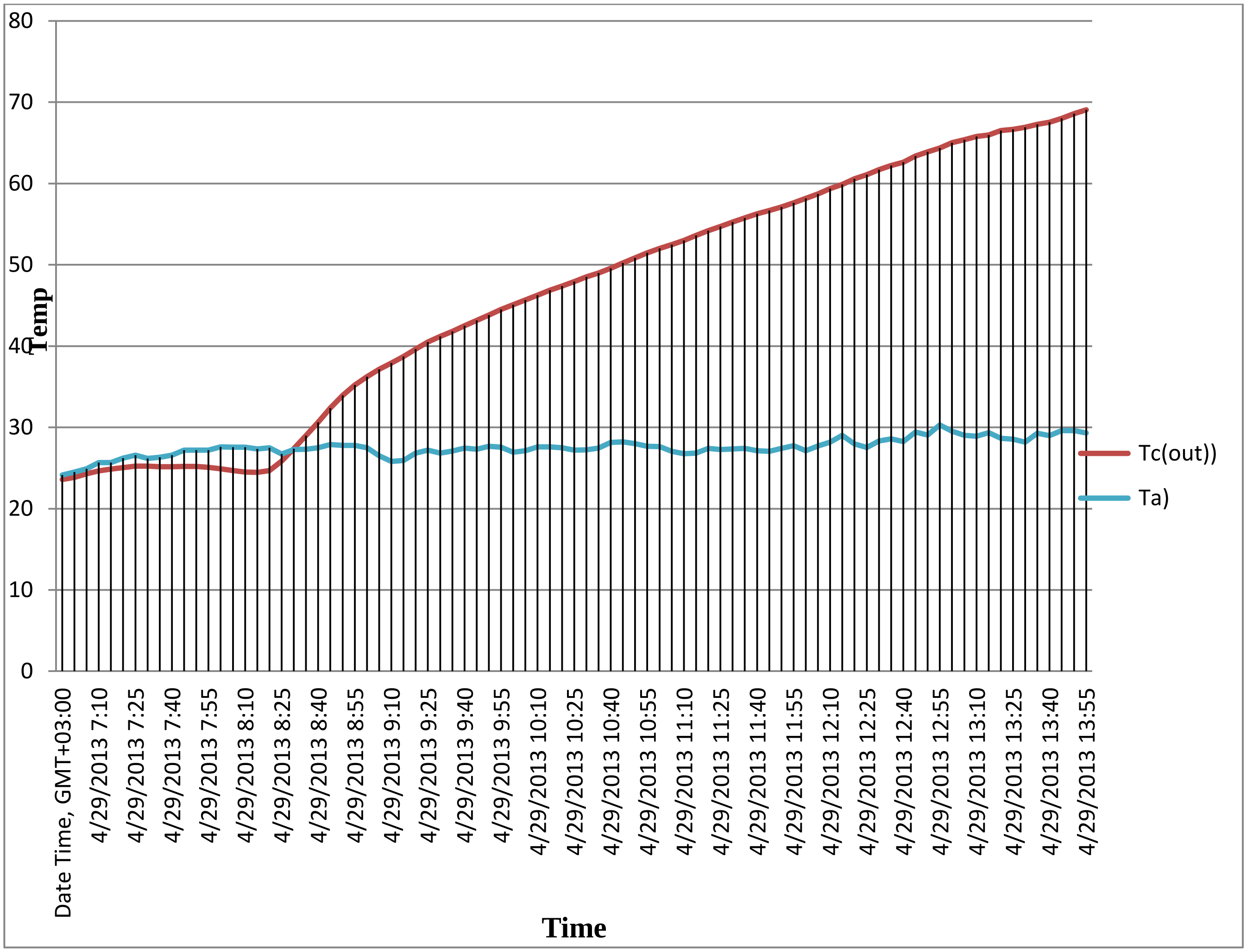


Figure (5.3) the collector temperatures with time

Where:

Sunn: Normal radiation at the earth's surface [W/m^2].

T_c: Temperature of collector[^{o}C].

T_a: Temperature of surrounding [^{o}C].

After the device is built, we make several tests to take temperature readings at evaporator, the tables below shows these readings.

The table (5.2) shows the evaporator temperature when the device charged with 6 litter of methanol, and the Fig. (5.4) show that by drawing.

