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Design and Construct a Solar Concentrator Using Fresnel Lenses to Sterilize Surgical Medical Equipment

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Submitted to the

College of Engineering at

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in Partial Fulfillment of the Requirements

For the Degree of Master in the

Mechanical Engineering Sciences

By

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2022 A.D **1444 A.H**

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

((وَلَسَوْفَ يُعْطِيكَ رَبُّكَ فَتَرْضَى))

صدقَ اللَّهُ العليُ العظيم

الضحى، آية (٥)

Supervisor Certification

We hereby certify that this thesis entitled " **Design and Construct a Solar Concentrator Using Fresnel Lenses to Sterilize Surgical Medical Equipment**" prepared by the student (**Mohammed Mohsen Jasim**) had been carried out completely under our supervision at the University of Kerbela, Mechanical Engineering Department, in the partial fulfillment of the requirements for the degree of Master in the Mechanical Engineering Sciences.

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EXAMINIATION COMMITTEE CERTIFICATION

We certify that we have read the thesis entitled "**Design and Construct a Solar Concentrator Using Fresnel Lenses to Sterilize Surgical Medical Equipment**" and as an examining committee, we examined the student "**Mohammed Mohsen Jasim**" in its content and in what is connected with it, and that in our opinion it is adequate as a thesis for the degree of Master of Science in Thermal-fluids Engineering.

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Dedication

To All Whom I Love

I Dedicate This Modest Effort

To Imam al-Mahdi (God hastens his fortune), my parents (father & mother), my family, and relatives and friends…

Mohammed Mohsen Jasim

Date: /   /2022

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Praise and thank Allah who eased and quadrated us to accomplish this work.

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Abstract

The current study includes the design and manufacture of an experimental model of an innovating solar system for sterilizing surgical medical equipment as the first work with this design. Where steam and air are used as sterilization fluids separately, this was done through two sterilization chambers; one of them contains water converted into steam at a temperature of 121.1 ˚C and a pressure of 2.1 bar to be used as a sterilizing fluid. The other contains air used as a sterilizing fluid after heating it to the required temperature (160˚C) for sterilization. This is done by using solar energy. The dimensions of the system are 2.3 m in length, 1 m in width, and 1.4 m in height. The system weight is 65 kg, approximately.

This system was developed by installing a cylindrical solar absorbent vessel between the two sterilization chambers. This vessel aims to generate steam at a temperature (160 ˚C) to be used as a medium to accelerate the production of sterilizing fluids, and thus the sterilization process is faster. A heat exchanger was installed in each sterilization unit for heat exchange between the sterilizing fluid and the steam generated inside the cylindrical vessel. Also, to accelerate the steam generation in the cylindrical vessel, a Fresnel lens and a reflective oval dish were used as solar concentrators to focus solar radiation on this vessel. The system also has a two-axis solar tracker to track the sun automatically.

The temperature and pressure of the sterilizing fluid (steam or air) and the steam generated in the cylindrical vessel were found theoretically and experimentally.

The results showed that using the solar absorbent vessel in its normal case (without solar concentrators) cannot convert water into steam. While after installing the reflective oval dish, steam (160 ˚C and 6.2 bar) was obtained inside the cylindrical vessel for 37 min experimentally and 33 min theoretically. After installing the Fresnel lens with the presence of the reflective dish, this time was reduced by 35% experimentally and 36.4% theoretically compared to the results of the oval dish alone. By comparing the

experimental results with the theoretical ones, it was found that there is a maximum difference about 17%.

According to the prices in Iraq, the system's economic feasibility evaluation found that it cost 664$.

Table of Contents

Nomenclature

Roman Letters		
Character	Description	Units
A	Area The altitude of the observer	m^2 km
C	Solar Radiation Concentration Ratio	-------
C_p	Specific heat at constant pressure	J/Kg. K
C_{sf}	experimental constant that depends on surface–fluid combination	
C_v	Specific heat at constant volume	J/Kg. K
D, d	Diameter	m
E	Energy	J
F	Shape factor	-----------
f	Focal length	m
Gon	Extraterrestrial radiation on a horizontal surface	W/m^2
Gsc	Solar constant (1367)	W/m^2
g	Gravitational acceleration (9.81)	m/s^2
H	Height	m
h	Convection heat transfer coefficient Height of dish Specific enthalpy	$W/m^2.k$ m KJ/ Kg
h_{fg}	Specific enthalpy of vaporization	J/kg

I	Hourly solar intensity	W/ m^2
I_{on}	Hourly extraterrestrial radiation	W/ m^2
k	Thermal conductivity	W/m. k
K_T	Hourly clearness index	-----------
L	Length	m
m	mass	Kg
N_u	Nusselt number	--------
n	Fresnel lens refraction index Number of days An experimental constant that depends on the fluid	--------
P	Pressure	Pa
P_r	Prandtl number	--------
Q	Heat transfer	W
R	Half of the Fresnel lens side Thermal resistance	m °C/W
R_a	Rayleigh number	------------
R_b	Geometric factor	------------
r	The minimum radius of the oval dish focus area Reflectivity	m ------------
S	Dish stability	
s	The maximum radius of the oval dish focus area	m
T	Temperature	°C

t	Thickness Time	m sec
U	Overall heat transfer coefficient	$W/m^2.k$
V	Velocity Volume	m/s m^3
υ	Specific volume	m^3/kg
W	Width	m
x	Dryness fraction	----------
Greek Symbols		
Character	Description	Units
β	coefficient of volume expansion Slope, the angle between the glass face and the horizontal	1/K Degree
ρ	Density The reflectivity of the reflective surface that coats the dish	Kg/m^3 ----------
τ	transmittance	----------
τ_b	Atmospheric transmittance for beam radiation	-------
τ_d	Atmospheric transmittance for diffuse radiation	----------
μ	viscosity	Kg/m. s
ν	Kinematics viscosity	m^2/s
α	Absorptivity The prism angle of the Fresnel lens	---------- Degree

σ	Stefan-Boltzmann constant ($5.67*10^{-8}$) Stress The surface tension of liquid–vapor interface	$W/m^2.K^4$ N/m^2 N/m
ε	Emissivity	-----------
φ	Latitude angle	Degree
ω	Hour angle	Degree
δ	Declination angle	Degree
θz	Zenith angle	Degree
θs	Solar angle (0.265°)	Degree
ψ	Rim angle of the dish	Degree
ζ_{opt}	Optical efficiency	------------
ζ_{opt}	Petela's efficiency	------------
ζ_{clean}	The factor which takes into account the dish paint surface cleanliness	------------

Subscripts	
1	First
2	Second
3	Third
4	fourth
abs	absorbed

AL	Aluminum
all,st	allowable of steel
alu	alucobond
amb	ambient
A.S.Ch	Air Sterilization Chamber
b	box
ch	chamber
cy	cylinder
d	Dish
exp	Experimental
f	Focus
f	Fluid, saturation
g	glass, saturated steam
g.w	Glass wool
H.E	Heat exchanger
h	Hoop
i	initial
in. cy	inside steam sterilization cylinder
in	input, inside
L	Fresnel Lens
l	Large, liquid, longitudinal
losses, v	losses from vessel

p	Pipe
rad	radiation
s	Surface, small, solar, surface of sun
s.e	surgical equipment
S.i.V	Steam inside vessel
S.S.Ch	Steam Sterilization Chamber
st	Steel
s, total	Total surface
theo	theoretical
u	useful
v	vessel
$v.in$	Vessel inside
v.o	outside of vessel
v	vapor
w	wind, water

Abbreviations

SYMBOL	DESCRIPTION
W.S.F	Working Solar Fluid
N.A.D	Not Available Data

Chapter One
Introduction

This chapter will discuss solar energy, solar concentration devices (Fresnel lenses and the reflectors and other than that), and sterilization of surgical equipment.

1.1 Solar Energy

The Sun is considered a very important source of renewable and clean energy. Solar energy can be defined as radiant sunlight that can be benefited from it in many areas of life. This is done by using solar collection techniques to generate electricity or produce pure water for human consumption ...etc. These techniques can be classified into two main parts passive solar techniques and active solar techniques. This classification is based on how these techniques are used to benefit from solar energy in practice life applications. In the first part, there is no external power source to control the solar system, but instead of that using conventional methods such as designing a building toward the Sun, choosing materials with excellent thermal properties and so on. While for the active solar techniques, an external source (for example, an electrical motor) is used to control these techniques and orientate them towards the Sun, as in the photovoltaic systems and others [1]. Exploiting solar energy and converting it into useful thermal energy requires solar concentrators.

1.2 Solar Radiation Concentration.

The solar concentration is reorientating solar radiation towards a specific area to obtain as high thermal energy possible. This energy may be used in numerous fields such as electricity generation, heating, industrial, sterilization, etc...

Three important elements that contribute to the process of solar concentration are as follows [2]: -

1. A solar concentrator is a device that redirects the solar radiation towards the required aim (for example, a solar absorbent vessel). Thus, collecting it in a limited space with a greater density,
2. A solar absorber or receiver, such as a solar absorbent vessel or container, receives and absorbs the light from the sun directly (without a solar concentrator) or indirectly (using a solar concentrator). It is often coated black to absorb the maximum amount of solar energy. It contains a fluid that absorbs heat to transfer it to the places of use and application,
3. A solar tracker is a device that controls the solar system and moves it towards the sun to obtain maximum solar energy.

Solar collectors can be classified into the follow: -

1.2.1 Solar Reflectors

They are unique systems that concentrate solar energy to convert it into thermal or electrical energy. This is because they have highly reflective surfaces. The high reflectivity of the surfaces comes from the paint they are coated with; the coating materials used are nickel plating, tin or reflective aluminum foil, and mirrors [3].

These reflectors are divided into two types according to the shape of the concentrated solar area, as follows:

a) Linear Solar Reflectors

In this type of solar reflector, the area of concentrated solar radiation takes a linear shape with a length equal to the length of the focusing element. They have a solar radiation concentration ratio of about (30-80) and a temperature at the focus area of approximately 400 °C [3].

This type of reflectors may also be divided into two types as follow: -

i. Parabolic Trough Collector (PTC): They have a parabolic cross-section. The solar absorber or receiver used with this type of reflector usually takes the form of a tube located in the focal line of the parabola. This tube is made of a material with high thermal conductivity, such as copper or steel, and is coated with black to increase its heat absorption. The solar absorber is usually installed inside a vacuum glass tube to reduce heat losses and speed up the heating. Figure (1.1) [4] shows that these reflectors usually need a uniaxial solar tracking system.

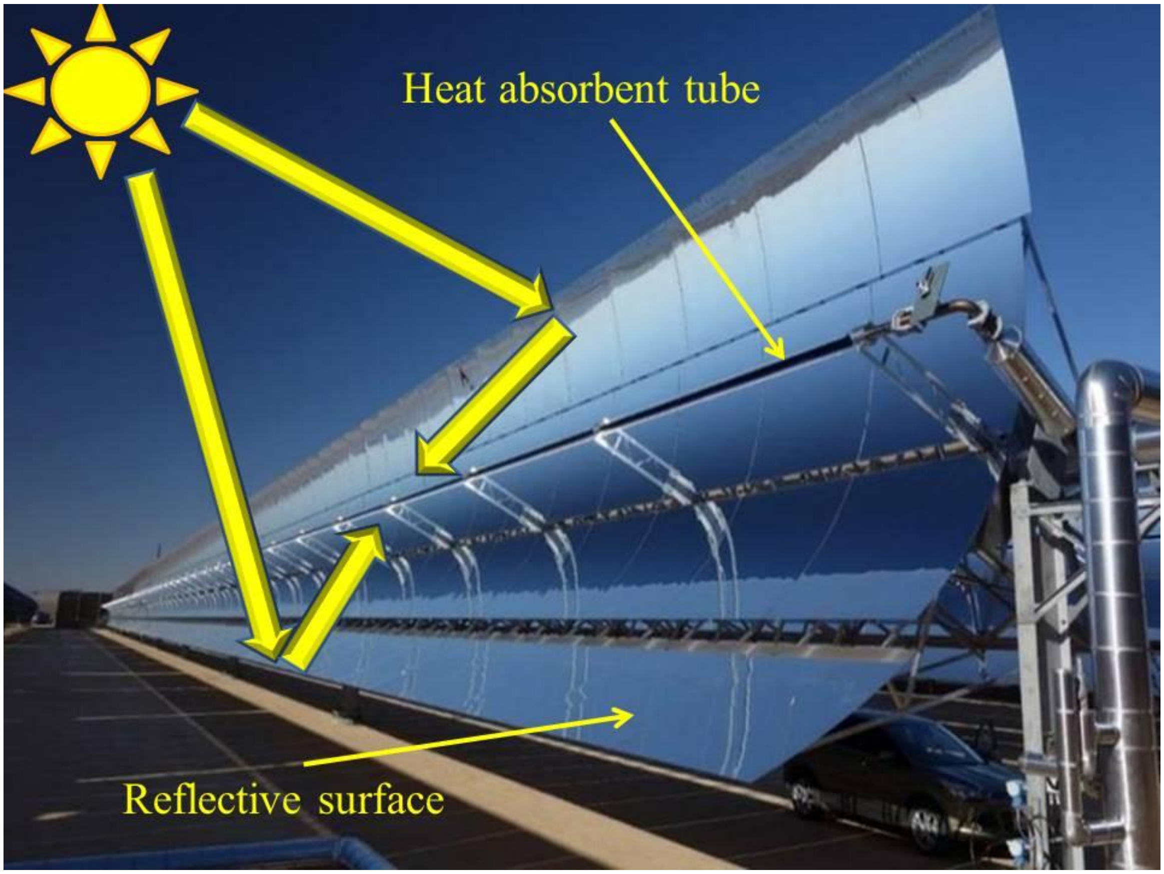


Figure (1.1): Parabolic Trough Collector [4]

ii. Linear Fresnel Reflectors (LFR) are flat mirrors arranged parallel and at a certain angle that direct the solar radiation towards the solar absorber. Also, a secondary arched mirror is located at the top of the solar absorber, reflecting the lost solar radiation from the primary mirrors. The solar absorber may consist of a group of tubes instead of one tube, and in this case, the secondary mirror can be dispensed as shown in the figure (1.2) [5].

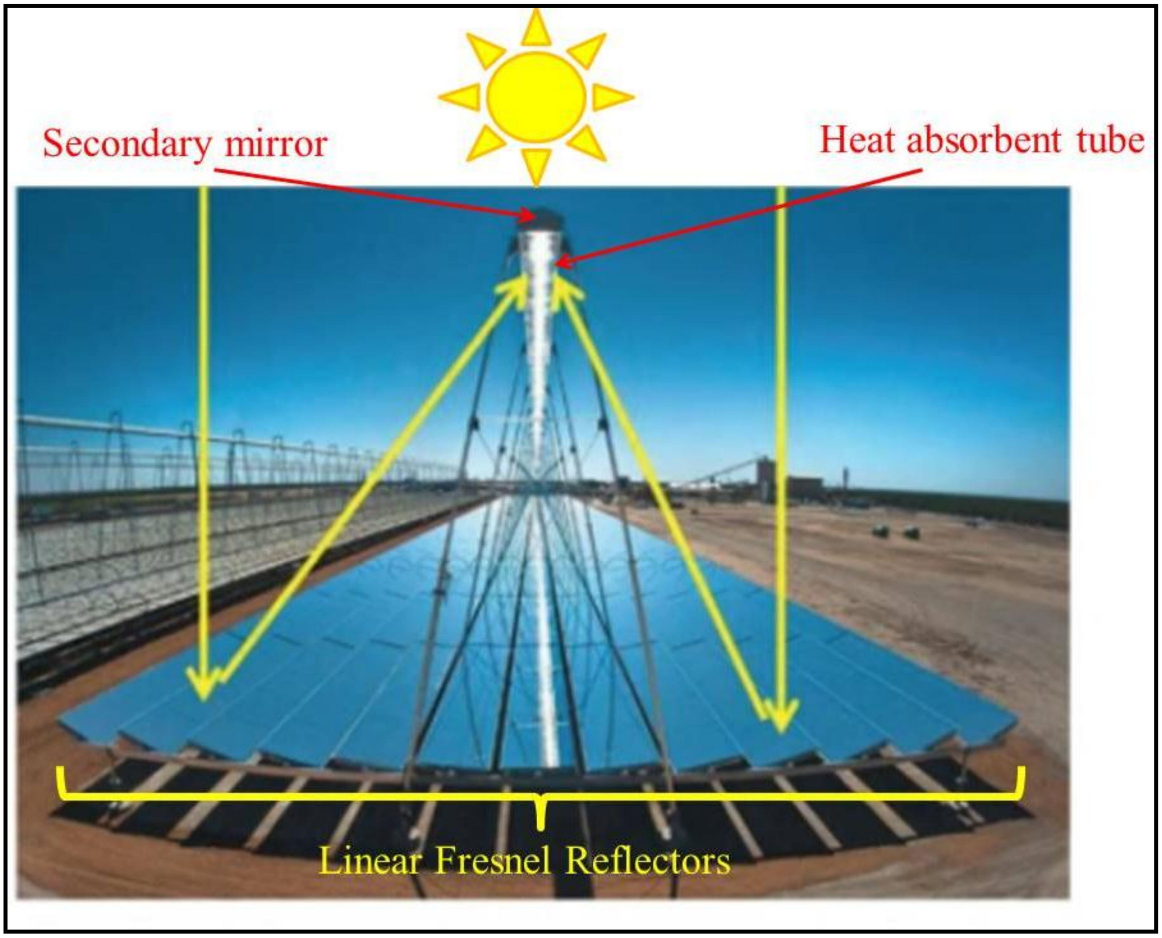


Figure (1.2): Linear Fresnel Reflectors (LFR) [5]

b) Point Solar Reflectors

In this type of solar reflector, the solar radiation is redirected toward the reflector's focal point, which locates on the surface of the solar absorber or receiver, as the Parabolic Dishes (DP): They are used with different surface areas. Usually, these dishes are coated with a reflective material like aluminum paper or others. In this type of reflector, the temperature at the focus may reach above 500 ˚C. These reflectors need a two-axis solar tracking system, as shown in a figure (1.3) [6].

Figure (1.3): Parabolic Dishes (DP) [6]

1.2.2 Solar Lenses

There are two types of solar collector lenses: convex lenses and Fresnel lenses. The convex lens is curved outward (convex) from one or both sides. This curvature ensures an inclined surface for the incident beam radiation on the surface of the lens perpendicularly. This will lead to refracting the light towards the axis of the lens. Therefore the lens becomes a collected lens. The point at which the light rays gather is called the focal point of the lens, and the distance between the lens and this point is called the focal length, as shown in figure (1.4).

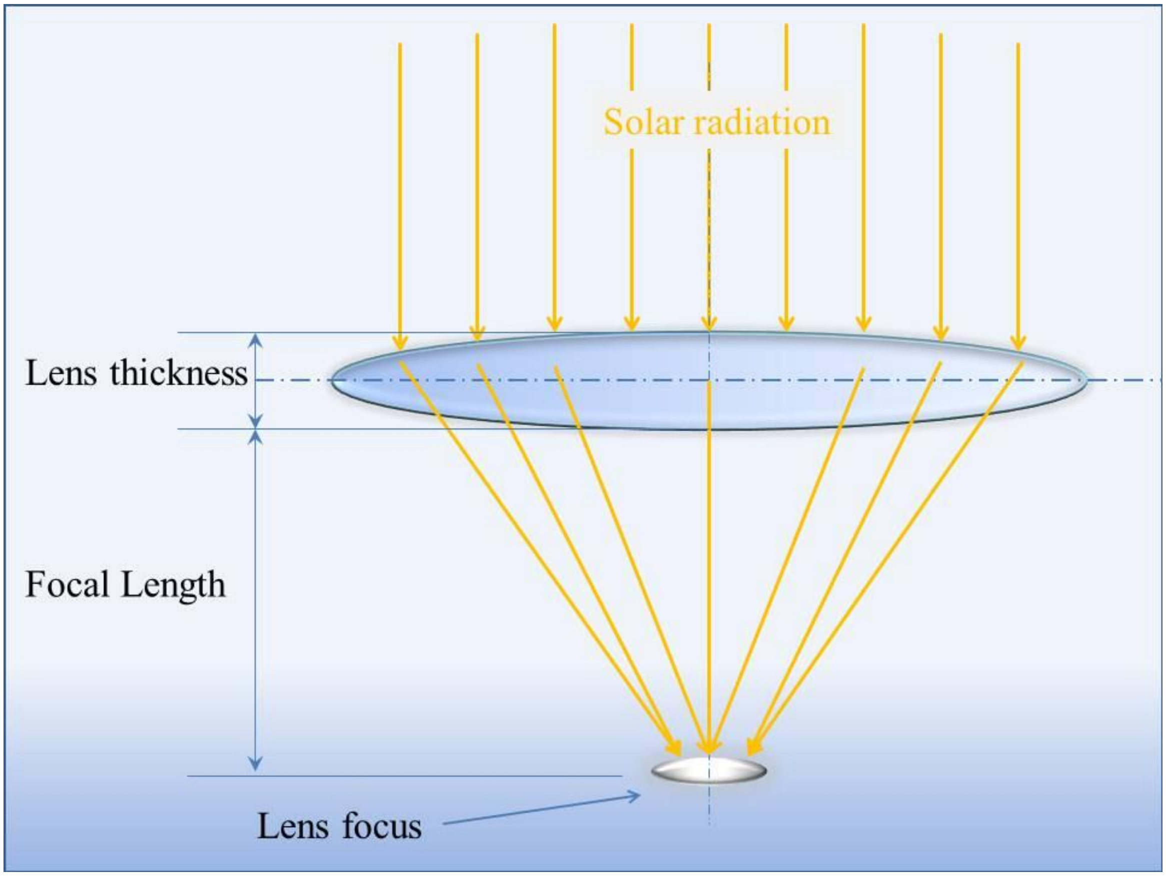


Figure (1.4): A convex lens, its focal length, and its focus area

The concentration ratio of the lens is proportional to its side curvature ; thus, as the large required value of this ratio is need a large of this curvature. This means that the thickness or size of the lens will be large. Consequently, it was necessary to search for alternatives for convex lenses to obtain a high concentration ratio with a small lens thickness [7]. French engineer and physicist Augustin Jean Fresnel (1788-1827) discovered a special Fresnel lens [7]. The Fresnel lens was one of the most important innovations in the 19th century. It was invented by the French engineer and physicist Augustin Jean Fresnel in 1822. Fresnel noted that in the case of making a lens with a curved surface, a large amount of lens material would be needed. So, it was thought that grooves substitute the lens curvature at one of the sides of the lens, and these grooves play the role of the curved surface, as shown in figure (1.5) [8]. This innovation was applied by using glass from 1822 until 1951. Then, after that, it was the production of a plastic lens. The plastic lens is distinguished by its lightweight, the possibility of producing it in large sizes, and a small thickness (a few mm) [9]. Generally, the Fresnel lens may be classified as an imaging lens (zoom). This is used in photographic equipment and non-imaging lens (prime) used in the solar concentration processes. The non-imaging lens may be divided into a spot lens and a linear lens. For the spot lens, the grooves are concentric rings, and thus the form of the energy collected at the lens's focus is pointy, as shown in the figure (1.6 a) [10]. While in the linear lens case, the grooves are in the form of lines parallel to one of the sides of the lens, and thus the form of the energy collected at the lens focus is in the form of a line, as shown in the figure (1.6 b) [11].

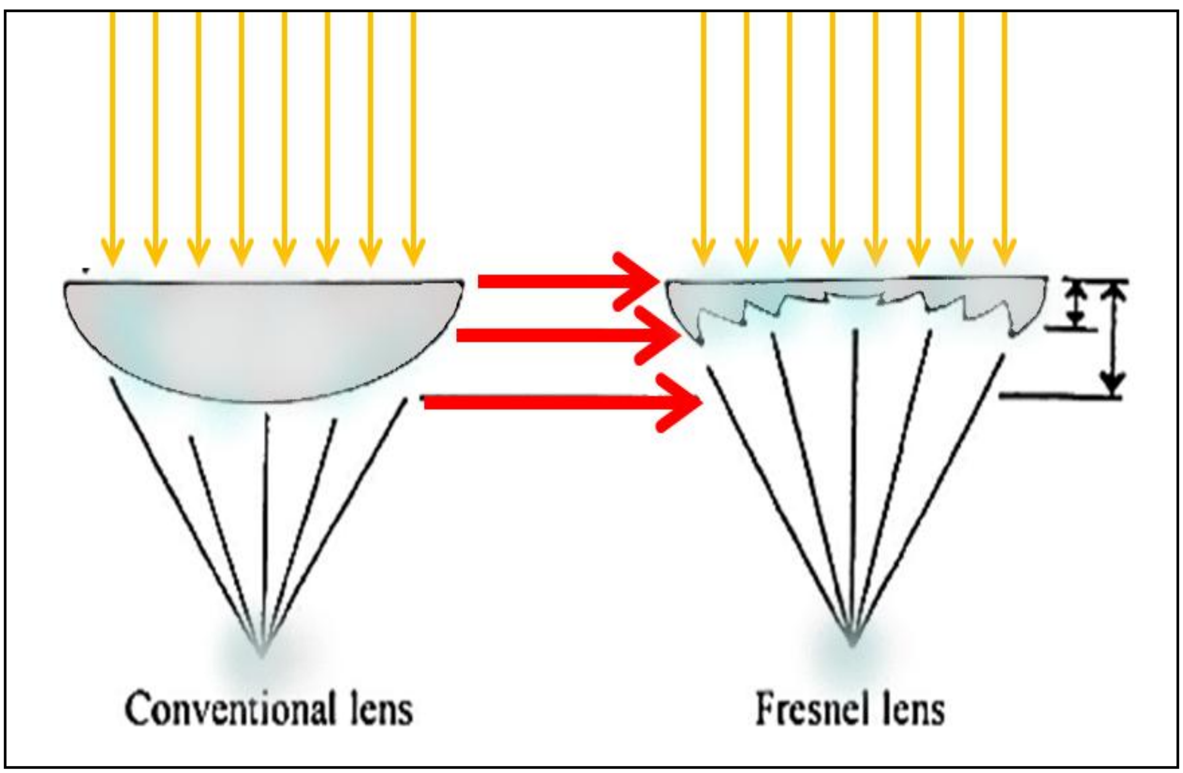


Figure (1.5): Converting a convex lens to a Fresnel lens [8].

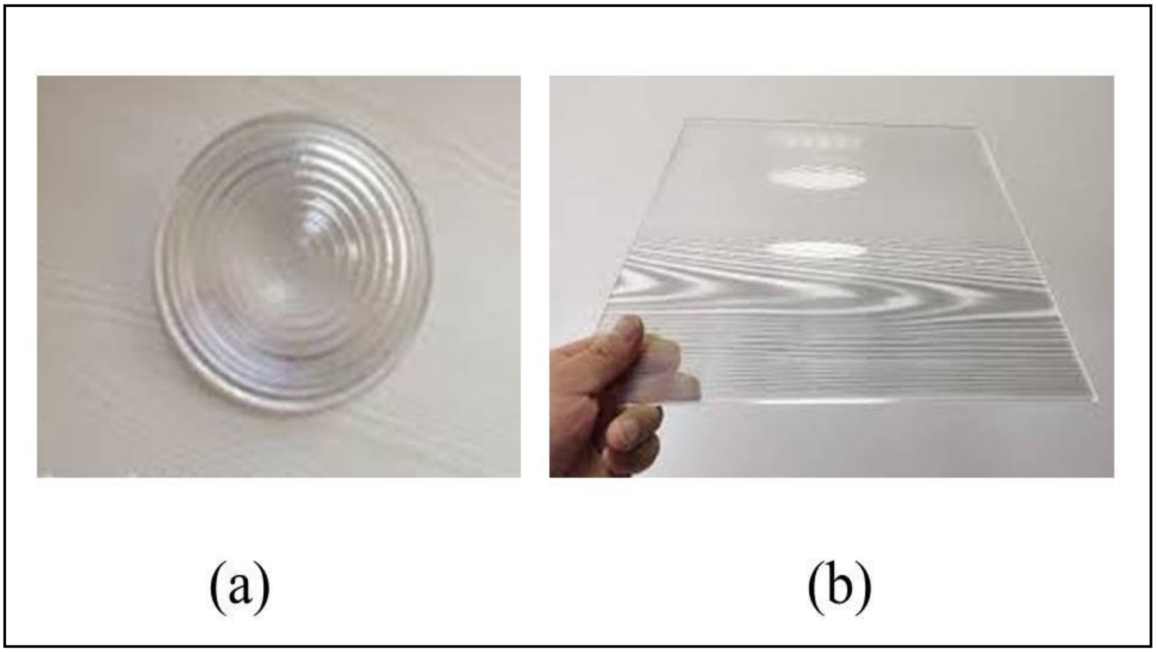


Figure (1.6): (a) Spot Fresnel lens [10] and (b) Linear Fresnel lens [11]

1.3 Surgical Equipment Sterilization

Sterilization eliminates all life forms of organisms (microbial life) that live on the surface of medical-surgical equipment and cause infection and then diseases [12].

Generally, the sterilization process is carried out in three methods [13]:

1.3.1 Physical Sterilization

The surgical equipment sterilization by this method is carried out using heat through one of the following means: -

i. Wet sterilization (**Autoclaving**): Or moist heat by directly exposing surgical equipment to wet steam. This steam must be at a temperature of 121.1 ˚C or greater than that and pressure of 2.1 bar for 15 - 30 minutes (according to the type of surgical equipment). This time may be reduced using steam with higher temperatures [14].

ii. Dry sterilization (Dry heating): This is done by exposing surgical equipment to dry hot air at a temperature of 160 ˚C or greater for not less than 60 minutes. Sometimes, the sterilization duration reaches 120 minutes according to the type of organisms to be disposed of [15 and 16].

1.3.2 Chemical Sterilization

The sterilization by this method is done by one of the following means [17]: -

a) Eto sterilization,
b) Vaporized H_2O_2 (VHO),
c) Chlorine dioxide (CLO_2),
d) Ozone (O_3),
e) Formaldehyde steam (HCHO-steam),
f) Aqueous glutaraldehyde solution,
g) Peracetic acid solutions,
h) Low-temperature gas plasma sterilization,
i) Hydrogen peroxide gas plasma.

1.3.3 Sterilization by Radiation

The sterilization by this method is divided into two types: lionizing UV radiation and non-ionizing UV radiation [18].

1.4 Solar Sterilization

The need for this type of sterilization came through the impossibility of using sterilizers in remote areas due to the lack of electricity. Therefore, it was necessary to use alternative energy, the most important of which is solar energy.

In 1976, it was the first time to use solar sterilization, where the parabolic dishes were used to concentrate solar radiation [19]. After that, solar sterilization began to develop over time using different techniques of solar collectors and others.

Figure (1.7), which was created by the researcher after thorough investigation into the references, depicts the chronological evolution of solar sterilization and the methods employed for this purpose.

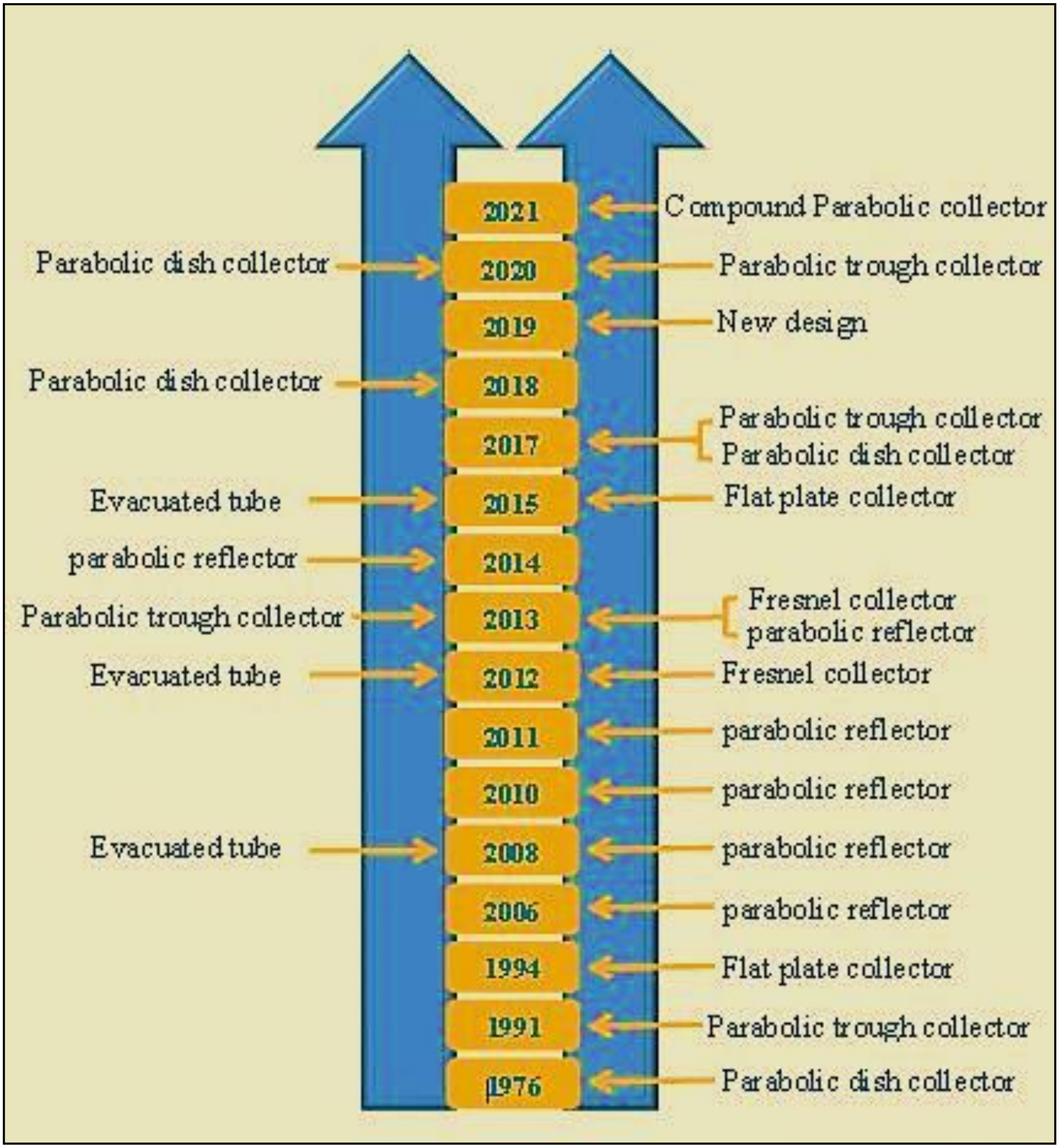
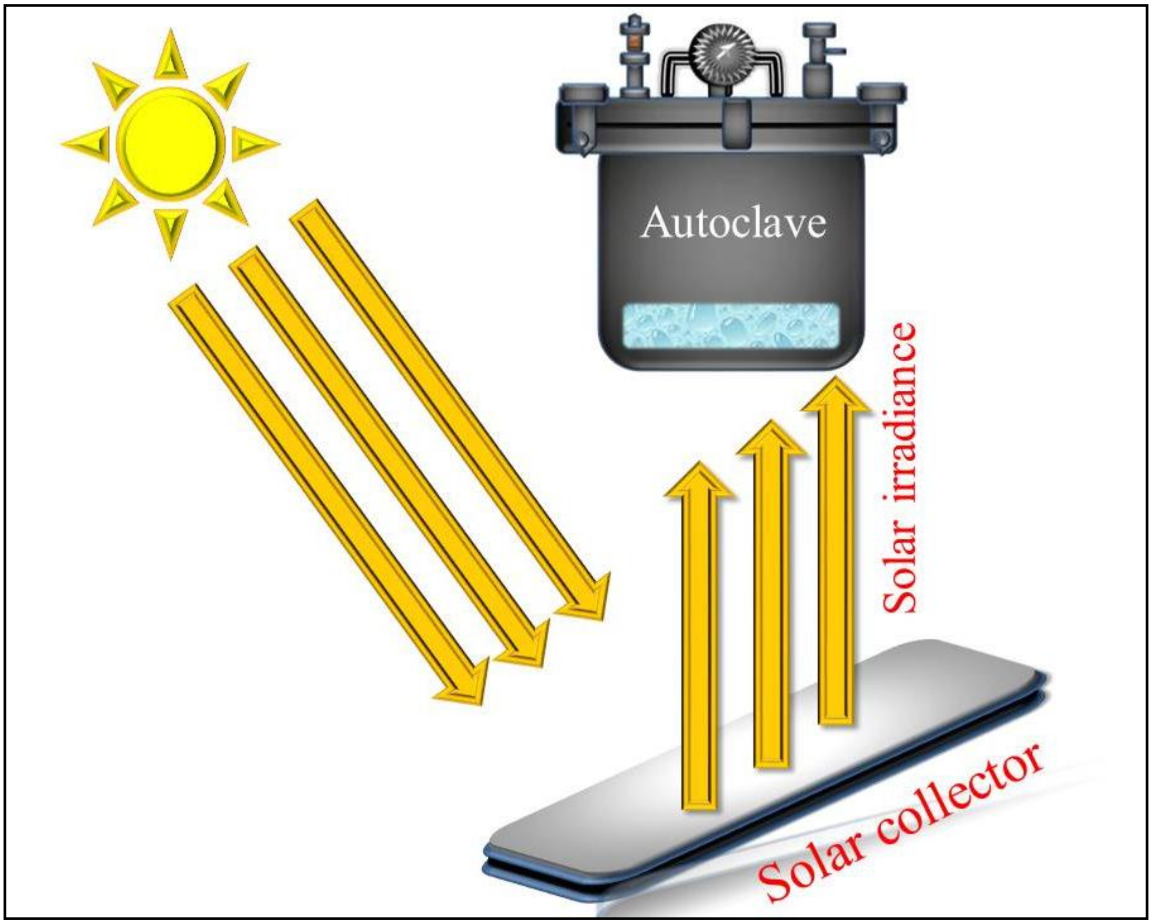


Figure (1.7): The temporal development of solar sterilization and a solar concentration used techniques

According to the heat transfer method to autoclave, solar sterilisers can be divided into two types:-

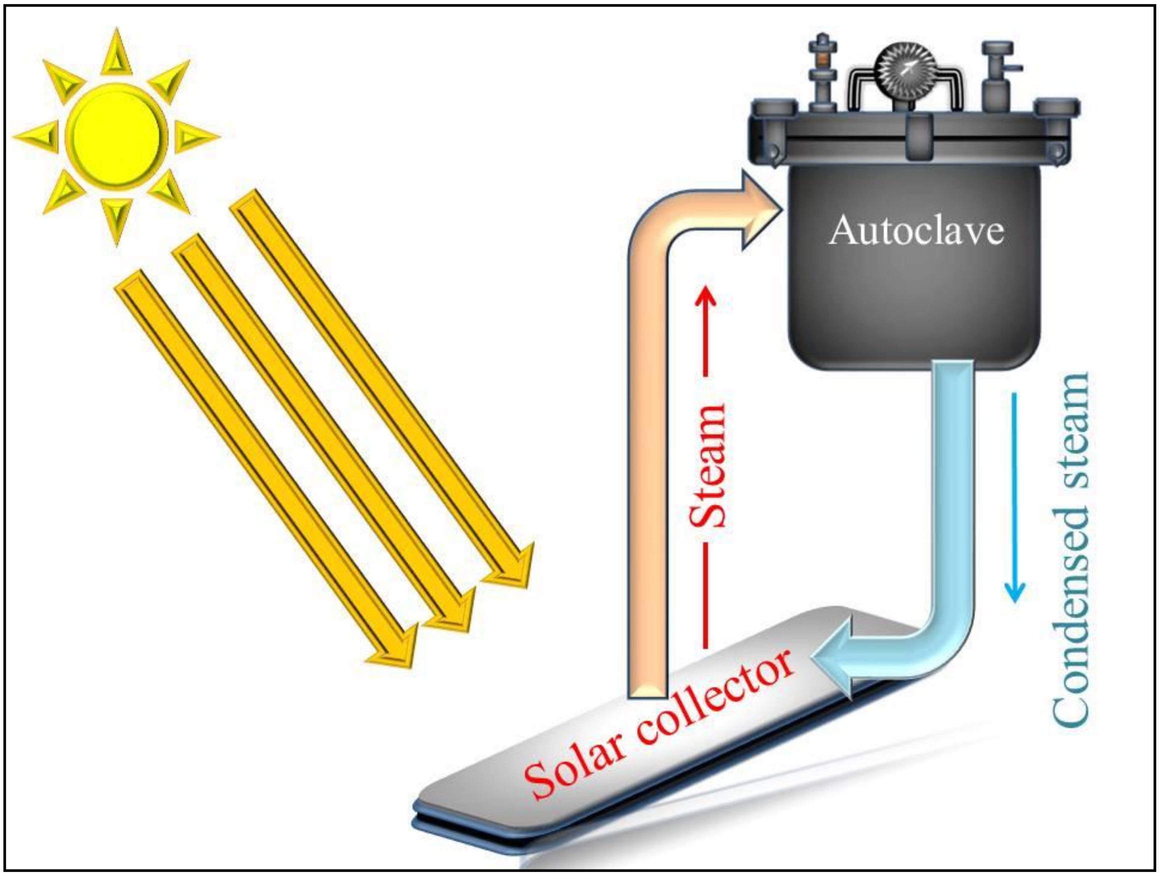
1. The direct method: In this method, the solar radiation is concentrated directly towards the sterilization unit. This radiation is converted into heat energy to generate the sterilizing fluid inside this unit., as shown in figure (1.7).



