Design Adsorption Refrigeration Cycle

By

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Supervisor:

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Submitted to the College of Engineering

in partial fulfillment of the requirements for the

Bachelor degree in Refrigeration and Air Conditioning Engineering

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Mechanical Engineering Department

Hebron – Palestinea

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Supervisor Signature

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Department Head Signature

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شكر وتقدير

لا فضل علينا إلا فضله، وما من نعمةٍ نحن بها إلا من عنده، وما توفيقنا إلا به فله الحمد والشكر عدد الأوراق والأشجار، وعدد ما ذكره الذاكرون الأبرار، وعدد ما سبح الطير وطار وما تعاقب الليل والنهار، حمداً كثيراً طيباً مباركاً لا انقضاء له في السعد والحزن، والسر والعلن.

كما ونتقدم بجزيل شكرنا، وعظيم امتناننا وتقديرنا وعرفانا إلى كل من ساهم في إنجاز مشروعنا هذا، متحدين كل الظروف والعقبات.

ونخص بالشكر أستاذنا الفاضل المهندس زهير وزوز المشرف والموجه، الذي لم يتوانى ولم يتأخر عن تقديم ما آتاه الله من علم وحلم لنا وبكل سعة صدر، ولم يدخر جهدا في توجيهنا والأخذ بأيدينا إلى طريق النجاح.

ونشكر طاقم دائرة الهندسة الميكانيكية كلٌ بمكانه، فقد كرّسوا وقتهم وجهدهم لمساعدتنا ومساعدة زملائنا طوال فترة الدراسة.

ونشكر زملائنا الأعزاء الذين لولا وجودهم لما تذوقنا حلاوة العلم، ولا شعرنا بمتعة المنافسة الإيجابية.

وختام القول مسك، فكل الشكر لآبائنا وأمهاتنا أصحاب الدور الأبرز في الوصول إلى ما وصلنا إليه.

Abstract

Our project is designing, building, and testing an adsorption ice maker machine; this machine uses the solar energy (radiation from the sun). The desired outcome from building is to freeze water ice this maker machine is a device that contains chemical materials (methanol + activated carbon). This project can be used in the rural areas which are not able to use the electricity to have the refrigeration effect; this technology is environment friendlyand can solvecooling problems in these areas.

الملخص

المشروع هو عبارة عن تصميم وبناء الة صنع الثلج باستخدام الطاقة الشمسية والهدف من بناء هذا الجهاز هو التبريد لحفظ الادوية او الحصول على الثلج والجهاز يحتوي على مواد كيميائية وهي الميثانول والكربون ويمكن استخدام هذا المشروع في المناطق النائية التي لا تتوفر فيها الكهرباء.

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Chapter one

Introduction

1.1 Introduction

Refrigeration and air conditioning demands are widely increasing because of the increase in population as well as the dramatically growth of industries. Many refrigeration technologies were developed during the last century. The vapor compression systems broadly dominate the human use for satisfying comfort conditions or food preservation. These traditional refrigeration systems consume a significant amount of electric power. In addition, such systems rely on refrigerants as chlorofluorocarbonsCFCs and hydrochlorofluorocarbons HCFCs which increase the depletion of the Earth's ozone layer. Consequently, alternative refrigeration technologies became very much needed; especially the current sources of energy such oil may run dry in the near future. The electricity is not also covering all human living areas. For now, there are numerous places without electricity especially in countryside of some developing countries. So people living in such areas cannot preserve their food and store vaccine in their local clinics. Accordingly, solar adsorption refrigeration technology has attracted some research interests since 1990 because it is clean, cheap and simple for use in air conditioning, ice making, food preservation and vaccine storage. The idea of these devices is the reversible physical adsorption of vapor on the surface of a porous solid. An intermittent adsorptive desorbed from the bed as it isheated to drive the refrigerant out of the bed and the refrigerant vapor is conveyed to a condenser. In the condenser, the refrigerant vapor is cooled and condensed to liquid. The low-pressure condensate passes to an evaporator where the low-pressure condensate is heat exchanged with the process stream or space to be conditioned to vaporize the condensate. When further heating no longer produces desorbed refrigerant from the adsorbent solar ice-maker is an attractive application that is composed from adsorbent bed as adsorptive reactor integrated into a solar collector for the desorption of the sorbent material during the day. During the night adsorption occurs by the adsorbent when the refrigerant comes back from the evaporator, in which the cooling effect is obtained and some ice may be produced. Bed, the bed is isolated and allowed to return to the adsorption conditions. When the adsorption conditions are established in the bed, the refrigerant vapor from the evaporator is reintroduced to the bed to complete the cycle. For the circulation of methanol in the system.

1.2 Project objectives

1. Design a solar adsorption ice maker that use methanol and carbon as refrigerant and adsorbent restively, which use the sun rays to produce the energy needed to complete the refrigeration cycle
2. Provide a Refrigeration system for the market based on renewable energy.

1.3 Literature Review

1. Heat Transfer Enhancement and Energy Conservation

   By Tchernev[1]. Solid adsorption refrigeration makes use of the unique features ofcertain-refrigerant pairs to complete refrigeration cycles for cooling or heat pumppurposes. Zeolite and ActivatedCarbon were used as absorbent in many systems. Inearly 1980's, Tchernev carried out an investigation of adsorption refrigeration with theZeolite and water pair. Also, Pons and Genier worked on solid adsorption pair of Zeoliteand water, to produce refrigerating effect achieving coefficient of performance of onlyabout 0.1.

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

By M. Li, H. B. Huang, R. Z. Wang[2]. Later, in 1987, they demonstrated that ActivatedCarbon 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 cyclefor solar cooling and concluded that, in general, Activated Carbon-Methanolcombination was preferable for solar cooling which given the best coefficient ofperformance achievable in a single-stage cycle.

3. By Steven Vanek[3]. In 1996, the American scientist Steven Vanek designs an icemaker which operates in solar energy. This design use the couple cooling gasesAmmonia-Calcium Chloride, this system consist of collector, which concentrate the sunlight on pipe in the center of thecollector and expansion valve, condenser, evaporatorand ice box.In this project solar adsorption cycle with Activated Carbon- Methanol will be used toproduce ice.

1.4 Time Planning

The following tables explain the expected timing plan for the first and second semester.

Table 1.1 Project Timing for the 1st semester Plan Table

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									■	■	■	■			
Documentation				■	■	■	■	■	■	■	■	■	■	■	

Table 1.2 Project Timing for the 2nd semester Plan Table

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													■	■	
Documentation				■	■	■	■	■	■	■	■	■	■	■	■

Chapter two

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.

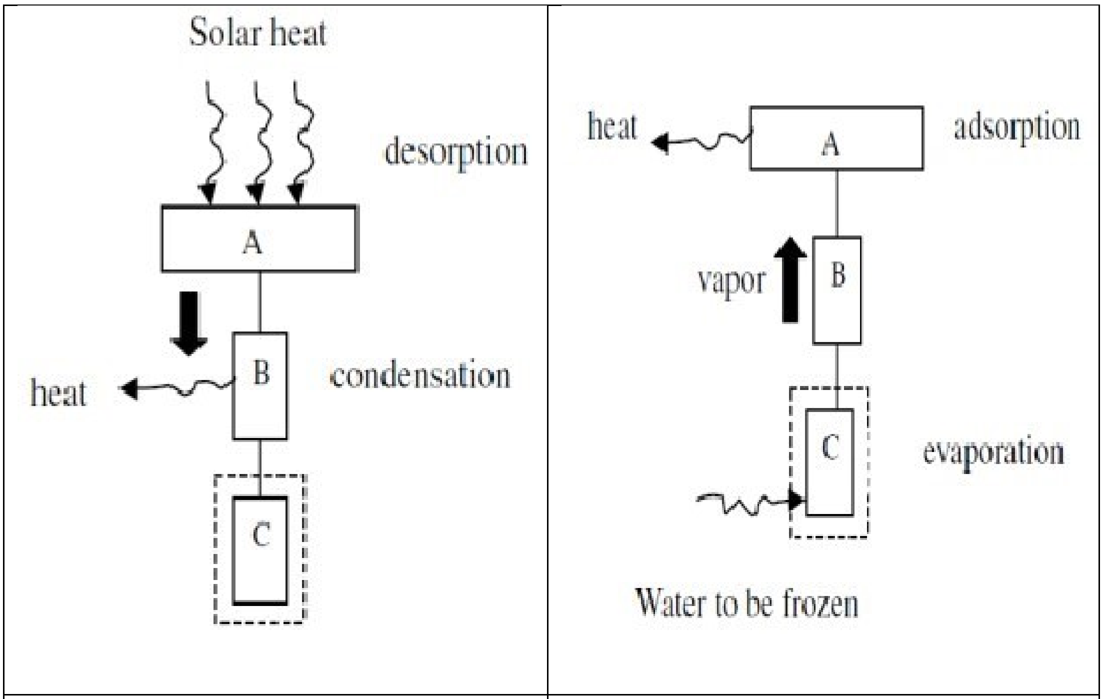
Before building any machine, a set of parameters must be considered, they are divided into two groups: the first one is related to machine itself such as: safety, cost, design, volume occupied by the machine, and special components such as movable collector. The second one is related to the refrigeration 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 closed system where no carrier gas exists. The 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 by the condenser and stored in the evaporator.



(a) Daytime (heat/desorption)

(b) Night-time (evaporation-adsorption)

Figure (2.1): Operation principle of solid adsorption refrigeration system utilizing solar heat A: Sorption 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. In this period, methanol begins to evaporate by absorbing 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. The principle of the solid adsorption cooler is explained using a Clapeyron diagram (lnPversus -1/T). Fig.2.2 shows the idealized process undergone by A.C+ methanol in achieving the refrigeration effect. The cycle begins at a point A where the adsorbent is at a low temperature TA and at low pressure Pe (evaporator pressure). During the daylight, AB represents the heating of A.C along with methanol. The progressive heating of the adsorbent from B to D causes some adsorbate to be desorbed and its vapor to be condensed at the condenser pressure Pc. When the adsorbent reaches its maximum temperature TD, desorption ceases. Then the liquid methanol is transferred into the evaporator. During night, the decrease in temperature from D to F induces the decrease in pressure from Pc to Pe. Then the adsorption and evaporation occur while the adsorbent is cooled from F to A. During this cooling period heat is withdrawn both to decrease the temperature of the adsorbent and to withdraw adsorption heat.