Table (5.2) the temperatures of evaporator on Mon. 06/05/2013

time	Temp (Ta)	T(eva)
06/05/2013 12:00	34	25
06/05/2013 01:00	34.3	25
06/05/2013 02:00	33.9	24.8
06/05/2013 03:00	31.2	25
06/05/2013 04:00	30.5	25
06/05/2013 05:00	29.4	25
06/05/2013 06:00	27.9	24
06/05/2013 07:00	26.8	23
06/05/2013 08:00	24.7	20
06/05/2013 09:00	25.6	20
06/05/2013 10:00	25.6	19
06/05/2013 11:00	25.2	19.6
06/05/2013 12:00	25	19
06/05/2013 01:00	25	18
06/05/2013 02:00	24.6	18
06/05/2013 03:00	24.2	17.2
06/05/2013 04:00	23.9	16
06/05/2013 05:00	24.6	17
06/05/2013 06:00	24.7	17
06/05/2013 07:00	25.6	17
06/05/2013 08:00	28	17
06/05/2013 09:00	28	17

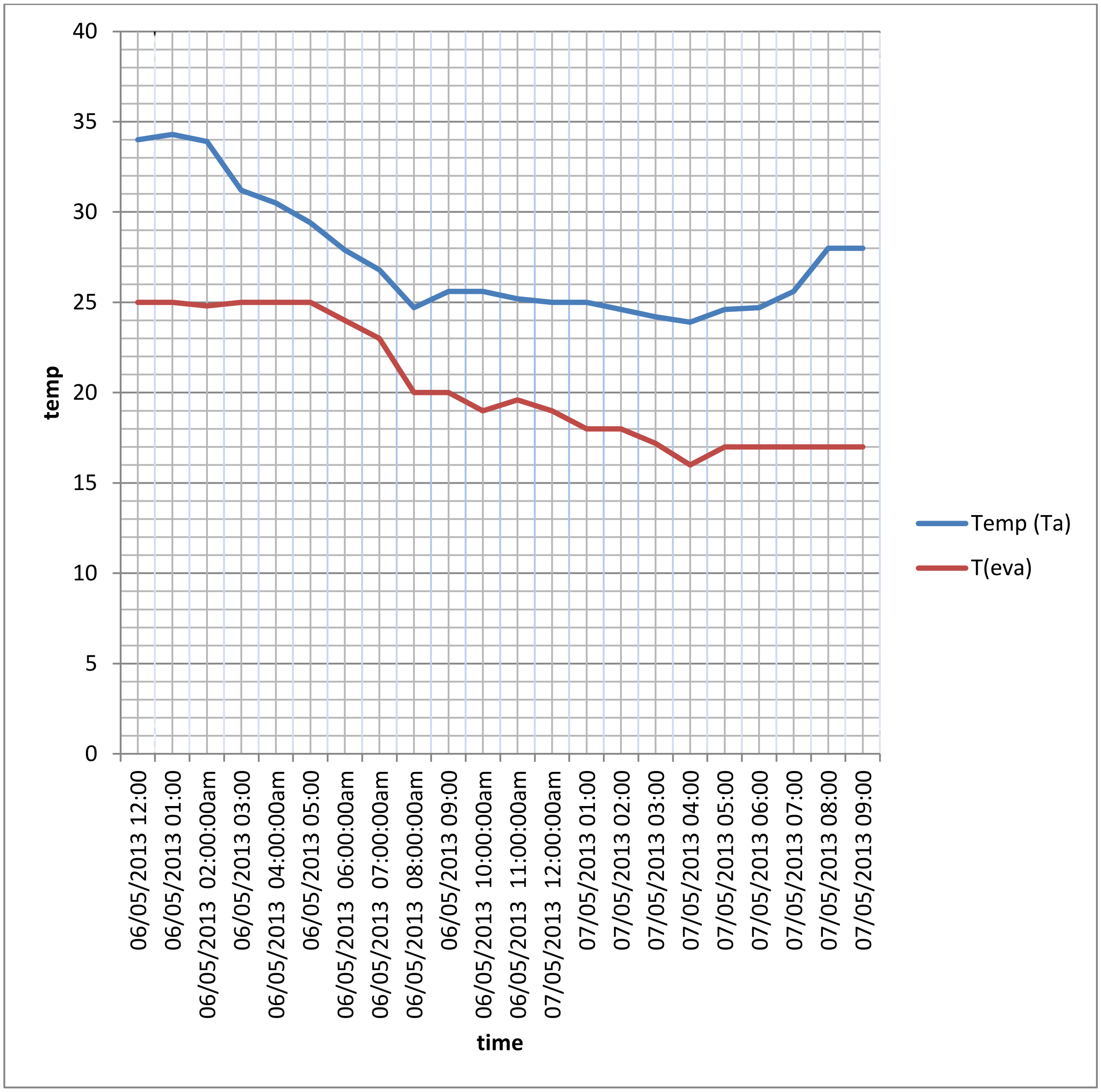


Figure (5.4) the evaporator temperatures with time at (6 L) of methanol.

As we show the result is not the desired temperature, because the amount of methanol is very large

So, we discharged all mount of methanol by heating.