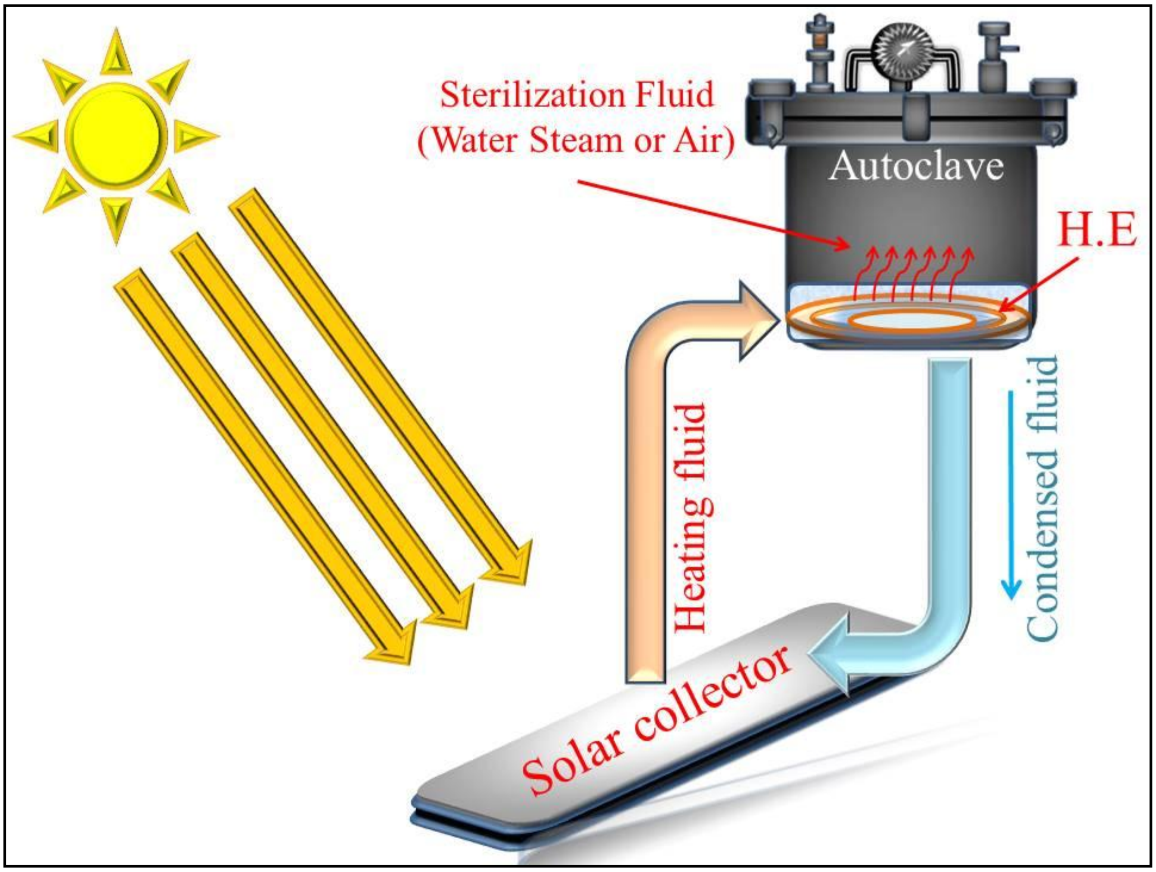
Figure(1.8): Direct method of heat transfer from solar collectors to the autoclave (without working fluid)

2. The indirect method: this method differs from the first method mentioned above. This method generates a fluid (steam or air) with a high temperature inside a solar absorbent vessel or any container. This is by using a solar concentrator to obtain this fluid in a short time. Then, this fluid is then

transmitted into the sterilization unit to be used directly as a sterilizing fluid (indirect system with one working fluid) as shown in figure (1.9), or the heating fluid is generated inside a solar absorbent vessel. Heating fluid can be any type of thermal fluid such as nanofluid, oil, or any other thermal fluid that might pollute the environment or surgical equipment if it comes into contact with them. This fluid is used to produce the sterilizing fluid in this unit. This is done through the heat exchange between the two fluids using a heat exchanger (H.E) installed inside the sterilization unit (an indirect system with two working fluids), as shown in figure (1.10).



Figure(1.9): Indirect method of heat transfer from solar collectors to the autoclave (with one working fluid)



Figure(1.10): Indirect method of heat transfer from solar collectors to the autoclave (with two working fluids)

1.5 Aim of Current Study

The current study aims to obtain a successful sterilization process of surgical instruments used in medical equipment in the shortest possible time. An experimental model of a novel solar system with low cost would be designed and manufactured to achieve this aim. This system would consist of two sterilization chambers; first, steam is used as a sterilizing fluid. In the second, the air is used as a sterilizing fluid after heated to a certain temperature.

To improve the solar system's performance, a heat exchanger would be used inside sterilization chambers. At the same time, a solar absorbent vessel would be installed to develop this system working. The task of this vessel is to obtain steam at a certain temperature and pressure, and then this steam is used to produce the sterilizing fluids.This is through the heat exchange between them using the heat exchanger presented in each sterilization chamber. The steam inside the solar vessel may not be generated without using solar concentrators. So, a reflective oval dish and Fresnel lens would be installed in the solar system to obtain the steam inside the solar vessel faster.

Chapter Two
Review of Previous Literature

Introduction

This chapter will summarize studies dealing with medical-surgical equipment sterilization using solar energy. Different methods or techniques were used in these studies to obtain a working fluid for the sterilization processes. Also, different techniques were used to increase the solar radiation concentration, such as the Fresnel lens, reflective mirrors, the reflective dish, and others.

2.1 Previous Studies

Kaseman et al. (2012) [20] made a solar system consisting of 2 m^2 of semi-parabolic mirrors made of aluminum foil called "Capteur Soleil" and mounted on a steel frame. At the front of the mirror's centre, a steel tube works as a boiler 1.5 m above the mirrors. It is filled with water by a small pump that operates manually. The sun-tracking mechanism was manually controlled to obtain the largest solar radiation. The solar radiation energy is transmitted by the mirrors to the water through the steel tube walls to generate steam at a temperature of 150°C for several hours. Then this steam is allowed to heat a plate that heats a thermally insulated autoclave containing medical equipment and an amount of water to generate steam as a sterilizer. The results showed that the system used in this study could produce a sterilizing fluid (steam at a temperature of 121 °C inside an autoclave) and keep it at 30 minutes.

Trabia (2012) [21] manufactured a solar autoclave consisting of 12 vacuum copper tubes placed on an inclined frame. All tubes are connected to the main tube located in the head of this frame, connected to an autoclave located at the top of the system with 25 liters. The main tube was insulated with a thickness of (0.5 in), and the autoclave was isolated with a thickness of (1.5 inches). It was found that this autoclave produces steam as a sterilizer at 121°C and 1.2 bar and is kept for 50 minutes.

Dravid et al. (2012) [22] designed and manufactured a solar collector consisting of a concave surface that forms a parabola. It covers an area of 2.75 m^2 made of ionized aluminum sheets. To focus solar energy towards its focus located in front of its center, where there is a metal ring to install the autoclave (pressure cooker) with a capacity of 40 liters. The results showed that the solar concentrator used in this research could generate steam at 115 °C. Because January is the coldest month of the year, it was difficult to achieve the required temperature in a short time during the experiments. However, the fastest time was obtained at under 25 minutes instead of 45 minutes by using black paint on the autoclave's body.

A closed system provided with a solar concentrator (0.67 m^2 plastic Fresnel lens) was constructed by **Neumann et al. (2013) [23]**. This lens focuses the solar radiation at its focal point, located on a small tank containing water. Nanomaterials are mixed with water in this tank to accelerate vapor generation. After that, the generated vapor is transferred by tubes into a pressure cylinder representing the sterilization chamber. The steam generation vessel, steam transfer tubes, and sterilization cylinder are insulated to eliminate or minimize heat losses. It was found that adding Fresnel lens and nanomaterials simultaneously improves the solar system performance greatly. Briefly, the sterilization fluid (steam at a temperature of 121 ˚C and 0.9 bar) can be generated during 126 minutes. It was also found that the insulation used in this study maintains the temperature at 121 ˚C for 20 minutes.

Lawrence et al. (2013) [24] used a parabolic shaped solar collector; its internal wall is coated with a reflective material. It is provided with a glass panel from the opposite side of the sun while the other sides are insulated with a thermal insulator. A tube made of galvanized steel is placed to keep it from corrosion, and this tube passes in the focal line of the parabolic reflector. Water passes through it to take the heat that the reflector focuses on the tube to gradually turn into steam, which rushes into the pressure chamber (autoclave). The study was conducted in the Department of Mechanical Engineering, Northern Arizona University. The results indicated that the autoclave system used in this study could generate steam with temperature and pressure at 118 °C and 1.2 bar, respectively. The results also indicated that the insulation could maintain the steam generated under these conditions for 15-20 min.

Chandler (2013) [25] used a solar sterilization system with a reflector covered with small square mirrors that reflect the solar radiation towards the isolated pressure vessel. The results showed that the system needs 40-60 minutes to produce steam at 121°C. The results also showed that this temperature might be maintained for about 20 minutes by stabilizing the pressure at 15 psi, sufficient for the sterilization process.

An autoclave of a parabolic trough with a surface area of 0.363 m^2, a focal length of 1.63 m, a radius of 0.191 m, and an aperture diameter of 0.270 m was used by **Sadhana et al. (2014) [26]**. This trough reflects the solar radiation towards a copper tube with an outer and inner diameter and a length of 0.038 m, 0.034 m and 3.048 m, respectively. This tube is covered with a glass tube with an outer and inner diameter of 0.04 m and 0.038 m, respectively. The copper tube is located along the focal line of a semi-cylindrical reflector where the maximum temperature is 150 °C – 300 °C. The water flow inside the copper tube is $0.220x10^{-3}$ kg/sec. The study was done at an average ambient temperature of 30 ˚C, and the average intensity of solar radiation was 281.2 W/m^2. It was found that the model used can generate steam with a temperature of 125 °C at the outlet of the endothermic. The steam generated inside the autoclave was at 121 °C and 1 bar for 30 min.

Buxbaum et al. (2015) [27] constructed a solar sterilization model (pressure cooker insulated with the cotton quilt) and provided an illustrative plate made of plastic and covered with Mylar. Two sizes of pressure cooker (8 and 22) liters were used. It was shown that, in the case of the smaller cooker, the temperature reached 90 °C for 20 minutes when the wind speed was 6.2 m/s. In the second group, the temperature increased up to 80°C for 40 minutes, when the wind speed was 2.7 m/s. It is believed that the required value of temperature (121 °C) to carry out the sterilization process may be achieved.

Sharma et al. (2017) [28] developed a design consisting of a reflective parabolic trough with a thickness of 0.04 cm and a surface area of 1 m * 1.6 m supported by wood tires. The trough has a focal length of 18.3 cm and a concentration ratio of about 17. It (the trough) reflects the solar radiation towards a metal tube of 58 mm in diameter and 1800 mm in length and passes inside a transparent evacuated tube. Water passes inside the metal tube to exchange the heat with the transparent evacuated tube to convert it into steam used as a sterilizing fluid. The findings indicated that the temperature and steam pressure inside the pressure cooker (the autoclave) are 132°C and 1 bar. The findings too indicated that the generated steam could be maintained with the above properties for more than 15 minutes.

Harikrishnan et al. (2017) [29] manufactured a parabolic trough that collects solar energy to generate steam for the autoclave, which is at the same time a water distillation system. The trough consists of a magnesium-coated aluminum reflector that contains a copper tube with a length of 2.5 feet and a diameter of 30 mm in its centre. The copper tube absorbs heat to generate steam used in the sterilization process. The tests were conducted in Kottayam, Kerala state, India, in 2017. The results indicated that the technique used in this study could produce steam with a temperature of 121°C and pressure of 1.8 bar inside the autoclave for 30min .

Jones et al. (2017) [30] used a model of a closed U-shaped copper tube containing water surrounded by an evacuated glass tube that is placed inclined. Steam is generated inside the copper tube to rise to the top, where it exchanges heat with water inside the autoclave, which was used in two sizes (13 liters and 1.5 liters). The results were the generation of sterilization steam inside the autoclave with properties of 121 °C to 134 °C with the pressure of 0.98 bar to 2.12 bar during (55 - 80) minutes when using the large size with 15 heating tubes. And during (40-65) minutes for small sizes using one tube.

The performance of a parabolic dish-shaped solar collector with a diameter of 1.75 m coated with reflective aluminum foils was studied by **Asfafaw et al. (2018) [31];** it reflects solar radiation towards its focal point, which locates on a solar absorbent vessel with a 3 mm thickness. It contains a thermometer, pressure gauge and relief valve to maintain the steam pressure at the required value for sterilization standards. The sidewalls of this vessel are insulated with 25 mm of glass wool except for the wall, which is faced the dish. The system is provided with a support structure and a solar tracking system. The intensity of solar radiation during the tests ranged between 816 W/m^2 and 964 W/m^2. The results showed that this technique could produce steam at a temperature of 147 °C and kept it at 15 minutes.

Birhanu and Kahsay (2018) [32] in an experimental study, used a parabolic dish as a concentration device to improve the performance of a solar sterilization model (cooker). The parabola dish is coated with reflective aluminum foils to increase the solar radiation concentration towards the sterilization unit. It was known that the average solar radiation intensity during the test period was about 750 W/m2. It was shown that the dish device could generate steam at a temperature of 121°C and pressure of 2 bars (the required conditions for the sterilization) maintained for 10 to 30 minutes. The relief valve was calibrated, and steam was obtained with temperature and pressure of 128 °C and 2.6 bar, respectively, within 40 to 60 minutes.

Chang et al. (2019) [33] designed and manufactured a solar sterilization model that consists of a double-walled manifold evacuated tube that serves as a heater that supplies heat to the pores of the evaporator. More heat is added to the generated steam using a network of copper tubes inside the evacuated tube to produce superheated steam without raising the pressure. It is known that the solar radiation intensity during the tests was 600 W / m2. The experimental results indicated that the manufactured model in this work could produce a sterilizing fluid (steam at 121 °C). The researchers believe that the model has the potential to generate steam at 165 °C.

A solar sterilization model (pressure vessel) modified by two reflective wings and 140 square pieces of reflective mirrors were designed and manufactured by **Liao V.T. and IIH Solarclave (2019) [34]** The reflective mirrors were fixed on a wood frame, separated by plywood. The pressure vessel is surrounded by fibreglass, except for the part which is faced the mirrors, followed by a cover of plastic. This cover forms a cavity at the bottom of the pot to receive more solar radiation reflected by the mirrors. It was found that the technique used in this work can produce steam at 148.8 °C and 2 bar.

A solar system (steam generator) consists of a coiled copper tube that serves as a solar collector based on a layer of floating foam was used by **Xinyu Wang et al. (2019) [35]**. The copper tube has surfaces coated with a super waterproof layer of black copper oxide to prevent tube corrosion, absorb heat, and prevent clogging. Solar steam is generated at the entrance to the copper tube through the evaporation of water, which is carried by a wick to the tube's inlet, and then heated inside the hot tube because it absorbs solar radiation when the steam moves from the tube inlet to its outlet. The solar system was tested in two cases; the first was installing the copper tube in a horizontal position completely in contact with the water. At the same time, the second case is an installation of the copper tube in a tilted position at a certain angle. The results showed that the horizontal position of the copper tube gives better results and larger matching with the sterilization criteria. The temperature of the generated steam exceeded 100 °C under direct sunlight and 250 °C with the use of a solar concentrator with a concentration ratio of 10. A biological indicator was used to verify the success of the sterilization process. It was placed in the tube outlet for 2.6 minutes, during which time the temperature of the steam was 132 °C. The indicator showed the success of the sterilization process.

Zhao et al. (2020) [36] designed and made a solar collector with an area of 2 m^2 consisting mainly of a heat-absorbing material (copper plate) coated by a black layer to absorb the solar radiation. Directly, it is connected to a group of tubes from the bottom.

Water passes inside the tubes to absorb heat from the black copper layer to convert it into steam, and this steam is used as a sterilizer for medical materials. There is also a parabolic aluminum trough on the sides that reflects the solar radiation towards the black copper plate to increase the amount of heat absorbed by the water and thus accelerate the steam generation process. The results showed that the modified model could generate steam at a temperature of 128 °C and pressure of 2.5 bar, and they can be kept at these values for 30 minutes which is enough time for the sterilization process.

Tyroller (2020) [37] built a solar autoclave consisting of a Scheffler reflector with an area of 10 m^2, concentrating the solar radiation on a mass of 230 kg of iron to raise its temperature to 500 C. Adjacent to this mass, there is a coiled copper tube in which steam generated and moves freely to the autoclave chamber (76 liters). The model can perform the sterilization process 3-4 times daily. The model is equipped with an electric or gas boiler to ensure continuous operation when the weather is not suitable.

Khan et al. (2020) [38] made an experimental model (black pressure cooker) provided with a parabolic dish covered with aluminum metal to increase the solar reflectivity. It contains 0.3 liter of water and 1.5 kg of medical instruments. The results displayed that the parabolic dish produces steam at 121°C and pressure of 1.029698 bar. The results also displayed that these properties can be kept for 15 minutes, considered enough to carry out the sterilization process.

Yadav et al. (2020) [39] developed a solar sterilization system using a parabolic reflector controlled manually. It (the parabolic reflector) is covered with a layer of glass and a transparent polycarbonate sheet to reduce the heat convection losses from the glass surface. The system contains a metal tube inside which water passes to the autoclave, where the sterilization of medical equipment is done. The intensity of solar during the test period is 700 watts / m^2. The results of this study exhibited that the maximum temperature of the generated steam does not exceed 100 ˚C, and this value does not match the required conditions for sterilization. So, the used technique in this study could not achieve its required aim.

2.2 Previous Studies Summery

No	Author(s), Country, Year	Solar thermal technology	Heat transfer way		Operating conditions		Reference
			Direct	Indirect W.S.F	T (°C)	P (bar)	
1	Kaseman et al. USA, 2012	Fresnel collector		Water	>121	1	[20]
2	S. S. Trabia, USA, 2012	Evacuated tube collector		Water	121	1.2	[21]
3	Dravid et al. India, (2012)	Parabolic cooker	Direct		115	0.9	[22]
4	Oara Neumann et al. USA, 2013	Fresnel collector		Nano-fluid	115	0.8	[23]
5	Blake Lawrence et al. USA, (2013)	Parabolic trough collector		Water	118	1.2	[24]

6	David L. Chandler Nicaragua, (2013)	Parabolic reflector	Direct		121	1.03	[25]
7	B. Sadhana et al. India, (2014)	Parabolic trough collector		Water	121	1	[26]
8	Buxbaum et al. Nicaragua, (2015)	Panel cooker	Direct		90	1	[27]
9	N. K. Sharma et al. India, (2017)	Parabolic trough collector		Water	132	1	[28]
10	Harikrishnan et al. India, (2017)	Parabolic trough collector		Water	121	1.8	[29]
11	Rhys Hardwick Jone et al. Australia (2017)	Evacuated tube		Water	121–134	0.98–2.12	[30]
12	Asfafaw Haile et al. Ethiopia, (2018).	Parabolic dish collector	Direct		147	0.9	[31]

13	Birhanu et al. Ethiopia, (2018)	Parabolic dish collector	Direct		121	2	[32]
14	Chang et al. China, (2019)	Double-walled vacuum tube	Direct		>121	N.A.D	[33]
15	Liao et al. Nicaragua, (2019)	Parabolic reflector	Direct		148.8	2	[34]
16	Wang et al. China, (2019)	Coiled copper tube	Direct		100-250	P_{amb}	[35]
17	Zhao et al. India, (2020)	Parabolic trough collector		Water	128	2.5	[36]
18	Michael Tyroller et al. India, (2020)	Parabolic reflector		Water	500	N.A.D	[37]
19	Khan et al. Bangladesh, (2020)	Parabolic dish collector	Direct		121	1.029	[38]
20	Manoj .K .Y et al. India, (2020)	Compound parabolic collector		Water	100	1.013	[39]

21	present work	Fresnel lens and reflective oval dish		Water			

2.3 Scope of Current Study

Previous research used different techniques such as Fresnel lens, reflective dishes, or reflective mirrors to develop solar sterilizers. At the same time, these techniques may be used in two ways (direct and indirect, as explained in chapter one of this study). In some research, they were used directly, and in other research, they were used indirectly.

In the current study , an experimental model of a solar system consisting of two sterilization chambers would be designed and manufactured. This chambers is designed in such a way as to give the system an initial heating. The sterilizing fluid in one of the two chambers is steam, and in the other is dry, hot air. After that, a cylindrical solar absorbent vessel would be installed in this system. This vessel contains water converted into steam at a specific temperature and pressure to generate sterilizing fluids. This is done through heat exchange by a heat exchanger installed in each chamber. To obtain this steam as quickly as possible, a Fresnel lens and a reflective oval dish would be used as solar concentrators to increase the intensity of incident solar radiation on the solar absorbent vessel.

These are research methods; the aim to obtain an advanced solar-powered system that can successfully perform its function as a surgical equipment sterilizer as soon as possible.

Chapter Three

Mathematical Modeling

This chapter deals with the mathematical calculations of the focal length, solar radiation concentration ratio, and concentrated heat quantity towards the solar absorbent vessel. This is calculated for both the Fresnel lens and the reflective oval dish. The rim angles of the oval dish are also calculated. Also included in this chapter are the calculations of the thickness, the steam generation time, and the useful heat quantity of the solar absorbent vessel with dish only and dish and lens together. In addition to the calculations of the time of producing wet steam or dry, hot air as sterilizer fluid inside the sterilization units with and without a heat exchanger, figure (3.1) shows a schematic diagram of the solar sterilization system used in the current study.

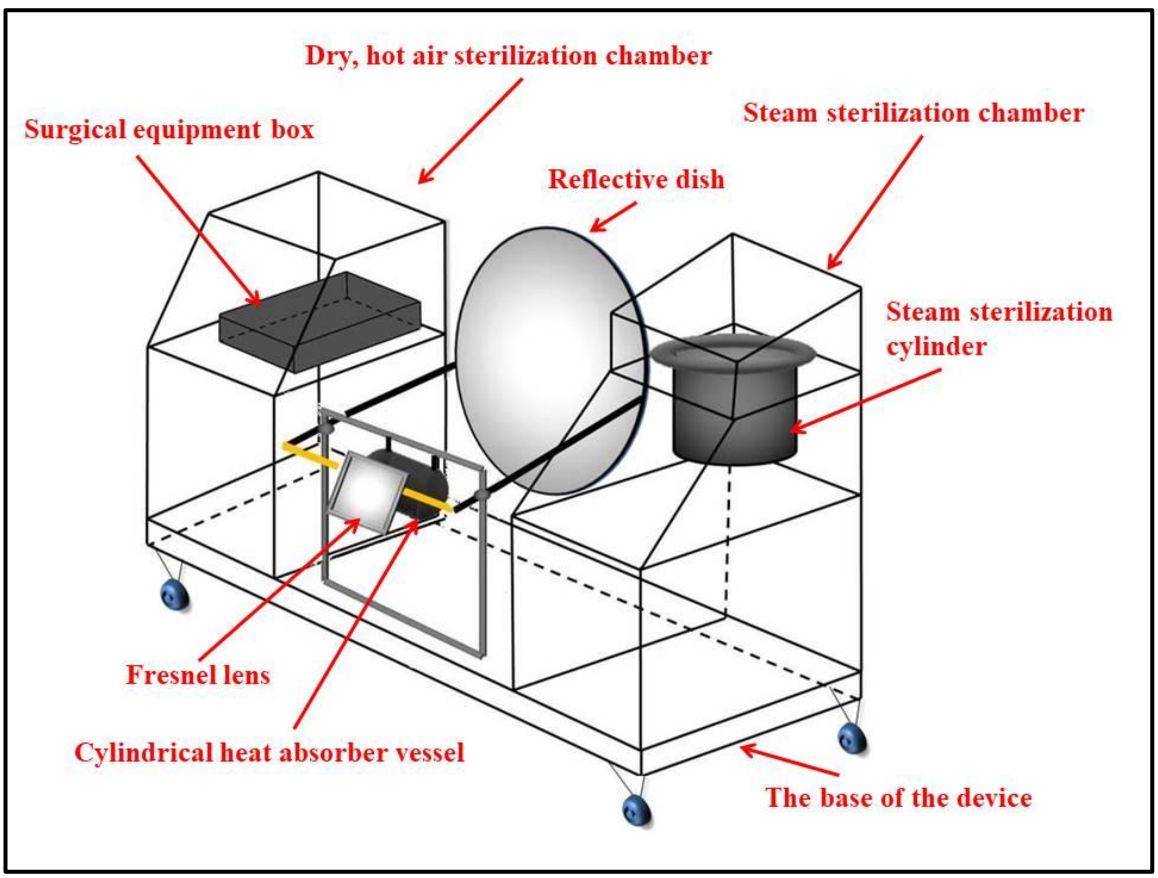


Figure (3.1) shows a schematic diagram of the solar sterilization system

3.1Analytical Accounts

In this study, the following principles were mainly relied upon in the design and evaluation of the solar autoclave, as they have a direct impact on the values of the required sterilization requirements, whether dry sterilization or steam sterilization:

1. Time and date: that means the climatic conditions (intensity of solar radiation, ambient temperature, wind speed), as well as the location where the model is used (latitude and longitude).

2. The materials used to make the parts of the solar system (the properties of the material used for each part).

3. The dimensions of the device.

In this part, a mathematical model for a solar sterilizer is constructed based on several assumptions:

1. The system is in thermal stability.

2. Air is a perfect gas.

3. Heat flows through the walls in one direction.

4. Friction is very small and can be neglected.

5. Considering the sky as a black body.

6- The reflective oval dish used has a large diameter of 100 cm, small diameter of 90 cm, and a height of 9.3 cm. Choosing the dish with these dimensions gives a focal length that ensures an appropriate height of the device for the average human height.

7- The used Fresnel lens (available in Iraq) is square with a side length of 31 cm, a transmittance of 0.92, and a prism angle of 42°.

8- The cylindrical heat absorbtion vessel volume is 0.704 liters (8 cm in diameter, 14 cm in length, and 0.3 cm in thickness). These dimensions are suitable to contain the area of solar radiation concentrated by the dish.

The following hypotheses were chosen (in accordance with the anticipated weather on April in Iraq, where the experiments would be conducted), in order to simplify the theoretical calculations:

a) The average solar radiation intensity is 600 W/m^2
b) The ambient temperature is 30 °C.
c) The average wind speed is 2 m/s.
d) The optical efficiency is 0.76% [40].
e) The effectiveness of a heat exchanger is one.
f) The diameter of the heat exchanger tube is 9.5 mm.
g) The initial water temperature inside the steam sterilization cylinder and the heat-absorbing vessel is 30°C.
h) The steam sterilization cylinder is made of aluminum, $\rho_{AL} = 2700\ kg/m^3$, $C_{p,AL}$= 896 J/kg. k [56].
i) The heat-absorbing vessel is made of stainless steel, ρ_{st} = 7865Kg/m³, $C_{p,st}$ =468 J/ Kg. K [56].

The goal of the computational model is to

a) Calculation the temperature and pressure of steam inside the cylindrical heat-absorbing vessel is done at regular intervals until the temperature reaches 160 °C and the pressure reaches 6.2 bar.
b) Calculation the temperature and pressure of steam inside the steam sterilization cylinder is done at regular intervals until the temperature reaches 121.1 °C and the pressure reaches 2.1 bar.
c) Calculation the air temperature inside the sterilization chamber with hot, dry air at regular intervals until it reaches 160 °C.

3.2 Reflective Oval Dish

The dish utilized in the current work is a concave reflective oval dish with the dimensions shown in figure (3.2). The calculations of the reflective oval dish also include calculating the focal length of the dish (f_d), the ratio of solar radiation concentration of the dish (C_d) and the rim angle of the dish. As well as the amount of heat energy concentrated by the dish towards the heat absorbtion vessel (Q_d).

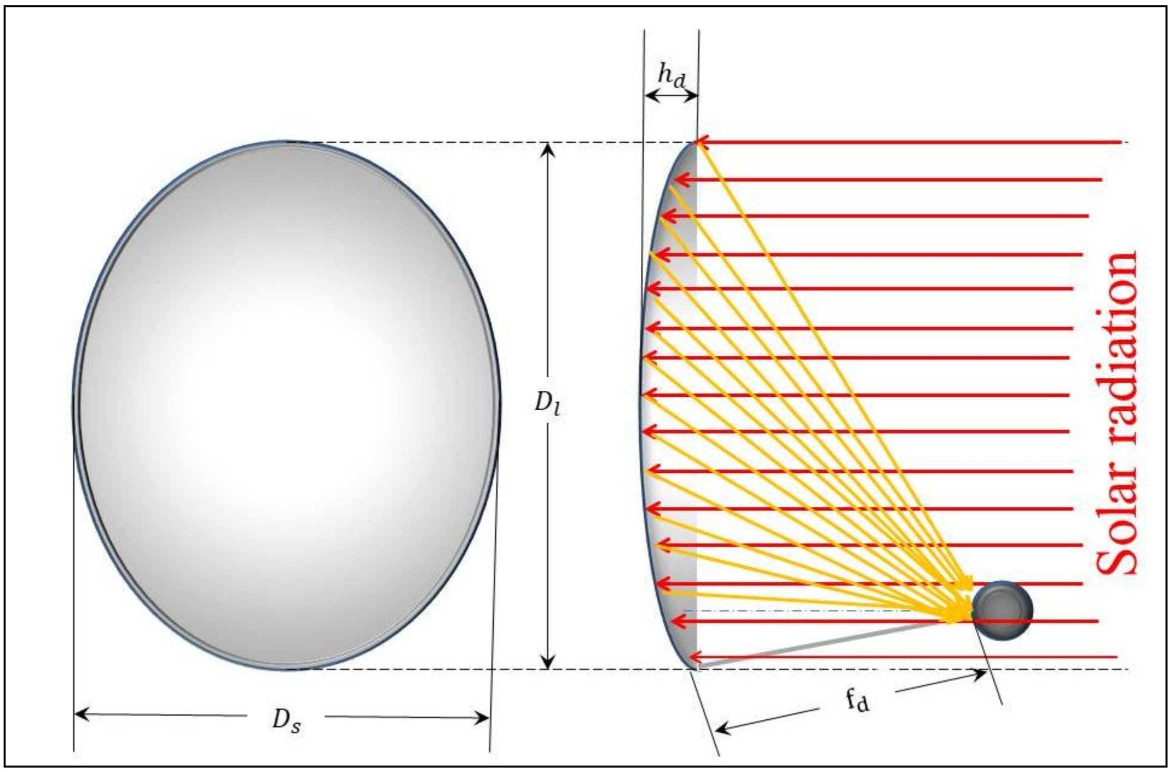


Figure (3.2): The Schematic Diagram of Reflective Oval Dish

3.2.1 Focal Length

The focal length of the reflective oval dish (f_d) can be found by the following equation [41&42]: -

$$f_d = \frac{(D_S)^3}{16\, h_d\, D_l} \quad \dots (3.1)$$

3.2.2 Rim Angles

The reflector oval dish has two rim angles. The first (ψ_1) is between the perpendicular line on the dish aperture surface from the solar radiation concentration point (the focus of the dish) and the connected line from one of the dish sides to the solar radiation concentration point. The second (ψ_2) is between the perpendicular line on the dish aperture surface from the solar radiation concentration point (the focus of the dish) and the connected line from the upper central point of the oval dish to its focus. This is shown in figure (3.3).

Two equations of computing the two rim angles of the reflector oval dish are as follow [43]: -

$$\tan\psi_1 = \left(\frac{f_d}{D_l}\right)\Big/\left[2\left(\frac{f_d}{D_l}\right)^2 - 0.125\right] \quad \ldots (3.2)$$

$$\tan\psi_2 = \left(\frac{f_d}{D_S}\right)\Big/\left[2\left(\frac{f_d}{D_S}\right)^2 - 0.125\right] \quad \ldots (3.3)$$

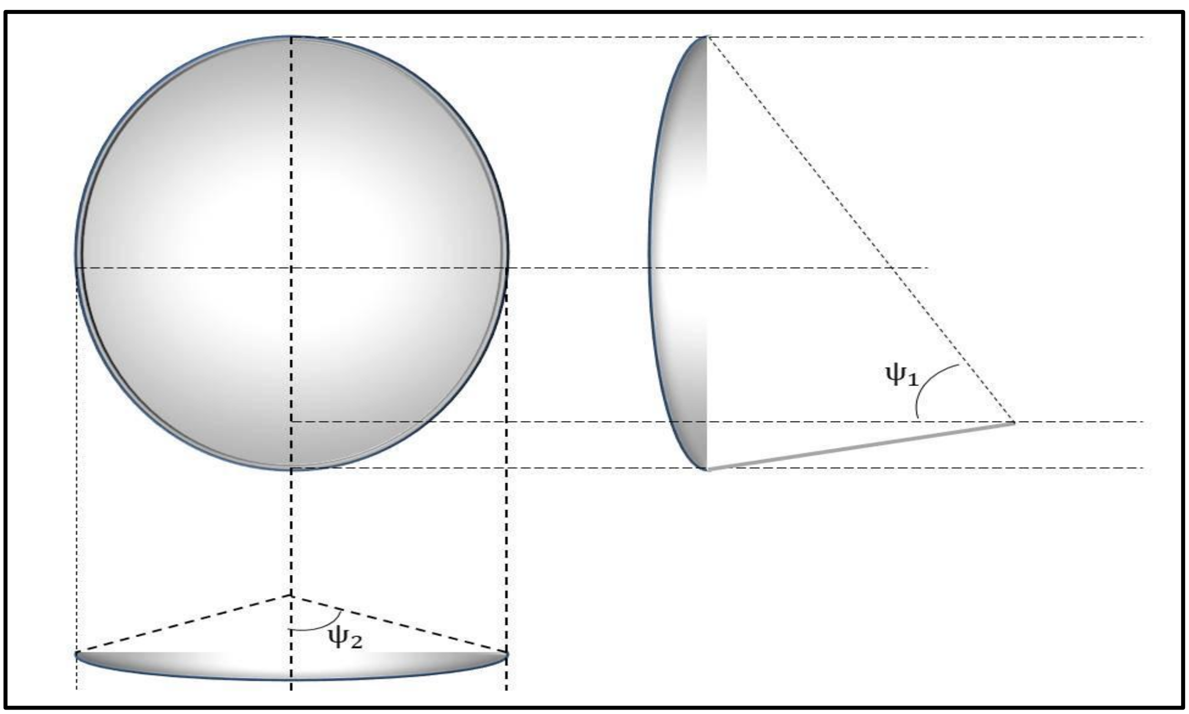


Figure (3.3): The Rim Angles of Reflective Oval Dish (Ψ)

3.2.3 Concentration Ratio

It is the ratio of the aperture area of the reflector dish (A_d) (the area which faces the solar absorber vessel) to the area of concentration of solar radiation on the surface of the heat-absorbing vessel (A_r) [44]

$$C_d = A_d/A_r \quad \text{... (3.4)}$$

To determine the surface area of the reflector oval dish (A_d), the following equation can be used as follow as **[**44**]**: -

$$A_d = \pi D_l D_s/4 \quad \text{… (3.5)}$$

To find the area of concentration of solar radiation at the focus point on the surface of the heat-absorbing vessel **[**44**]**: -

$$A_r = \pi \, s \, r \quad \text{… (3.6)}$$

Where:

s and r are the maximum and minimum radius of the oval dish focus area , respectively, as shown in figure (3.4). They can be found by applying the following two equations [44]: -

$$r = f_d \ \theta s/(1 + \cos\psi_2) \quad \text{… (3.7)}$$

$$s = f_d \, \theta s/[(1 + \cos\psi_1)\cos(\psi_1 + \theta s)] \quad \text{… (3.8)}$$

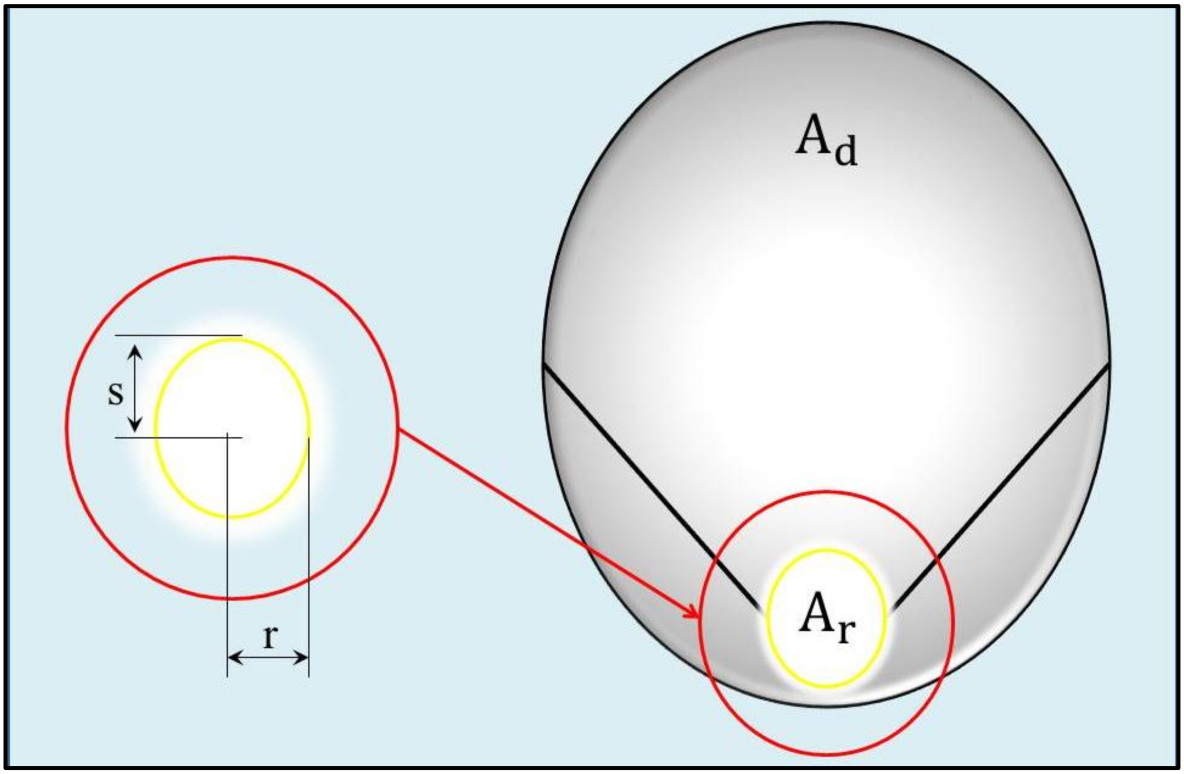


Figure (3.4): The Dimensions of the Oval Dish Focus Area

3.2.4 Concentrated Heat Quantity by Dish

The function of the reflector oval dish is also collecting the solar radiation (I) and reorientating it towards the solar absorber vessel (Q_d).