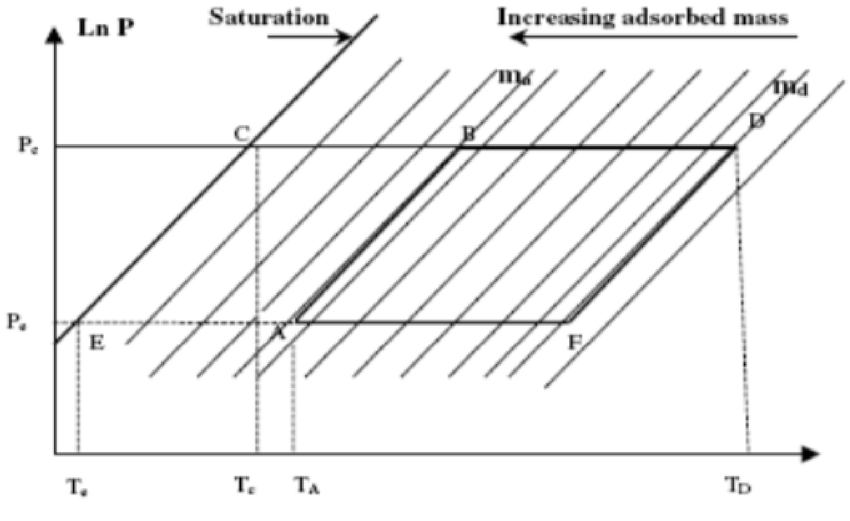


Figure (2.2) Clapeyron diagram (ln P versus -1/T) of ideal adsorption cycle.

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. (2.3), (2.4).

2.4.2 Adsorption phases

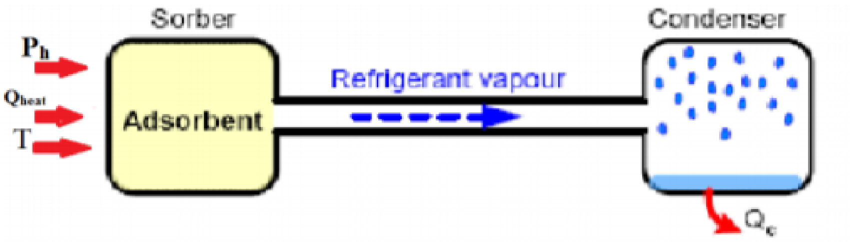


Figure (2.3) Adsorption phase at Day

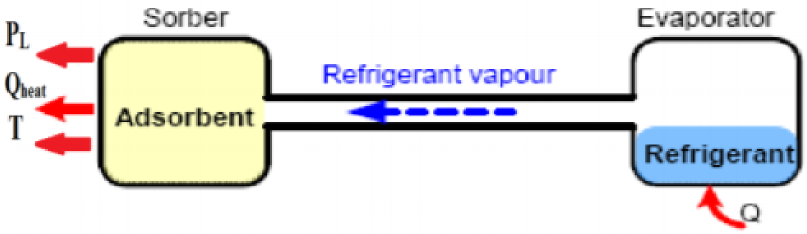


Figure (2.4) Adsorption phases at Night

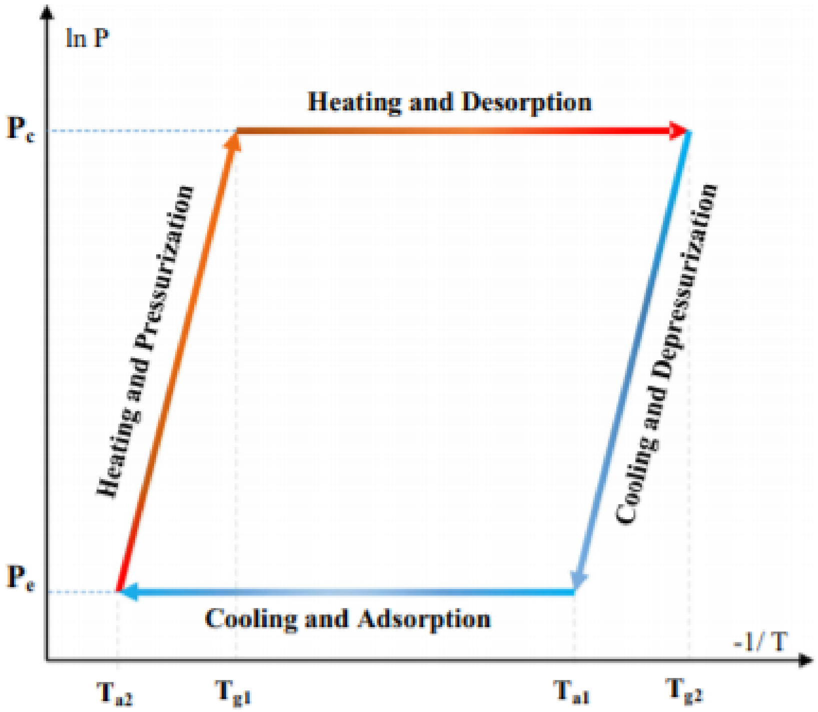


Figure (2.5) P-T diagram for basic adsorption cycle

2.4.2.1 Heating and pressurization

During this phase, adsorber absorbs heat thus increasing the adsorbent's temperature which induces a pressure increase from evaporation pressure to condensation pressure. This phase is also known as isosteric heating and is similar to compression in compression cycles. The temperature of adsorbent bed increases from Ta2 to Tg1. After this vapors of adsorbent starts rising and moves towards condenser where they cools down and lowering of temperature takes place. See Fig (2.5)

2.4.2.2 Heating and desorption with condensation

Heating, desorption and condensation In this phase, adsorber while receiving heat continues to increase temperature but being connected to condenser, desorption of vapor get induced and liquefaction of desorbed vapor in condenser further takes place. This is similar to condensation in compression cycles. The temperature of the adsorbent bed increases from Tg1 to Tg2. This phase is also known as isobaric desorption. Here, the heated vapors of adsorbent cools down and thus temperature get reduced which could easily be verified with the rightward movement in Fig (2.5)

2.4.2.3 Cooling and depressurization

Cooling and depressurization During this phase, low pressure vapor enters adsorber passing from evaporator. Temperature of adsorbent reduces due to release of heat which induces pressure decrease from condensation pressure to evaporation pressure. This phase is also known as isosteric cooling and is similar to expansion in compression cycles. The pressure get reduced from Pc to Pe and temperature also decreases to Ta1. This pressure change can be verified with the downward shift in Fig. (2.5). In this phase, vapors change their state and turns into liquid.

2.4.2.4 Cooling and adsorption with evaporation

The adsorbent temperature continues to reduce due to further release in heat which causes adsorption of vapor due to connection with evaporator. This adsorbed vapor is vaporized in the evaporator due to heat supplied by heat source. This is similar to evaporation in compression cycles. This phase is also known as isobaric adsorption. The adsorbent is cooled from Ta1 to Ta2. During this phase, cooling is produced which causes temperature of the region to lower. See Fig(2.5). The whole process of adsorption cooling only requires heat energy which can be supplied through gas or oil fired or solar energy thus eliminating the need of electricity and hence beneficial to areas where grids are not yet installed.

2.5 Refrigerant and adsorbent

While selecting the adsorbent – refrigerant pair one has to be very cautious, as for a successful and effective operation of a solid adsorption system this is necessary. There are several combinations available and each possess certain merits and demerits thus resulting in varying performances. The proper selection depends on the desired characteristics of refrigeration system, properties of the adsorbent/ adsorbate pair, temperature of heat source and their cost, availability and environmental impact. One must remember that for any refrigerant application, the adsorbent must be having low absorptivity at high temperature and pressure or high absorptivity when accounts to room temperature and low pressure.

2.5.1 Choice of adsorbent

While selecting adsorbent, the most important features that must be taken care of are:

- High adsorption and desorption capacity thus improving cooling characteristics.
- Low specific heat.
- Nontoxic and non-corrosive.
- Chemically and physically compatible with chosen refrigerant.
- Must be cost effective and should be available in plenty.

2.5.2 Choice of Refrigerant

The refrigerant must satisfy the following requisites for an effective performance

- For better adsorption, molecular size should be small.
- High latent heat per unit volume.
- High thermal conductivity.
- Low viscosity and low specific heat.
- Low toxicity and must not be inflammable and corrosive.
- Low saturation pressures.
- Must be environment friendly.

2.5.3 Refrigerant (Methanol)

It is also known as methyl alcohol, wood alcohol is a chemical compound with formula CH_3OH 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) Chemical identity and chemical/physical properties of methanol.

Characteristic/Property	**Data**
Molecular Formula	CH_4O
Physical State	colorless liquid
Molecular Weight	32.04 g mol^{-1}
Melting Point	-97.8°C
Boiling Point	64.7°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/m3 = 0.76 ppm
Dynamic viscosity	$5.9*10^{-4}$ Pa

2.5.4 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 reaction.

Chapter three

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.

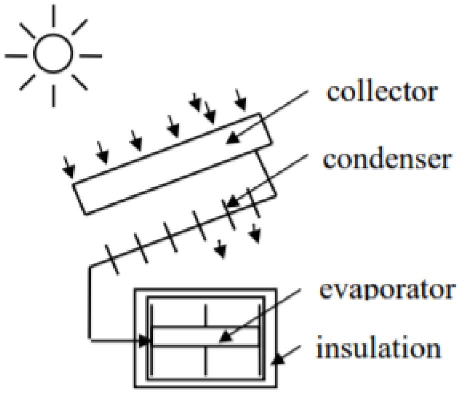


Figure (3.1) Schematic of a prototype adsorption ref

3.2 Thermal energy balance for evaporator

3.2.1 Thermal energy balance

The description of the thermal theory and modeling of evaporator 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 evaporator is:

$$Q_e = m_{ice}((Cp_w(T_w - T_d) + h_{il}) \qquad (3.1)$$

Where:

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

m_{ice}: The amount of ice [kg/day].

h_{il}: Latent heatof fusion [kJ/kg.]

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

T_w:The water temperature [°C].