The table (5.3) show the temperature readings at evaporator when the device charged with 0.5 litter of methanol, and Fig. (5.5) show that by drawing.

Table (5.3) the temperatures of evaporator on Sun. 12/05/2013

time	Temp (Ta)	T(eva)
12/05/2013 12:00	30	25
12/05/2013 01:00	32	25
12/05/2013 02:00	32	24.8
12/05/2013 03:00	30	24
12/05/2013 04:00	29	24
12/05/2013 05:00	27.7	23
12/05/2013 06:00	26.5	20
12/05/2013 07:00	23.4	20
12/05/2013 08:00	21.5	19
12/05/2013 09:00	21	18.7
12/05/2013 10:00	21.2	18
12/05/2013 11:00	20.7	17.5
13/05/2013 12:00	21	16
13/05/2013 01:00	21.4	16
13/05/2013 02:00	21.6	15.5
13/05/2013 03:00	20.5	15
13/05/2013 04:00	20.3	14.5
13/05/2013 05:00	21	14
13/05/2013 06:00	21.3	14
13/05/2013 07:00:	22.8	14
13/05/2013 08:00	24	14
13/05/2013 09:00	27	14

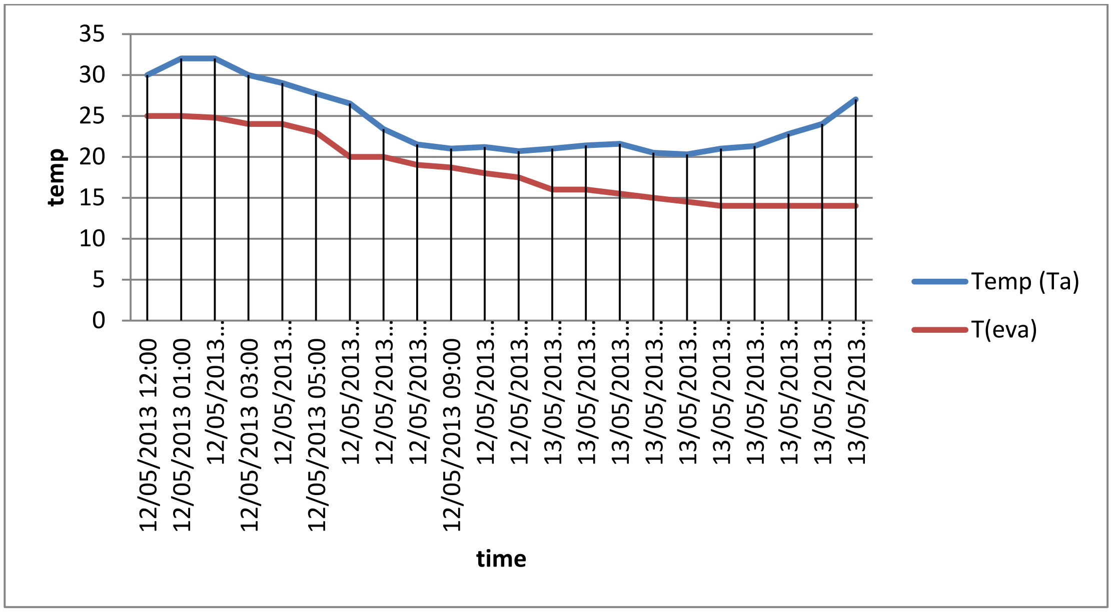


Figure (5.5) the evaporator temperatures with time at (0.5 L) of methanol.

Although, the temperature is decrease; these temperature readings is not the desired temperatures.