The amount of heat concentrated by the oval dish towards the solar absorber vessel depends on the following points [44]: -

1- The main dimensions of the oval dish,
2- The reflectivity of the paint of the dish,
3- The cleanliness of the reflective layer (the dust collection),
4- Inaccuracy errors in the solar tracking system,
5- Vibrations caused by the strong wind،
6- The heat absorbtion potential of the metal of the solar absorber vessel, and
7- water condensation at the dish surface during the early hours of the day.
8- This in addition to the intensity of the incident solar radiation.

To calculate the amount of heat which is concentrated by the oval dish towards the heat absorber vessel, the next equation is applied as follows: -

$$Q_d = I\, A_d \zeta_p \zeta_{opt}\; C_d \qquad \ldots (3.9)$$

Where: ζ_{opt} is the optical efficiency of the oval dish is the percentage of solar energy striking the sun-facing surface of the reflector dish that then reaches the solar absorber vessel, which can be found using the following two equations as following [45]: -

$$\zeta_{opt} = \propto_V \rho\, S\, \zeta_{clean} \qquad \ldots (3.10)$$

ζ_p is Petela's efficiency in converting radiation energy [46]

$$\zeta_p = 1 - \frac{4T_{amb}}{3T_s} + \frac{1}{3}\left(\frac{T_{amb}}{T_s}\right)^4 \qquad \ldots (3.11)$$

Where:

T_s is the sun's surface temperature, about 5770 K [47].

3.3 Fresnel Lens

In this study, a square and spot Fresnel lens is used with a side length equal diameter of the large circle of its grooves. For the Fresnel lens calculations, three parameters must be calculated: the focal length of the lens (f_L) and the ratio of solar radiation concentration of the lens (C_L). In addition to the quantity of heat concentrated by the Fresnel lens towards the solar absorber vessel (Q_L), it is considered the most important parameter[48] .

3.3.1 Focal Length

The calculation of the focal length of the Fresnel lens depends on the diameter of the largest circle of the lens grooves (R), the angle of the prism of the grooves (α), and the lens position in terms of the position of the groove. The location of grooves may be on the side that faces the receiver (grooves-in) or on the side which faces the sun (grooves-out) [48].

The following equation is to calculate the focal length of the Fresnel lens in the case of the location of grooves facing the receiver (grooves-in) depending on the prism angle (Appendix B).

$$\tan\alpha = R \Big/ \left(n\sqrt{R^2 + (f_L)^2} - f_L\right) \qquad \ldots (3.12)$$

The lens's focal length value is obtained using the trial and error method from the above equation.

3.3.2 Concentration Ratio of Lens

It is the ratio of the heat quantity collected at the focus area of the lens to the incident solar energy quantity perpendicularly on the lens. It also equals the ratio of the effective lens area ($A_L = D^2$) to the solar radiation concentration area at the focus ($A_f = \frac{\pi}{4} d^2$).

The next equation is to find the solar radiation concentration ratio (C_L) **[**49**]**: -

$$C_L = A_L/A_f = 0.83\, D^2 \Big/ \frac{\pi}{4} d^2 \qquad \ldots (3.13)$$

Where:

The number 0.83 for the effective lens area,

D is the Lens side length, and d is the focus area diameter of the lens, as shown in the figure (3.5), and the diameter d can be calculated by the following equation [50]:

$$d = \Delta x + 2\, f_L \tan\theta_s \qquad \ldots (3.14)$$

Where:

Δx: The Diameter of The smallest grooves circle for the Fresnel lens

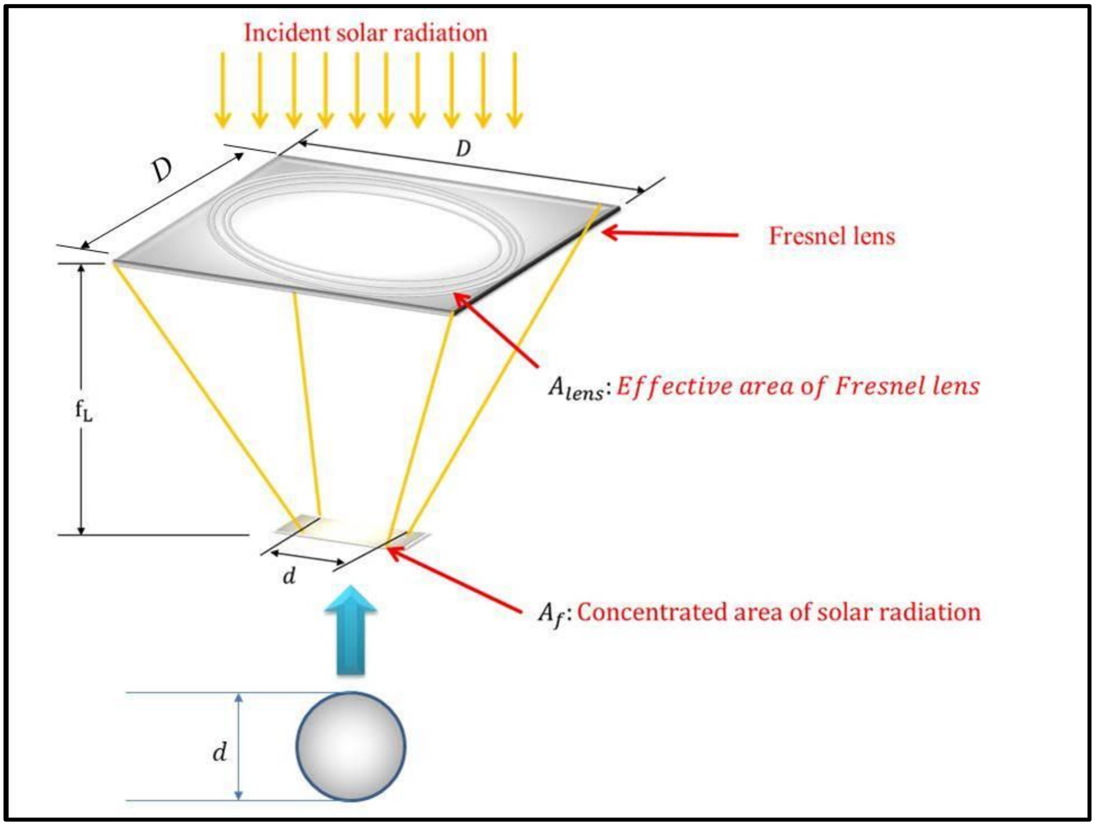


Figure (3.5) : Effective Fresnel Lens Area and Focus Area

3.3.3 Concentrated Heat Quantity by Fresnel Lens

The Fresnel lens function is to collect the solar radiation (QL) and redirect it towards the heat absorber vessel. The Concentrated Heat Quantity by Fresnel Lens depends on the next factors [51]: -

1. The intensity of solar radiation (I),
2. The transmittance of the lens (τ_L),
3. Fresnel lens area (A_L), and
4. The solar radiation concentration ratio of the lens (C_L).

To calculate the amount of heat which is concentrated by the Fresnel lens towards the heat absorber vessel, the following equation is used as follows as [51]: -

$$Q_L = I\,\zeta_p \tau_L\, A_L\, C_L \qquad \dots (3.15)$$

3.4 Solar Absorber Vessel

It is a cylindrical steel vessel placed horizontally at the meeting of the focus points of the lens and dish. To calculate the thickness of the solar absorbing vessel (t_V) is very important because it is considered an incubator for the steam generated. This is because choosing the vessel thickness in an uncalculated way may lead to the explosion of the vessel. For this reason, calculating the thickness is to save the vessel against dangers. There are two types of stresses due to the high pressures on the wall of a cylindrical vessel: longitudinal stress (σ_l) and tangential or hoop stress (σ_h) [52].

The following equation is for calculating the thickness of the solar absorbing vessel according to the longitudinal stress:

$$t_V = P\ D_{V.in}/4\sigma_l \qquad \dots (3.16)$$

Where: P is the steam pressure, $D_{V.in}$ is the inner diameter of the heat absorber vessel.

The following equation is for calculating the thickness of the solar absorbing vessel according to the tangential stress:

$$t_V = P\ D_{V.in}\ /2\sigma_l \qquad \dots (3.17)$$

The effect of longitudinal stress and the tangential stress on the solar absorbent cylindrical vessel is shown in Figures (3.6) and (3.7), respectively. Tangential stress is the most severe and has the greatest effect on the vessel. Therefore, the design of the thickness of the vessel will depend on the effect of tangential stress.

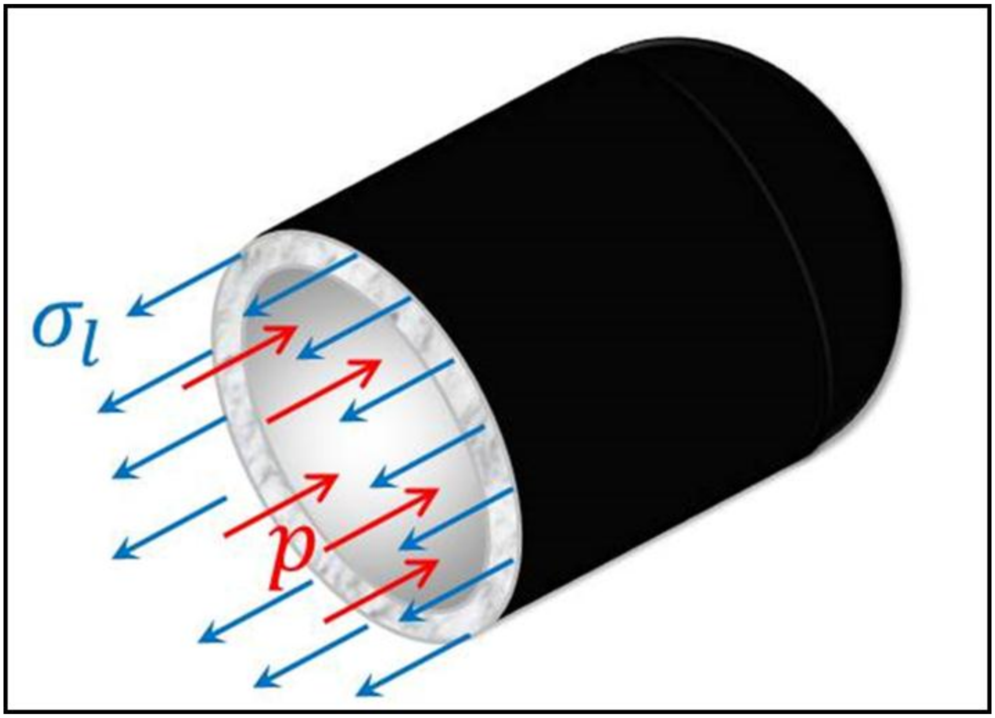


Figure (3.6): The Effect of Longitudinal Stresses on the Cylindrical Solar Absorbent Vessel

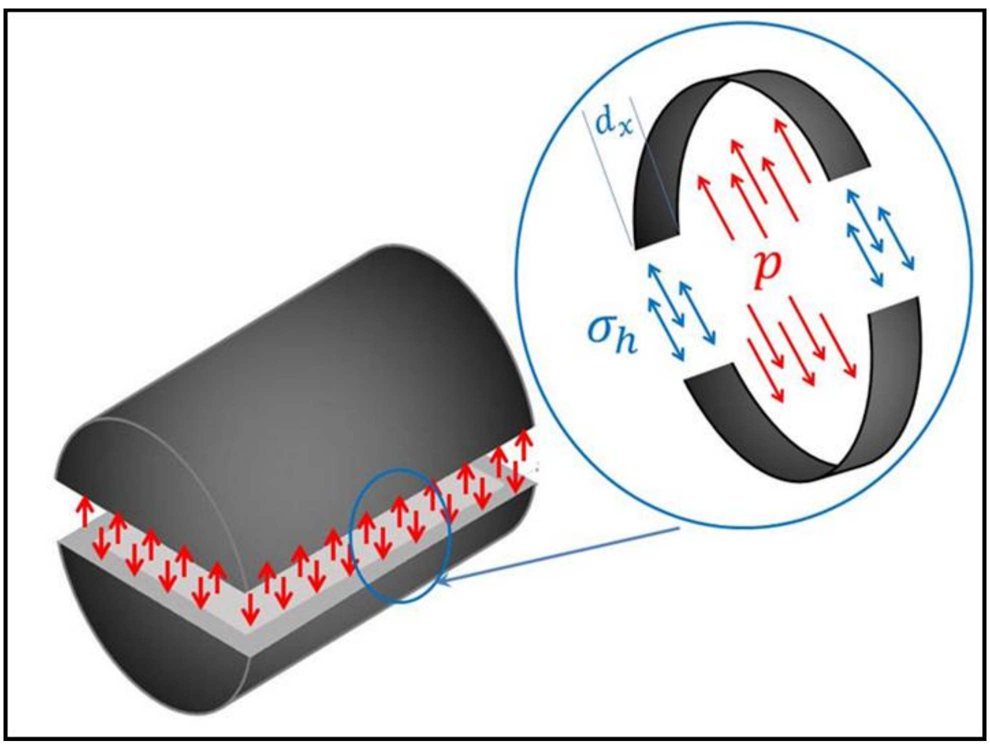


Figure (3.7): The Effect of Tangential Stresses on the Cylindrical Solar Absorbent Vessel

3.4.1 Useful Heat Quantity

The amount of heat required to convert water from the liquid state to the wet steam (from state 1 to state 4) is shown in the T-S diagram in figure (3.8). Thermal balancing of the heat absorbent pan is applied. The total useful heat quantity (Q_u) transferred into the fluid presented inside this vessel**.**

3.4.1.1 Vessel Without Solar Concentrators

This is the case of the heat-absorbing vessel without solar concentrators, where heat is transferred to the water inside the vessel under direct sunlight.

The equation of the thermal energy balance of the solar absorber vessel is as follows:

$$Q_{in} - Q_{losses,v} - Q_{abs,v} = Q_u \quad \dots (3.18)$$

Where: Q_{in} is the solar energy entered into the solar absorbent vessel, and it can be found as follow as [53]:

$$Q_{in} = I\, \zeta_p\, A_s \quad \dots (3.19)$$

Where: A_s is the surface area of the absorbent vessel facing the sun.

$$A_s = 0.5\pi D_{V.O}\, L_V \quad \dots (3.20)$$

And $Q_{losses,v}$ is the thermal energy left in the solar absorber vessel by the heat radiation and convection (heat losses) and can be calculated as following [54]: -

$$Q_{losses,v} = h_W A_{s,total}(T - T_{amb}) + \sigma\, \varepsilon\, A_{s,total} F\left(T^4 - {T_{sky}}^4\right) \quad \dots (3.21)$$

Where:

T is the surface temperature of the vessel at any time, T_{sky} is the effective temperature of the sky, and h_W is the effective coefficient of heat convection of the solar absorber vessel and can be obtained by applying the following equation as follow as [55]: -

$$h_W = 5.7 + 3.8\, V_w \quad ... (3.22)$$

Where:

V_w is the wind speed

The next equation is to obtain T_{sky} [55]: -

$$T_{sky} = 0.0552\,(T_{amb})^{1.5} \qquad \dots (3.23)$$

$Q_{abs,v}$: is the amount of heat absorbed by the walls of the heat-absorbing vessel [56].

$$Q_{abs,v} = \rho_{st} A_{S,total}\, t_V C_{st}(T - T_i)/t \qquad \dots (3.24)$$

By substituting the equations (3.19), (3.21), and (3.24) in equation (3.18), the equation of the total useful heat quantity becomes as follows: -

$$Q_u = I\,\zeta_p\, A_s - h_W\, A_{s,total}(T - T_{amb}) - \sigma\,\varepsilon\, A_{s,total}\, F\left(T^4 - {T_{sky}}^4\right) - \rho_{st} A_{S,total}\; t_V C_{st}(T - T_i)/t \qquad \dots (3.25)$$

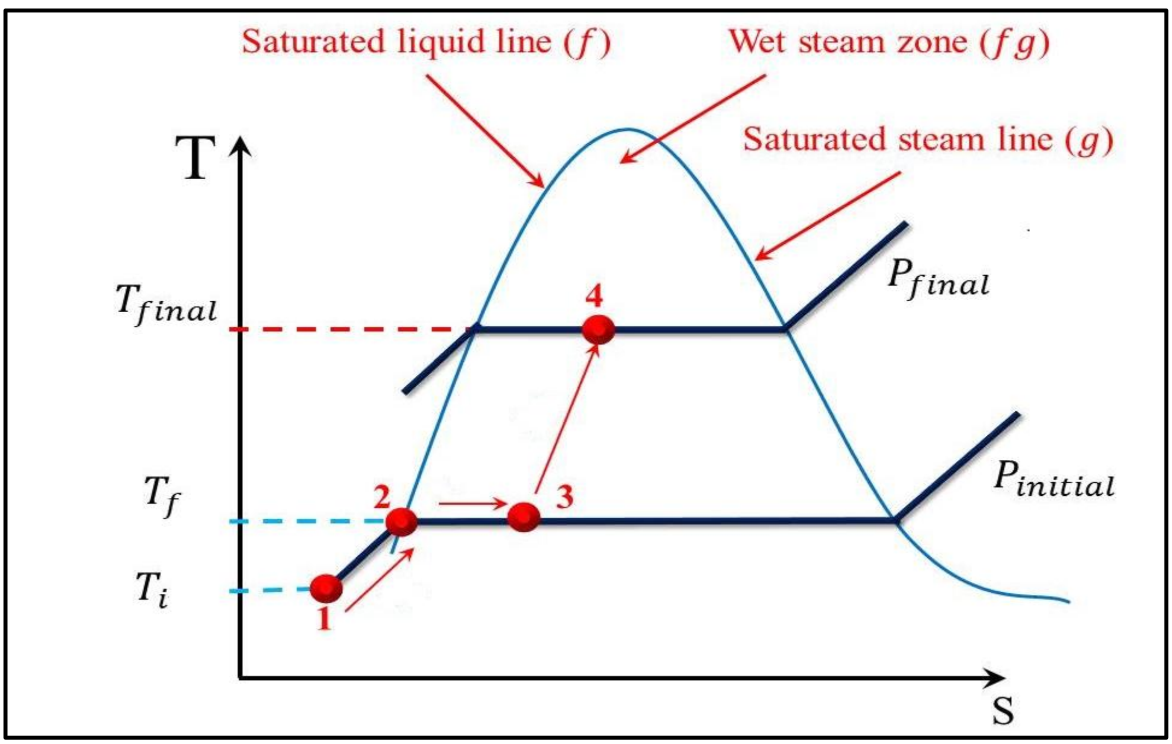


Figure (3.8) :T-S Diagram of the Water Phase Changes Between the Working Pressure Limits

3.4.1.2 Vessel with Dish

In this case, the addition is the heat concentrated by the reflective oval dish Q_d (from equation 3.9) and hence, as shown in the figure (3.9), the equation (3.25) (the total useful heat equation) would be as follow:

$$Q_u = I\,\zeta_p\,A_s + I\,A_d\zeta_p\zeta_{opt}\;C_d - h_W\;A_{s,total}(T - T_a) - \sigma\,\varepsilon\,A_{s,total}F\left(T^4 - T_{sky}{}^4\right) - \rho_{st}A_{S,total}\,t_V C_{st}(T - T_i)/t \quad \dots (3.26)$$

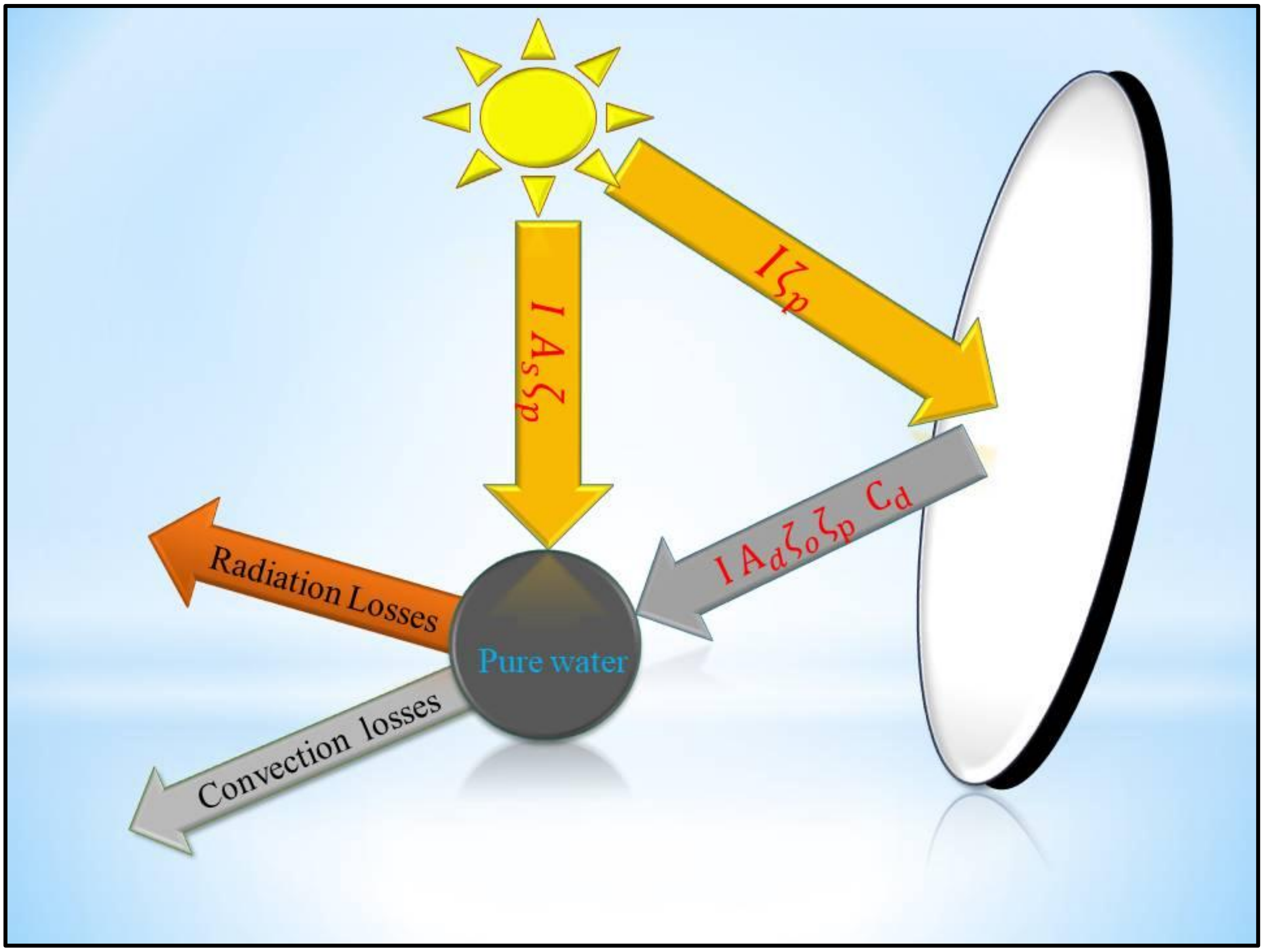


Figure (3.9) : The Schematic Diagram of the Heat Balance of the Solar Absorbent Vessel with the Dish

3.4.1.3 Vessel with Dish and Lens Together

The accounts for this subsection are very similar to the accounts for the subsection (3.4.1.2) in equation 3.26. In this case, the addition is the heat added by the Fresnel lens Q_L (from equation 3.15) omitting the term ($I\ \zeta_p\ A_s$) from equation 3.26 because the lens will shade over the heat absorbent vessel and prevents the direct rays from reaching to the vessel. Thus, as shown in figure (3.10), the useful total heat equation will become:

$$Q_u = I\ A_d \zeta_p \zeta_{opt}\ C_d + I\ \zeta_p \tau_L\ A_L\ C_L - h_W A_{s,total}(T - T_a) - \sigma\ \varepsilon\ A_{s,total} F\ \left(T^4 - T_{sky}{}^4\right) - \rho_{st} A_{S,total}\ t_V C_{st}(T - T_i)/t \qquad \ldots (3.27)$$

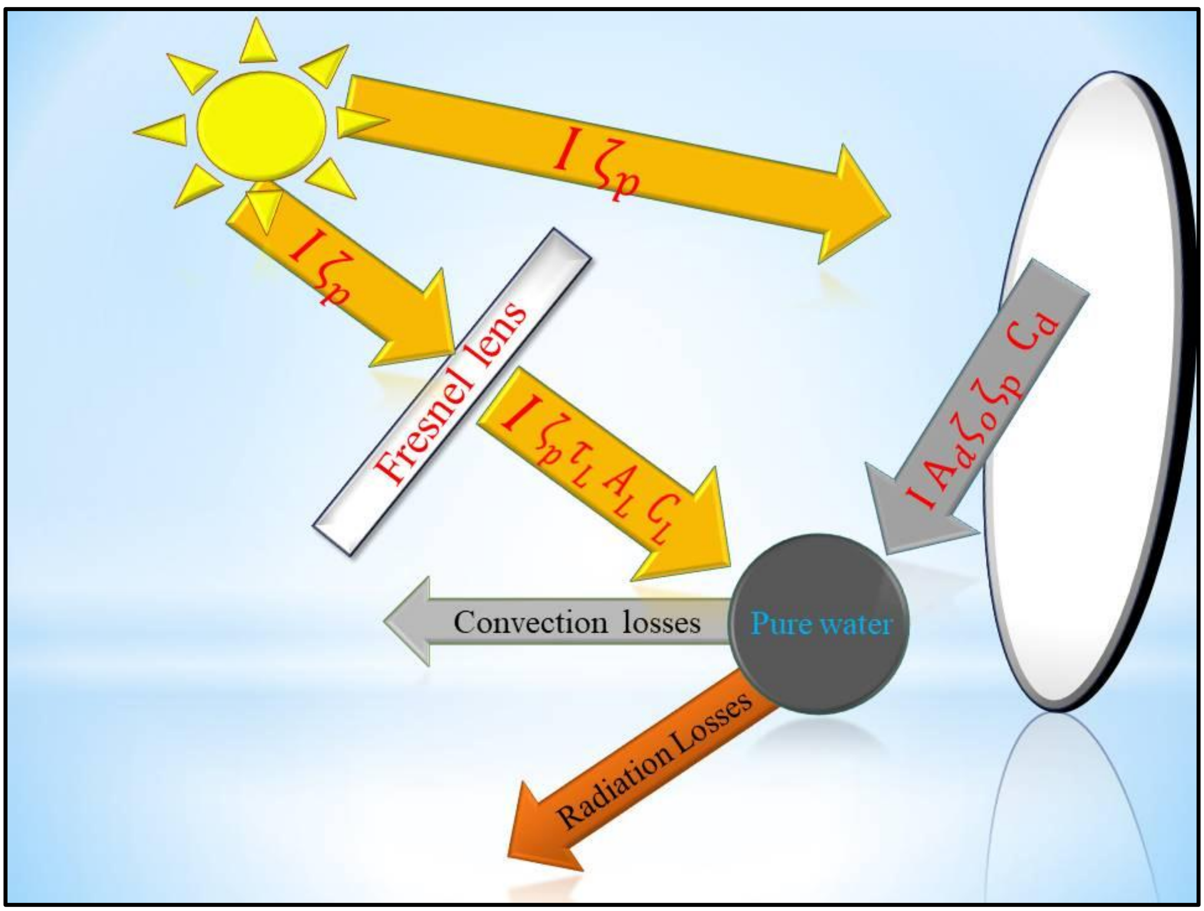


Figure (3.10): The Schematic Diagram of the Heat Balance of the Solar Absorber Vessel with Lens and Dish

3.4.2 Steam Generation Time inside Vessel

After calculating the total useful heat (Q_u) the required time to generate the wet steam with the required conditions can be found by the equation [54]:

$$t = m(h_4 - C_w T_i)/Q_u \quad \dots (3.28)$$

Where: h_4 is the specific enthalpy of wet steam at the final pressure (point 4), and it can be obtained as follow: -

$$h_4 = h_f + x\, h_{fg} \quad \dots (3.29)$$

h_f, h_{fg} From steam tables at final pressure.

$$\frac{V}{m} = v_f + x\left(v_g - v_f\right) \quad \dots (3.30)$$

V: vessel volume

v_f, v_g: specific volumes from steam tables at the final pressure.

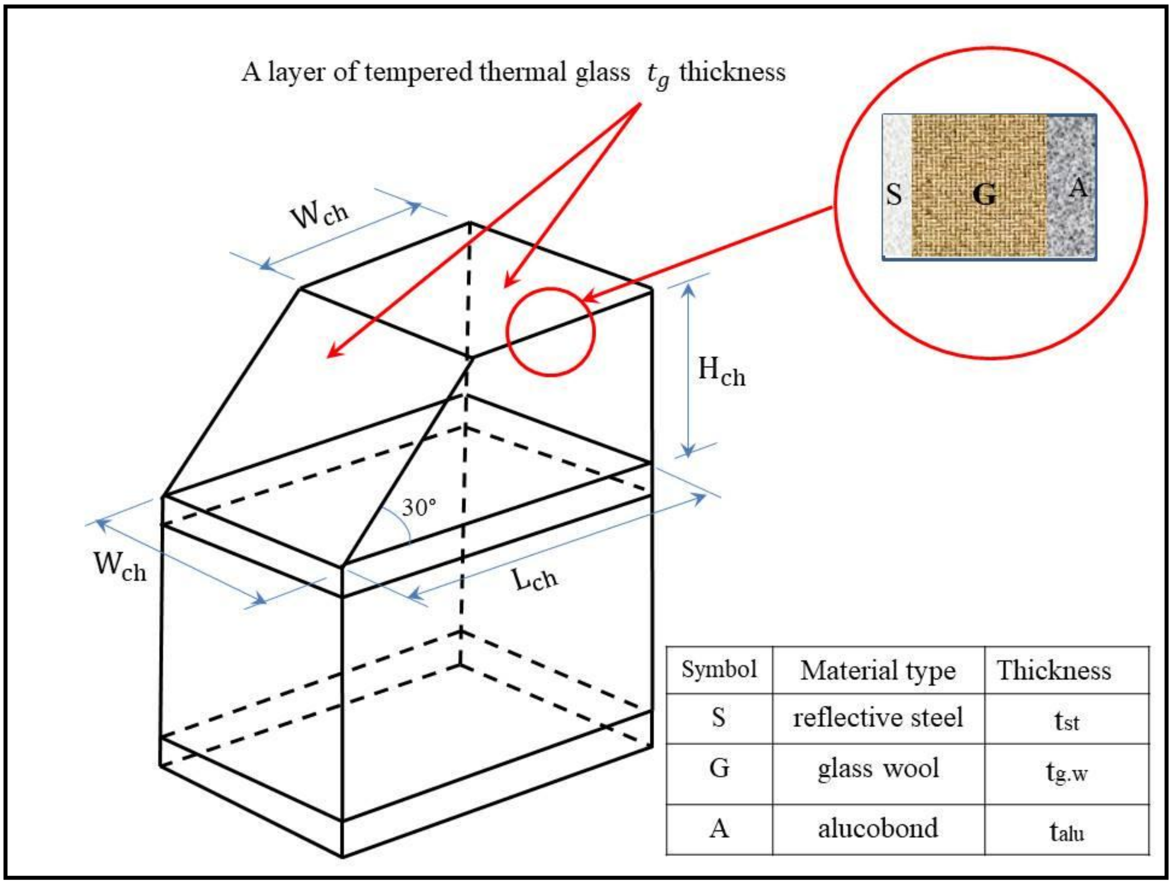
m: The amount of water in the vessel

3.5 Sterilization Units

The sterilization unit or chamber used in the current work was designed with dimensions of (W_{ch}) in width, (H_{ch}) in height and (L_{ch}) in length. All the chamber walls except the front face were made from three layers: an inner layer of the reflective steel, a middle layer of the glass wool, and an outer layer of the alucobond. While the front face is a layer of the tempered thermal glass with a thickness of t_g Inclined at an angle of 30°, as shown in figure (3.11). The thicknesses of the above three layers ($t_{st,}$ $t_{g.w}$ and t_{alu}) are also shown in this figure.

The most important in the sterilization unit calculations is calculating the required time to obtain the working fluid (steam or air) with the required properties (temperature and pressure) to sterilize surgical equipment. The heat balancing for each chamber is applied. The heat entering the chamber, heat absorbed by chamber parts, and heat losses due to convection and radiation are calculated. The result calculates the amount of useful heat absorbed by the sterilizing fluid to achieve the required sterilization properties over time. The required time is then calculated.

In this work, two sterilization chambers were used: one of them contains water converted into steam to be used as a sterilizing fluid. While the other contains air as a sterilizing fluid. Thus, this section would be divided into two subsections as follow: -



Symbol	Material type	Thickness
S	reflective steel	t_{st}
G	glass wool	$t_{g.w}$
A	alucobond	t_{alu}

Figure (3.11): The Schematic Diagram of the Sterilization Unit

3.5.1 Sterilization by Steam

As shown in the section (3.4) that each sterilization unit includes two main tests; accordingly, this subsection would be divided into two subsections for calculations as follows: -

3.5.1.1 Normal Sterilization Unit

By applying the heat balance equation for the sterilization unit by steam, the required time to obtain the steam with the needed conditions for sterilization can be calculated. This is for the normal (without development techniques) sterilization unit or chamber. As shown in figure (3.12).

The equation of the heat balance for the sterilization chamber by steam is as follows:

$$Q_{in} - Q_{losses} = Q_{\mathrm{S.S.Ch}} \quad \dots (3.31)$$

Where:

Q_{in} is the heat entered into the sterilization chamber and passes through the glass layer of this chamber. This heat depends on the intensity of the incident, total solar radiation (I), the area of the glass layer (A_g), the transmittance of glass (τ_g), and the geometric factor (R_b) to convert the incident solar radiation vertically to perpendicular to the inclined surface. It (Q_{in}) can be calculated by the following equation as follow as:

$$Q_{in} = I\, \zeta_p\, A_g \tau_g \quad \dots (3.32)$$

And Q_{losses} is the heat losses by the heat conduction, convection, and radiation, and it can be found as follow as [58]: -

$$Q_{losses} = U\, A_{s,total}\, (T - T_{amb}) \quad \dots (3.33)$$

Where:

U is the overall heat transfer coefficient, and it can be gotten as follow:

$$U = \frac{1}{\sum R} \quad \dots (3.34)$$

Where:

$\sum R$ is the sum of thermal resistances, and it can be found as follow: -

$$\sum R = R_{conduction} + R_{convection}$$

$$\sum R = \left(\frac{t_{st}}{K_{st}} + \frac{t_{g.w}}{K_{g.w}} + \frac{t_{alu}}{K_{alu}}\right) + \frac{1}{h_W + h_{rad}} \quad \dots (3.35)$$

Where:

t_{st}, $t_{g.w}$, and t_{alu} are the thickness of the steel layer, glass wool, and alucobond respectively.

K_{st}, $K_{g,w}$, and K_{alu} are the thermal conductivity of steel, glass wool, and alucobond (W/m. K).

h_{rad} is the heat transfer coefficient of radiation at the outer surface of the heat sterilization chamber wall, and it can be determined as follow [58]:

$$h_{rad} = \varepsilon_s \sigma (T + T_{sky})(T^2 + {T_{sky}}^2) \quad \dots (3.36)$$

The heat entered into the sterilization chamber by the steam is divided into four parts: one part to heat the cylinder metal inside this chamber, and another goes to heat the water inside this cylinder to convert it to steam under the required conditions. Another is absorbed by the surgical equipment inside the sterilization chamber, While; the remained part of the input heat represents the heat losses (Q_{losses}) as shown in above (equation (3.33)). This was shown in equation (3.31) (the heat balance for the sterilization chamber).