T_d:The desired temperature[°C].

$$Q_e = 0.8 * ((4.18 * 25) + 330)$$

$Q_e = 347.6\ W$

$$COP = \frac{Q_e}{Q_H} \qquad (3.2)$$

Where:

COP: Coefficient of performance.

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

$COP = 0.5$ (by figure (3.8))

$$Q_H = \frac{347.6}{0.5}$$

Q_H =695.2 W

3.3 Thermal energy balance for ice box

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 a$\Delta T$and inversely proportional to the distance in the same directionΔx.

Thus:

$$\frac{\dot{q}}{A} = \alpha \frac{\Delta T}{\Delta x} \qquad (3.3)$$

For very small changes inΔT andΔx and changing the relationship Eq. (3.5) to an equality, the Fourier's equation of conduction is as follows:

$$\frac{\dot{q}}{A} = -k \frac{dT}{dx} \qquad (3.4)$$

Where: Thermal conductivity of the material through which conduction takes place. [W/m.°C] from table (3.1)

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

Material	Thickness (cm)	Thermal conductivity (W/m.°C)
Stainless steel	0.1	15
Foams	5	0.036

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

$$\frac{\dot{q}}{A} = \frac{x}{k}(T_1 - T_2) \qquad (3.5)$$

Where:

x : distance separating the two surfaces whoes temperatures are T_1 and $T_2$where$T_1$is greater thanT_2.

Where $R_{cond} = \frac{x}{k}$ (3.6)

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:

$$R_{th} = R_o + \sum\nolimits_{j=1}^{n} (R_{cond})_j + R_i \tag{3.7}$$

Where:

$$\sum\nolimits_{j=1}^{n} (R_{cohd})_j = R_1 + R_{2+\dots} + R_2 \tag{3.8}$$

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 films [m^2. °C/W] which are listed in table(3.2) and (3.3). The overall heat transfer coefficient of the wall is defined as follows:

$$U = \frac{1}{R_{th}} \tag{3.9}$$

Inside and outside film thermal resistances is defined as follows:

$$R_i = 0.12\, m^2.\,°\mathrm{C}/W$$

$$R_o = 0.06\, m^2.\,°\mathrm{C}/W$$

$$R_{th} = 0.12 + \frac{0.001}{15} + \frac{0.05}{0.036} + \frac{0.01}{15} + 0.06$$

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

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

$$U = 0.64\ m^2.\,°C/W$$

$$Q = UA\Delta T \tag{3.10}$$

$$\Delta T = (T_{out} - T_{in})$$

Where:

T_{out}: outside box temperature.

T_{in}: inside box temperature.

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

$$Q = 3.8\, W$$

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

Element	Heat Direction	Material Type	R_i $m^2.°C/W$
Wall	Horizontal	Construction materials	0.12
		Metals	0.31
Ceiling and floors	Upward	Construction materials	0.1
		Metals	0.21
	Downward	Construction materials	0.15

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

Outside Resistance, R_o $m^2.°C/W$		Wind speed		
Elements	Material Type	Less than 0.5 m/s	0.5-5 m/s	5 m/s
Wall	Construction materials	0.08	0.06	0.03
	Metals	0.1	0.07	0.03
Ceilings	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 condenser

3.4.1 Condenser design

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

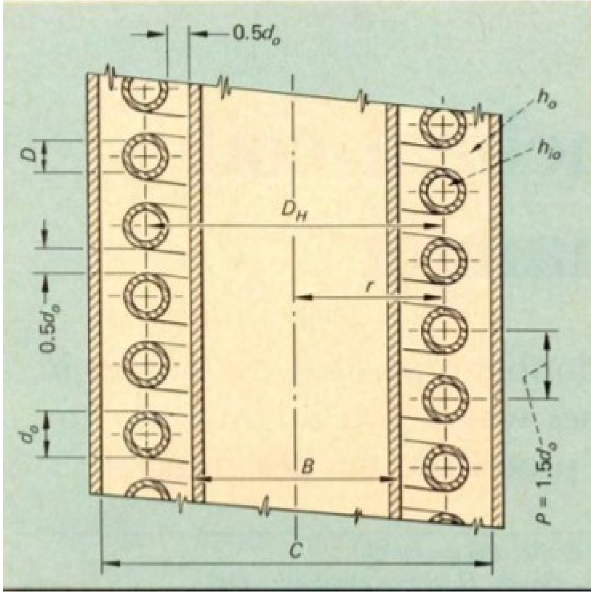


Figure (3.2) Schematic helical coil condenser.[14]

$$L = N\sqrt{(2\pi r)^2 + p^2} \tag{3.11}$$

Where:

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

N: Theoretical number of turns of helical coil.

$$p = 1.5 * d_0 \tag{3.12}$$

Where:

d_0: Outside diameter [m].

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

$\mathrm{L} = 0.04\ \mathrm{N}$[m].

$$V_c = (\pi/4){d_0}^2 LN \qquad (3.13)$$

Where:

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

$V_c = (\pi/4)(0.0012)^2 * 0.04$

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

$$V_a = (\pi/4)C^2 PN \qquad (3.14)$$

Where:

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

C: The inner diameter of the tank [m^3].

$V_a = (\pi/4)(0.34)^2 * 0.018$

$V_a = 1.62 * 10^{-3}\ N$

$$V_f = V_a - V_c \qquad (3.15)$$

Where:

V_f: The volume available for the flow of fluid in the annulus [m^3].

$V_f = (1.62 * 10^{-3}) - (5.3 * 10^{-8}\ )$

$V_f = 1.62 * 10^{-3}\ N$

$$D_e = \frac{4V_f}{\pi d_0 L} \tag{3.16}$$

Where:

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

$$D_e = \frac{4 * (1.62 * 10^{-3})}{\pi * 0.012 * 0.04}$$

$$D_e = 0.18\ m$$

The mass velocity of the fluid is:

$$u = \frac{\dot{v}}{A} \tag{3.17}$$

Where:

u: The methanol velocity [m/s].

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

A: Cross section area of coil [m^2].

$$A = \pi r^2 [m^2]$$

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

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

$$\dot{v} = \frac{\dot{m}}{\rho} \tag{3.18}$$

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

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

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

$$u = 107\ m/s$$

$$R_e = \frac{\rho u D}{\mu} \qquad (3.19)$$

Where:

μ: Dynamic viscosity [Pa].

ρ : Density of methanol [0.8 g/cm^3].

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

$$R_e = 1450$$

$$Pr = \frac{Cp\mu}{k} \qquad (3.20)$$

Where:

Pr: prantl number.

k : Thermal conductivity of methanol [w/m.$°C$].

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

$$Pr = 0.13$$

$$h_i = \frac{j_H * k * (pr)^{1/3}}{D} \qquad (3.21)$$

Where:

j_H: Colburn factor for heat transfer, from Fig. (3.4) for (R_e= 1450) is 25.

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

$$h_i = 260 \text{ w/m}^2.°C$$

$$h_o = h_i \left(\frac{D}{d_o}\right) \qquad (3.22)$$

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

$$h_o = 216\mathrm{w/m^2.°}C$$

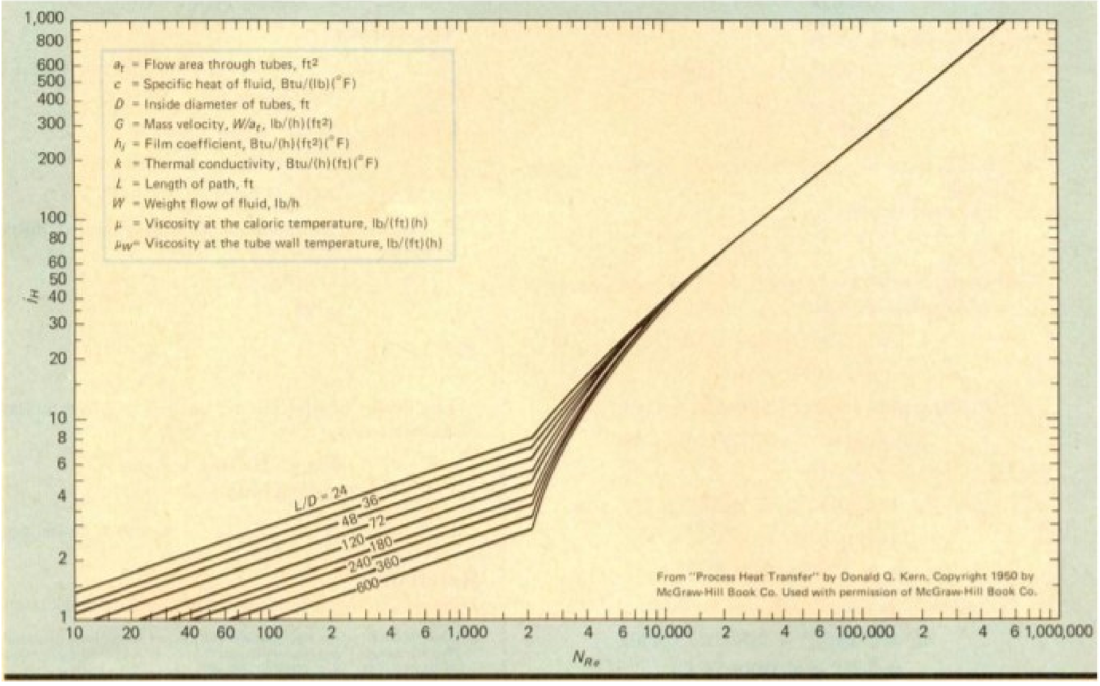


Figure (3.3) Colburn factor [14]

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.

$$U = \frac{1}{\frac{1}{h_i} + \frac{r_i \ln\left({}^{r_o}/_{r_i}\right)}{k} + \frac{r_i}{r_o} + \frac{1}{h_o}} \qquad (3.23)$$

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

U =1.23 W/m^2.°C

To find the heat transfer area for the coil:

$Q = UA\Delta T$

$1.1758 = 1.18 * A * 39$

$A = 0.024\, m^2$

Determine the number of turns of coil. Since $A = \pi d_0 L$, and$L$ is expressed in terms of N, the number of turns of coil needed can be calculated by:

$$N = \frac{A}{\pi d_0 (\frac{L}{N})} \tag{3.24}$$

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

$N = 15\, turn$

The find the height of coil:

$$H = (N * P) + d_o \tag{3.25}$$

Where:

H: the coil height [m].