The table (5.4) show the temperature readings at evaporator when the device charged with 0.7 litter of methanol, and Fig. (5.6) show that by drawing.

Table (5.4) the temperatures of evaporator on Tues. 21/05/2013

time	Temp (Ta)	T(eva)
21/05/2013 12:00	32	25
21/05/2013 01:00	31	25
21/05/2013 02:00	31	25
21/05/2013 03:00	29	24
21/05/2013 04:00	28	24
21/05/2013 05:00	27.7	23
21/05/2013 06:00	26.5	23
21/05/2013 07:00	23.4	21
21/05/2013 08:0	20	18
21/05/2013 09:00	18	16
21/05/2013 10:00	17.5	16
21/05/2013 11:00	18	16
22/05/2013 12:00	16.7	15
22/05/2013 01:00	16.3	14.2
22/05/2013 02:00	15.3	13
22/05/2013 03:00	15	12.3
22/05/2013 04:00	14.9	10.6
22/05/2013 05:00	12	10
22/05/2013 06:00	14	10
22/05/2013 07:00	18	10
22/05/2013 08:00	21	10
22/05/2013 09:00	23	10

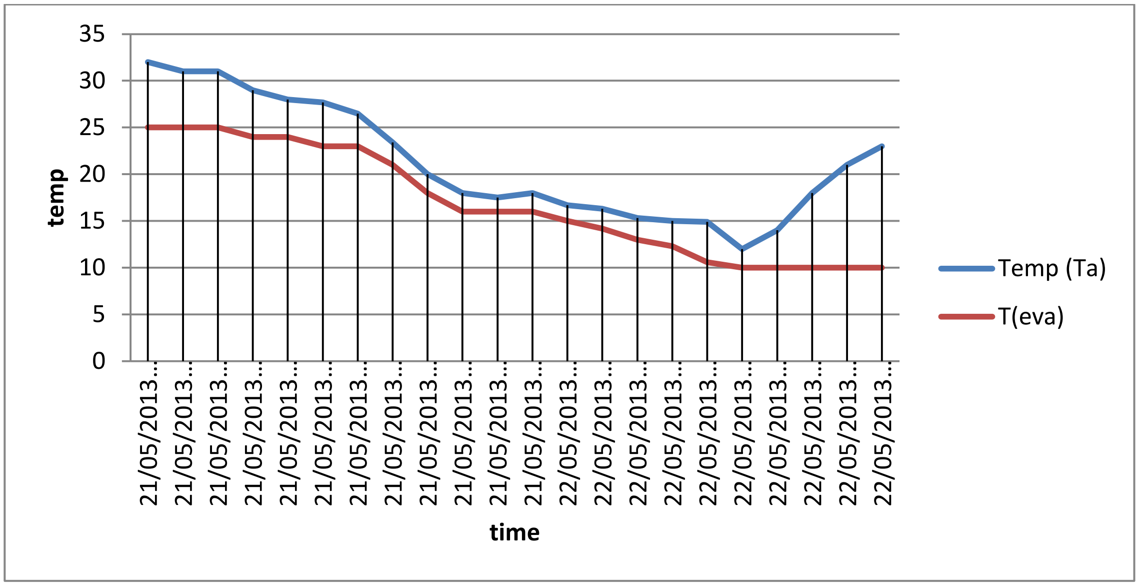


Figure (5.6) the evaporator temperatures with time at (0.7 L) of methanol.

These reading better than the previous readings, but they are not the desired.

After that many tests were done, but the temperature stay the same.

Chaptre 6

Conclusions and recommendations

6.1 Conclusions:

From the data that took from experiments and tests, we conclude that:

1. Because the amount of methanol that we charged is too large, and the pressure is small so, the refrigerating effect will be low and that will prevent the water to freeze.
2. The value of vacuum which reached (24 inch Hg) wasn't enough to freeze the water in ice box.
3. Because of the activated carbon reached the saturation state, the methanol will not be completely adsorbed and the evaporator will not reach the desired temperature (0^oC).

6.2 Recommendations:

To have better results and to come over all problems that we faced for who want to rebuild or redesign the project, here some recommendations:

1. Install electrical heaters on the collector instead of sun radiation (if the sky is cloudy for testing).

2. install many valves to make maintenance is easy.

3. The water in the tank should be in cycle to increase the heat transfer.

4. Rebuild the machine and avoid all problems that faced as previous.

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