And ($Q_{S.S.Ch}$) is the total heat absorbed by the sterilization chamber contents (the cylinder, water, and surgical equipment). Mathematically, it can be written as follow:

$$Q_{S.S.Ch} = (E_{cy} + E_w + E_{s.e})/t \quad \dots (3.37)$$

Where:

$E_{s.e}$ does the surgical equipment absorb the energy, and it can be calculated by the next equation as follow [58]:

$$E_{s.e} = m_{s.e}\, C_{s.e}(T - T_i) \quad \dots (3.38)$$

And: E_{cy} is the energy absorbed by the aluminum cylinder and can be found by the next equation as follow: -

$$E_{cy} = \rho_{AL}.V_{cy}.C_{AL}(T - T_i) \quad \dots (3.39)$$

Where: V_{cy} is the volume of the steam sterilization cylinder, and it can be calculated by the following equation as follow as: -

$$V_{cy} = \pi D_{cy.in} H_{cy} t_{cy} + 2\left\{\frac{\pi}{4}\left(D_{cy.in} + 2t_{cy}\right)^2 t_{cy}\right\} \quad \dots (3.40)$$

And E_w are the energy absorbed by the fluid (water then converts into wet steam) inside the sterilization cylinder, and it can be found by the next equation as follow: -

$$E_w = m(h_4 - C_w T_i) \quad \dots (3.41)$$

Where: h_4 is the specific enthalpy of steam at the needed conditions for the sterilization. It can be determined by the equation (3.29) but at sterilization pressure (2.1 bar).

Now and after calculating these thermal energies (E_w, E_{cy}, $E_{s.e}$, Q_{in}, and Q_{losses}), the required time to convert m kg of water from the liquid state at the initial temperature (T_i) to the wet steam at the needed conditions can be found as follow: -

$$t = (E_{cy} + E_W + E_{s.e})/(Q_{in} - Q_{losses}) \quad \dots (3.42)$$

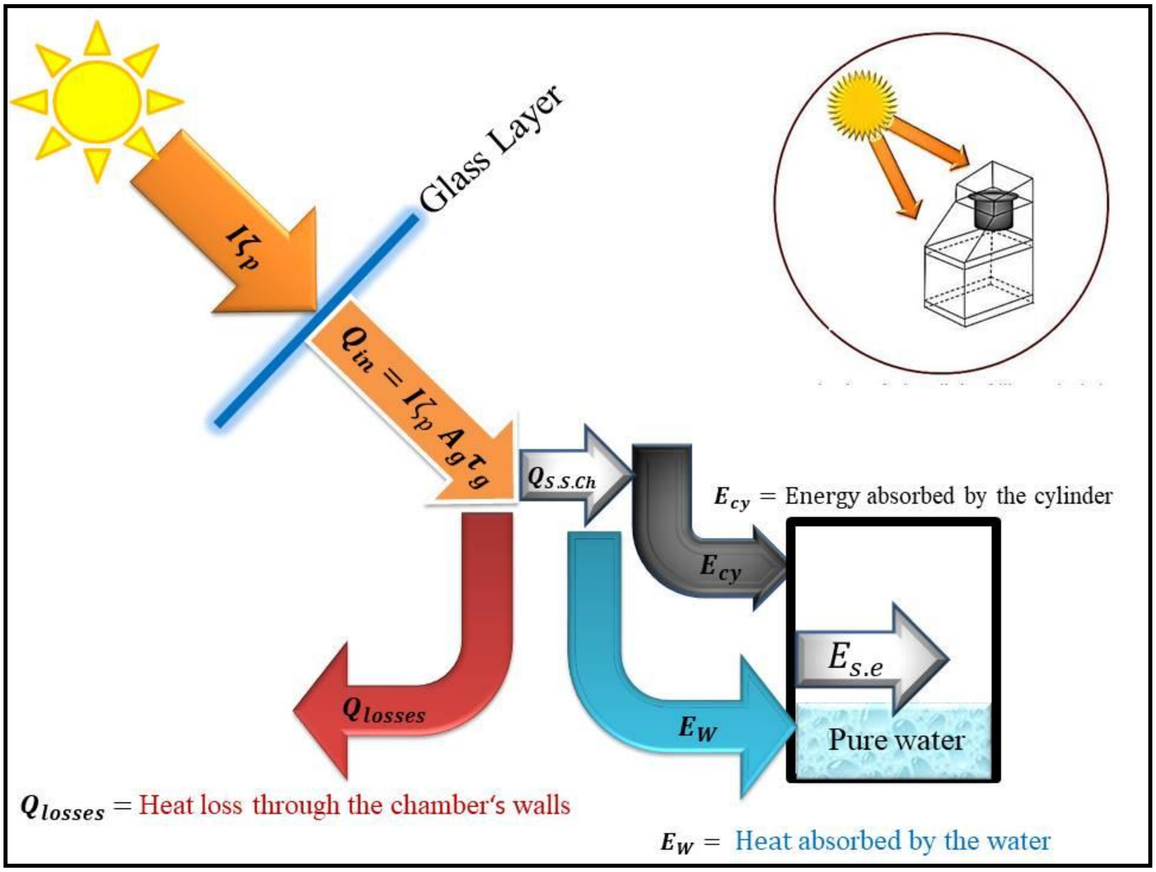


Figure (3.12): Heat Balancing Diagram for the Steam Sterilization Chamber

3.5.1.2 Sterilization Unit with Heat Exchanger

The calculations of this section are the same calculations of section (3.5.1.1) with adding a new term ($Q_{H.E}$) to the left side of equation (3.31). This term is the heat energy added by the heat exchanger presented inside the sterilization cylinder. The heat is added through the heat exchanging process between the steam coming from the solar absorber vessel and the sterilization fluid. It can be determined by the following equation [58]: -

$$Q_{H.E} = \pi d_p L\, \mu_l\, h_{fg} \left[\frac{g(\rho_l-\rho_v)}{\sigma}\right]^{1/2} \left[\frac{C_{pl}(T_s-T_{sat})}{C_{sf} h_{fg} Pr_l{}^{n}}\right]^3 \quad \ldots (3.43)$$

3.5.2 Sterilization by Dry Hot Air

Similar to the subsection (3.5.1), this subsection would also be divided into three subsections as follow: -

3.5.2.1 Normal Sterilization Unit

The heat balancing for the hot, dry air sterilization chamber will be applied without any optimization techniques. This is to calculate the required time to obtain hot, dry air in the required conditions for the sterilization process.

As shown in figure (3.13), The equation for the heat balance of the sterilization unit by hot, dry air is similar to equations (from 3.31 to 3.37) with the replacement of the term (E_w) by (E_{air}) and the term ($E_{s.c}$) by (E_{box}) in equation (3.37).

Where: E_{box} is the energy absorbed by the surgical equipment box, and can be found by the next equation as follow: -

$$E_{box} = \rho_{st}\, V_{box}\, C_{p,st}(T - T_i) \qquad \ldots (3.44)$$

Where: - E_{air} does the air inside the sterilization chamber absorb the energy, and it can be found by the next equation as follow: -

$$E_{air} = \rho_{air}\, \{ H_{ch}(W_{ch})^2 + \ 0.5\, (L_{ch} - W_{ch})\, H_{ch}W_{ch}\}\, C_{v,air}(T - T_i) \qquad \ldots (3.45)$$

And V_{box} is the volume of the sterilization box material, and according to figure (3.14), it can be calculated by the following equation as follow: -

$$V_{box} = 2t_b\{H_bL_b + (W_b + L_b)H_b\} \qquad \ldots (3.46)$$

Then, the required time to produce dry, hot air under the needed conditions for the sterilization process can be found as follow: -

$$t = (E_{box} + E_{air} + E_{s.e})/(Q_{in} - Q_{losses}) \qquad \ldots (3.47)$$

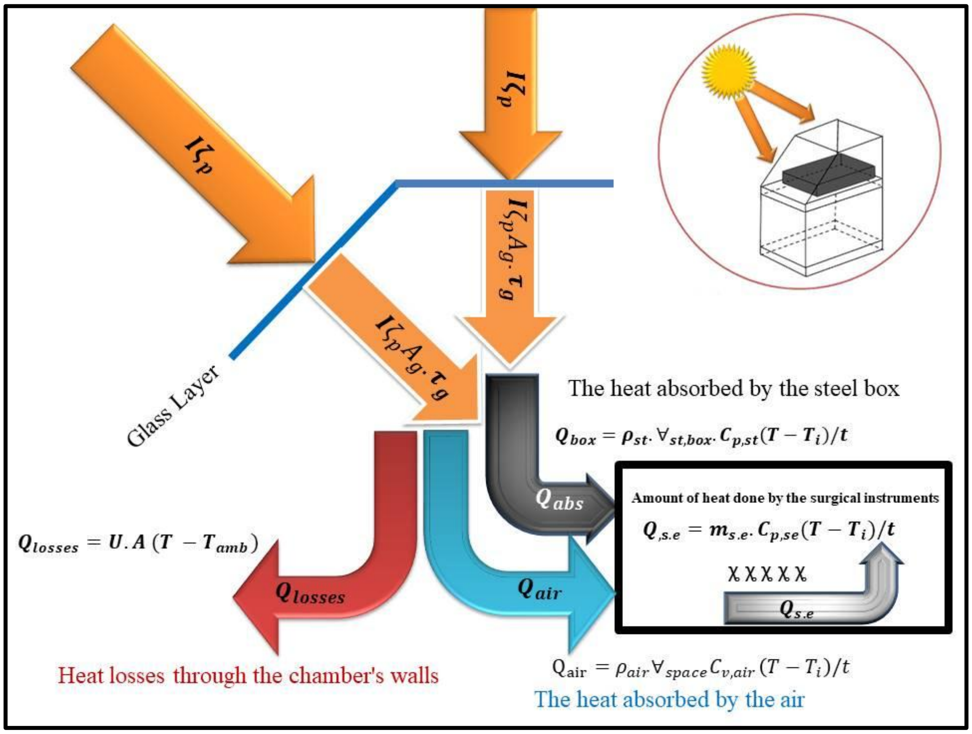


Figure (3.13): Thermal Balancing Diagram for the Dry Hot Air Sterilization Chamber

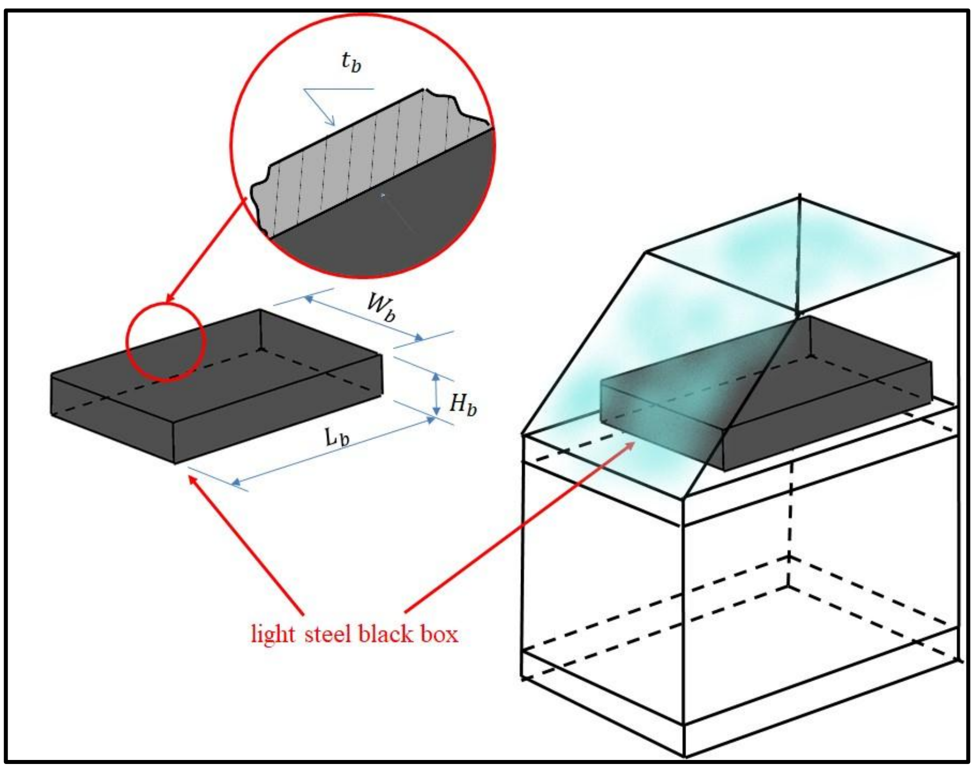


Figure (3.14): Dimensions of the Surgical Equipment Box in the Dry Hot Air Sterilization Chamber

3.5.2.2 Sterilization Unit with Heat Exchanger

The calculations of this section are not different from the calculations of section (3.5.2.1) greatly. The only difference is an addition of a new term ($Q_{H.E}$) to the of equation (3.47). This term is the heat energy added by the heat exchanger inside the sterilization chamber [58].

Where:

$$Q_{H.E} = \frac{K}{d_p} N_u\left(\pi d_p L\right)(T_s - T_i) \quad \dots (3.48)$$

$$R_a = \frac{g\beta(T_s - T_i){d_p}^3}{\nu^2} P_r \quad \dots (3.49)$$

$$N_u = \left\{0.6 + \frac{0.387\ (R_a)^{1/6}}{\left[1+\left(0.559/P_r\right)^{9/16}\right]^{8/27}}\right\}^2 \quad \dots (3.50)$$

Chapter Four
Experimental Work

This chapter includes a description of the experimental rig with all its parts, the method by which it operates, and the experimental measurement devices used in the current work. This chapter also explains the experimental procedure (the steps of the experimental work) and the calibration of the measurement devices used.

4.1 Experimental Rig Description

The experimental rig used in this study is a novel solar system; its main function is sterilizing surgical equipment with steam or dry, hot air using solar energy. It consists of seven main parts:

1. Surgical equipment sterilization unit, which consists of:
    a. Steam sterilization chamber that houses the autoclave.
    b. The hot, dry-air sterilization chamber that houses the equipment box.
2. Solar absorbtion unit,
3. Solar radiation concentration unit, which consists of:
    a. Fresnel lens
    b. Reflective oval dish,
4. Solar tracking unit,
5. Heat exchanging unit,
6. Steam transmission tubes,
7. Experimental rig base.

These parts were installed on an iron base, as shown in the in figure (4.1).

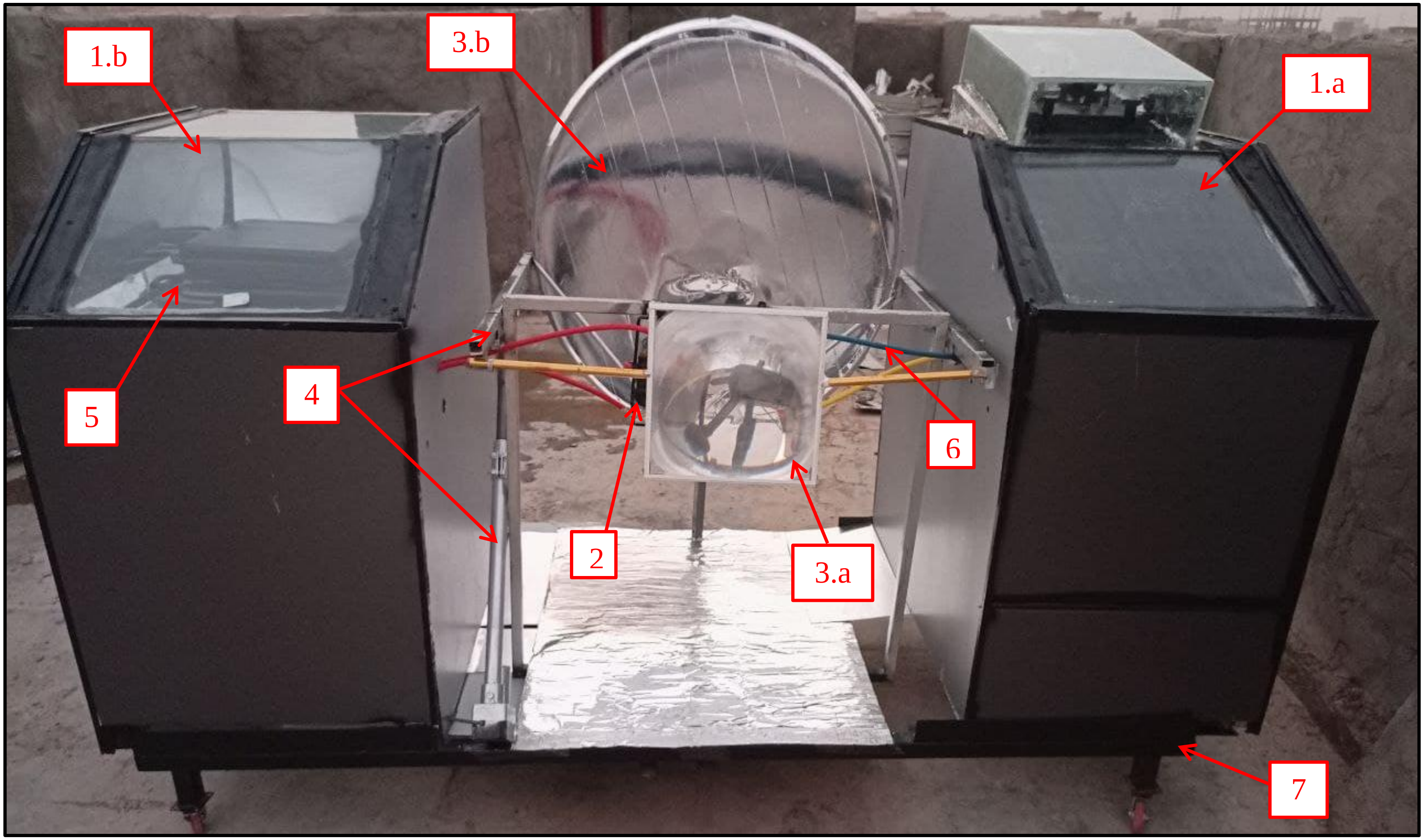


Figure (4.1): The Photograph of the Experimental Rig; (1.a): Steam sterilization chamber that houses the autoclave, (1.b): The hot, dry-air sterilization chamber that houses the equipment box, (2): Solar absorbtion unit, (3.a): Fresnel lens, (3.b): Reflective oval dish, (4): Solar tracking unit, (5): Heat exchanging unit, (6): Steam transmission tubes, (7): Experimental rig base.

4.1.1 Surgical Equipment Sterilization Unit

It is a chamber in which the sterilization fluid (steam or hot, dry air) is generated to sterilize surgical equipment.

In this work, two chambers were used for the above purpose. The first is for sterilization with dry, hot air. The second is inside, where the steam required for steam sterilization is generated. To produce the sterilizing fluids (steam and dry, hot air) inside the two chambers, there is a heat exchanger to extract heat energy from the heating fluid (steam coming from the solar absorber vessel). This can be obtained through heat exchange between the sterilizing fluid (steam or air) and the heating fluid (steam). Both sterilization chambers have the same geometry and volume (0.1395 m^3). The interior dimensions of each compartment are 93 cm long, 50 cm wide, and 30 cm high. Each chamber's bottom, side, and rear faces consist of three layers: an inner layer of 0.6mm thick reflective steel, a middle layer of 75mm thick insulating glass wool, and an outer layer of 6mm thick Alucobond. The two sterilization chambers were designed to extract a large amount of steam energy that flows through the heat exchanger coming from the solar absorbtion unit. In addition to pre-heating the same chamber due to sunlight falling on it. The back wall of each chamber is a portal constructed from the same layers as the other walls of the chamber, as shown in the photograph on the figure (4.2). At the same time, the front face is a layer of thermoplastic tempered glass with a 10 mm thickness, tilted at an angle of 30° with the horizontal surface. As for the upper face, it varies according to the sterilization chamber. In the steam sterilization chamber, it is a light galvanized iron frame on which an aluminum cylinder (It was in origin a tabletop autoclave cylinder and has been rehabilitated) with an inner diameter of 290 mm, a height of 230 mm and a thickness of 5 mm was installed as shown in the photograph in the figure (4.3). Its cover is provided with manual locks to secure it to the cylinder body .

The lid was provided with a pressure gauge and a relief valve to control the vapour pressure value inside the cylinder. It was set at 2.1 bar with a manual opening and closing valve to remove the air before the sterilization process began and for the steam removed after the sterilization process was completed. As shown in the photograph in the figure (4.4).

Figure (4.2): The Photograph of the Portal of Sterilization Chamber

figure (4.3): Steam Sterilization Chamber: (1) Aluminum cylinder (Autoclave)

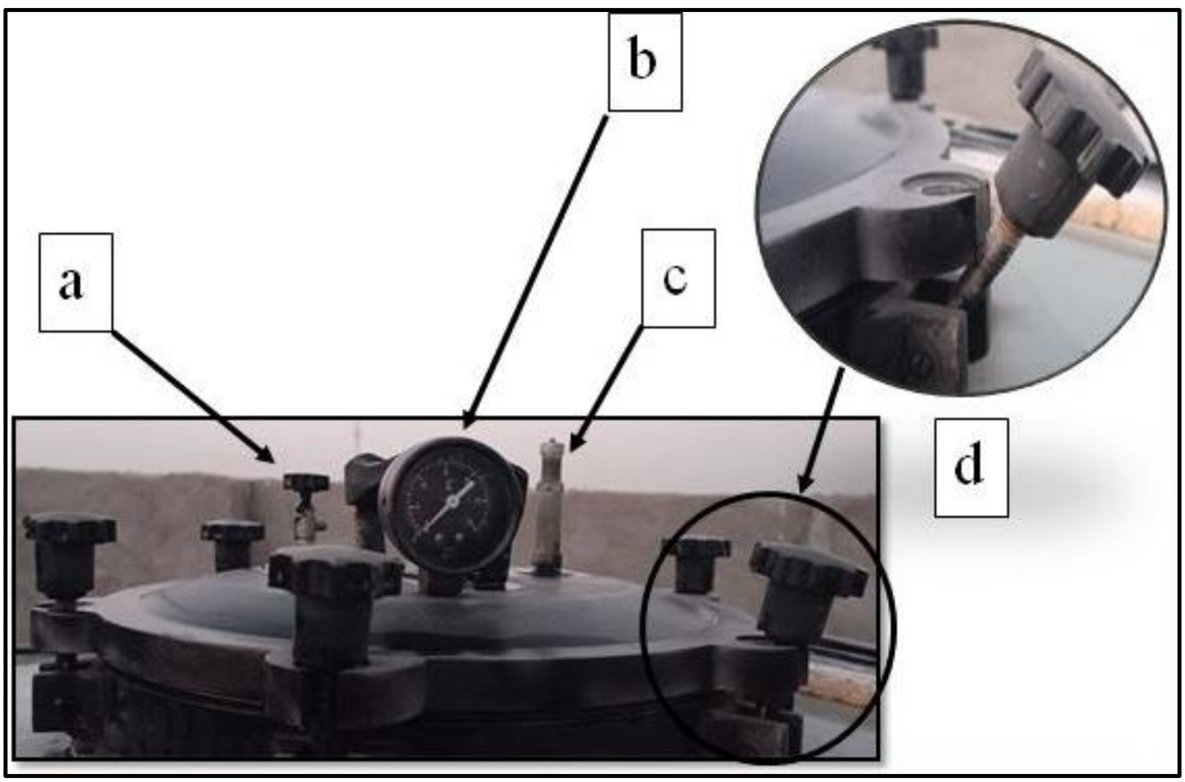


Figure (4.4): The photograph of the steam sterilizer cylinder cover

(a): Exhaust valve, (b): Pressure gauge, (c): Safety valve, (d): Manual lock.

To avoid the heat losses from the cylinder's upper surface to the ambient environment, a semi-pyramidal cover whose front face is a layer of thermoplastic tempered glass inclined at an angle of 30° was added. In addition, the inner walls of this cover are covered with reflective aluminum foil to provide a heated environment resulting from trapping the solar radiation inside the glass cover, as shown in a photograph on a figure (4.5). The outer surface of the cylinder and its cover are painted with matte black paint to absorb the maximum heat from solar radiation. Surgical instruments to be sterilized are placed inside the cylinder. Thus, the steam sterilization chamber appears with the glass cover of the sterilization cylinder head, as shown in the photograph on a figure (4.6). Inside the cylinder, the copper tube for the heat exchanger passed and is in the form of a spiral to match the space of the cylinder bore. As for the sterilization chamber by dry, hot air, the upper face of the sterilization chamber is a layer of thermal tempered glass horizontally. The surgical equipment to be sterilized by hot, dry air is placed in a thin stainless-steel box with dimensions (60 × 30 ×12 cm) placed directly on the heat exchanger in this chamber, as shown in figure (4.7).

Figure (4.5): The photograph of the glass cover of the sterilization cylinder head

Figure (4.6): The Photograph of The final view of the steam sterilization chamber

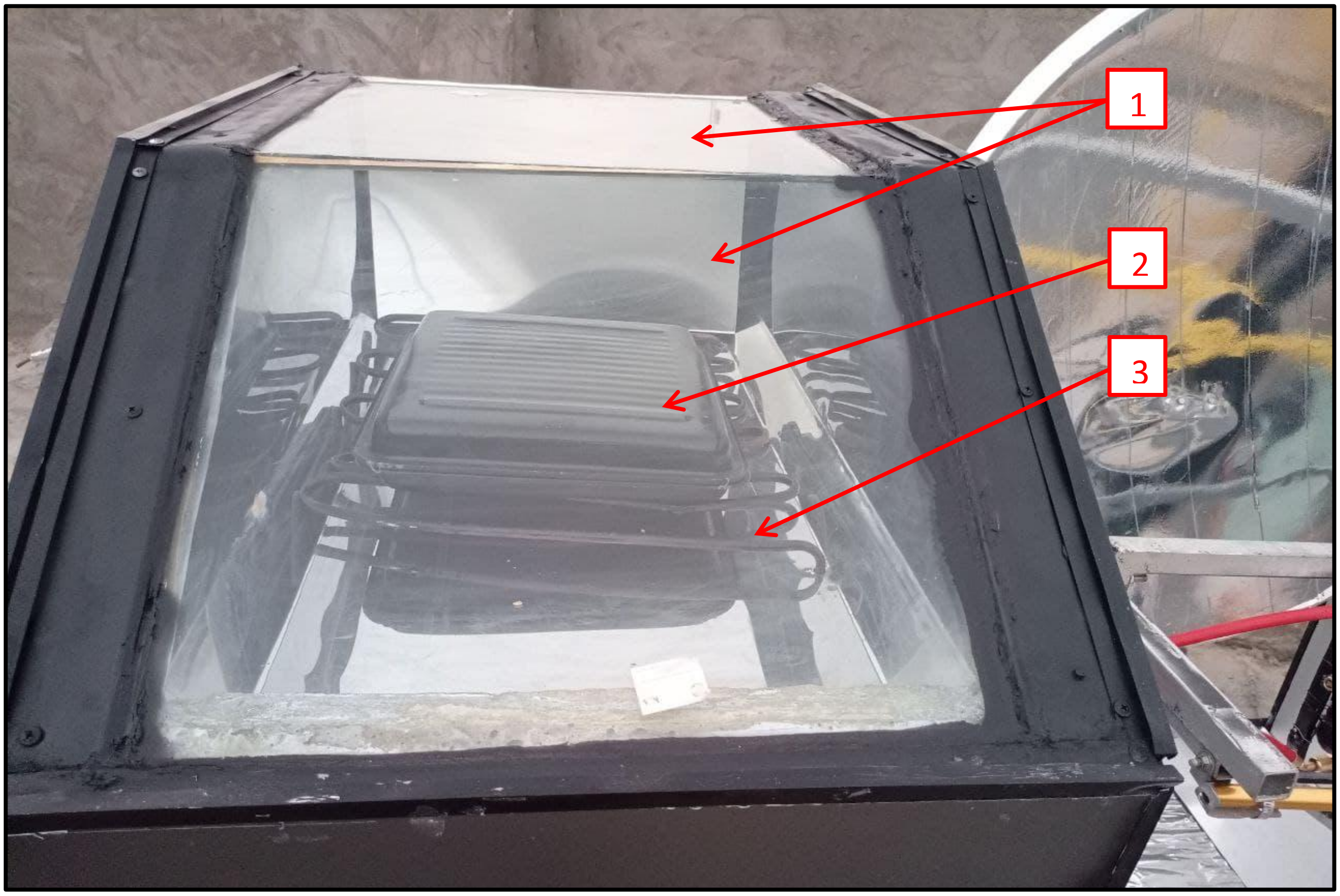


Figure (4.7): Dry, Hot Air Sterilization Chamber

(1): Thermal glass layer, (2): The black box for medical equipment,

(3): Copper tube heat exchanger

4.1.2 Solar Absorbtion Unit

It is a cylindrical container vessel that contains a quantity of pure water. It absorbs the energy of solar radiation to generate steam (Heating Fluid) at a certain pressure and temperature. This steam is then used to generate sterilizing fluids (steam and air) by heat exchangers in sterilization chambers. To sterilize surgical equipment. In this work, the vessel was used with dimensions 8cm in diameter, 14 cm in length, and 0.3 cm in thickness. The vessel was fixed horizontally in the solar system to obtain a constant distance between the vessel and the lens from one side and the vessel and dish from the other side at all times of the experiments. In addition to ensuring that all the solar radiations reach the reflective oval dish, some of these radiations will be blocked by the vessel in the vertical position.

figure (4.8): shows a photograph of the solar Absorbtion unit (the cylindrical vessel).

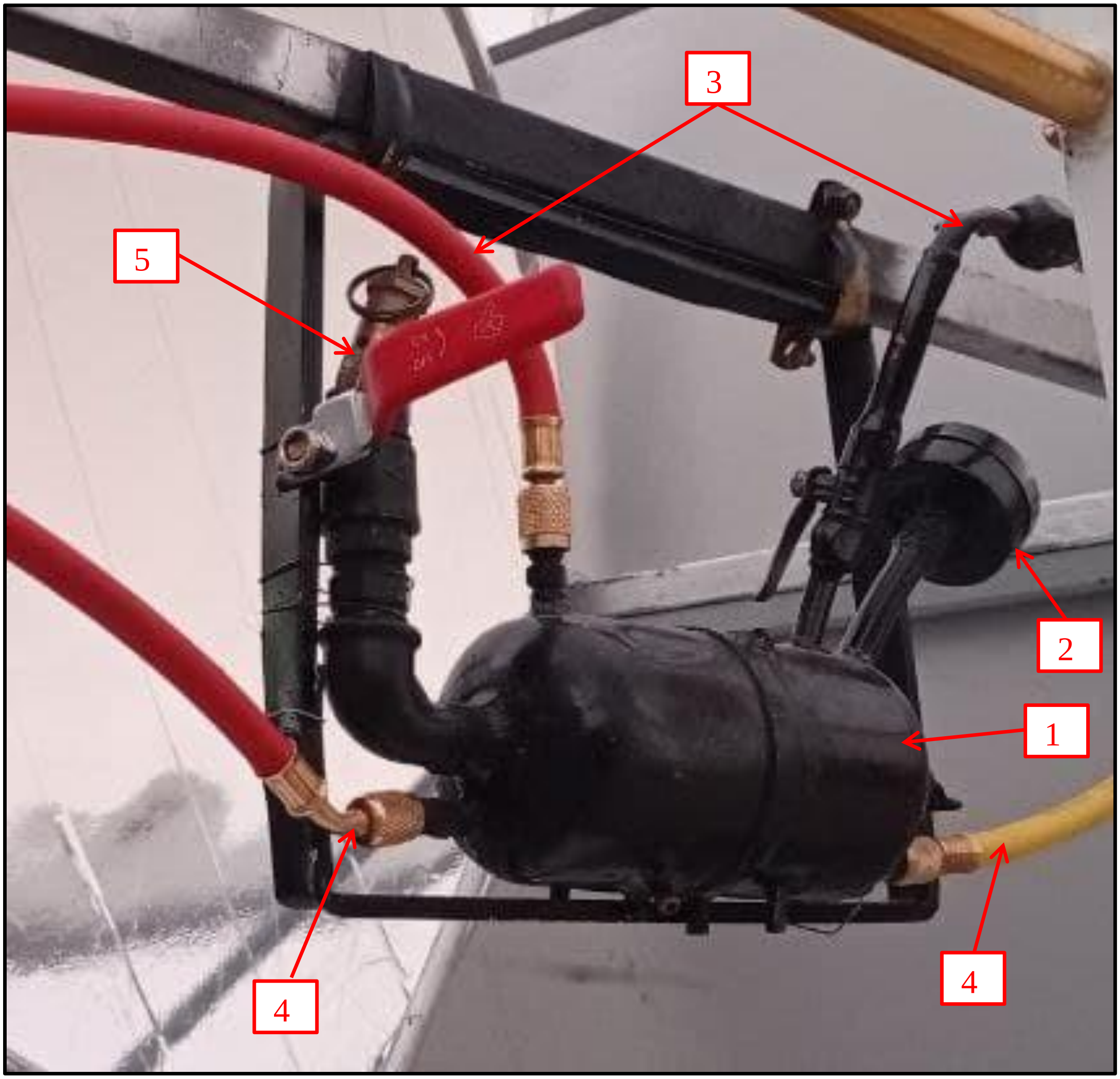


Figure (4.8): The Photograph of the Solar Absorbtion Unit

(1): Cylindrical vessel, (2): Pressure gage, (3): Steam export tube, (4): Return tubes

(5): Relief valve

4.1.3 Solar Radiations Concentration Unit

Many gadgets can concentrate the solar radiation towards a certain point or body to get the maximum amount of solar energy. Two types of these gadgets were used: a Fresnel lens and a reflective oval dish. Firstly, only the reflective oval dish was used then the Fresnel lens was added to the solar system. This concentrates the solar radiation to the solar Absorbtion vessel. Resulting in a decrease in time required to achieve the desired heating fluid (steam) pressure and temperature (6.2 bar and 160 °C).

The reason for choosing the properties of the heating fluid (steam inside the heat absorber vessel) at 160 °C and 6.2 bar is due to:

The need for a hot, dry air sterilization temperature to be 160°C. To ensure the stability of the temperature at this value, the thermal balance between the heating steam and the air inside the air sterilization chamber must be taken advantage of. When thermal equilibrium occurs, the temperature of the heating steam and the sterilizing air are equal by the heat exchanger. The safety valve in the heat absorbent vessel ensures a constant pressure of 6.2 bar. In wet steam, the fixed pressuremeans that the temperature remains at saturation. According to steam tables, the saturation temperature at 6.2 bar is 160°C. Therefore, the heating vapor stabilizes at 160 °C, and therefore, after thermal equilibrium occurs through the heat exchanger in the air sterilization chamber, the air temperature will be stabilized.

4.1.3.1 Fresnel Lens

In this study, square-shaped of a spot Fresnel lens with a side length of 31 cm and a thickness of 3 mm was used and fixed to an aluminum frame connected to a solar tracking system to ensure orthogonality to sunlight during the experiment time. In addition to the ability to move the lens on the frame to control the focal length, therefore concentrating the solar radiations towards the surface of the heating fluid (steam) generation vessel. Table (4.1) shows details of the Fresnel lens, and the figure (4.9) shows a photo of this lens.

Table (4.1) The Fresnel lens details

No	Property	Value
1	Thickness	3 mm
2	Groove Pitch	0.3 mm
3	Focal Length/Magnification	120 mm
4	Flexural Modulus	390- 470 $\times 10^3$ psi
5	Transmittance	92%
6	refraction index	1.49
7	Hardness	M80-M100 (Rockwell)
8	Thermal Expansion	76×10^{-6} / °C
9	Specific Gravity	1.19

Figure (4.9): The Photograph of Fresnel lens

4.1.3.2 Reflective Oval Dish

Using the reflecting circular dish as a solar collector to collect the solar radiation and then redirect it towards the heat-absorbing cylindrical vessel to generate the heating fluid (steam) was excluded. Because this dish has a negative property, its focal point is located in front of its geometric center. When the solar absorber vessel is installed on the dish, it blocks part of the sun's rays from reaching the dish. Thus, the efficiency of the dish will decrease, so in the present work, an oval dish was used where the above negative characteristic is not present, and its focal point is in front of the lower point of its frame, so the heat-absorber vessel does not block the solar radiation from the dish. The latter was used with a large diameter of 1 m and a small 0.9 m. Reflective nickel paper was used as a material for coating the dish to obtain the maximum amount of concentrated solar energy. This type of coating material was chosen for its high reflective properties and lightweight. Note that the oval dish was not used in previous studies. Table (4.2) shows details of the dish used in this work.

Table (4.2): The Details of the Oval Dish

No	Description	Unit	Value
1	Height	m	0.093
2	Aperture area	m^2	0.7
3	Focal length	m	0.49
4	Concentration ratio	Non	22

4.1.4 Solar Tracking Unit

To obtain maximum solar radiation and at all times of the experiment, a DC electric motor performed sun-tracking. It was fixed in the experimental rig by two screws. The sliding arm of this motor is attached to a U-shaped frame of light iron that holds the dish and the lens, and it is hinged around two hinges at the top of another frame installed vertically between the two sterilization chambers, its dimensions are 90 cm in hight and 90 cm in width. On the middle top point of this fixed frame, the heat absorbtion vessel is fixed where the focal points of the dish and the lens meet. Figure (4.10) shows the solar tracking mechanism.