$H = (15 * 0.018) + 0.012$

$H = 28.2\, cm$

3.4.2 Potential of solar energy in Palestine

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.[8]

Figure (3.4) Palestine potential

varies from 2.63 kWh/m2 -day in December to 8.4 kWh/m2 -day in June because it is located between 29°-33°N and 34° -36° as shown Fig (3.6).[9]

3.4.3 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

$$I_i = I_{DN}\, cos\ \theta + I_{D\theta} + I_r \tag{3.26}$$

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

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.[8]

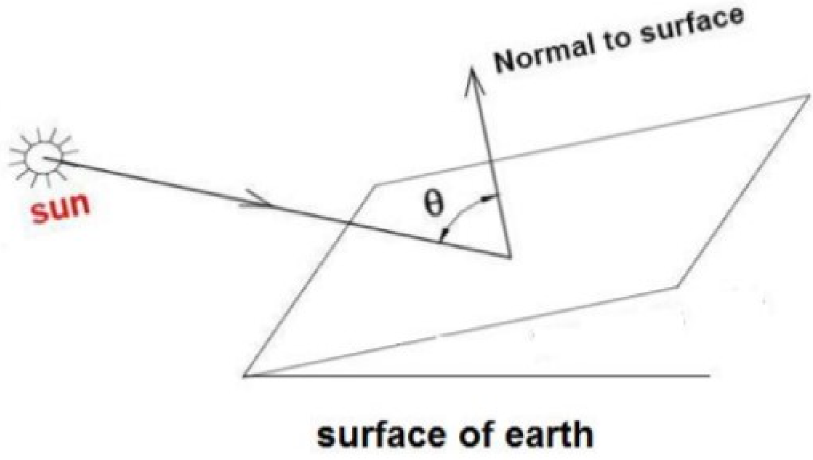


Figure (3.5) Angle of incidence

3.4.4 Solar geometry

The angle of incidence θ depends upon:

1. Location on earth
2. Time of the day, and
3. Day of the year

The above three parameters are defined in terms of latitude, hour angle and declination,

respectively as shown in Fig. (3.7).

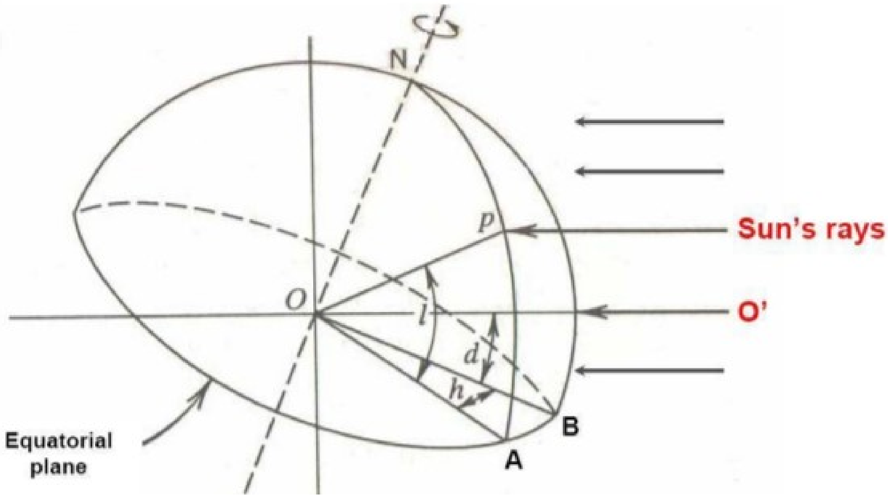


Figure (3.6) Definition of latitude (L), declination (d) and hour angles (h).[8]

With reference to Fig. (3.7), 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.

$$l = angle\ (POA)$$

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:

$$h\ = angle\ (AOB)$$

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:

$$d\ =\ angle\ (O'OB)$$

3.4.5 Collector angle (β)

In Palestine the solar collector is tilted by an angle of 32o 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

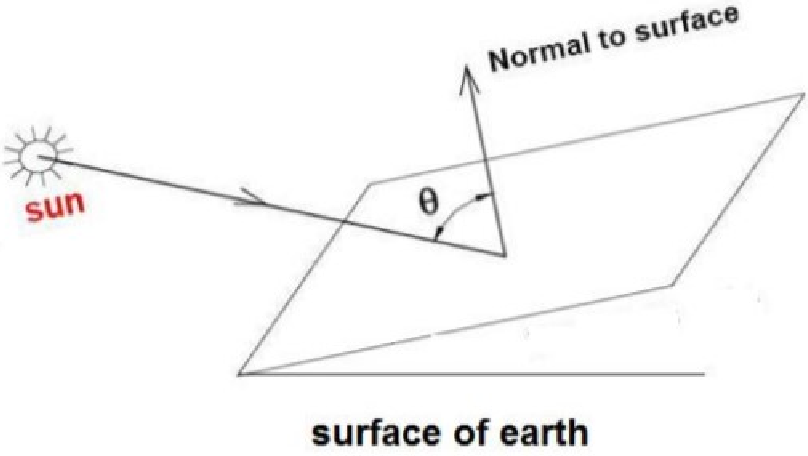


Figure (3.7) Angle of incidence

3.4.6 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 adsorbed bed given by:

$$Q_H = \eta * s * A \qquad (3.27)$$

Where:

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

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

η : collector efficiency.

$$Q_H = 180\ W$$

$$Q_H = \eta * s * A$$

$$A\ =\ 180/(0.6 * 1000)$$

$$A = 0.3\ m^2$$

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

Type of glazing	U, W/m^2.k
Unglazing	13-14
Single	6-7
Double	3-4

For the purpose of selecting collector, disgen often use a graph of collector efficiency, as shown in Fig. (3.8). The efficiency is a function of the optical and thermal properties of the cover plate and the adsorber and also the term$\frac{(t_{ai}-t_{\infty})}{I_i}$. As the temperature tai increases, the losses increase and the efficiency drops. Similarly, at low ambient temperatures the efficiency is low because of high losses. As the solar irradiation on the cover plate$I_i$increases, the efficiency 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. (3.8) 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 than the additional transmission loss through the second cover plate.[9]

The absorptivity and emissivity of a surface may vary with the wavelength of the incident radiation. Surface coatings for the absorber bed can be selected in such a way that the surface is highly adsorbing at the short wavelength of solar radiation $(\alpha = 0.9)$ but has a low emissivity $(\epsilon = 0.5)$ at the longer wavelength's characteristic of a surface radiating at 100 to 200 ℃. 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. (3.8).

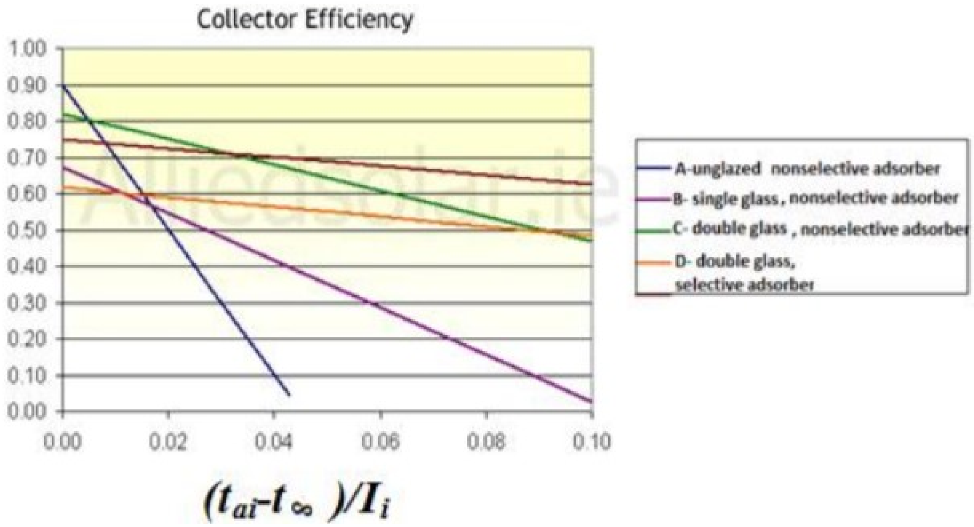


Figure (3.8) Collector efficient of typical Flat-plate collector. [9]

$$\frac{(t_{ai}-t_{\infty})}{I_i} \qquad (3.28)$$

Where:

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

t_{∞}: Temperature of surrounding [°C]

$$\frac{64-73}{1000}=0.027$$

From Fig. (3.8)

$$\eta = 60\%$$

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

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

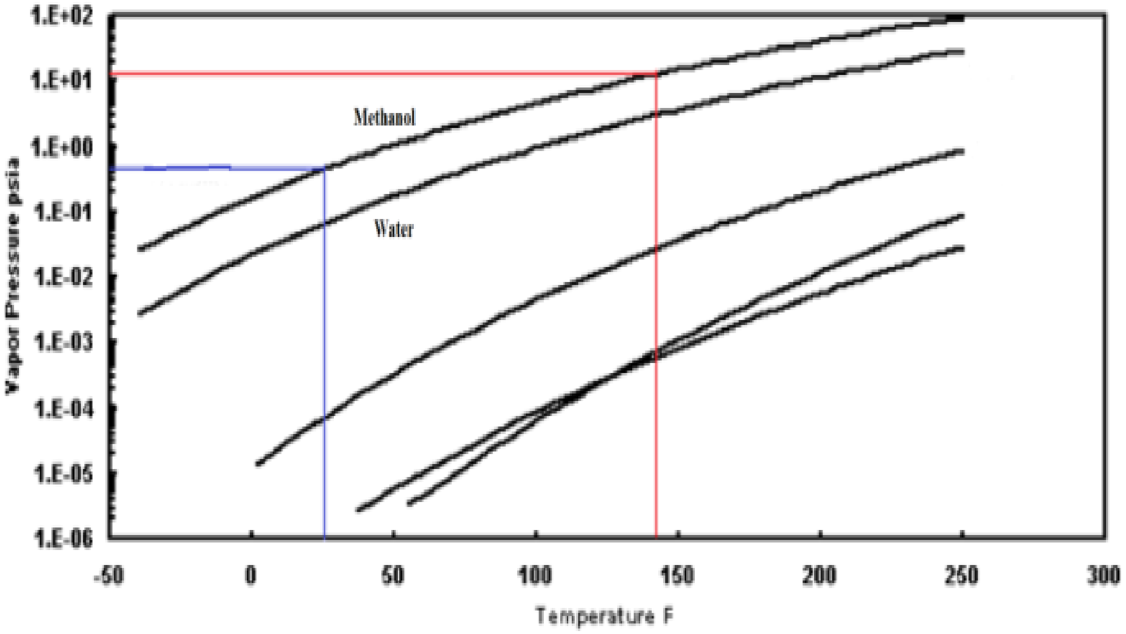


Figure (3.9) Comparison of Calculated Solvent Vapor Pressure as a Function of Temperature.[15]

From Figure (3.11):

P_{cond}= 10 psi

P_{evap}= 0.4 psi

Chapter Four

Design and Pipe Selection

4.1 Introduction

Pipes are used to carry fluids at high pressure and deliver it to all cycle components inorder to complete the refrigeration process to get ice, Theselection of pipes should besuitable for its purpose, it must be able to resistthe wear, rust, and the changing intemperature and pressure in the fluid which flows inside it.

4.2 Pipe selection

In this project the methanol will be used as a refrigerant, the selected material must notreact with methanol should not corrode; so that the steeltube 1006/1010 (SAEJ526) andcopper tube will be used in all parts of cycle,the mechanical and Physical-chemicalproperties of steel and copper tube areshown in Table (4.1), Table (4.2) and Table(4.3).

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 maximum
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) $g\cdot mol^{-1}$
Density	8.94 $g\cdot cm^{-3}$
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 $W \cdot m^{-1} \cdot K^{-1}$

4.3 Adsorbent bed (collector) design

The collector is the main part of the system, it works as compressor in refrigerationcycle to make the compression process, it used to collect thesolar 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 thecollector is parallel rectangular(cuboid), and for dimension design the equation as follow can be used:

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

Where:

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

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

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

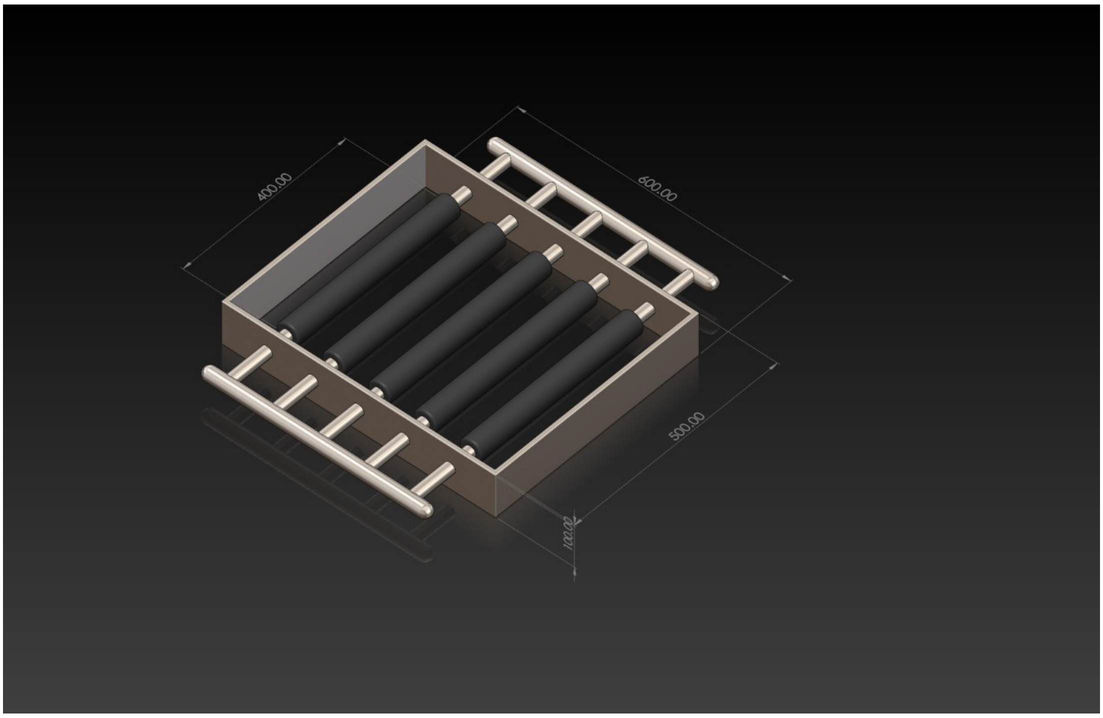


Figure (4.1) collector design

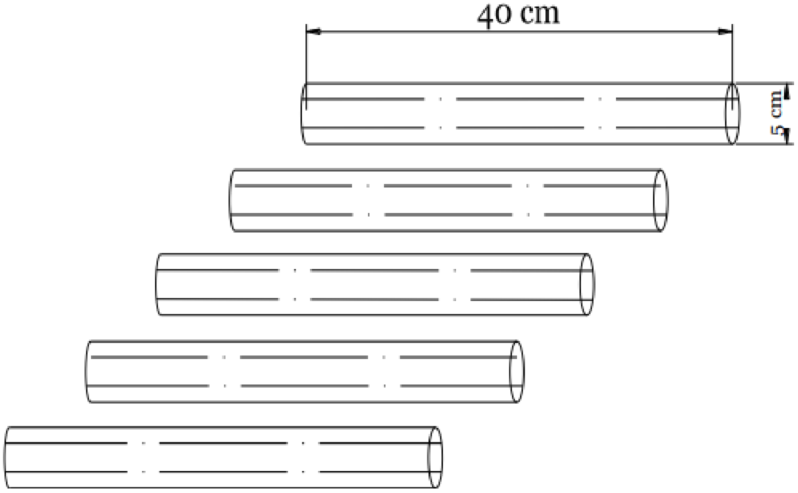


Figure (4.2) pipes contain activated carbon

$$l = d_o * N_t * S * N_s \tag{4.2}$$

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 spaces, 6

$$0.6 = 0.05 * N_t * 0.04 * 6$$

$$N_t = 5$$

The volume of tubes is:

$$V_{tupe} = \pi r^2 L \tag{4.3}$$

Where:

V_{tupe}: Volume of tubes inside the collector [m^3].
r: Radius of the tube [m].
L: Length of the tube [m].

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

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

In one tube:

$$V_{ac} = V_{tupe} = 7.85 * 10^{-4} m^3$$

In all tubes

$$V_{ac} = V_{tupe} * 5$$

$$V_{ac} = 7.85 * 10^{-4} * 5$$

$$V_{ac} = 39.25 * 10^{-4}\ m^3$$

The amount of activated carbon that we used:

$$\rho = \frac{m}{v} \tag{4.4}$$

Where:

ρ: Density of activated carbon [kg/m^3].

m: Mass of activated carbon [kg].

v: Volume of activated carbon [m^3].

$$0.4 * 10^{-3} = \frac{m}{39.25 * 10^{-4}}$$

$$m = 1.55\ kg$$

1kg activated carbon → 0.26kg methanol

$$m_{methanol} = 1.55 * 0.26$$

$$m_{methanol} = 0.4\ kg$$

4.4 Condenser design

As we mention previous in condenser designing we used a copper tubes withspecificproperties 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

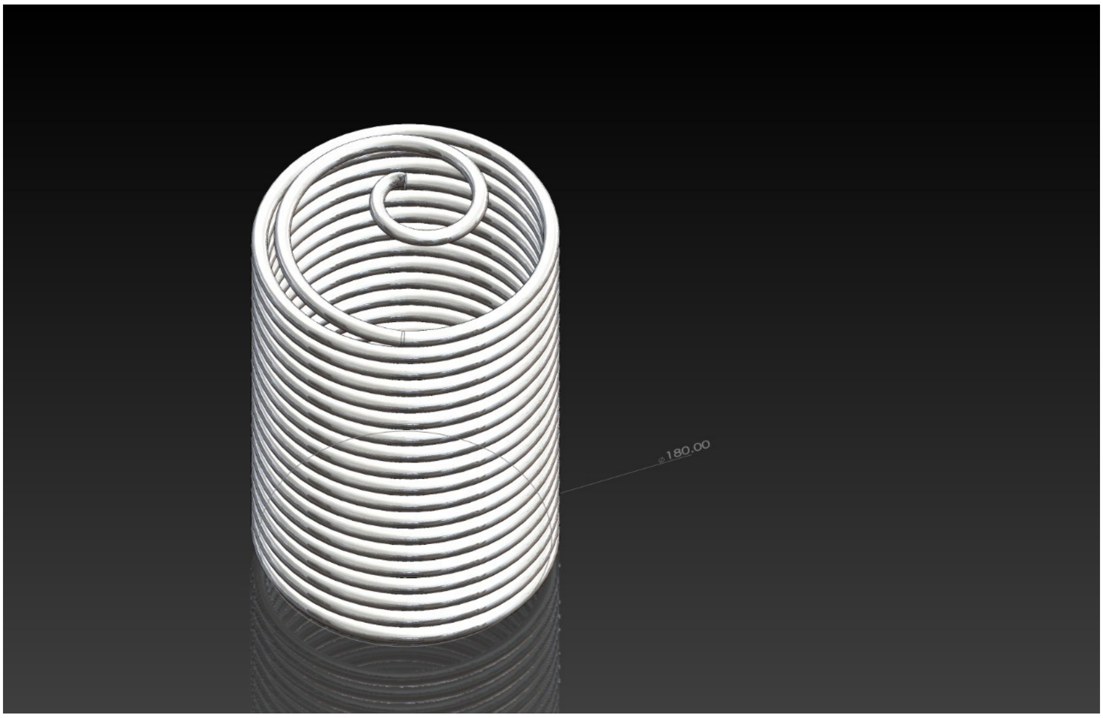


Figure (4.3) condenser design

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).