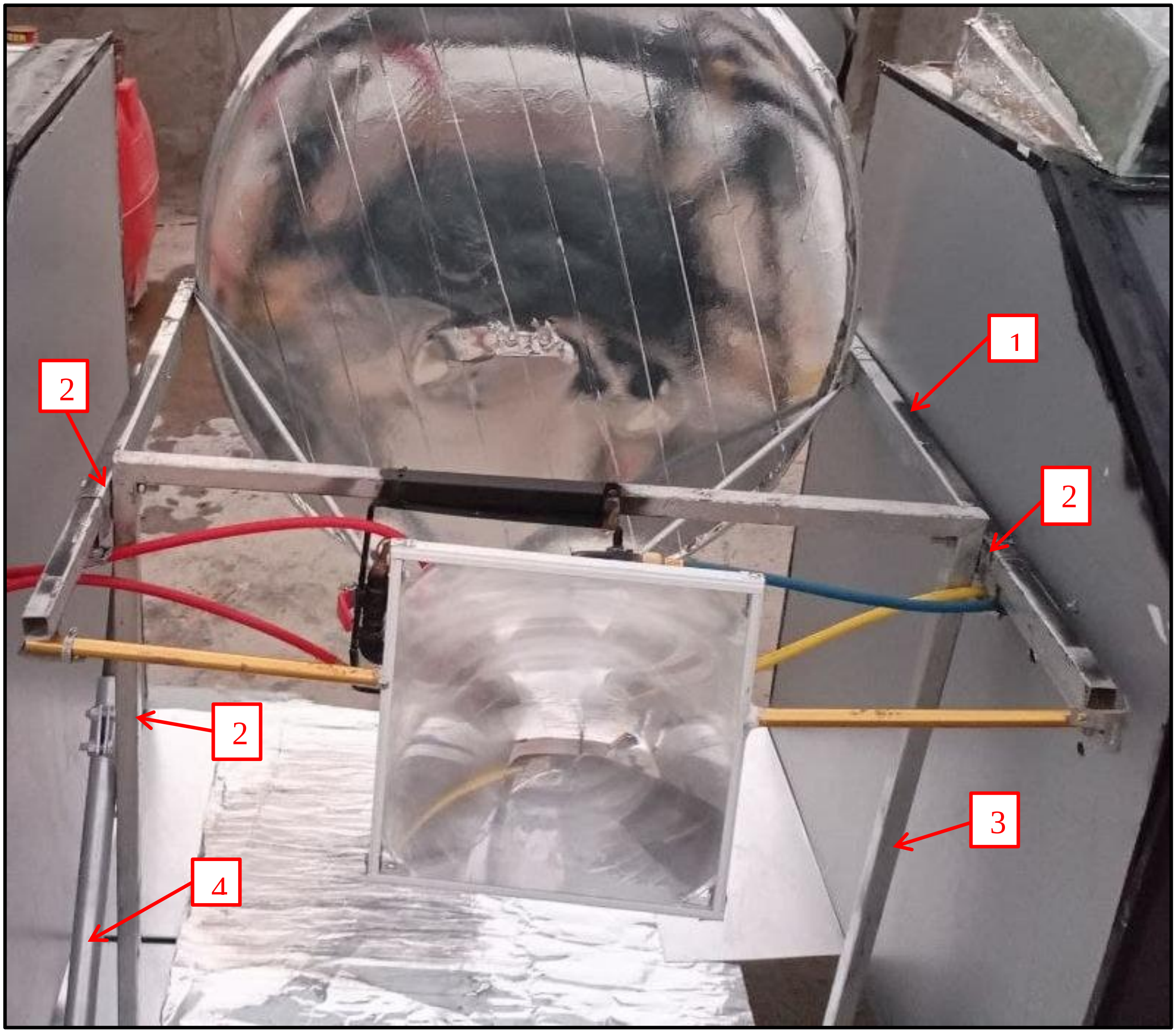


Figure (4.10): Mechanical mechanism for solar tracking

(1): Swing frame, (2) Hinge, (3) Fixed Iron frame, (4): Sliding motor

4.1.5 Heat Exchanging Unit

For the heat exchange process between the generated steam inside the solar absorber, a cylindrical vessel due to the consecrated solar radiation and the fluid inside the two sterilization chambers, a copper tube diameter of 9.25 mm (Appendix B) was used as a heat exchanger. It (the copper tube) was coiled inside these two chambers and in a slightly inclined shape to ensure that the condensed steam descends into the return tube. The geometrical shape of this exchanger in each chamber is different from the other as it is given a spiral shape inside the steam sterilization cylinder with a diameter of 27 cm for the outer circle and the other circles start decreasing in diameter so that the circles are separated by a distance of 5 mm to allow water to penetrate between the coils of the exchanger. It is given a rectangular shape with dimensions of 40 cm × 70 cm in the hot, dry air sterilization chamber . The heat exchanger was used with a large length (3 m in each chamber) for extracting as much heat as possible from the steam flowing inside it. The geometrical shapes of the exchangers were chosen to be proportional to the place of their use. The spiral shape came to match the cavity of the sterilization cylinder. The rectangular shape served as the convection stove for the sterilization box for surgical equipment with hot, dry air. The reason for choosing the heat exchanger with a length of 3 m was to make the copper heat exchanger cover the cross-section area of the bore of the sterilization cylinder with the spaces between its coils.

4.1.6 Steam Transmission Tubes

In this work, special rubber tubes were used for transferring the steam from the solar absorbtion cylinder to sterilization chambers for the surgical equipment. In addition to transferring the condensed steam from the sterilizing chambers to the solar absorbtion cylinder again. These tubes have a high resistance to high temperature and high pressure.

In this work, these tubes were insulated with 2.5 cm [59] of insulating glass wool to eliminate heat losses while transporting steam within the solar system.
Figure (4.11) shows the rubber tubes used in the current work.

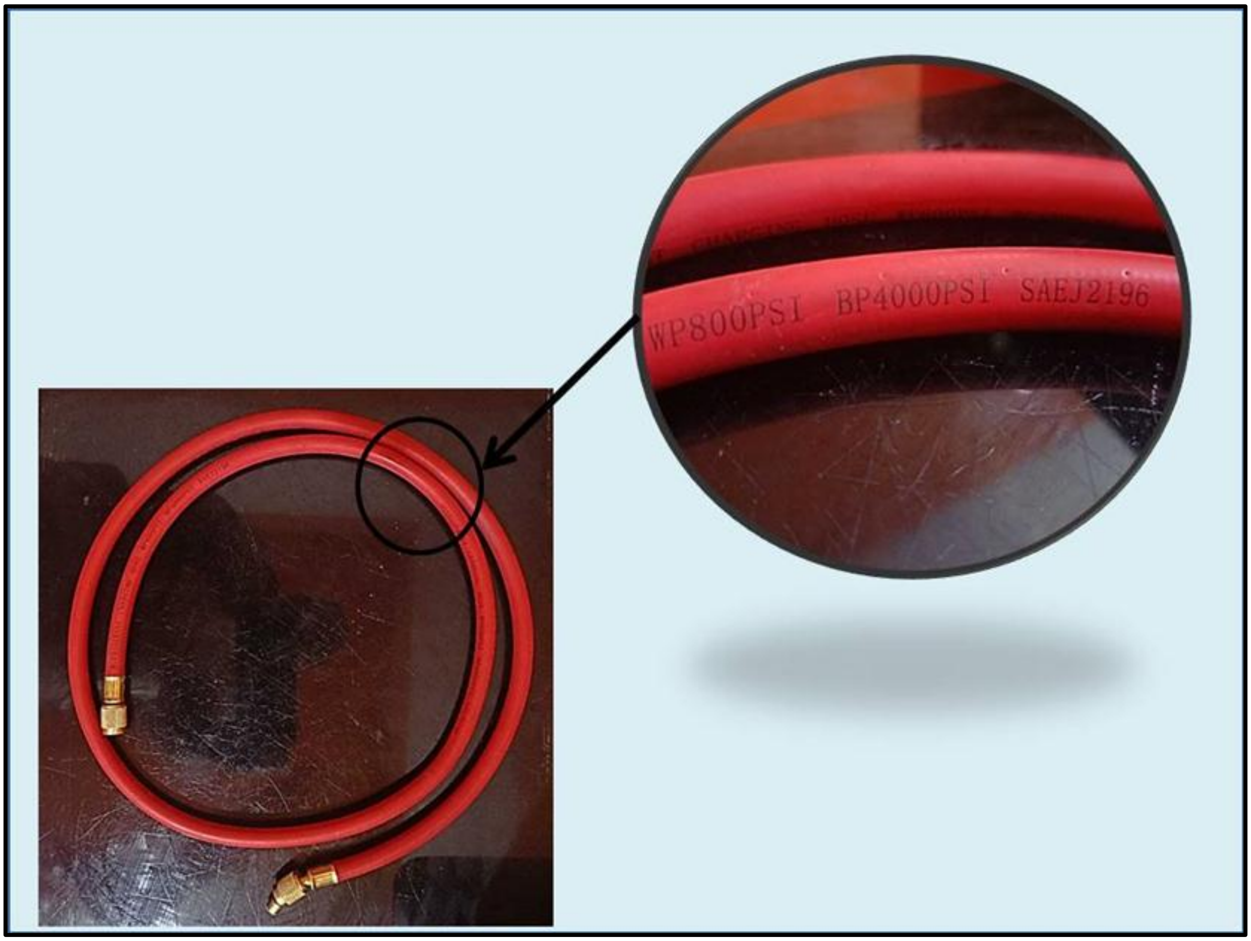


Figure (4.11): Steam Transmission Tubes and The Max Limits of its Tolerance to Pressure

4.1.7 Experimental Rig Base

Before manufacturing the parts of the experimental rig, a rectangular structure of heavy iron with dimensions of (1×2.3) m was made and supported by iron bars in the middle to be the base on which the parts of the solar system (the experimental rig) are installed. Four wheels (with a high 0.2m) were added to the four corners of the base for ease of transportation of the solar system from one place to another and easy rotation around its center during the solar tracking process.

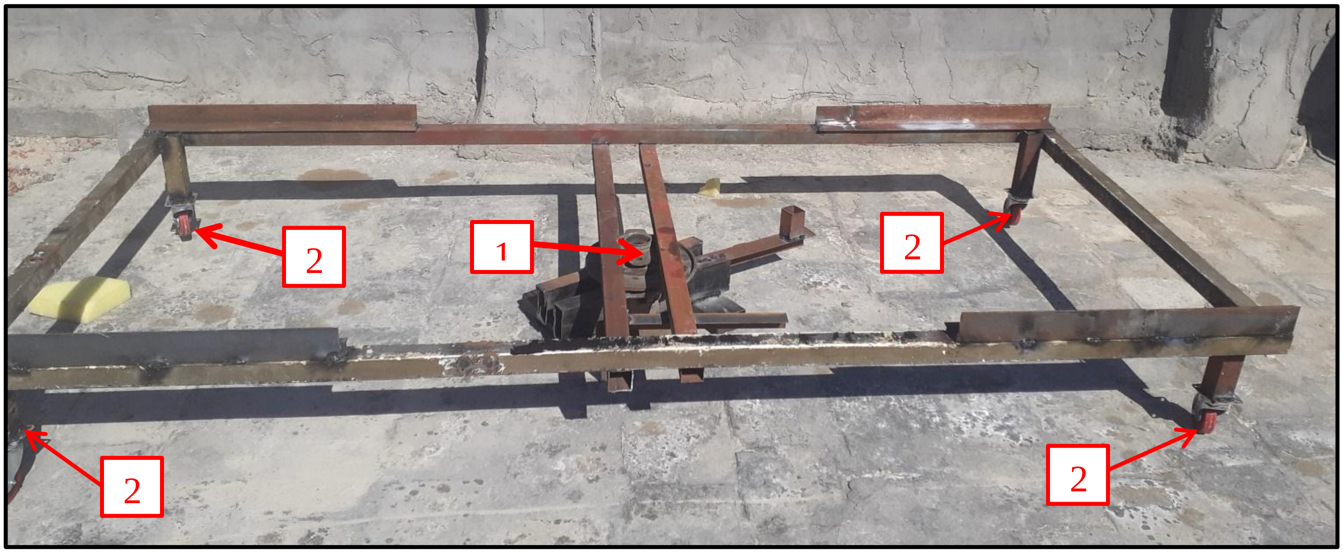


Figure (4.12): The Photograph of the Experimental Rig Base

(1): Axis of rotation, (2): Solid wheels

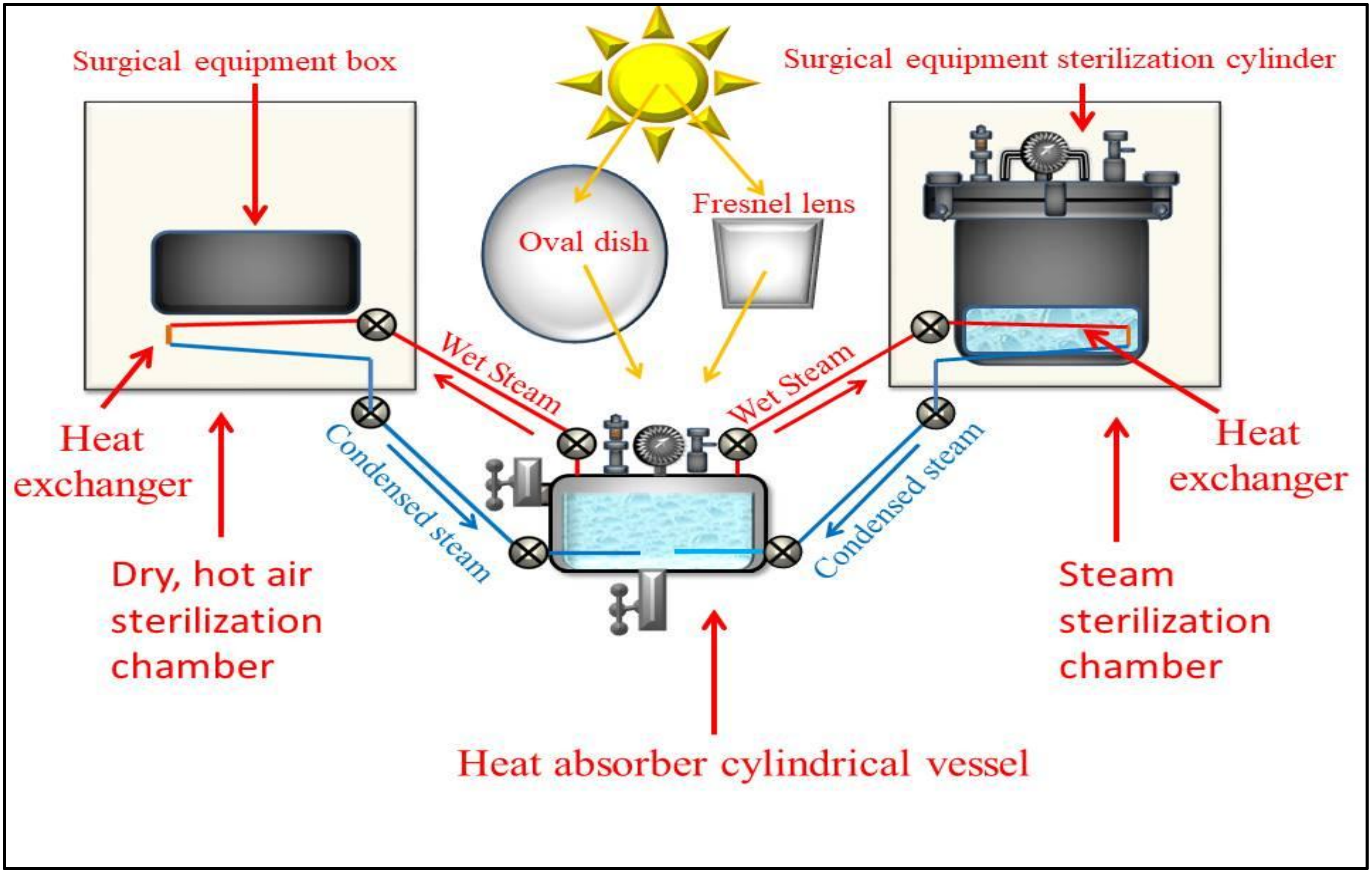
4.2 Description of Solar System Working Mechanism

The design idea of this system is based on the use of high-pressure steam in the wet steam stage to control the pressure. The most important characteristic of wet steam is the stability of temperature and pressure of the steam at the saturation case. When the pressure is constant, whatever the thermal energy is added to the steam, converts to latent thermal energy. Therefore a constant value of the required temperature can be obtained. The influence of gravity can be exploited during evaporation and condensation of steam to ensure achieving the process of steam circulation between the main components of the system.

The steam is generated in the cylindrical solar absorbtion vessel by concentrating the solar radiation by a square spot Fresnel lens and a reflective oval dish. A sufficient quantity of pure water is poured inside this vessel. Due to the incident solar radiation on the surface of the cylindrical vessel, the water begins to convert to steam gradually, and the pressure begins to rise until it reaches the saturation pressure. It is known that the steam density is less than the water density, so the steam rises to the upper surface of the cylindrical vessel. Due to the high pressure inside the vessel and its constant volume, the steam begins to flow towards the two surgical equipment sterilization chambers, but after it is allowed to flow. This is to heat the two fluids in these chambers through the heat exchange process. The steam is transferred from the cylindrical vessel to the sterilization chambers through rubber tubes with high resistance to high pressures and temperatures. Knowing that the pressure inside the cylindrical vessel is controlled by a safety valve calibrated at the required pressure value.

There is a heat exchanger in each chamber as a twisted copper tube. One of these chambers contains air and is called the dry, hot air sterilization chamber, and the other contains water and is called the steam sterilization chamber. After each fluid acquires sufficient heat through the heat exchange process with the steam coming from the solar absorbent vessel, sterilizing the surgical equipment is carried out. In the dry, hot air sterilization chamber, the sterilization process is carried out by the hot air. While in the steam sterilization chamber, it is done by the steam presented in this chamber (this steam is not the steam generated inside the solar absorbent vessel). The hot air and steam are produced through the above heat exchange process.

After that, it (the steam generated inside the solar absorbent vessel) condenses. Thus, its density increases, and because of the earth's gravity, it returns to the solar absorbent vessel to gain heat energy from sunlight falling on the vessel again, to return to the two surgical equipment sterilization chambers to exchange the heat with the two fluids present in those two chambers. Thus, the process of steam circulation continues between the parts of the solar system. To avoid the water rushing from the endothermic vessel in the opposite direction when the pressure inside the vessel rises. Which prevents steam from flowing from the vessel to the chamber's heat exchanger. So, the end of the return tube from the sterilization chamber was extended to a point close to the vessel's centre . The pressure affects the vessel wall more than the center of the water, thus getting the fluid circulation condition. The figure(4.13) shows the parts and working mechanism of the solar system.



Figure(4.13): The parts and working mechanism of the solar system

4.3 Measurement Devices

Temperature and pressure should be measured as two variable properties in the present work. The fluids whose temperature and pressure must be measured are the steam generated inside the solar radiation absorbtion vessel and the steam inside the autoclaving, and temperature of the air inside the second sterilization chamber. To achieve the aims of the present study, the temperature and pressure of these fluids should be measured at all the tests.

A thermocouple type K and a digital thermometer reader type 12channels SD Data Logger were used to obtain the temperature data of the working fluids used. A pressure gauges was used to measure the pressure of the working fluid.

Figure (4.14 a and b) show the digital data logger and thermocouples images.

The thermocouples nodes were distributed as shown in figure (4.15).

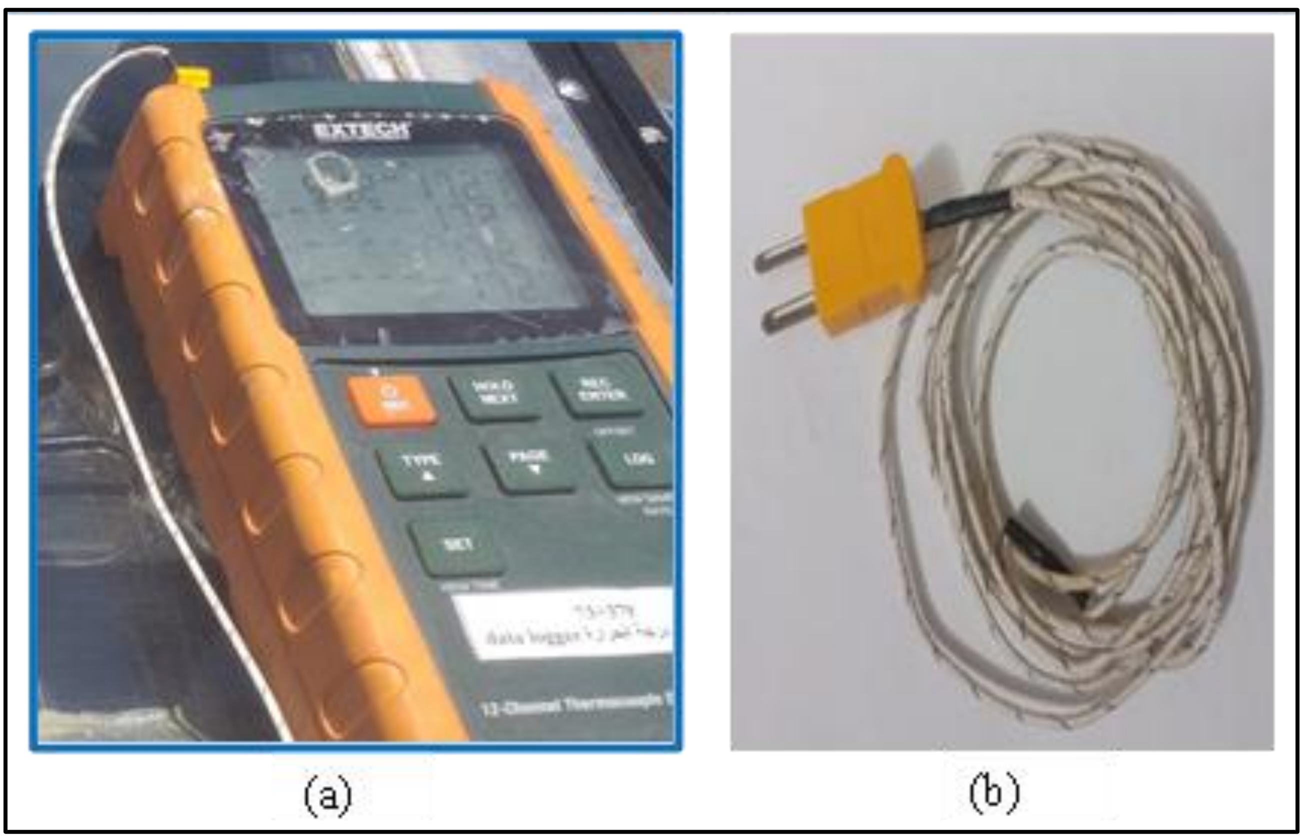


Figure (4.14): Photographs of (a) The Digital Data Recorder and (b) The Thermocouple

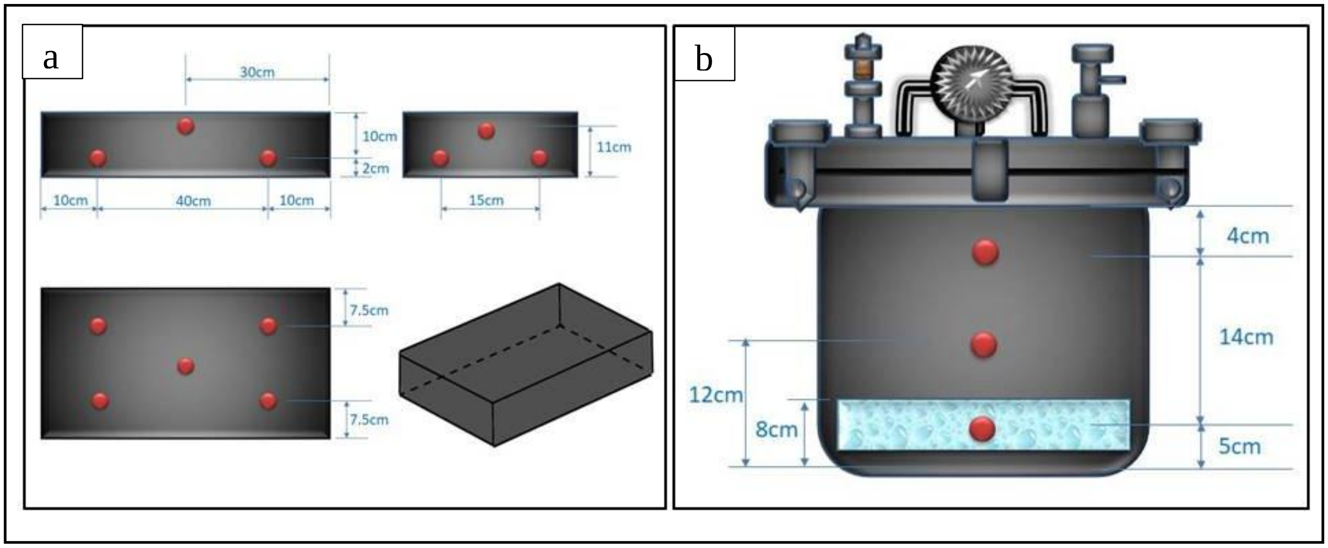


Figure (4.15): The Locations of Thermocouples Inside (a): The Surgical Equipment Sterilization box by Dry, Hot Air (b): The Steam Sterilization Cylinder

4.4 Experimental Procedure

The practical steps below were carried out after manufacturing all the parts of the experimental rig (the solar system), installing them on one base, and installing the measuring devices in their designated places. It is noteworthy that before carrying out the practical steps, the system was located in a place that ensures that the sunlight reaches it totally during all the experiments—knowing that the time of the one experiment is different from one experiment to another according to the ambient conditions and the Technologies used to improve performance of the solar system.

The intensity of solar radiation and ambient temperature were recorded in all tests.

After placing 0.5 kg of pure water inside the heat-absorbing vessel, The temperature and pressure inside the vessel were recorded. And put 1 liter of pure water inside the steam sterilization cylinder, with 1.2 kg of surgical equipment (stainless steel) inside each of the sterilization cylinder and box. The temperature and pressure inside the sterilizing cylinder were recorded. Also, the air temperature inside the sterilization box with hot, dry air was recorded. This was in the following cases:

1. Exposing the absorbent vessel to the sun from 7 a.m. to 5 p.m. That was without solar concentrates. This case has been called the "normal case."

2. Exposing the absorbent vessel to the sun at 10am with reflective oval dish as a solar concentrator until steam generation at 160°C and 6.2bar.

3. Exposing the absorbent vessel to the sun at 10am with reflective oval dish and Fresnel lens as a solar concentrators until steam generation at 160°C and 6.2bar.

4. Exposing the sterilization chambers (steam sterilization chamber and hot, dry air sterilization chamber) to sunlight until it produces steam at 121.1 °C and 2.1 °C inside the steam sterilization cylinder, and heating the air inside the dry hot air sterilization chamber to 160 °C. This case is called the "normal case for sterilization unit".

5. Repeat steps (3 and 4) until steam is generated at 121.1 and 2.1 bar inside the sterilizing cylinder.

6. Repeating steps (3 and 4) until even heating the sterilization box's air to 160 ° C.

7. Repeating step (3), in two periods before and in the afternoon with the same average of intensity of solar radiation.

8. Repeat step (3), but from 7 am to 5 pm (that is, during active brightness hours).

9. Exposing the steam sterilization chamber to sunlight with allow the heating steam (from step 3) to transfer from the solar absorber vessel to the steam sterilization chamber to utilization its heat to quick the generation of the sterilization steam by the heat exchanger until even generation the steam at 121.1 ° C and 2.1 bar, in two periods before and in the afternoon with the same average of intensity of solar radiation.

10. Exposing the steam sterilization chamber to sunlight with allow the heating steam (from step 3) to transfer from the solar absorber vessel to the steam sterilization chamber to utilization its heat to quick the generation of the sterilization steam by the heat exchanger until even generation the steam at 121.1 ° C and 2.1 bar, this from 7 am to 5 pm (that is, during active brightness hours).

11. Exposing the dry hot air sterilization chamber to sunlight with allow the heating steam (from step 3) to transfer from the solar absorber vessel to the dry, hot air sterilization chamber to utilization its heat to quick the generation of the sterilization air by the heat exchanger until even heating the sterilization box's air to 160 ° C, this in two periods before and in the afternoon with the same average of intensity of solar radiation.

12. Exposing the dry hot air sterilization chamber to sunlight with allow the heating steam (from step 3) to transfer from the solar absorber vessel to the dry, hot air sterilization chamber to utilization its heat to quick the generation of the sterilization air by the heat exchanger until even heating the sterilization box's air to 160 ° C, this from 7 am to 5 pm (that is, during active brightness hours).

13. Repeating steps (5 and 6) at the same time.

4.5 Measurement Devices Calibration

The Renewable Energy Directorate calibrated the experimental measurement devices in the Ministry of Science and technology according to the document offered in the appendix (G).

Chapter Five
Results and Discussion

This chapter includes a presentation, discussion, and comparison of the theoretical and experimental results. The results are the temperature and pressure of the steam inside the cylindrical solar absorbent vessel with and without a reflective oval dish and Fresnel lens. Also, the temperature and pressure of steam and air inside the sterilization units with and without a heat exchanger. The experimental results of the test's execution time effect on the properties of the sterilizing fluid (steam or hot air) are also presented and discussed in this chapter. This chapter includes the checking process of the solar system used in this study to know if it can perform its task as a sterilizer for surgical equipment or not. In addition to an economic feasibility study, to show the details of the manufacturing costs of this system with all its parts are shown in this chapter.

5.1 Theoretical Temperature and Pressure

This section is divided into two parts. The first involves the theoretical results of temperature and pressure of the fluid (initially water) inside the cylindrical solar absorbent vessel with and without a reflective oval dish and Fresnel lens. At the same time, the second section includes the theoretical results of the temperature and pressure of sterilizing fluid (steam or dry, hot air) in the sterilization units with and without a heat exchanger.

The average value of solar radiation intensity was assumed to be 600 W/ m^2. The average ambient temperature was also considered to be 30 °C (in accordance with the anticipated weather on April in Iraq, where the experiments would be conducted). This is for all the theoretical calculations.

5.1.1 Solar Absorbent Vessel

This section includes the theoretical results of fluid properties (temperature and pressure) inside the cylindrical solar absorbent vessel. For the normal case (without modification), with a reflective oval dish only, and a Fresnel lens with the reflective oval dish simultaneously.

5.1.1.1 Normal or Unmodified Vessel

Figure (5.1) shows the theoretical results of the temperature and pressure of water inside the normal cylindrical solar absorbent vessel (without any modification). As shown in this figure, the higher temperature of water obtained is about 65 ˚C, and the higher pressure is 0.2 bar. These results cannot be accepted because they are very little compared with the required steam conditions (160 ˚C and 6.2 bar) to produce the sterilization fluid. So that solar concentration devices would concentrate the solar radiation towards the vessel and thus generate the steam quickly.

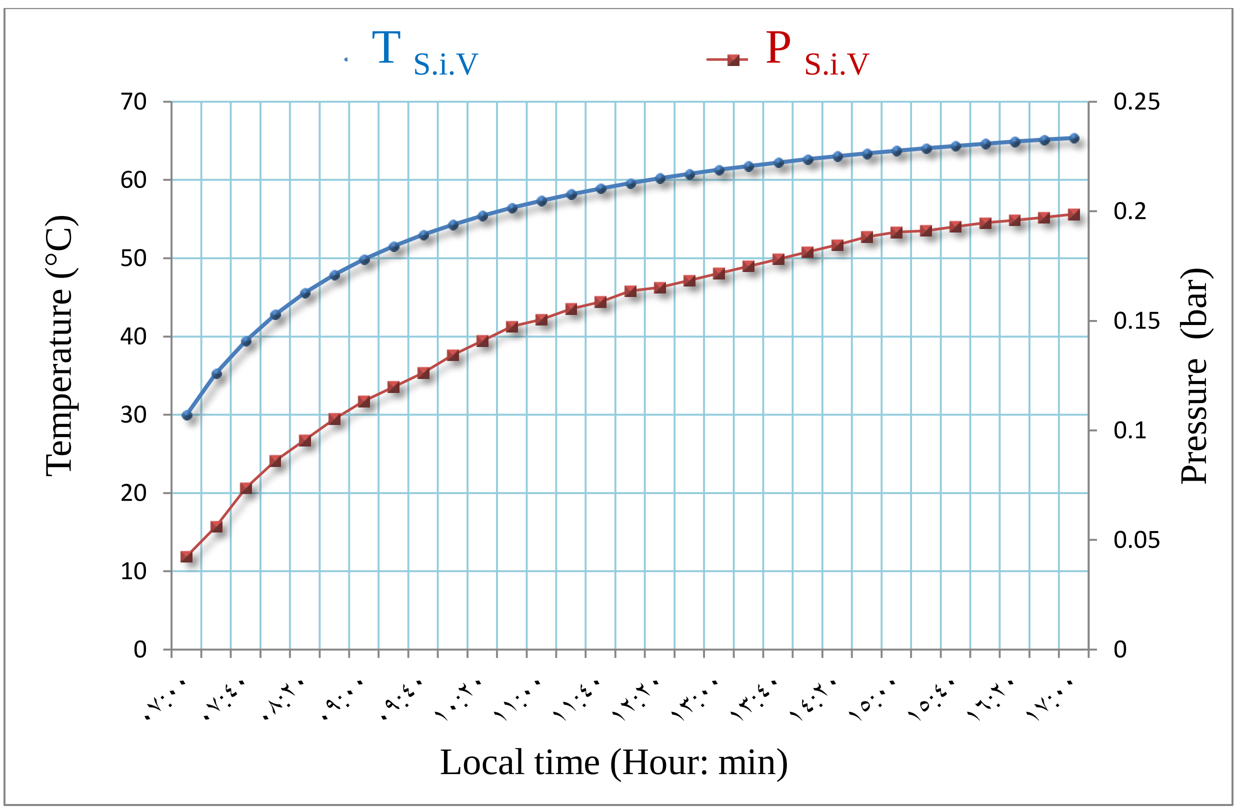


Figure (5.1): The Theoretical Temperature and Pressure of Steam inside the Normal Solar Absorber Vessel (without solar concentrators) versus Time

5.1.1.2 Reflective Oval Dish Effect on Vessel Performance

The theoretical results of the properties of steam (temperature and pressure) in the solar absorbent vessel with a reflective oval dish are presented in figure (5.2). This figure shows that using the oval dish technique rapidly increases the water's temperature and pressure in this vessel, thus decreasing the steam generation time. The necessary steam conditions for the heat exchanging (160 °C and 6.2 bar) were obtained during 33 minutes. This is considered a good result compared to the normal case (without the dish). This is because the dish collects the solar radiation on the solar absorbent vessel with a higher intensity, which causes faster water heating inside this vessel. This is since it (the dish) has a large ratio of solar radiation concentration and a large focus area (it covers almost the solar absorbent vessel surface totally). Therefore, the amount of heat transferred to the water inside this vessel will be increased.

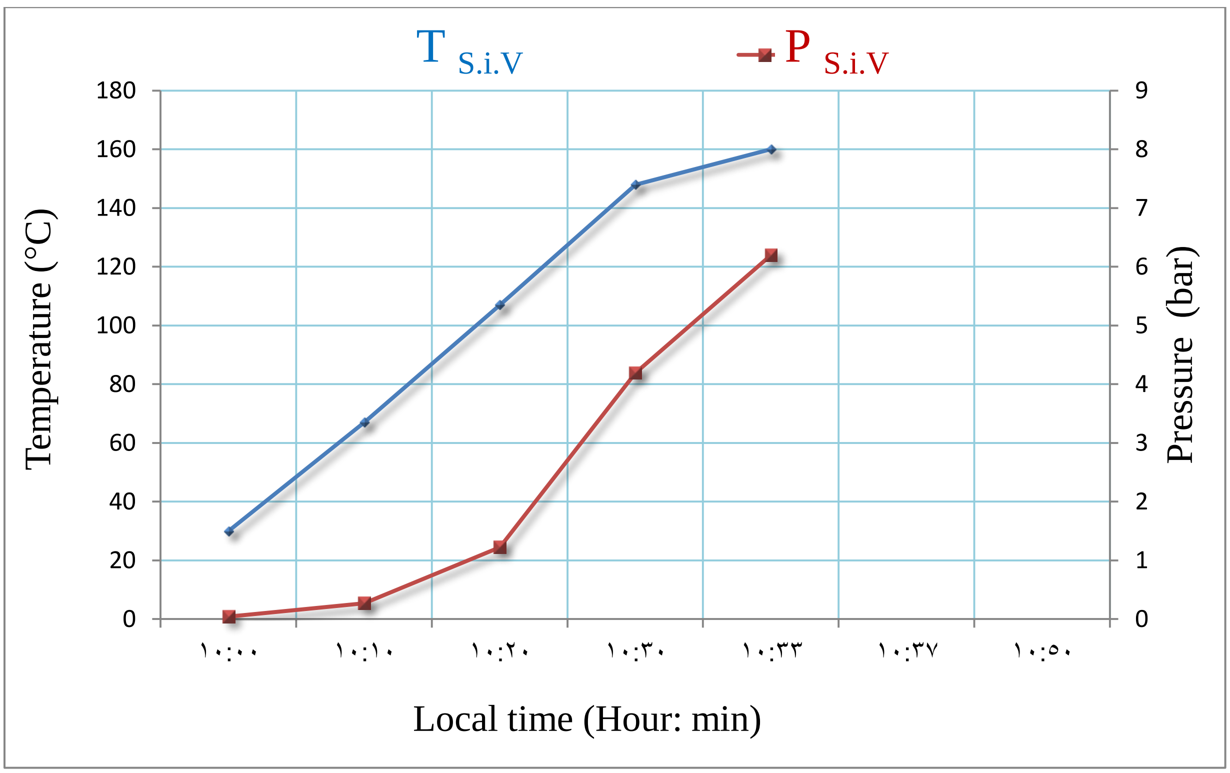


Figure (5.2): The Theoretical Temperature and Pressure of Steam inside the Solar Absorbent Vessel with the Reflective Oval Dish as a Solar Concentrator versus Time

5.1.1.3 Fresnel Lens Effect on Vessel Performance

Figure (5.3) theoretically shows the effect of the addition of the Fresnel lens with the reflective oval dish on the temperature and pressure of water inside the solar absorbent vessel. It is evident through this figure that adding the lens leads to a significant increase in the properties of water. In other words, it reduces the steam formation time by 36.4% compared to the previous case (using the dish only). The required properties of steam (160°C and 6.2 bar) can be obtained in 21 minutes.