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

$$1.1758 = m * 4.18 * 39$$

$$m = 0.03\ kg$$

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

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

$$v = 0.03\ m^3$$

$$v = 30\ \text{L}$$

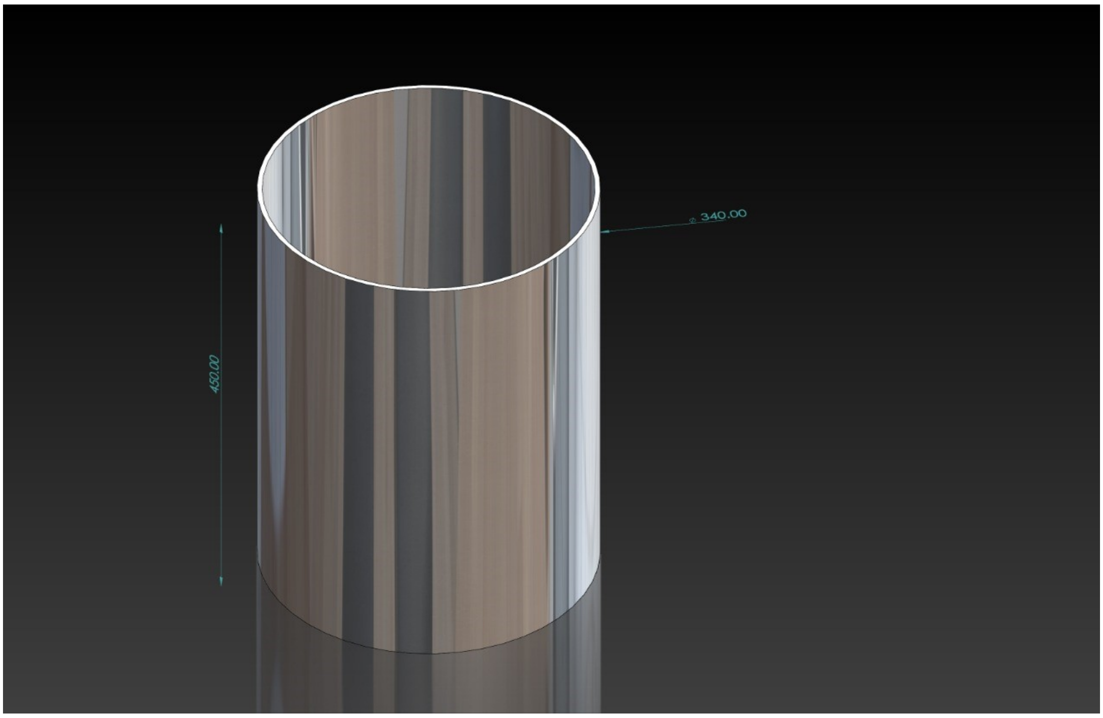


Figure (4.4) Tank design

4.6 Evaporator design

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

$$A_{evp} = w * l \qquad (4.6)$$

Where:

A_{evp}: Cross section Area of evaporator [m²].
w: Width of evaporator [m], 0.2 m.
l: Length of evaporator [m]. 0.2 m.

$$A_{evp} = 0.2 * 0.2$$

$$A_{evp} = 0.04\, m^2$$

$$V_{evp} = w * l * h \qquad (4.7)$$

Where:

V_{evp}: Evaporator volume [m³].
h: The height of evaporator [m], 0.05 m

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

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

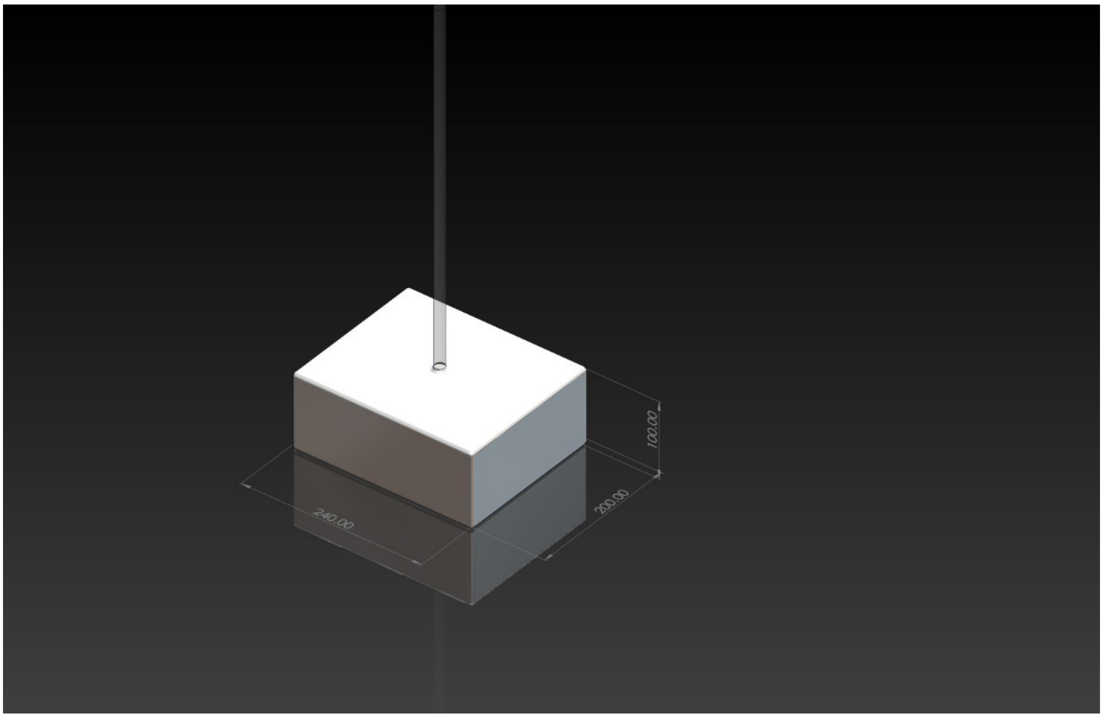


Figure (4.5) evaporator design

4.7 ice box design

The dimension of the evaporator is 20*20*5 cm, so the dimension of ice box is largerthan 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)

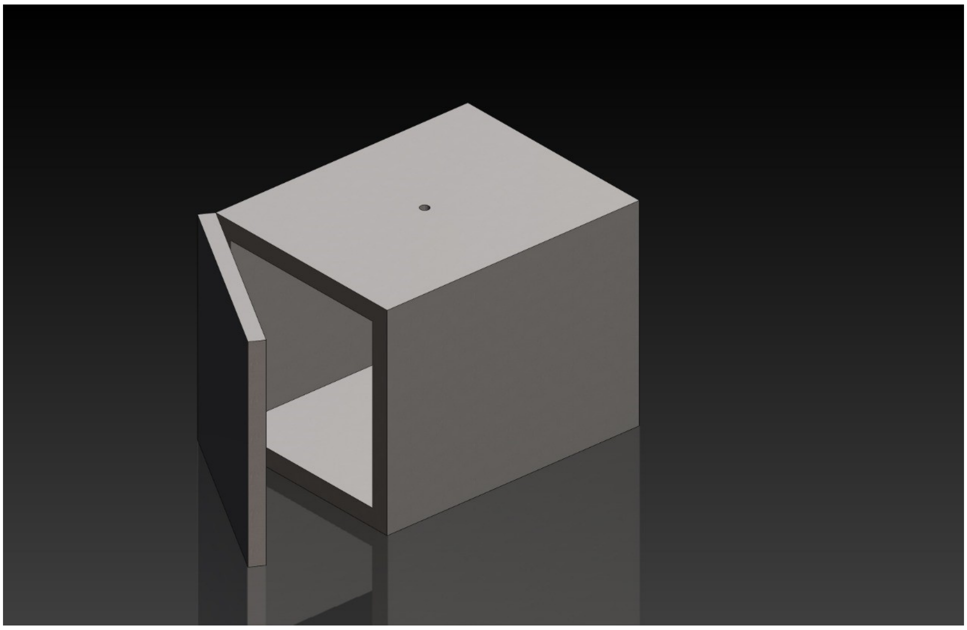


Figure (4.6) ice box design

4.8 Total Project Design

All parts are designed with solid works and fig (4.7) Shows the final form of the project after assembling parts on the program.