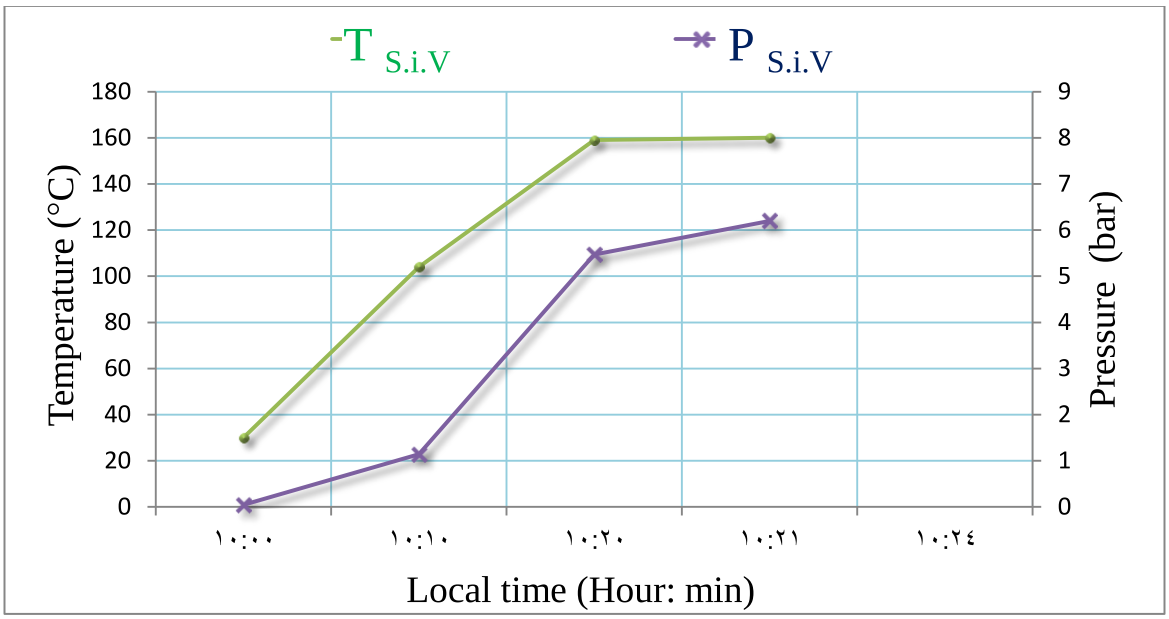


Figure (5.3): The Theoretical Temperature and Pressure of Steam inside the Solar Absorbent Vessel when the Reflective Oval Dish and Fresnel Lens are used as a Solar Concentrators versus Time

5.1.2 Medical Equipment Sterilization Units

5.1.2.1 Normal or Unmodified Sterilization Units

Figures (5.4 a and b) show the theoretical results of properties (temperature and pressure) of water and air in normal (without any development technique) sterilization units, respectively. In these cases, the sterilizing fluid can be generated for two hours and 41 min for the steam and about three hours for the air. Generally ،these results may not be accepted because they are considered long times to sterilize medical equipment. So, a heat exchanger was used in each sterilization unit to reduce these times.

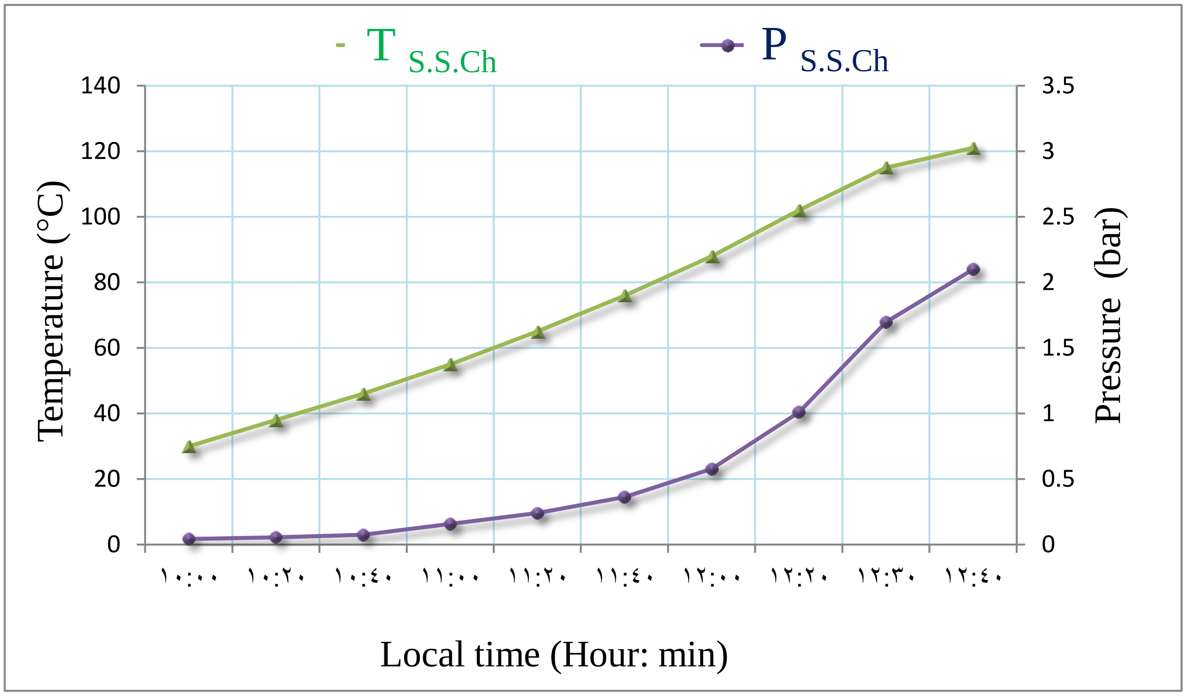


Figure (5.4 a): The Theoretical Temperature and Pressure of Steam inside the steam Sterilization Chamber (Normal Sterilization unit case) versus Time

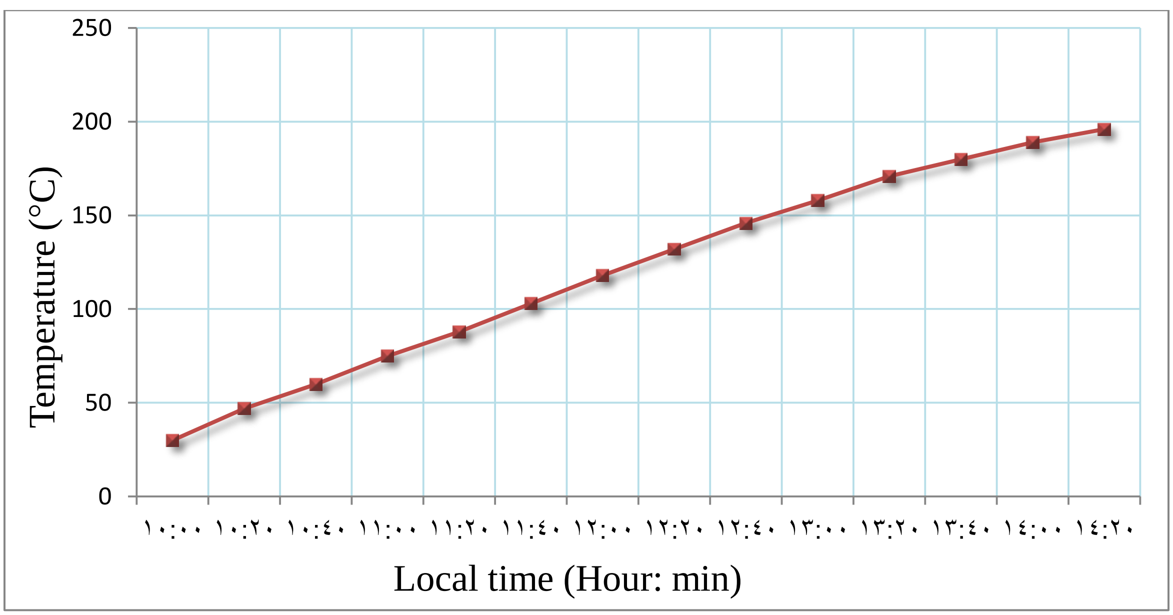


Figure (5.4 b): The Theoretical Temperature of Air inside the Dry Hot Air Sterilization Chamber (Normal Sterilization unit case) versus Time

5.1.2.2 Heat Exchanger Effect on Sterilization Units Performance

Figures (5.5 a and b) show an effect of heat exchange on the theoretical results of properties of water and air inside the sterilization units, respectively. The heat exchange process involves the steam from the solar absorbent vessel and the fluid (steam or dry, hot air). These results show that this technique (the heat exchanger) has a very positive effect on the properties of sterilizing fluid. It leads to rising the temperature from 30 to 121 ˚C and pressure from 0.04 bar to 2.1 bar during 8 min for the steam and from 30 to 160 ˚C during 8.5 min for the air. In other words, it reduces the necessary time to obtain the required conditions of the sterilizing fluid by 94.4% for the steam and 95% for the air. This is because of the high thermal energy of the steam coming from the solar absorbent vessel, which is extracted by the fluid in the sterilization unit.

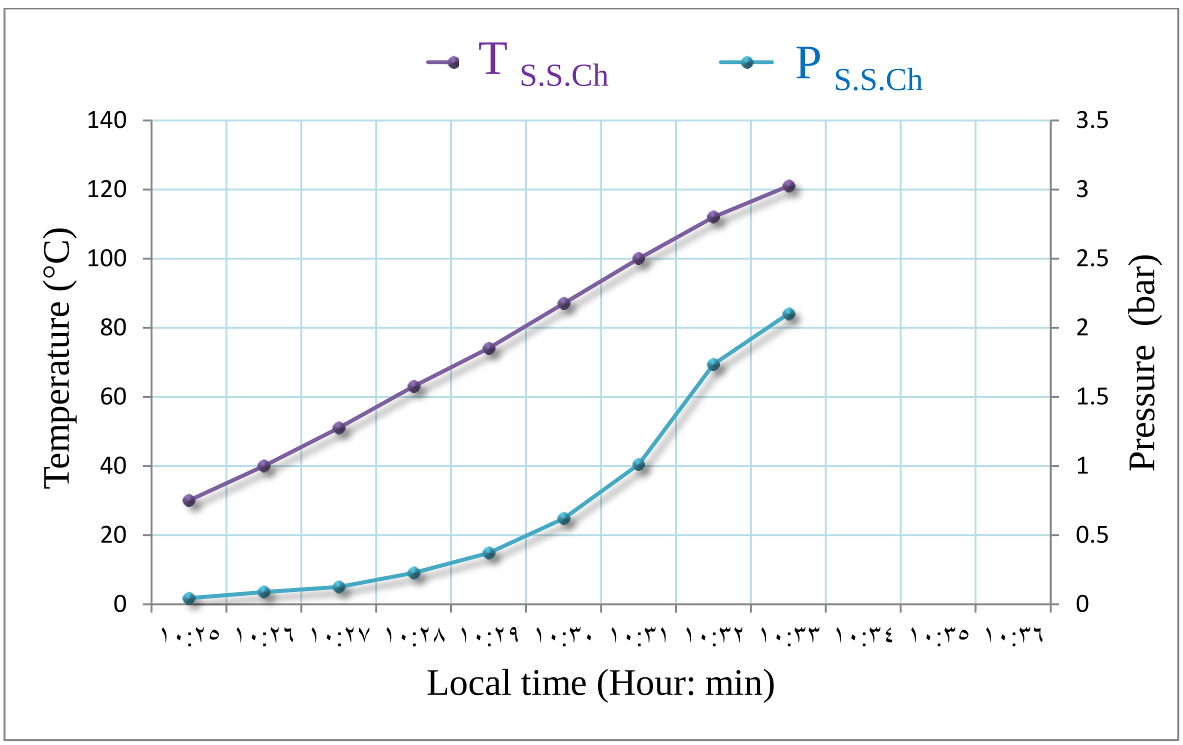


Figure (5.5 a): The Theoretical Temperature and Pressure of Steam in the Steam Sterilization Chamber with the Heat Exchanger versus Time

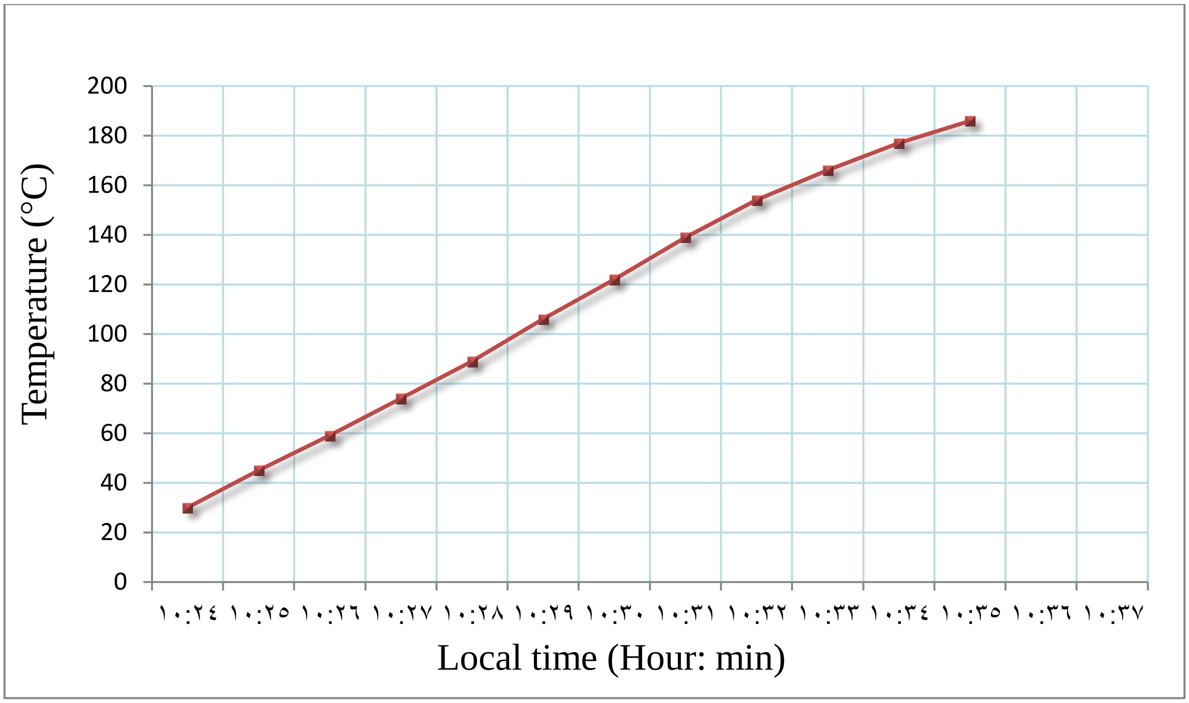


Figure (5.5 b): The Theoretical Temperature of Air in the Sterilization Chamber with the Heat Exchanger versus Time

5.2 Experimental Temperature and Pressure

Similarly, with the section on theoretical results (section 5.1), this section would be divided as follows: -

5.2.1 Solar Absorbent Vessel

This section presents the experimental results of fluid properties (temperature and pressure) inside the cylindrical vessel with and without a reflective oval dish and Fresnel lens. Knowing that these properties are controlled by a safety valve set at 6.2 bar. One of the important properties of wet steam is the stability of its temperature at saturation value when fixing pressure.

5.2.1.1 Normal or Unmodified Vessel

Figure (5.6) shows the experimental results of the temperature and pressure of water inside the normal (without modification or addition) cylindrical solar absorbent vessel.

This is for the period from 7:00 am until 5:00 pm according to the time of the city of Karbala. As is the case in the theoretical aspect, it is impossible to obtain steam without using solar concentrators, and the greatest temperature of water obtained is about 55.3°C. This is at 3:00 pm when the ambient temperature is at its highest value.

Knowing that this test was conducted on Apr 21, 2021, the minimum, maximum and average values of solar radiation intensity on this day were around 538, 879, and 708.5 W/ $m^{2,}$ respectively. The average ambient temperature was about 29 °C.

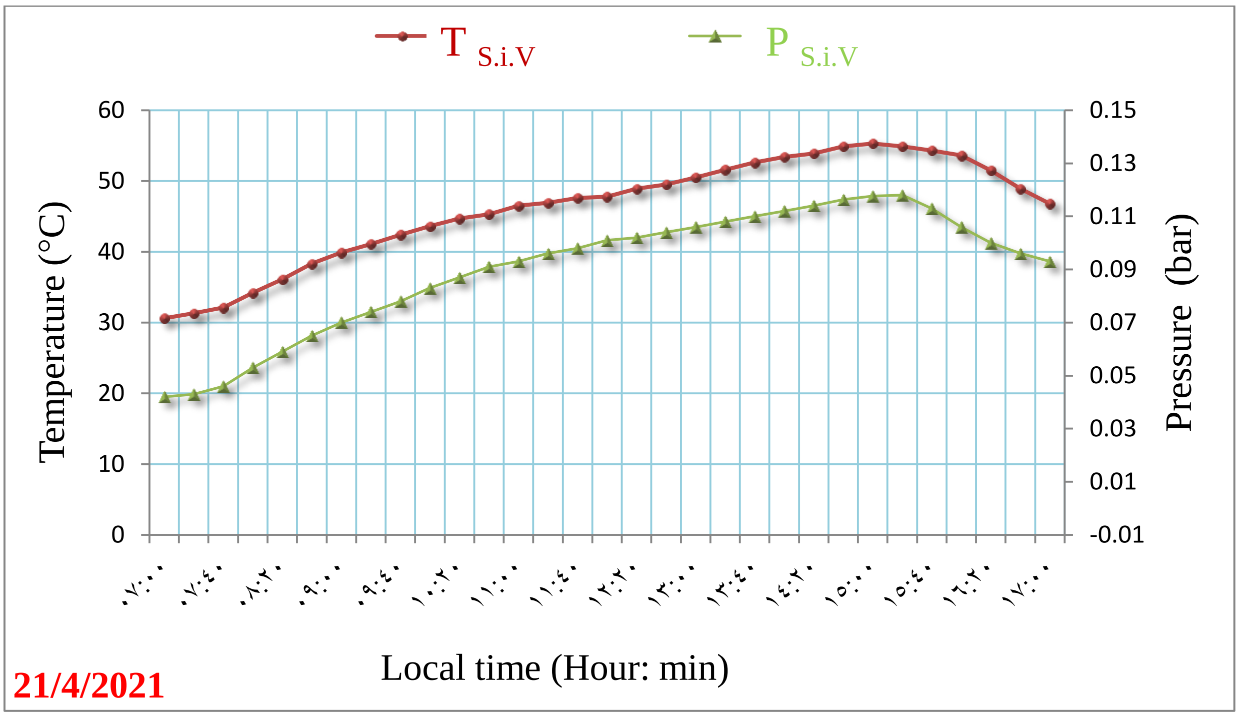


Figure (5.6): The Experimental Temperature and Pressure of Water inside the Normal Solar Absorbent Vessel (without any solar concentrators) versus Time

5.2.1.2 Reflective Oval Dish Effect on Vessel Performance

This section includes the experimental results of the properties of water (temperature and pressure) inside the solar absorbent vessel with a reflective oval dish. This is shown in figure (5.7). This is for the period from (10:00 - 10:50) am. As shown in this figure, the dish has a positive effect on the temperature and pressure of the steam.

Experimentally by using the dish, the steam (160 °C and 6.2 bar) can be obtained for 37 min. This is for the same reasons shown theoretically (section (5.1.1.2)).

Knowing that this test was done on Apr 25, 2021, the minimum, maximum and average values of solar radiation intensity during this day are 591, 992 and 791.5 W/ m^2, respectively. The average ambient temperature is about 34 °C.

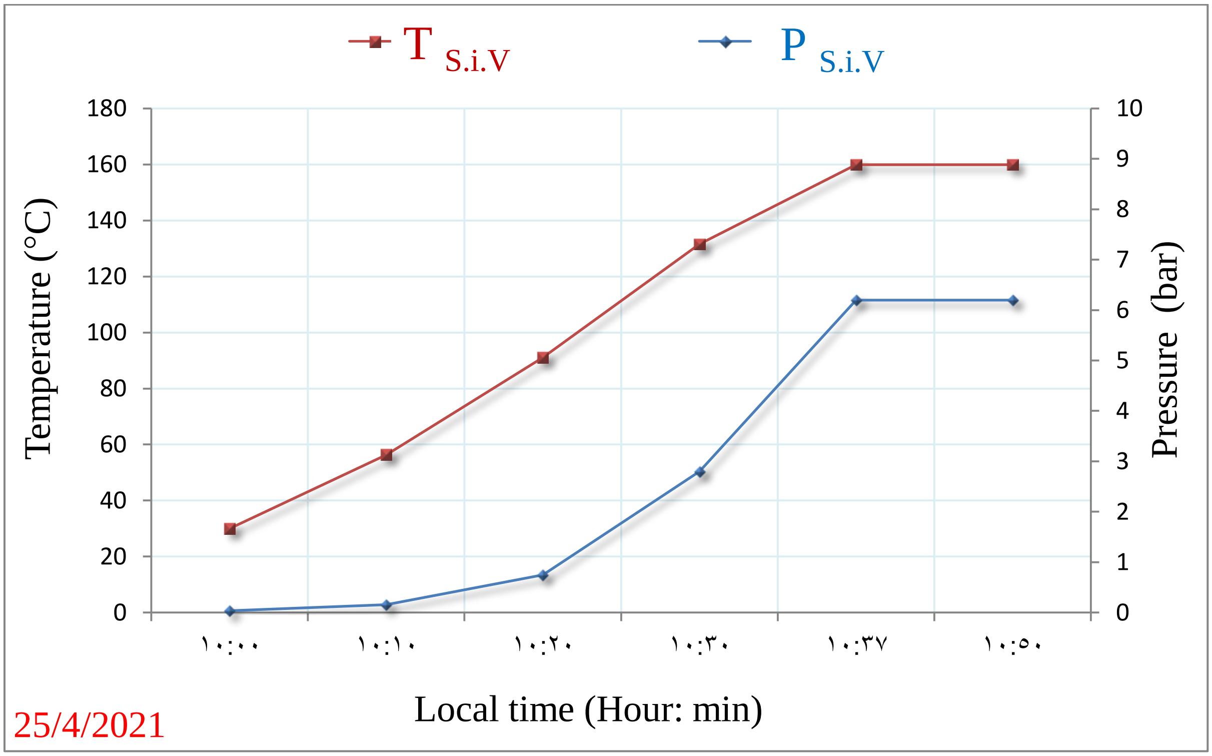


Figure (5.7): The Experimental Temperature and Pressure of Steam inside the Solar Absorbent Vessel with the Dish as a solar concentrator versus Time

5.2.1.3 Fresnel Lens Effect on Vessel Performance

Figure (5.8) experimentally shows the influence of the Fresnel lens on the properties of fluid inside the solar absorbent vessel with the oval dish presence. This is for the duration from (10:00 - 10:25) am. Experimentally, the use of the lens reduces the required time to obtain the needed properties of steam by 35% compared with the results of the dish alone. This confirms the theoretical results (section (5.1.1.3)). Experimentally, the reasons for obtaining steam properties during a very short time compared to the other results is that The lens increased the amount of heat concentrated on the vessel because it has a high concentration ratio for the solar radiation.

Knowing that these experiments were carried out on May 1, 2021, the minimum, maximum and average values of solar radiation intensity during these experiments are about 621, 996, and 808.5 W/ m^2, respectively. The average ambient temperature is about 35 C°.

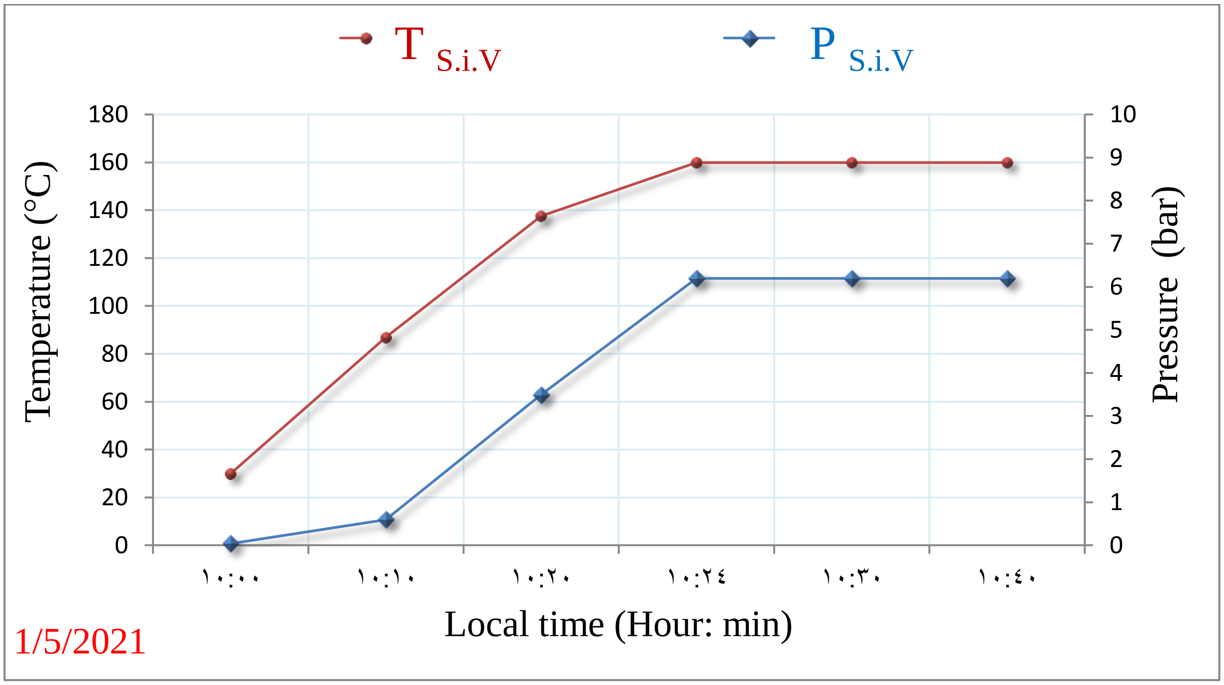


Figure (5.8): The Experimental Temperature and Pressure of Fluid inside the Solar Absorbent Vessel with the Dish and the Fresnel lens as a solar concentrator versus Time

5.2.2 Medical Equipment Sterilization Units

5.2.2.1 Normal or Unmodified Sterilization Units

Figures (5.9 a and b) show the experimental results of steam and air properties (temperature and pressure) in sterilization units, respectively. This is for the test duration of 10 am to 1:20 pm.

These results show that sterilization units in their normal cases (without modification) take a long time to achieve the sterilization task.

Knowing that these tests were carried out on May 7, 2021. The minimum, maximum and average values of solar radiation intensity during these tests are about 894, 1005, and 949.5 kW/ m^2, respectively. The average ambient temperature was about 35 C°.

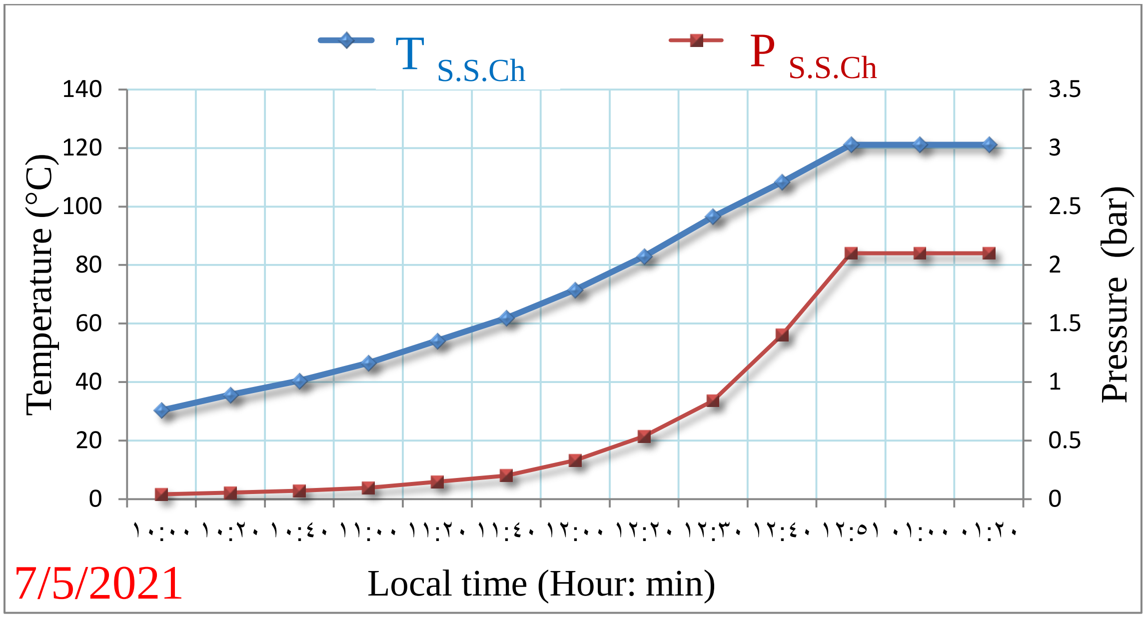


Figure (5.9 a): The Experimental Temperature and Pressure Results of Steam inside the Steam Sterilization Chamber (Normal Sterilization unit case) versus Time

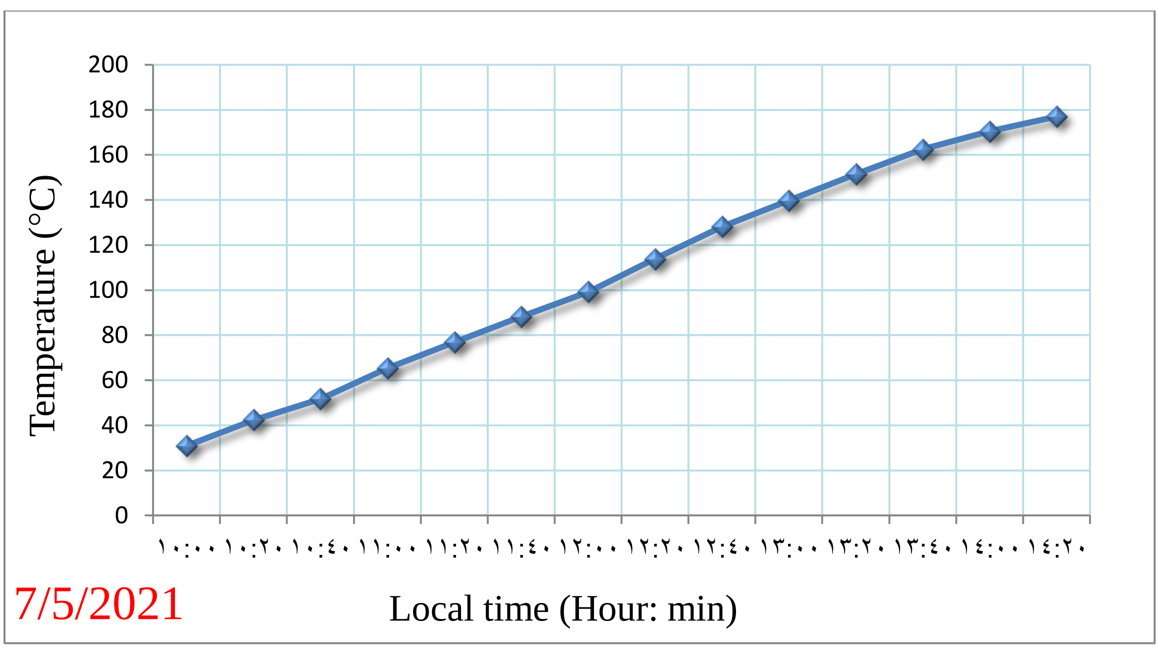


Figure (5.9 b): The Experimental Air Temperature inside the Normal Sterilization Chamber Versus Time

5.2.2.2 Heat Exchanger Effect on Sterilization Units Performance

Figures (5.10 a and b) experimentally show an effect of heat exchange on the properties of steam and air inside the sterilization chambers, respectively. This is for 15 minutes, from 10 to 10:15 am. Through these results, it is clear that the heat exchanger affects the properties of sterilizing fluid positively. Experimentally, it increases the temperature from 34 to 121.1 ˚C and pressure from 0.04 bar to 2.1 bar during 11 min for the steam and the air; the heat exchanger rises its temperature from 30.6 to 160 ˚C in 11 min. In other words, it reduces the necessary time to obtain the required conditions of the sterilizing fluid by 92.6 % for steam and 93.16 % for air. This is for the same causes shown in the theoretical aspect (section (5.1.2.2)).

Knowing that the steam test was carried out on May 10, 2021. The minimum, maximum and average value of solar radiation intensity during the test period is about 895, 1008 and 951.5 kW/ m^2, respectively. The average ambient temperature is about 36 °C. For air, a test was carried out on May 11, 2021. The minimum, maximum and average value of solar radiation intensity during the test period is about 894, 1009 and 951.5 kW/ m^2, respectively. The average ambient temperature is about 36 C˚.

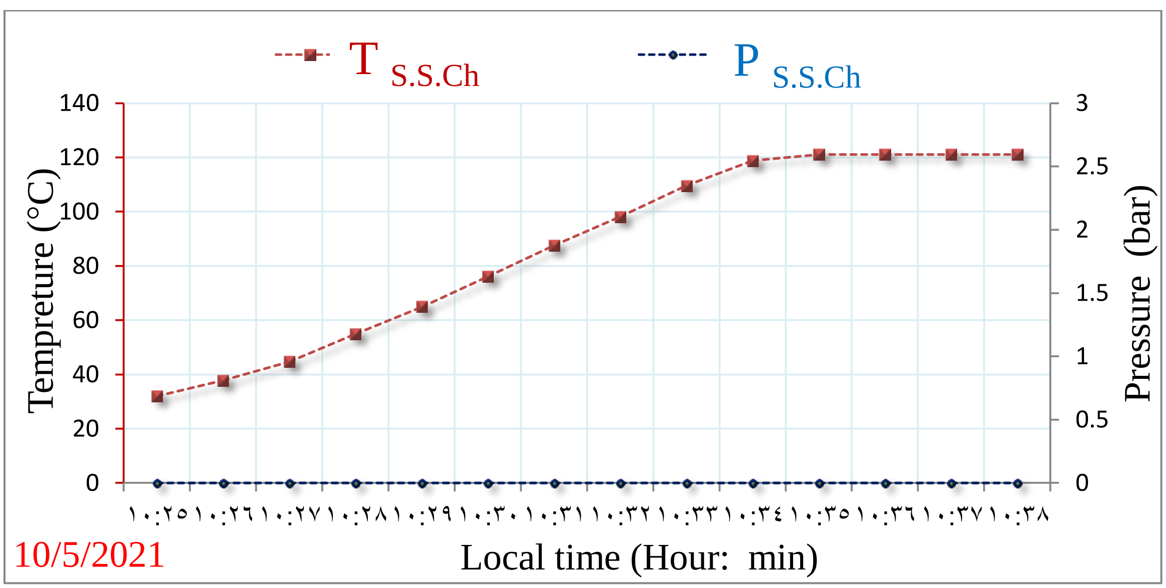


Figure (5.10 a): The Experimental Temperature and Pressure of Fluid in the Sterilization Chamber with the Heat Exchanger versus Time

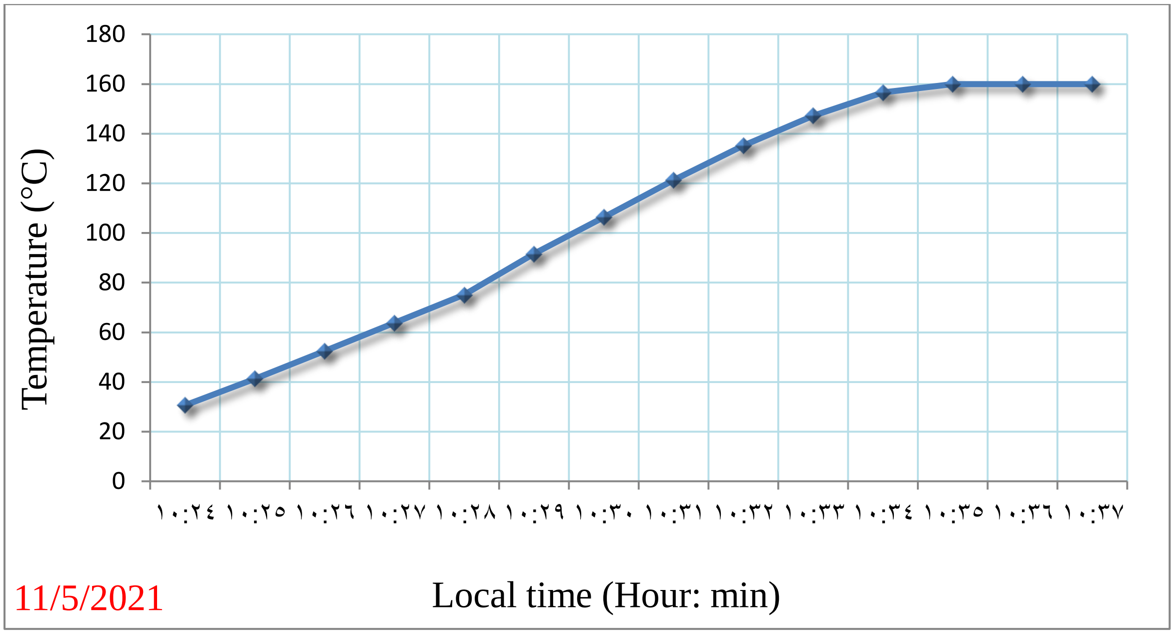


Figure (5.10 b): The Experimental Results of the Air Temperature in the Sterilization Chamber with the Heat Exchanger versus Time

5.2.3 Experiments Execution Time Effect

5.2.3.1 Solar Absorbent Vessel

Several experimental tests were carried out using 0.5 liters of pure water at 30 °C in each test to know the effect of the experimental test execution time on the results of the temperature and pressure of steam inside the solar absorber vessel. This is with a Fresnel lens and a reflective oval dish simultaneously.

Firstly, two experimental tests were carried out separately in two symmetrical periods around the peak of the solar radiation intensity. The two tests have the same average solar radiation intensity. The first test was done in the morning (from 10:00 to 10:20) am, and the second test was carried out in the afternoon (from 01:40 to 02:00) pm, as shown in figure (5.11). As it is clear, During the afternoon experiment, steam with the required properties was achieved in a shorter time than in the morning experiment. Knowing that the average intensity of solar radiation at both tests was about (966 W/ m^2), but the ambient temperature was different (35 °C at the first test and 40 °C at the second test).

Secondly, multiple experimental tests were carried out (at the head of each hour, one test is done) from 07:00 am, until 05:00 pm, as shown in figure (5.12). These results show that the required time to obtain the needed properties of steam (160 ˚C and 6.2 bar) decreases towards noon. This is because, over time, the earth becomes saturated with heat. As a result, the ambient temperature increases, the heat losses from the system to the environment decrease and increase the solar radiation reflected by the earth on the system. The change in the intensity of solar radiation and ambient temperature during the test day is shown in the figure (5.13).

The behavior of incident solar radiation and ambient temperature during the test day is shown in Fig. The solar radiation intensity curve appears to increase until the peak at 12:06 pm and then begins to decrease. The ambient temperature curve continued to increase even after the curve of radiation intensity decreased until 3:00 pm, after which it began to decline.

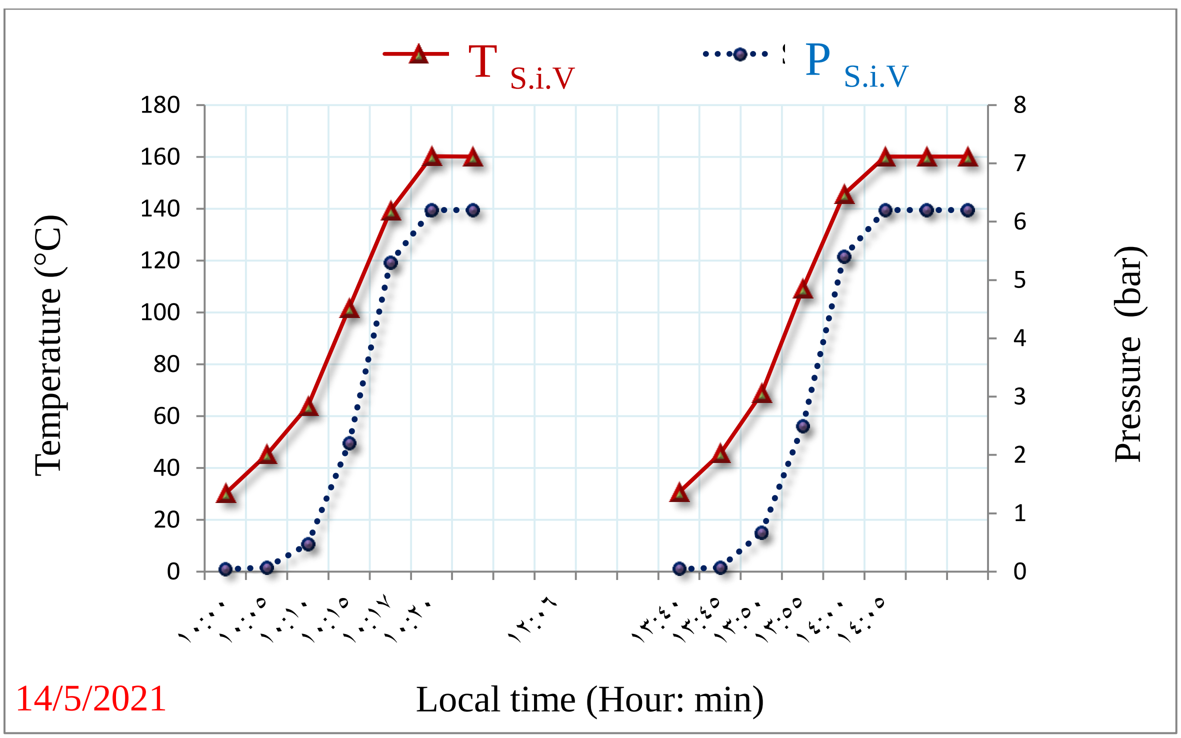


Figure (5.11): The Steam Temperature and Pressure in Solar Absorbent Vessel (Two Tests in Two Symmetrical Durations around Peak Solar Radiation Intensity)

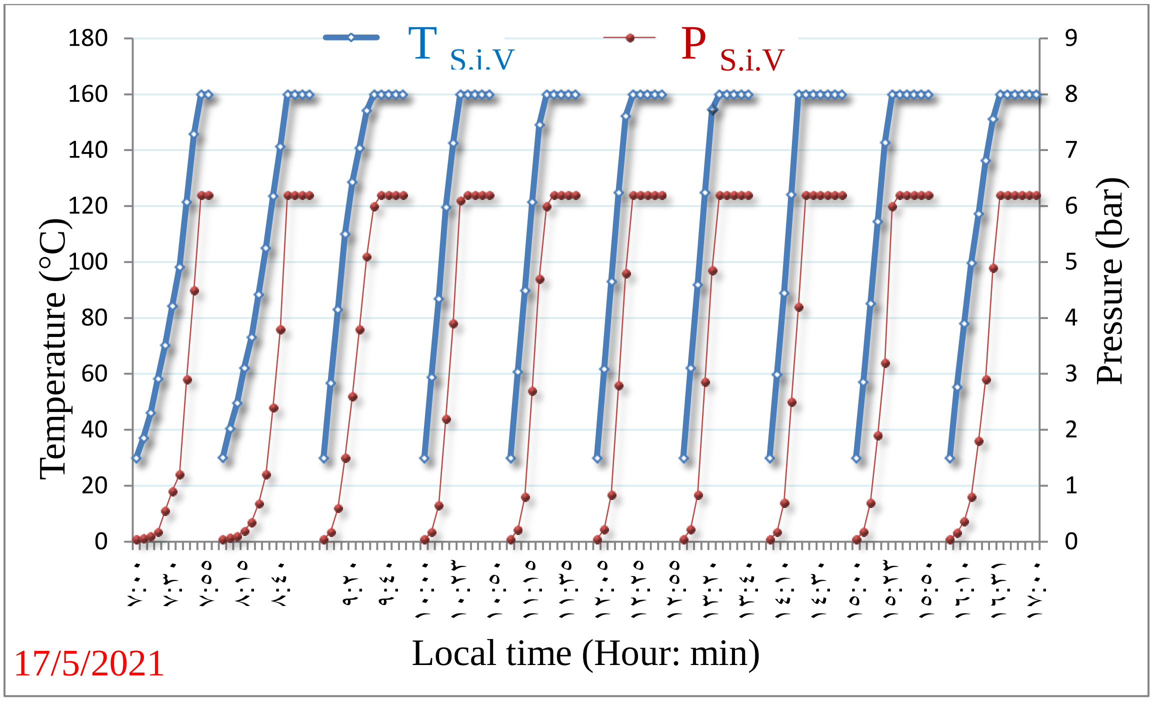


Figure (5.12): The Steam Temperature and Pressure Inside the Solar Absorber Vessel versus the Time (Multiple Tests from 7am to 5 pm)

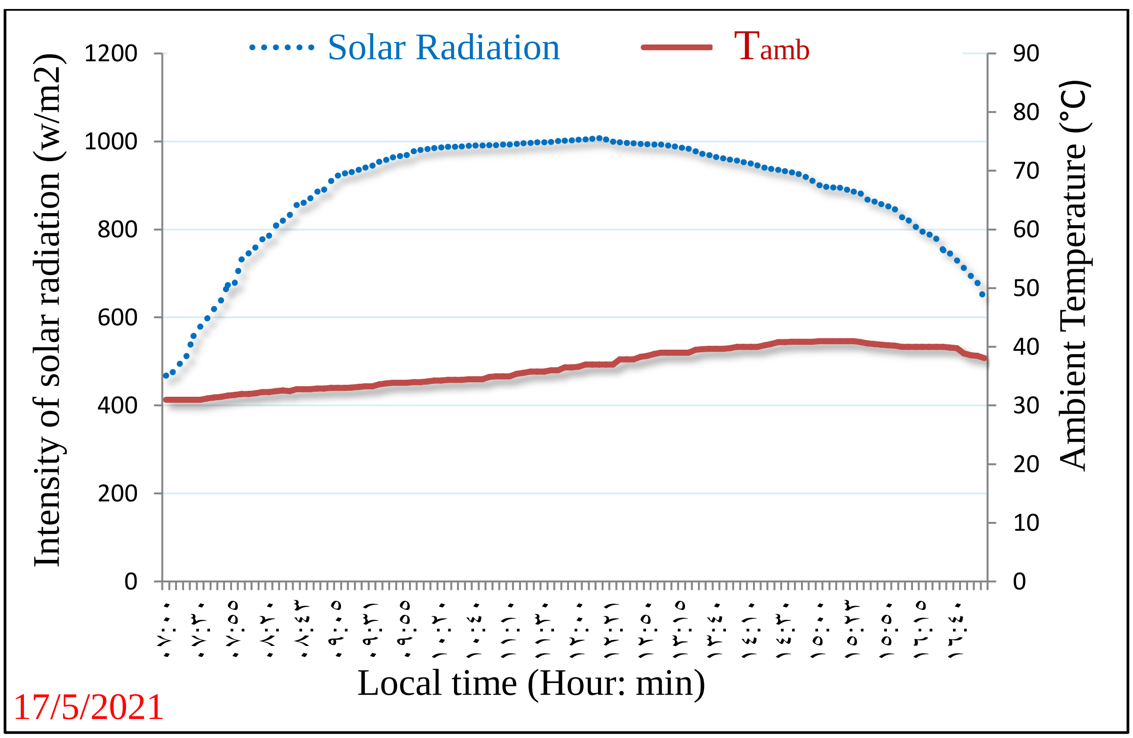


Figure (5.13): The Distribution of Solar Radiation Intensity and Ambient Temperature During the Test Day (from 7 am to 5 pm) Over Time

5.2.3.2 Sterilization Unit by Steam

Several experimental tests of the steam inside the surgical equipment sterilization chamber were carried out with the heat exchanger. This shows the effect of the time of carrying out the experiments on the results of the temperature of sterilization fluids (steam and air) and the pressure of sterilization steam. After the heating steam inside the absorbent vessel had achieved the required properties, these tests were carried out. The control valve was then opened to allow steam to flow towards the heat exchanger into the autoclave chamber.

In the first scenario, two experimental tests were carried out separately in two symmetrical periods around the peak of the solar radiation intensity. The two tests have the same average solar radiation intensity. The first test was conducted in the morning, and the second was performed in the afternoon pm, as shown in figure (5.14). As it is apparent from this figure, the results of both the tests were that the evening test was faster by about two minutes, for the same reason mentioned earlier. Knowing that the average intensity of solar radiation at both tests is about the same (996 W/m^2), the average ambient temperature differs (37 °C at first and 41 °C at the second test).

Multiple experimental tests were carried out (for each hour, one test) from 07:00 am until 05:00 pm, as shown in figure (5.15). This figure shows that the required time to get the wanted properties of steam (160 C and 6.2 bar) reduces at about noon for the same reason shown above.

Knowing that the average intensity of solar radiation on that day is about 769W/ m^2 and the average ambient temperature is about 37°C.

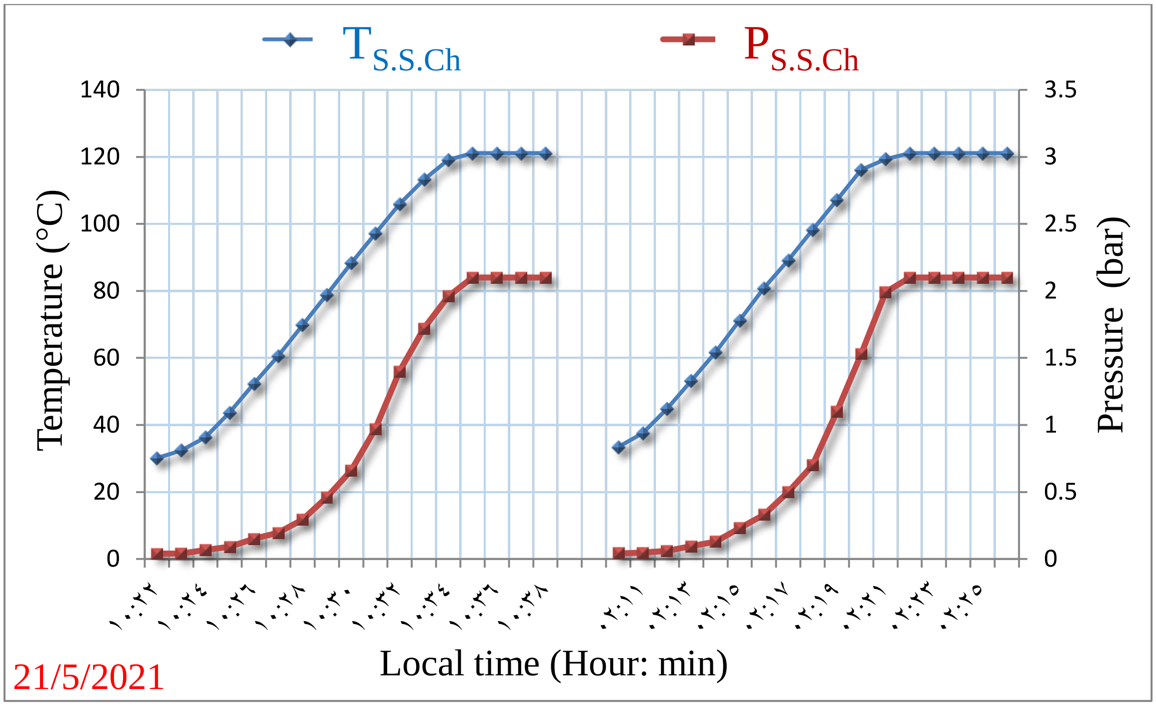


Figure (5.14): The Temperature and Pressure of Steam in the Sterilization Chamber (Two Tests in Two Symmetrical Periods Two Tests in Two Symmetrical Periods about the peak of solar radiatio)

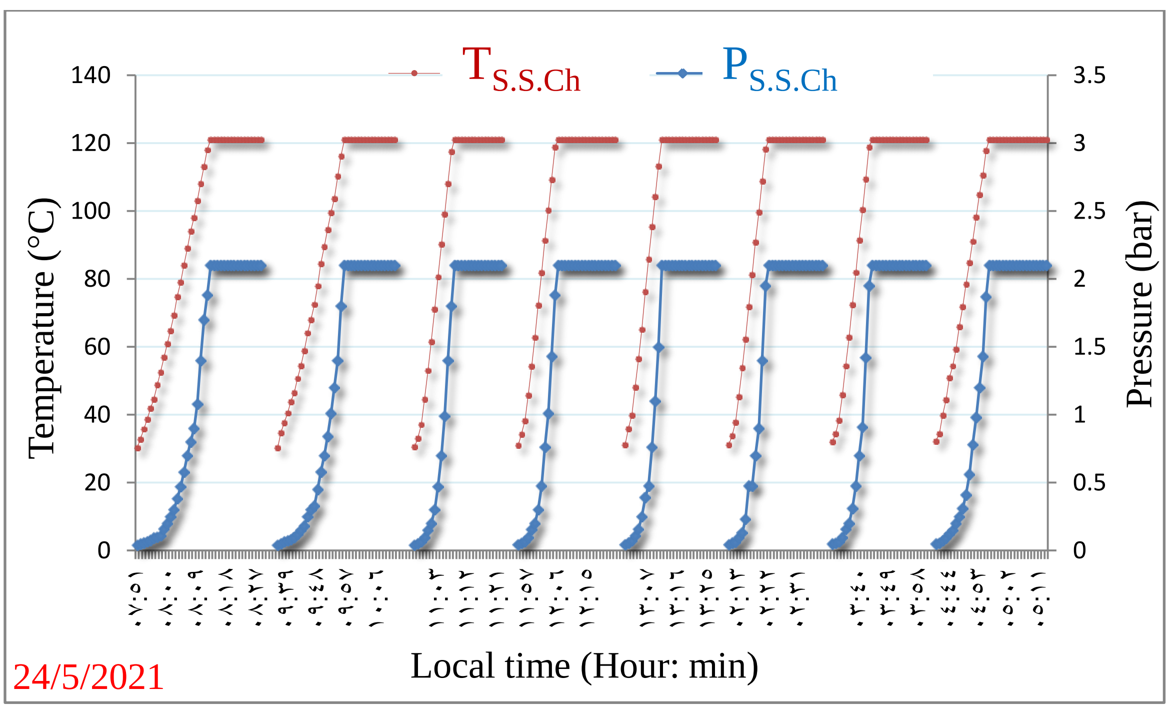


Figure (5.15): The Steam Temperature and Pressure inside the Sterilization Chamber versus The Time (Multiple Tests from 7 am to 5 pm)

5.2.3.3 Sterilization Unit by Hot Dry Air

Several experimental tests were carried out to know the effect of test execution time on the air temperature readings inside the surgical equipment sterilization box. This is with the presence of the heat exchanger.

Initially, two experimental tests were carried out separately in two symmetrical periods about the peak of solar radiation. The first test was carried out in the morning, and the second was made in the afternoon, as shown in figure (5.16). As explained in this figure, the required air temperature faster obtained at the after-noon time is for the same resons shown above. Knowing that the average intensity of solar radiation in both tests is about equal (998 W/m^2), and the average ambient temperature is somewhat dissimilar (37 °C at the first test and 41°C at the second test).

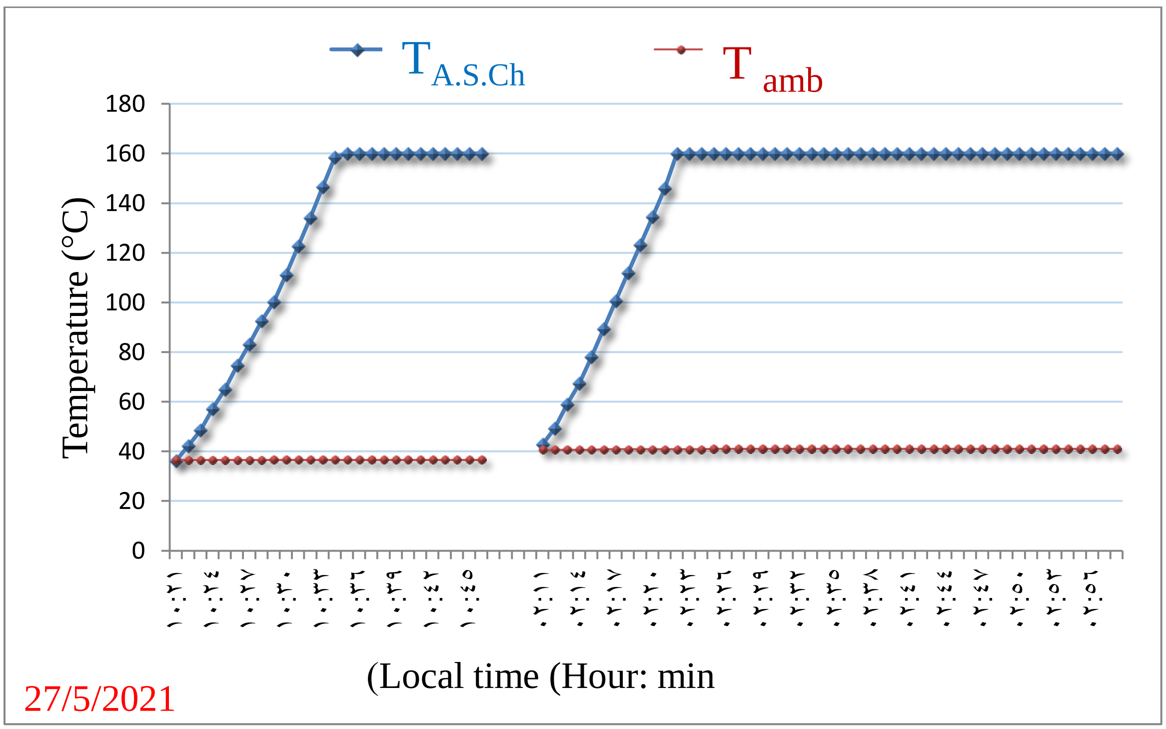


Figure (5.16): The Temperature of Air in the Sterilization Chamber (Two Tests in Two Symmetrical Periods Two Tests in Two Symmetrical Periods about the peak of solar radiation)

Multiple experimental tests were carried out (at each hour, one test) from 07:00 am until 05:00 pm, as explained in figure (5.17). Through these results, the effect of experiment execution time on the results of the temperature of the air is clear. At noon and around its time, the needed value of the temperature can be achieved faster than the other times (away from the noontime). That is for the same reasons explained above.

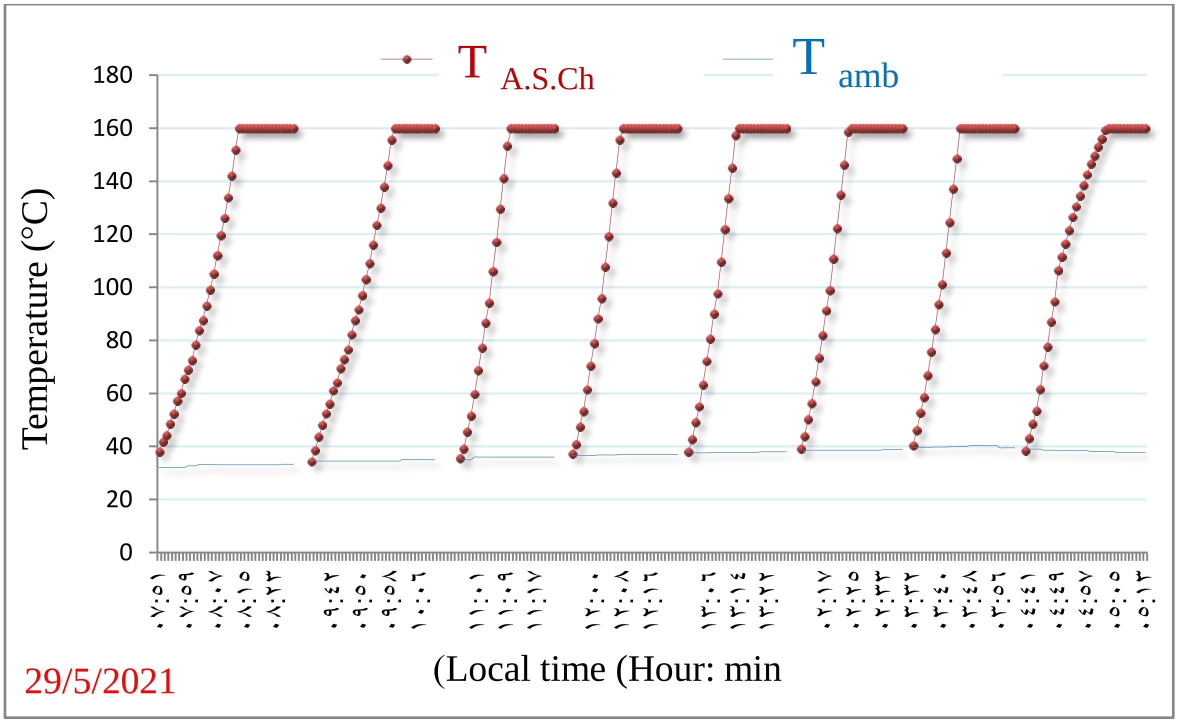


Figure (5.17): The Air Temperature Inside the Sterilization Chamber versus the Time (Multiple Tests from 7 am to 5 pm)

To evaluate the system's ability to carry out both steam and air sterilization processes simultaneously. Steam from the heat-absorbing vessel was allowed to flow to the two sterilizing chambers.

The test was conducted on June 1, 2022, at 10:23 a.m., the test was conducted.

The figure (5.18) shows that the generation of the sterilization steam (at 121.1°C and 2.1 bar) inside the steam sterilization chamber was achieved within 16 minutes from water at 30 °C at the start of the test. The air within the surgical equipment box was heated to 160 °C over 17 minutes from 30.6 °C.

The reason for the increase in the achieving time of the sterilizing fluids is the doubling in the expansion volume of the heating steam. where the expansion volume includes the transfer and exchanger tubes for the two sterilizing chambers. Thus, the pressure of the heating steam is decreas, and its temperature also decreases. This means that the energy of the heating steam is lower.

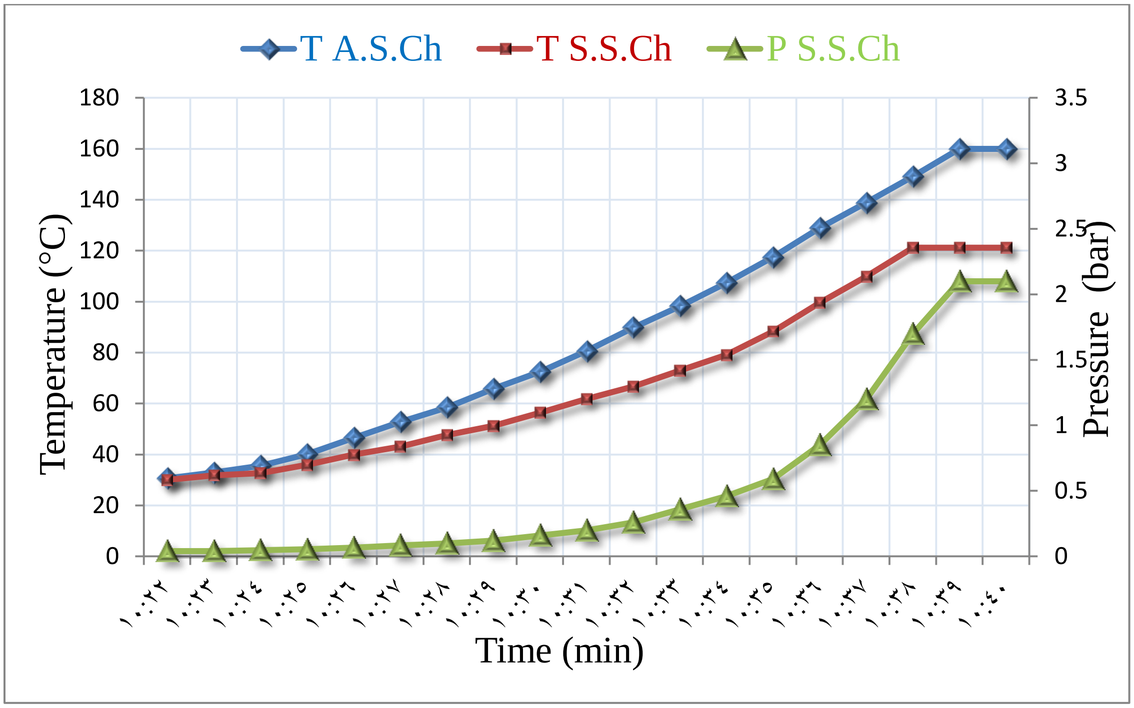


Figure (5.18): Temperatures inside Two Sterilization Chambers and Steam Pressure inside the Steam Sterilization Chamber (Case of the flow of heating steam from the heat-absorbing vessel to the two sterilizing chambers at the same time) over time

5.3 Results Comparison

Figures (5.19 a, b, and c) show comparisons between the theoretical results and the experimental results of the current study. This is for the temperature and pressure of the fluid inside the solar absorbent vessel for the normal case, with the reflective dish, and with the Fresnel lens that is added to the dish, respectively.

Figures (5.20 a and b) also show comparisons between the theoretical results and experimental ones for the steam (temperature and pressure) and air (temperature) in the sterilization chambers, respectively. This is for the normal case of the sterilization units. Figures (5.21a and b) show the same comparisons as figures (5.19a and b) but with the presence of the heat exchangers in the sterilization chambers. This shows a deviation ratio of the experimental results from the theoretical ones. This deviation is mainly due to some assumptions considered in this study's theoretical aspect: flow type (two or three-dimensional, steady or unsteady, and compressible or incompressible).

Other factors that cause this deviation are external conditions like solar radiation intensity, cloudiness, ambient temperature, etc., that cannot be controlled and the different measurement errors—also, with assuming an ideal heat exchanger and a constant value of solar radiation and ambient temperature for the theoretical calculations.

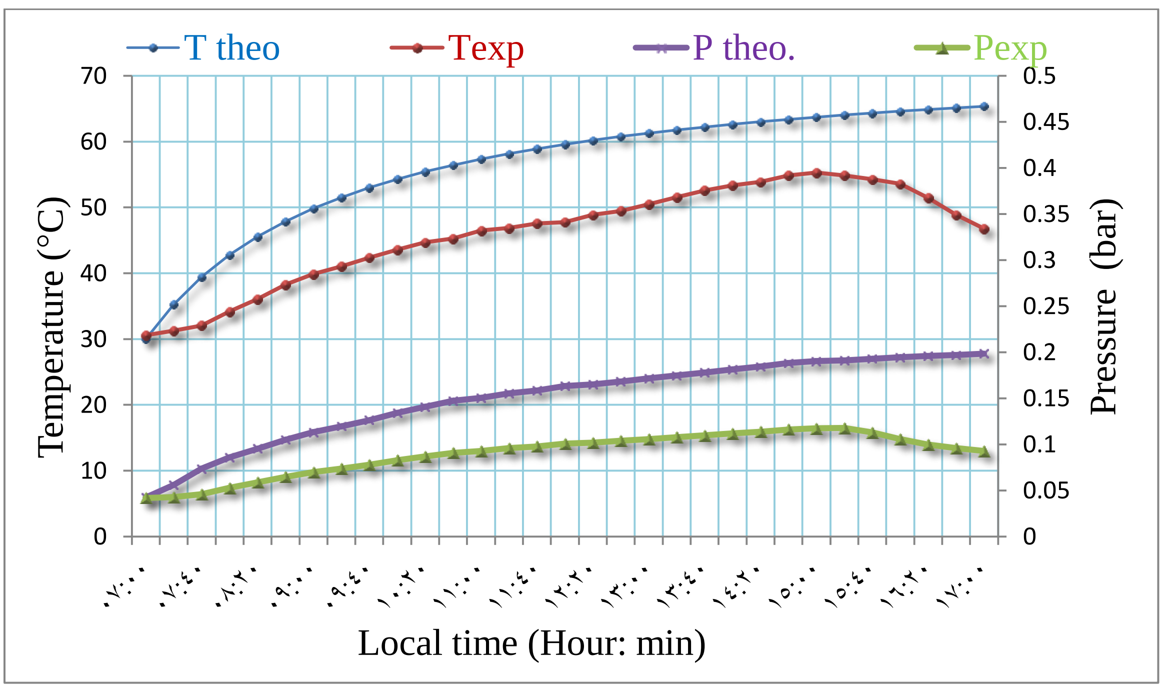


Figure (5.19 a): The Experimental and Theoretical Results Comparison of the Solar Absorber Vessel with the Normal Case(without solar concentrators)

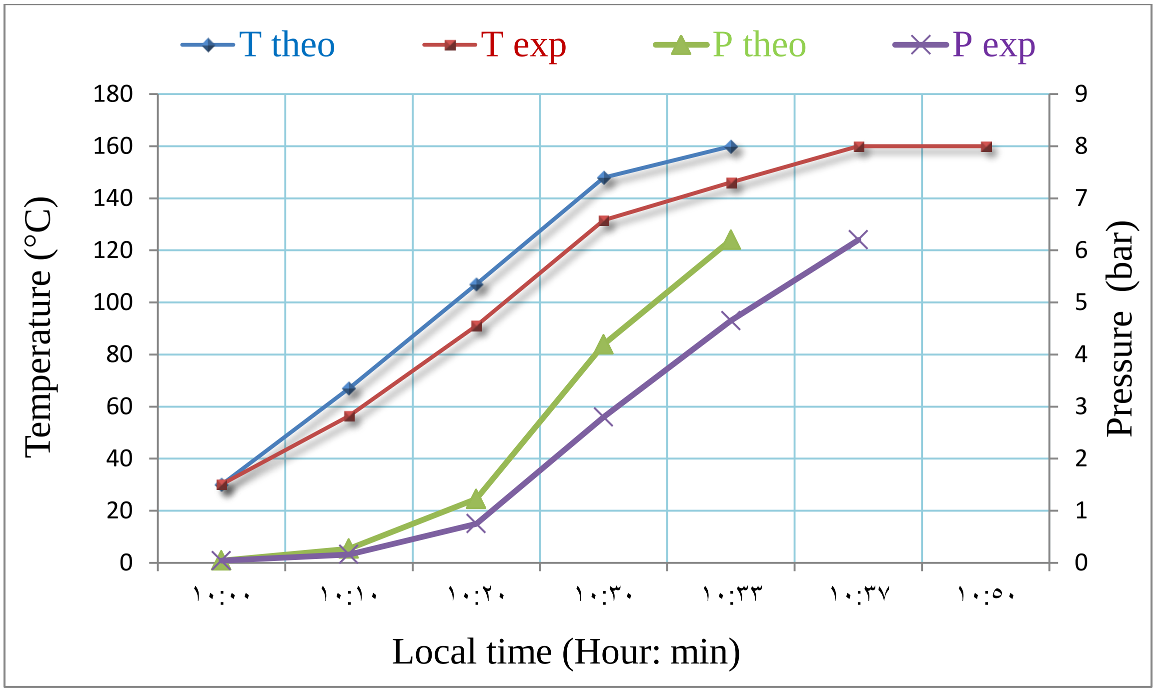


Figure (5.19 b): The Experimental and Theoretical Results Comparison of the Solar Absorber Vessel with the Presence of the Dish as a Solar Concentrator

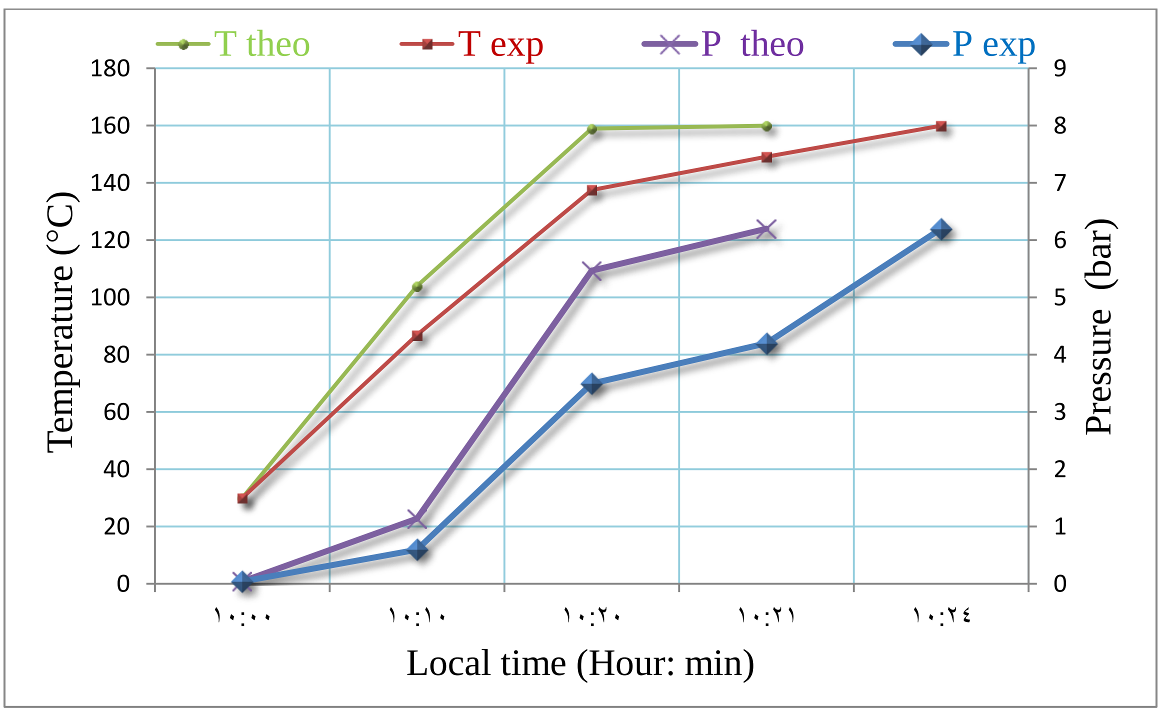


Figure (5.19 c): The Experimental and Theoretical Results Comparison of the Solar Absorbent Vessel with the Presence of Dish and Fresnel Lens together as a Solar Concentrators

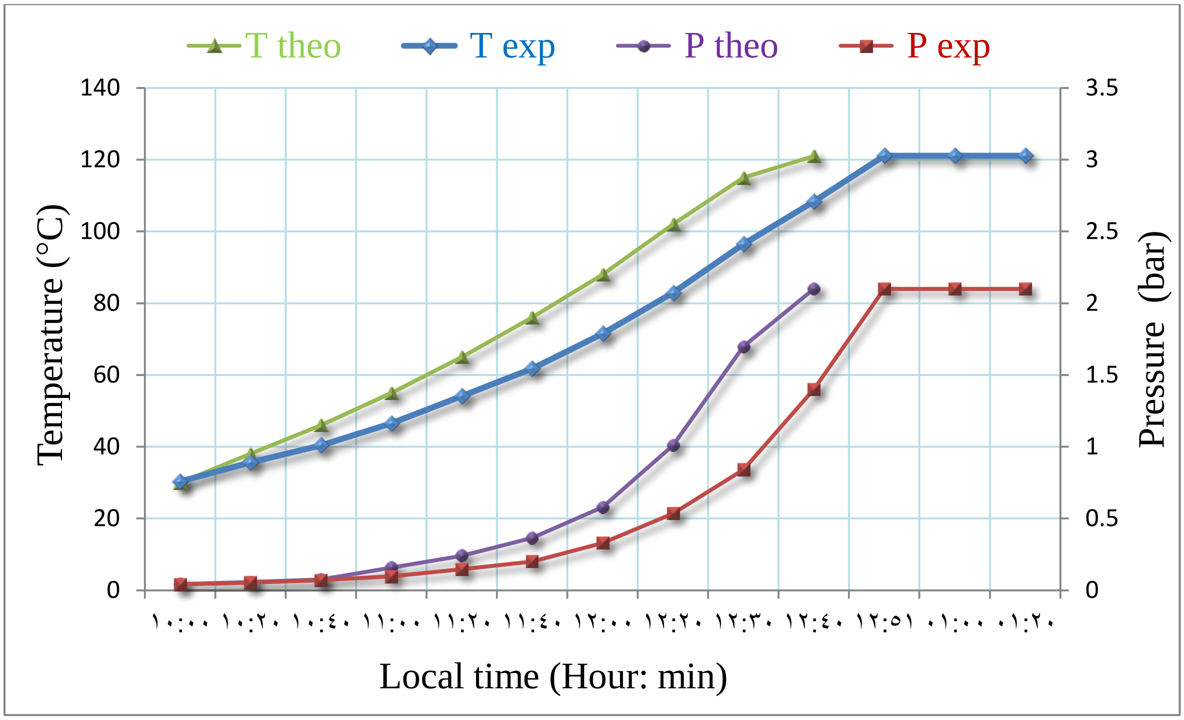


Figure (5.20 a): The Experimental and Theoretical Results Comparison of the Steam inside the Sterilization Chamber with the Normal Case (without heat exchanger)