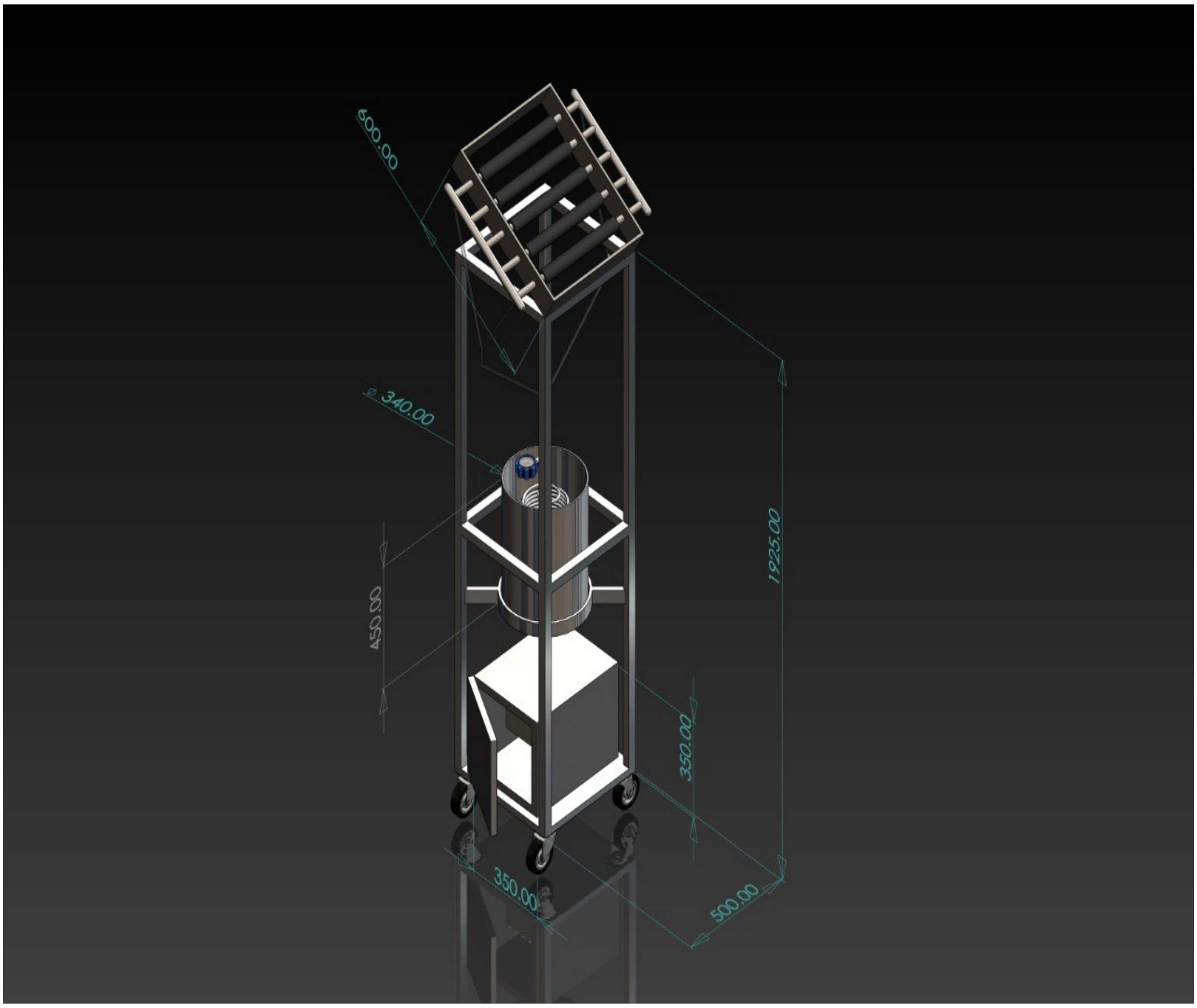


Figure (4.7) Total Project design

Chapter Five

Experimental Work, Result and Discussions

5.1 Integration of the Subsystem

The collector, condenser, evaporator were checked for vacuum proof and then wereconnected with each other using stainless steel pipe of 38 mm,and later with anotherpipe of 12mm. The whole system was mounted onframe bracket installed with wheels,so that it can be moved easily when necessary. Only one valve is installed besidecondenser, which helps tovacuum the whole system as well as to charge the system withrefrigerant. A pressure gauge is installed behind condenser to check for the pressureconditions in the system. Besides, no any other valves or measuringinstruments are usedin the system. A thermocouple is used for monitoringthe temperature only. In order toensure that the system can work normally,it is essential that the whole system should bevacuum 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 performedto ensure good sealing, since any kind of air leakage inside the system will lead failure in the process, since such system work under vacuum The total pressure mayincrease due to leaks or desorption of air from activated carbon, then the adsorption ofmethanol is reduced.Furthermore, the boiling temperature of the methanol increases and the rate ofevaporation decreases, and as a result the cooling effect decreases. The system wascompletely 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 outentrapped air and moisture using a vacuum pump until the pressurein the systemdecreased. This was also used to test the system forany leakage. Manyattempts were done to overcome the leakage problem,and the system was left forsufficient time for leakage monitoring.

5.4 Result's

We added different amounts of methanol during several days and the results were written in the tables (Tables (5.1) ,(5.2) ,(5.3),(5.4),(5.5))

Table (5.1) Results when adding 100 gm of methanol

Time	$T_{surrounding}$ (°C)	$T_{collector}$ (°C)	$T_{evaporator}$ (°C)	$T_{condenser}$ (°C)
8.30 (Am)	23	35	22	24
10 (Am)	24	40	21	25
11 (Am)	24	41	21	25
12 (Pm)	26	47	20	27
2 (Pm)	28	50	20	29

Table (5.2) Results when adding 200 gm of methanol

Time	$T_{surrounding}$ (°C)	$T_{collector}$ (°C)	$T_{evaporator}$ (°C)	$T_{condenser}$ (°C)
8.30 (Am)	20	30	19	21
10 (Am)	22	35	18	24
11 (Am)	24	41	15	26
12 (Pm)	24	42	15	26
2 (Pm)	25	47	15	27

Table (5.3) Results when adding 300 gm of methanol

Time	**$T_{surrounding}$ (°C)**	**$T_{collector}$ (°C)**	**$T_{evaporator}$ (°C)**	**$T_{condenser}$ (°C)**
8.30(Am)	19	28	19	20
10(Am)	22	34	18	23
11(Am)	23	40	16	25
12(Pm)	23	45	13	26
2(Pm)	25	52	12	28

Table (5.4) Results when adding 400 gm of methanol

Time (Am)	**$T_{surrounding}$ (°C)**	**$T_{collector}$ (°C)**	**$T_{evaporator}$ (°C)**	**$T_{condenser}$ (°C)**
8.30 (Am)	20	30	17	23
10 (Am)	22	38	15	26
11 (Am)	23	45	12	26
12 (Pm)	24	53	8	28
2 (Pm)	25	60	7	30

Table (5.5) Results when adding 500 gm of methanol

Time (Am)	**$T_{surrounding}$ (°C)**	**$T_{collector}$ (°C)**	**$T_{evaporator}$ (°C)**	**$T_{condenser}$ (°C)**
8.30 (Am)	23	35	18	24
10 (Am)	24	43	14	27
11 (Am)	24	51	10	28
12 (Pm)	25	60	6	31
2 (Pm)	25	68	5	31

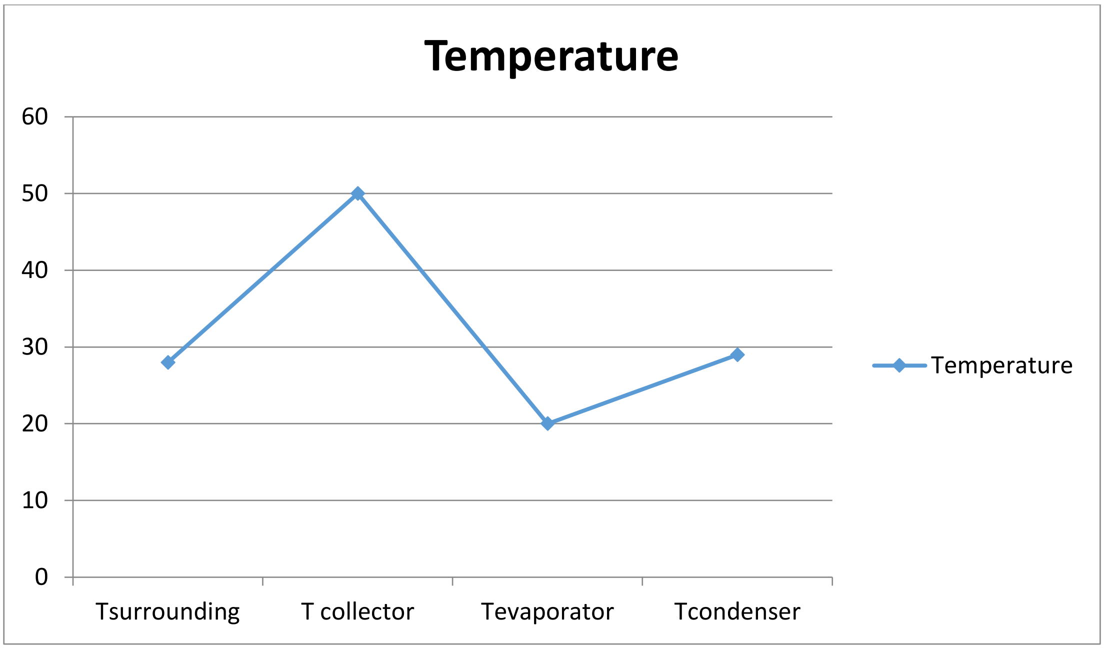


Figure (5.2) graph showing the temperature when adding 100 grams of methanol at 2 pm.

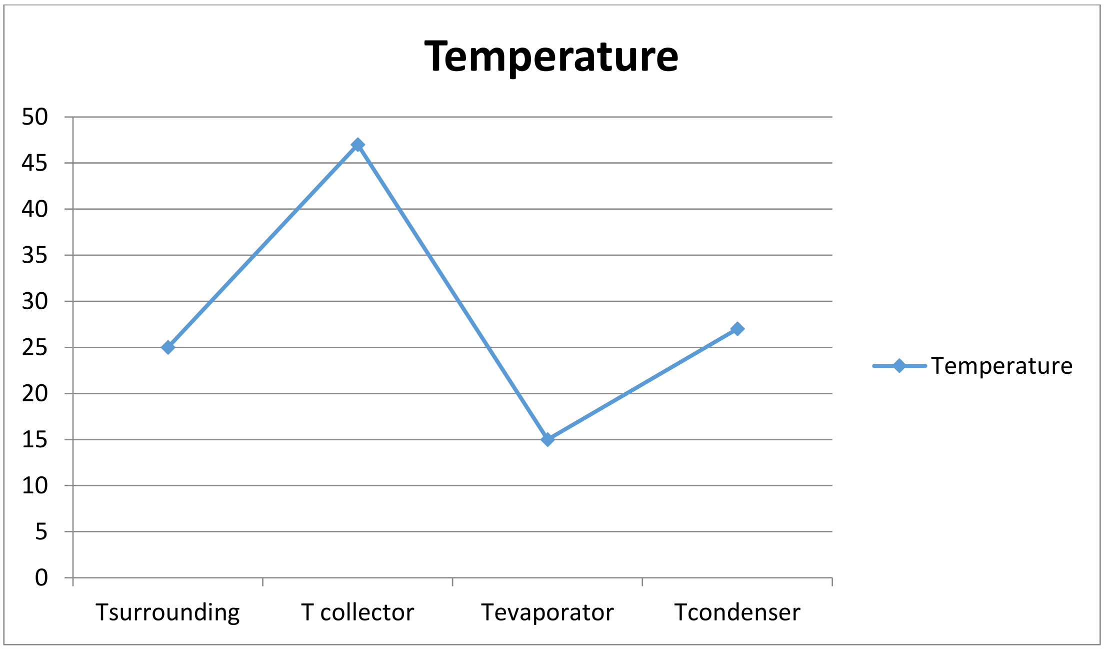


Figure (5.3) graph showing the temperature when adding 200 grams of methanol at 2 pm.

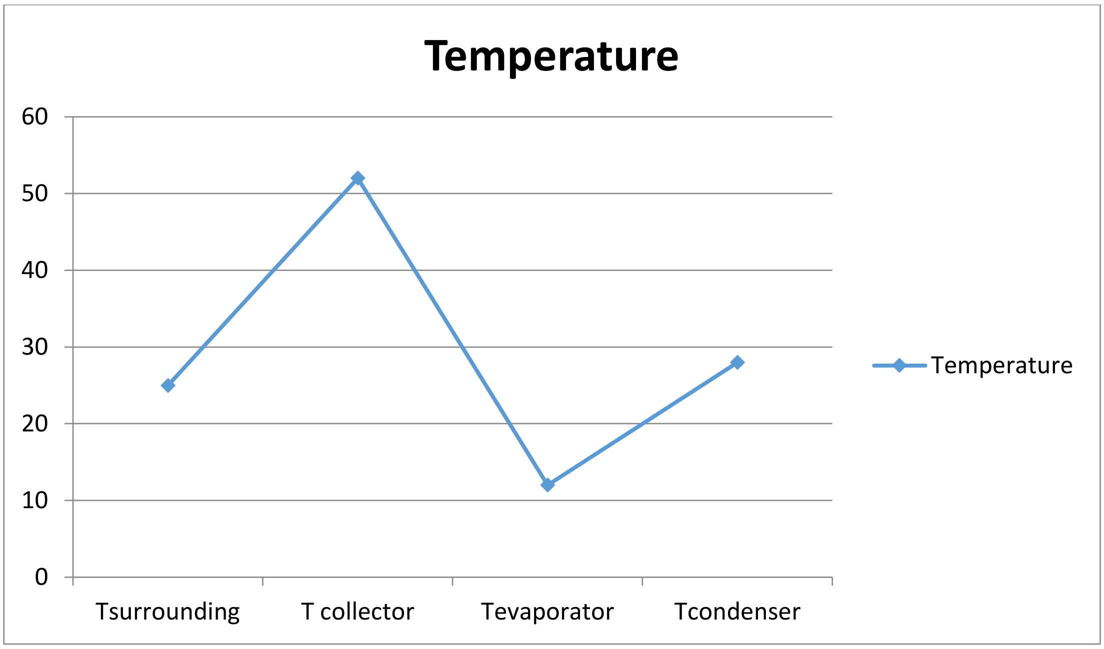


Figure (5.4) graph showing the temperature when adding 300 grams of methanol at 2 pm.

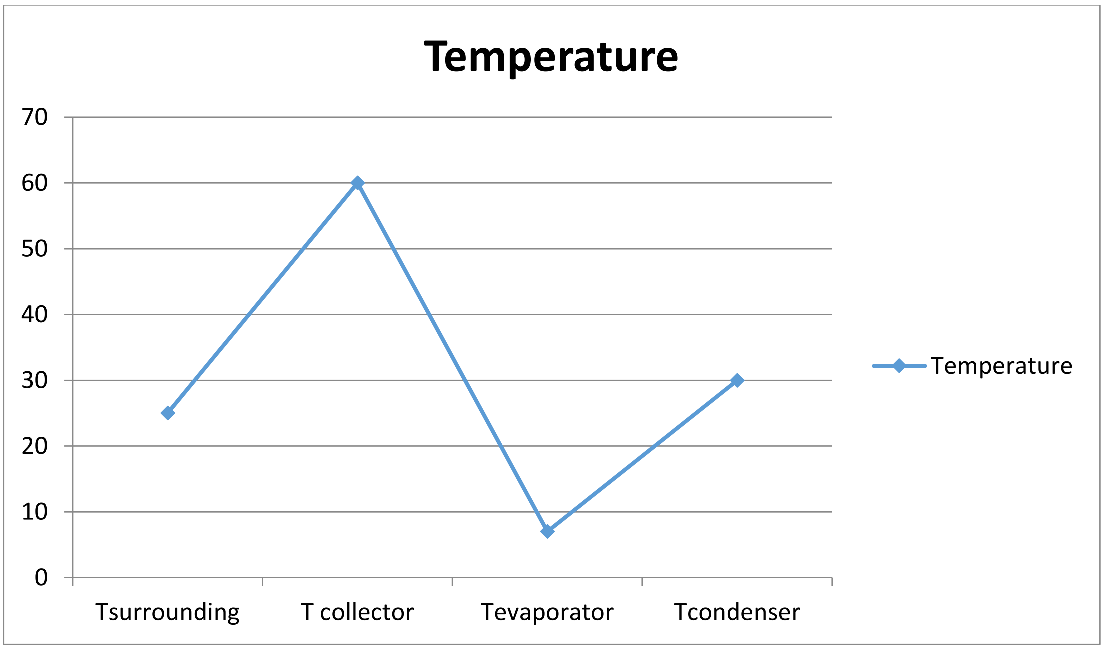


Figure (5.5) graph showing the temperature when adding 400 grams of methanol at 2 pm.

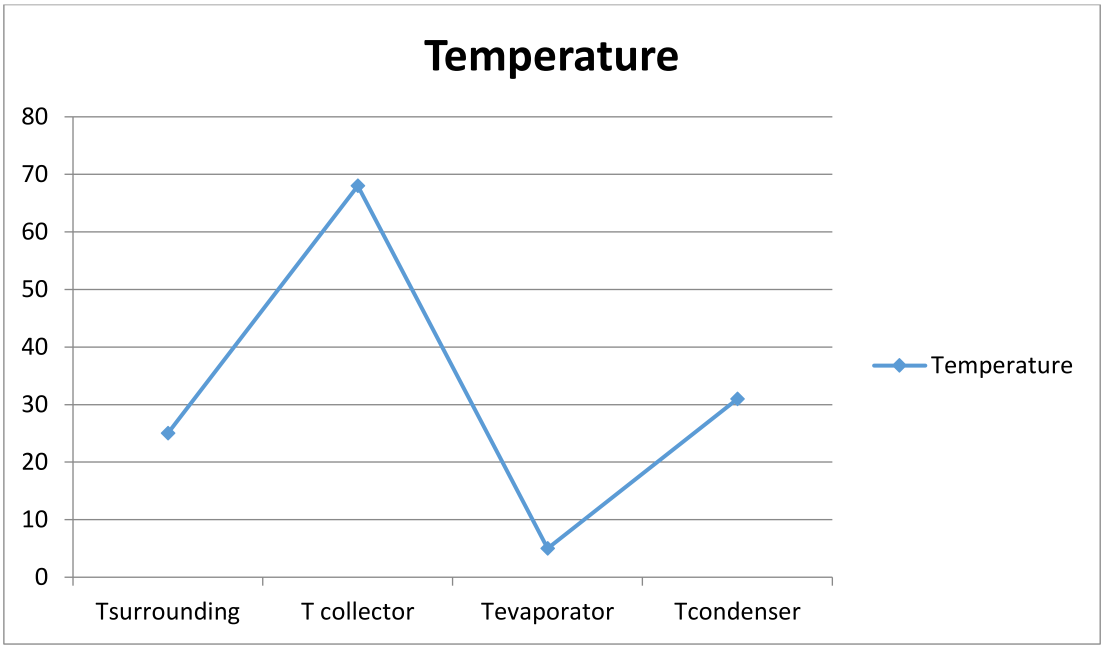


Figure (5.6) graph showing the temperature when adding 500 grams of methanol at 2 pm.

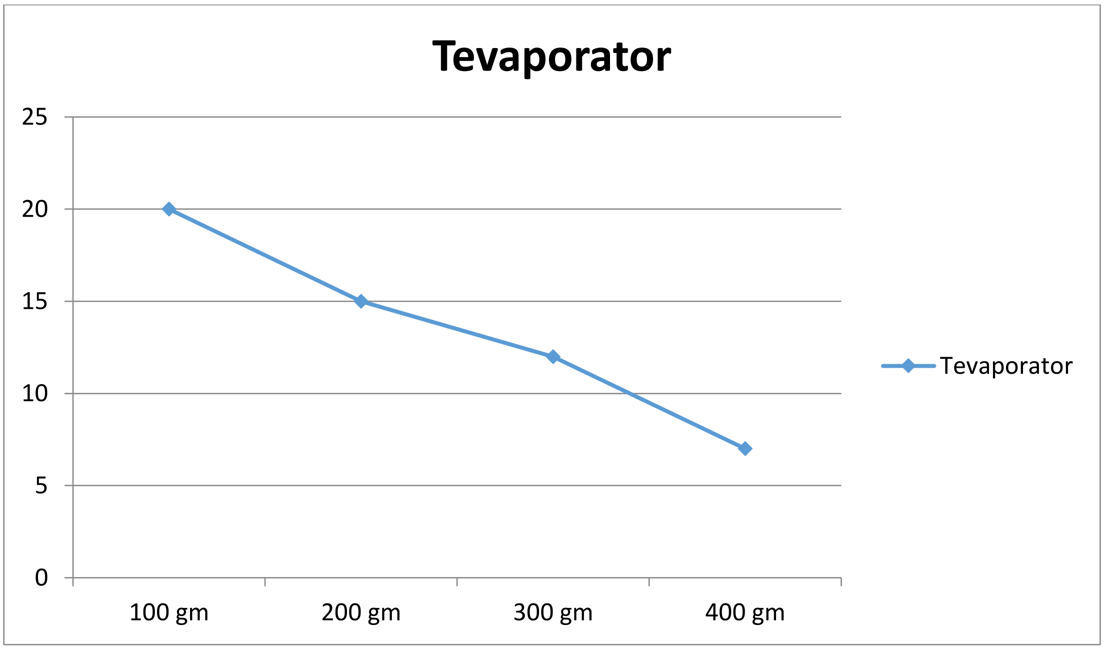


Figure (5.7) The relationship between Tevaporator and the amount of methanol added at 2 pm.

Chapter six

Conclusions and recommendations

6.1 Conclusions

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

1. A solar powered solid adsorption icemaker using an activated carbon/methanol adsorbent pair has been successfully designed,constructed and tested
2. When increasing the amount of methanol added and the temperature of collector increasedthe evaporator temperature decreases.
3. When the condenser temperature increases, the evaporator temperature decreases.
4. Because we are in the winter, the highest temperature of collector is(68°C) and the evaporator temperature is (5°C)

6.2 Recommendations

To have better results:

1. Operation of the project in the summer because the temperature of the collector is higher and consequently the efficiency of the project is greater.
2. The use of substances other than methanol has higher efficiency in adsorption, such as ammonia.

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