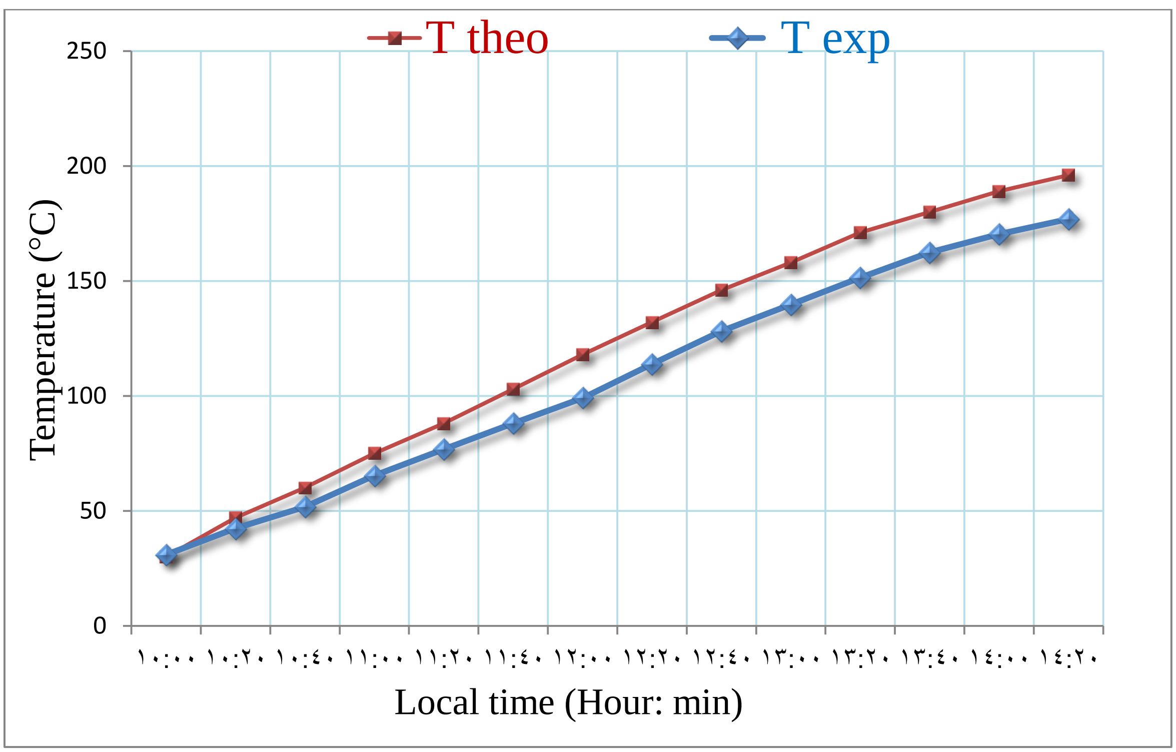


Figure (5.20 b): The Experimental and Theoretical Results Comparison of the Air inside the Sterilization Chamber with the Normal Case (without heat exchanger)

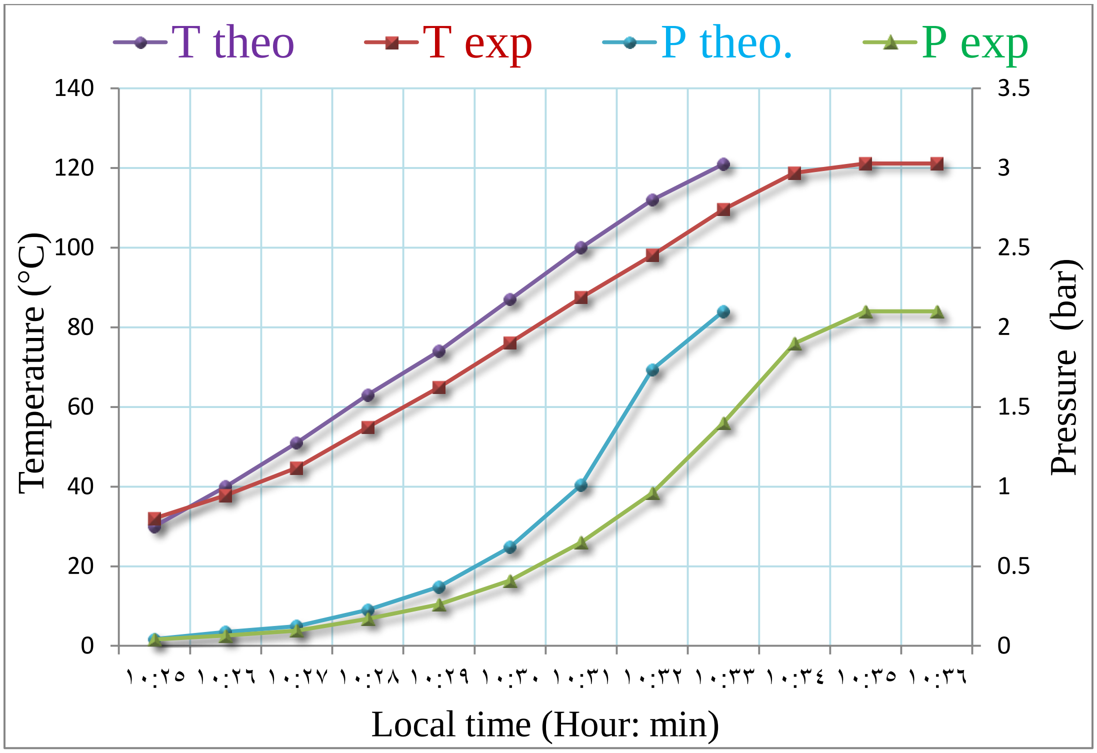


Figure (5.21 a): The Experimental and Theoretical Results Comparison of the Steam inside the Sterilization Chamber with the Presence of Heat Exchanger

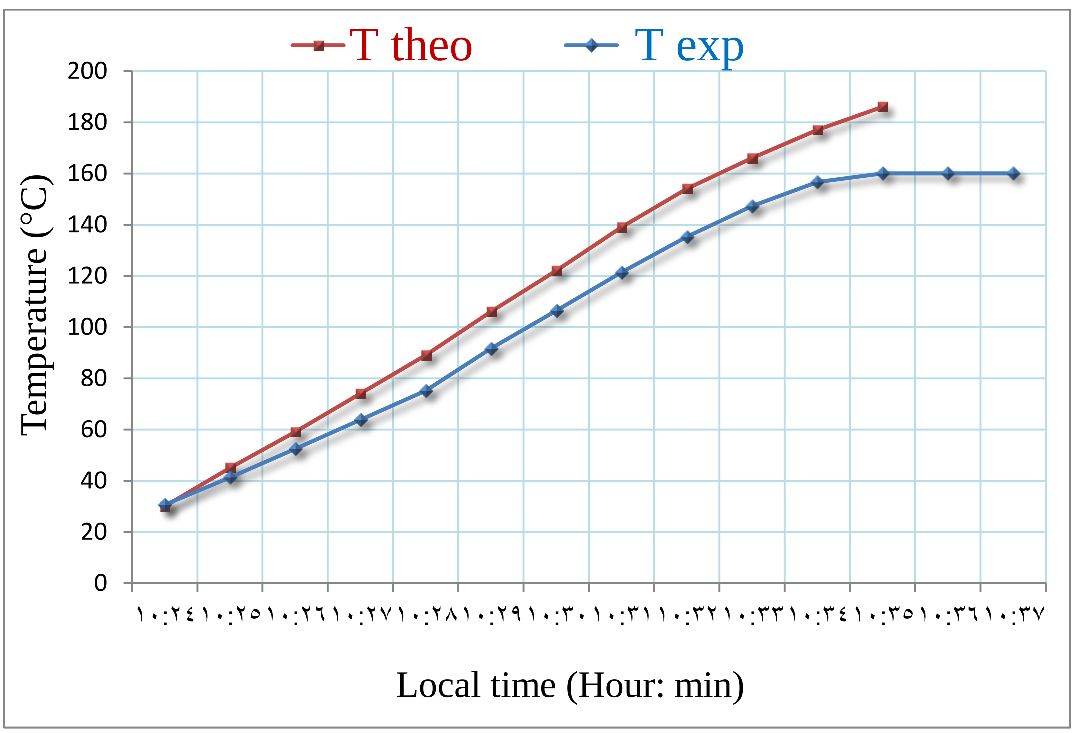


Figure (5.21 b): The Experimental and Theoretical Results Comparison of the Air inside the Sterilization Chamber with the Presence of Heat Exchanger

5.4 Monitoring Sterilization Process

It is very important to verify the surgical equipment sterilization process. Thus, it was necessary to watch the sterilization mechanism to satisfy the required health standards. Mechanical and chemical techniques, among many others, can achieve this goal. Both mechanical and chemical techniques were used in the present study.

5.4.1 Mechanical Validation

This technique involves checking the required temperature and pressure of the working fluid (steam or air) and the required time to complete the sterilization process. All the results are positive in this work, as shown in table (5.1).

Table (5.1): The Experiments Results of the Mechanical Validation

<table>
<tr><th>No</th><th colspan="2">Criteria of validation</th><th>Status</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Temperature</td><td>Achieving the required temperature (T_{steam}=121.1°C, T_{air}= 160°C)</td><td>Fulfilled</td></tr>
<tr><td>Maintaining the required temperature</td><td>Fulfilled</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Pressure</td><td>Achieving the required pressure (P_{steam}= 2.1)</td><td>Fulfilled</td></tr>
<tr><td>Maintaining the required pressure</td><td>Fulfilled</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Sterilization time</td><td>Time of the steam sterilization cycle (15 min)</td><td>Fulfilled</td></tr>
<tr><td>Time of the dry, hot air sterilization cycle (60 min)</td><td>Fulfilled</td></tr>
</table>

5.4.2 Chemical Validation

In this technique, the autoclave vapor indicator tape (3M™) is used, a strip of crepe paper with light yellow or light brown color containing slanted pink lines as shown in figure (5.22). Using this tape is to place it inside the sterilization chamber. If the pink color of the slanted lines changes to black, this means that the success of the sterilization process, as shown in Figure (5.23) [31].

Figure (5.22): 3M™ Autoclave Steam Indicator Tape, which is Used to Check the Success of the Sterilization Process

Figure (5.23): The change of the color of the slashes of the 3M™ autoclave indicator tape indicates the success of the sterilization process.

5.5 Economic Evaluation

5.5.1 Solar Sterilization System Costs

After confirming the ability of the manufactured system in this work to achieve the sterilization task, it is necessary to evaluate the extent of the benefit which can be obtained from it. This is for the manufacturing cost and to compare this cost with the cost of the nearest sterilizers of this system in terms of capacity. Table (5.2) shows the cost details for all system parts and the total manufacturing cost.

Table (5.2): The Details of the Sterilization System Manufacturing Costs

Unit	Material (Number)	Cost ($)
Collector	Fresnel lens (1)	100
	Reflective oval dish (1)	12
Subtotal		112
Receiver	Heat absorber cylinder (1)	1.5
	Pressure-gauge (1)	4
	Relief valve (1)	10
	Filling valve (1)	2.5
	Serrated connection ports (4)	3
Subtotal		21
Transport	Rubber tube (4)	16
	Open and close valves (10)	16
	Connections (8)	14
Subtotal		48
	Steam sterilization cylinder with accessories (1)	70
	Tempered Thermal Glass Layer (3)	60
	Copper heat exchanger tubes (6m)	12
	Alucobond (7.68 m^2)	75

Sterilization chambers	Glass wool (20 m^2)	9
	Reflective steel sheet (4 m^2)	47
	Iron structure	50
Subtotal		323
Device base		60
Subtotal		60
Solar tracking process		100
Subtotal		100
Total Cost		664

5.5.2 Electric Sterilization Apparatuses Costs

Usually, electric apparatuses are used in clinics or hospitals to sterilise surgical equipment. The working fluid used in these apparatuses is either steam or dry, hot air, and the cost of each is different from the other. Generally, the total cost of each apparatus is the summation of costs that are the cost of purchase, the cost of maintenance and the cost of electrical consumption. So, the total cost of these devices is not fixed and not limited, and it is considered an increased cost with the continuous use of the apparatus. Table (5.3) shows the costs of electric sterilization apparatuses used in hospitals. Knowing that these apparatuses are the closest to the solar system used in the current work in terms of capacity.

Table (5.3): The Costs of Electric Sterilization Apparatuses Used in Hospitals

Sterilizer type / Cost type	Steam sterilizer		Dry, hot air sterilizer	
	Cost ($)	Cost status	Cost ($)	Cost status
Cost of purchase	30,000	Semi-fixed	4,000	Semi-fixed
Electricity consumption	20KVA	Increased	500W	Increased
Maintenance	4,100 Per year	No fixed	500	No fixed

Chapter Six

Conclusions and Recommendations

6.1 Conclusions

There are general conclusions. The first is the ambient conditions (Solar radition intinsity and ambient temperature) significantly affect the solar system performance for the sterilization process. The second general conclusion is after comparing the experimental results and the theoretical ones, it was found that the max deviation ratio in the experimental results iwas (about 17%).

The following points can be concluded through the results of the current solar sterilization system follow: -

1- Installing a cylinder and a box of the surgical equipment sterilization inside two thermally insulated chambers with a glass face turned toward the sun was lead to pre and faster heating of these chambers, which leads to reduced heat losses.

2- Installing a heat exchanger inside the sterilization chamber (Utilization of energy from the heating steam) causes a reduction in the time of obtaining the sterilizing fluid by almost 92.6% for steam and 93.16% for air experimentally and 94.4% and 95% theoretically. This means an increase in the number of sterilization cycles per day.

3- Using a solar absorbent vessel without solar concentrators, steam cannot be generated at arequired properties**.**

4- Installing a reflective oval dish as a solar concentrator leads to producing steam inside the solar absorbent vessel for 37 min experimentally and 35 min theoretically.

5- Using Fresnel lens with the oval dish (at the same time), as a solar concentrators leads to reducing the time of generating the steam inside the vessel by 35% experimentally and 36.4% theoretically compared to the results of the reflective dish alone.

6.2 Recommendations

The following points may be recommended as suggestions for future work: -

1-The system frame and base can be made of aluminum bars to reduce the weight of the system,

2- A heat storage system can be added to the solar sterilization system to give the ability to work at night times or on cloudy days,

3- The vent valve of the solar absorbent vessel may be set to a higher pressure to obtain steam at a higher temperature. To take advantage of this in the process of charging the thermal storage system when adding it to reduce the charging time,

4-The heat absorbent vessel may be placed inside a closed glass container, which contributes to increasing the speed of steam generation and thus achieving the goals of the system in a shorter time,

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Appendix A

Calculations of Solar Radiation

Solar radiation is classified into two components: beam and diffuse radiation. The total solar radiation is the summation of these components.

Equation (A-1) can be used to calculate total solar intensity on a horizontal plane for an hour.

$$I = I_{b.T} + I_d \qquad \text{... (A.1)}$$

For solar calculations, it is often necessary to calculate the hourly beam radiation on a tilted surface of a collector from solar radiation on a horizontal surface. So, the geometric factor R_b (the ratio of beam radiation on the tilted surface to that on a horizontal surface at any time) must be found. For Iraq, we can find R_b from equation (A.2) for the northern hemisphere.

$$R_b = \frac{\cos\theta}{\cos\theta_z} = \frac{\cos(\emptyset - \beta)\cos\delta\cos\omega + \sin(\emptyset - \beta)\sin\delta}{\cos\emptyset\cos\delta\,\cos\omega + \sin\emptyset\,\sin\delta} \qquad (A.2)$$

After finding the R_b value, we can find the beam radiation from equation (A.3):

$$R_b = \frac{I_{b.T}}{I_{cb}} \qquad (A.3)$$

First, we must calculate the beam radiation on a horizontal surface at any time. Estimating the beam radiation transmitted through clear atmospheres considers zenith angle and altitude for a standard atmosphere and four climate types. The atmospheric transmittance for beam radiation τ_b is:

$$\tau_b = a_o + a_1 e^{\left(\frac{-k}{\cos\theta_z}\right)} \qquad (A.4)$$

The constants a_o, a_1 , and k for the standard, atmosphere with (23 km) visibility, are found from $a^*{}_o, a^*{}_1, and\ k^*$, which are given for altitudes**,** less than 2.5 km by: -

$$a^*{}_o = 0.4237 - 0.00821(6 - A)^2 \qquad \ldots (A.5)$$

$$a^*{}_1 = 0.5055 + 0.00595(6.5 - A)^2 \qquad \ldots (A.6)$$

$$k^* = 0.2711 + 0.01858(2.5 - A)^2 \qquad \ldots (A.7)$$

Where :

A is the altitude of the observer in Kilometers.

Correction factors are applied to $a^*{}_o, a^*{}_1$ and k^*, to allow for changes in climate types. The correction factors are: -

$$r_0 = \frac{a_o}{a^*{}_o} \qquad r_1 = \frac{a_1}{a^*{}_1} \qquad r_k = \frac{k}{k^*} \qquad \ldots (A.8)$$

For mid-latitude summer, they are 0.97, 0.99, and 1.02, respectively. The angle of incidence **is** the zenith angle of the sun θz

$$\cos\theta_z = \cos\varphi\ \cos\delta\ \cos\omega + \sin\varphi\ \sin\delta \qquad \ldots (A.9)$$

Where:

φ: is the latitude, the angular location north or south of the equator

δ: The declination, the angular position of the sun at solar noon. That can be found as follows: -

From $\delta = 23.45\ \sin\left(360\frac{284+n}{365}\right)$

ω: Hour angle, the angular displacement of the sun east or west of the local meridian due to the rotation of the earth on its axis

At any point in time, the solar radiation incident on a horizontal plane outside the atmosphere is a normal solar radiation incident.

$$G_{on} = G_{sc}\left(1 + 0.033\cos\frac{360\,n}{365}\right)\cos\varphi\cos\delta\cos\omega + \sin\varphi\sin\delta \qquad \dots \text{(A.10)}$$

The hourly extraterrestrial radiation can also be approximated by writing equation (A.10) in terms of I, evaluating **ω** at the midpoint of the hour. For periods **of** an hour, the clear-sky horizontal beam radiation is: -

$$I_{cb} = I_{on}\,\tau_b\cos\theta_z \qquad \dots \text{(A.11)}$$

To estimate the clear-sky diffuse radiation on a horizontal surface, it is also necessary to get the total radiation from the equation (A.12).

$$I_{cd} = I_{on}\,\tau_d\cos\theta_z \qquad \dots \text{(A.12)}$$

Where: $\tau_d = 0.271 - 0.294\,\tau_b$

The total radiation on a horizontal plane in a clear sky for an hour is:

$$I = I_{cb} + I_{cd} \qquad \dots \text{(A.13)}$$

After calculating the total beam radiation for the incline surfaces, we must calculate the diffuse radiation for clear and cloudy hours to find the total radiation (Id). The

The usual approach correlates I_d /I, the fraction of the hourly radiation on a horizontal plane that is diffused, with K_T, the hourly clearness index. An hourly clearness index K_T can also be defined:

$$K_T = \frac{I}{I_{on}} \qquad \ldots \text{(A.14)}$$

There are three correlations derived from separate databases.

$$\left.\begin{aligned} &\frac{I_d}{I} = 1 - 0.09K_T && for\ K_T < 0.22 \\ &\frac{I_d}{I} = 0.9511 - 0.1604K_T + 4.388{K_T}^2 - 16.638{K_T}^3 + 12.336{K_T}^4 \\ &\qquad for\ 0.22 < K_T \leq 0.8 \\ &\frac{I_d}{I} = 0.165 && for\ \ K_T > 0.8 \end{aligned}\right\} \qquad \ldots \text{(A.15)}$$

Appendix B
Calculations of Fresnel lens

Fresnel lenses are treated as 2D lenses. The focal length of the lens is one of the most important parameters. Fresnel lenses follow the same principle of geometric optics as other lenses. And for this, the Fresnel lens is given in the usual lens formula, i.e.:

$$\frac{1}{\mathrm{f}} = \frac{1}{i} + \frac{1}{x} \qquad \text{… (B.1)}$$

Where: f is the focal length, i is the image distance from the lens's center, and x is the object distance from the lens, as shown in figure (B.1).

Since the distance to the sun is very large, it can be considered as $x = \infty$.

$\therefore$ $\mathrm{f} = i$, i.e., the sun's image is formed as the focal point from a distance.

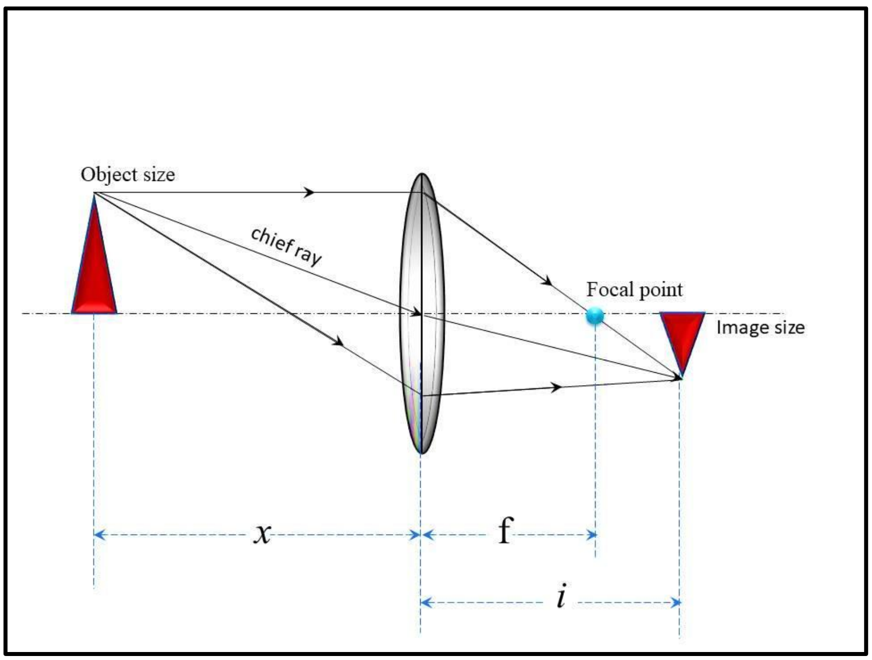

Figure (B.1): Schematic lens diagram, focal length and focus image

The most important parameter in Fresnel lens design is the prism angle (α), and this angle has a direct relationship with the focal length (f_L). And the relationship between them will be derived for the grooves-in lens case as follows:

According to Snell's law:

$$n \sin \propto = \sin \beta \qquad \dots (B.2)$$

Where:

n is the refractive index (which is unit-less) of the Fresnel lens

From figure (B.2)

$$\tan \omega = \frac{R}{f_L} \qquad \dots (B.3)$$

$$\beta = \alpha + \omega \qquad \dots (B.3)$$

Substituting β in equation (B.1) to get:

$$n \sin \propto = \sin(\alpha + \omega)$$

$$n \sin \propto = \sin \alpha \cos \omega + \cos \alpha \sin \omega \qquad \dots (B.4)$$

$$n \sin \propto - \sin \alpha \cos \omega = \cos \alpha \sin \omega \qquad \dots (B.5)$$

$$\sin \propto (n - \cos \omega) = \cos \alpha \sin \omega$$

$$\frac{sin \propto}{cos\, \alpha} = \frac{sin\, \omega}{(n - cos\, \omega)}$$

$$tan\, \alpha = \frac{sin\, \omega}{(n - cos\, \omega)} \qquad \dots (B.6)$$

Also, from the figure (B. 2):

$$\sin \omega = \frac{R}{\sqrt{R^2 + (f_L)^2}} \qquad \dots (B.7)$$

$$\cos \omega = \frac{f_L}{\sqrt{R^2 + (f_L)^2}} \qquad \dots (B.8)$$

Substituting equations (B.7) and (B.8) in (B.6) to get: -

$$\tan\alpha = \frac{\frac{R}{\sqrt{R^2+(f_L)^2}}}{\left(n-\frac{f_L}{\sqrt{R^2+(f_L)^2}}\right)}$$

$$\tan\alpha = \frac{\left(\frac{R}{\sqrt{R^2+(f_L)^2}}\right)}{\left(\frac{n\sqrt{R^2+(f_L)^2}-f_L}{\sqrt{R^2+(f_L)^2}}\right)}$$

$$\therefore \tan\alpha = \frac{R}{n\sqrt{R^2+(f_L)^2}-f_L} \qquad \ldots \text{(B.10)}$$

Equation (B.10) calculates the lens's focal length in the case of grooves-in depending on the prism angle.

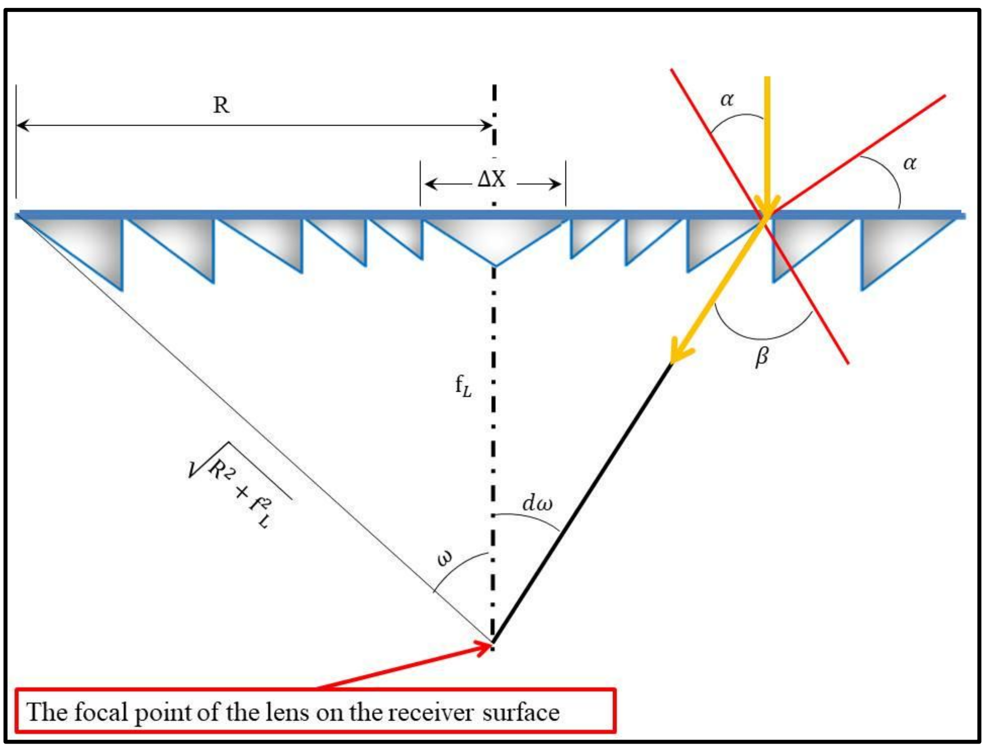

Figure (B.2): Fresnel Lens with Grooves-in

The lens used in this study has a prism angle of 42°, a radius (R) of 155 mm, and a refractive index of 1.49. Therefore, using equation B.10, the value of the focal length is 120 mm.

Appendix C

Calculations of Heat Exchanger

Heating steam flows into the heat exchanger tube at 160 °C. This temperature is constant because the steam condenses at a constant temperature and pressure when its heat is thrown through the walls of the tube [58].

Assume that the initial and ambient temperature is 30 °C

1- For Steam Sterilization Chamber

From the steam tables and at 2.1 bar and 121.1°C, h_f, h_{fg}, v_g and v_f can be obtained as follow: -

$$h_f = \frac{504.7\text{KJ}}{\text{Kg}},\ h_{fg} = 2201.6\frac{\text{KJ}}{\text{Kg}},\ v_g = \frac{0.88578m^3}{Kg},\ \text{and}\ v_f = 0.001061\text{m}^3/\text{Kg}$$

By using:

$$x = (\frac{V_{s.c}}{m_W} - v_f)/(v_g - v_f) \quad \text{(C.1)}$$

Where:

$V_{s.c}$ is the volume of sterilization cylinder= 0.0152 m^3

$\therefore x = 0.035$

∴ The necessary energy to convert 1 kg of water from the liquid state at 30°C to the wet steam state at 2.1 bar and 121.1°C is

$$E = m_w(h_{121.1°C} - h_{30°C}) \quad \text{(C.2)}$$

Where:

$$h_{121.1°C} = h_{f,at121.1°C} + xh_{fg,at121.1°C} \quad \text{(C.3)}$$

$$h_{30°C} = C_w(T = 30°C) \quad \text{(C.4)}$$

$E = 456.4\ KJ$

And let's say we want to achieve steam at these conditions within 10 minutes.

$$\therefore\ Q_w = \frac{E}{t} = \frac{456.4}{600} = 0.76\ kW$$

Since it is:

$$\dot{q}_w = \mu_l\ h_{fg} \left[\frac{g(\rho_l - \rho_v)}{\sigma}\right]^{1/2} \left[\frac{C_{pl}(T_s - T_{sat})}{C_{sf} h_{fg} Pr_l{}^n}\right]^3 \quad \text{(C.5)}$$

Where: h_{fg} at 121.1 °C = 2203 KW

Properties The properties of water at the saturation temperature of 121.1 °C are

From (Tables 10-1) [58]

$\sigma = 0.055\ N/m$,

And from (Tables 10-9) [58]

$\rho_l = 943.4\ kg/m^3$, $\rho_v = 1.121\ kg/m^3$ $C_{pl} = 4244\frac{J}{kg}K$, $\mu_l = 0.232 * 10^{-3}$ kg m/s

and $Pr_l = 1.44$

Also, C_{sf} = 0.0130 and *n* = 1.0 for the boiling of Water–copper (polished) (Table 10-3).

$\therefore \dot{q}_w = 8721.21448\ W/m$

Since it is:

$Q_w = A\dot{q}_w = \pi dL\ \dot{q}_w \rightarrow 760 = \pi(0.0095)(L)(8721.21448) \rightarrow L = 2.92 \approx 3m$

2- For Dry, Hot Air Sterilization Chamber

$$T_f = \frac{T_a + T_s}{2} = \left(\frac{30 + 160}{2}\right) = 95\ °C + 273 = 368\ K$$

The properties of air at the film temperature of $T_f = 95\ °C$ and 1 atm are (Table A–15) [58]

K=0.030595 W/m °C, Pr= 0.71215, $v = 2.2535 \times 10^{-5}\ {m^2}/{s}$

$$\beta = \frac{1}{T_f} = \frac{1}{368} = 0.0027174\ {1}/{K}$$

$$R_a = \frac{g\beta(T_s - T_i){d_p}^3}{v^2} P_r = \frac{9.81 \times 0.0027174(160-30)0.0095^3}{(2.2535 \times 10^{-5})^2}(0.71215)$$

$$R_a = 4.166 \times 10^3$$

For Horizontal Pipe with $R_a \leq 10^{12}$, the natural convection Nusselt number to be

$$N_u = \left\{0.6 + \frac{0.387{R_a}^{1/6}}{\left[1+(0.559/P_r)^{9/16}\right]^{8/27}}\right\}^2 = \left\{0.6 + \frac{0.387(4.166\times10^3)^{1/6}}{\left[1+(0.559/0.71215)^{9/16}\right]^{8/27}}\right\}^2 \qquad N_u = 3.568$$

$$Q_{H.E} = \frac{K}{d_p} N_u(\pi d_p L)(T_s - T_i) = \frac{0.030595}{0.0095}(3.568)(\pi\ 0.0095\ L)(160-30) \qquad \ldots(C.6)$$

The required heat energy to raise the temperature of the air and the surgical equipment box from 30 °C to 160 °C during 10 min is:

$$Q_u = \frac{m}{t} C_p(T - T_i) = \frac{PV}{RTt} C_v(T - T_i) + \frac{\rho_{st}}{t} V_{box}\, C_{p,st}(T - T_i)$$

Where:

V: is the inside volume of chamber and V_{box} is the volume of the sterilization box material.

$$Q_u = \frac{100 \times 0.15725 \times 718}{0.287 \times (30 + 273) \times 600}(160 - 30) + \frac{7865}{600} 6.48 \times 10^{-5} \times 468(160 - 30)$$

$Q_u = 79.8.1\ W$ substitute it into equation (C.6) to get

$$79.8.1 = \frac{0.030595}{0.0095}(3.568)(\pi\ 0.0095\ \text{L})(160 - 30)$$

L= 1.79 m

The largest length value will be chosen $\therefore L = 3m$

Appendix D

Theoretical Calculations

The hypotheses imposed at the beginning of the third chapter were used and applied in the chapter equations according to the following steps to do the theoretical, computational model.

1- Calculation of the focal length of the oval dish

$$f_d = \frac{(D_S)^3}{16\ h_d\ D_l} = \frac{0.9^3}{16*0.093*1} = 0.49\ m$$

2- Calculation of the rim angles of dish

$$\tan\psi_1 = \frac{f_d}{D_l} \Big/ \left[2(\frac{f_d}{D_l})^2 - 0.125\right] = \frac{0.49}{1} \Big/ \left[2(\frac{0.49}{1})^2 - 0.125\right] = 1.3795$$

$$\psi_1 = \tan^{-1} 1.3795 = 54°$$

$$\tan\psi_2 = \frac{f_d}{D_S} \Big/ \left[2(\frac{f_d}{D_S})^2 - 0.125\right] = \frac{0.49}{0.9} \Big/ \left[2(\frac{0.49}{0.9})^2 - 0.125\right] = 1.16374$$

$$\psi_2 = \tan^{-1} 1.16374 = 49.327°$$

3- Calculation of aperture area of the reflector dish (A_d) and the area of concentration of solar radiation on the surface of the heat-absorbing vessel (A_r)

$$A_d = \frac{\pi\ D_l\ D_s}{4} = \frac{\pi \times 1 \times 0.9}{4} = 0.7068\ m^2$$

$$r = \frac{f_d\ \theta s}{1+\cos\psi_2} = \frac{0.49\times0.265}{1+\cos 49.327} = 0.076\ m$$

$$s = \frac{f_d\ \theta_s}{(1+\cos\psi_1)\cos(\psi_1+\theta_s)} = 0.135\ m$$

$$A_r = \pi\ s\ r = \pi \times 0.135 \times 0.076 = 0.03223\ m^2$$

4- Calculation of the Solar Radiation Concentration Ratio of Dish

$$C_d = \frac{A_d}{A_r} = \frac{0.7068}{0.03223} = 22$$

5- Concentrated Heat Quantity by Dish

$$\zeta_p = 1 - \frac{4T_{amb}}{3T_s} + \frac{1}{3}\left(\frac{T_{amb}}{T_s}\right)^4 = 1 - \frac{4 * 30}{3 * 5770} + \frac{1}{3}\left(\frac{30}{5770}\right)^4 = 0.99$$

$$Q_d = I\,\zeta_p \zeta_{opt}\, A_d\, C_d$$

$$Q_d = 600 \times 0.99 \times 0.76 \times 0.7068 \times 22 = 7019.711\ W$$

6- Focal Length of Fresnel Lens

$$\tan\alpha = \frac{R}{n\sqrt{R^2 + (f_L)^2} - f_L}$$

$$\tan 42 = \frac{0.155}{1.49\sqrt{(0.155)^2 + (f_L)^2} - f_L} \rightarrow f_L = 0.12\ m$$

7- Solar Radiation Concentration Ratio of Lens

$$C_L = \frac{A_L}{A_f} = \frac{0.83\ D^2}{\frac{\pi}{4} d^2} = \frac{0.83 \times 0.31^2}{\frac{\pi}{4}(\Delta x + 2\ f_L \tan\theta_s)^2} = \frac{0.83 \times 0.31^2}{\frac{\pi}{4}(\Delta x + 2\ f_L \tan\theta_s)^2} = 1015$$

Where:

Δx: The Diameter of The smallest grooves circle for the lens=7mm

θ_s: Solar angle= 0.265°

8- Concentrated Heat Quantity by Fresnel Lens

$$Q_L = I\,\tau_L\, A_L\, C_L = I\,\tau_L\,(0.83 * 0.31^2)\, C_L$$

$$Q_L = 600 * 0.92\ (0.83 * 0.31^2)1015 = 44689.6\ W$$

9- Heat absorber vessel thickness pressure endurance test:

The pressure tolerance of the thickness of the vessel will be tested based on the largest stress, which is the tangential stress (σ_h).

$$t_V = \frac{PD_{in.V}}{2\sigma_h} \rightarrow 0.003 = \frac{6.2 \times 10^5 \times 0.08}{2\sigma_h} \rightarrow \sigma_h = 8.6 \text{ MPa}$$

$$\therefore \sigma_h = 8.6 \text{ MPa} \ll \sigma_{all,st} = 87.5 \text{ MPa}$$

$$\therefore t_V = 3 \text{ mm} \qquad \text{OK}$$

10- Calculation of the temperature and pressure of steam inside the heat-absorbent vessel over time until achieving 160 °C and 6.2 bar.

11- The temperature will be calculated first based on the thermal balance equation. The pressure is found from water steam tables based on the calculated temperature. This will be done for the following cases:

a) A vessel at normal case

$$mC_W(T - T_i)/t = I\,\zeta_p\,A_V - h_W\,A_s(T - T_{amb}) - \sigma\,\varepsilon\,A_s F\left(T^4 - {T_{sky}}^4\right) - \frac{\rho_{st}V_V C_{st}(T - T_i)}{t}$$

Where:

$T_i = T_{amb}$=30°C

ζ_p =0.99

$$A_V = 0.5\pi D_{O.V} L_V = 0.5 \times \pi \times 0.08 \times 0.14 = 0.0376\, m^2$$

$$A_s = 2A_V + 2\frac{\pi}{4}{D_V}^2 = 2 \times 0.0376 + 2\frac{\pi}{4}(0.08)^2 = 0.0852\, m^2$$

$$h_W = 5.7 + 3.8\,V_w = 5.7 + 3.8 \times 2 = 13.3\, W/m^2K$$

$$\sigma = 5.67 \times 10^{-8}\,\frac{w}{m^2k^4}$$

$T_{sky} = 0.0552\ (T_{amb})^{1.5} = 9\ °C$

ρ_{st}[56]= 7865 Kg/m³

C_{st}[56]= 468 J/ Kg. K.

ε[58] = 0.97

$$V_V = \pi D_{in.V} H_V t_V + 2\left\{\frac{\pi}{4}(D_{in.V} + 2t_V)^2 t_V\right\}$$

$$V_V = \pi * 0.08 \times 0.14 \times 0.003 + 2\ \left\{\frac{\pi}{4}(0.08 + 2 \times 0.003)^2 \times 0.003\right\}$$

$$V_V = 4.54 * 10^{-5}\ m^3$$

By assuming multiple values for temperature and substituting them in the above equation to obtain the time as shown below

Assume the first guess of temperature= 35 °C

$$0.5 \times 4200(35-30)/t = 600 \times 0.99 \times 0.0376 - 13.3 \times 0.0852(35-30) - 5.67 \times 10^{-8} \times 0.97 \times 0.0852 \times 1\left((35+273)^4 - (9+273)^4\right) - \frac{7865 \times 4.54 \times 10^{-5} \times 468(35-30)}{t}$$

t = 1193.7321 Sec = 1200 Sec

The results are shown in the table below for chosen values. The table also includes the pressure values obtained from the steam tables according to the temperatures.

No	T(°C)	Time(sec)	P(bar)	No	T(°C)	Time(sec)	P(bar)
1	30	0	0.0425	17	60.2	19200	0.16524
2	35	1200	0.0562	18	60.8	20400	0.16848
3	39.4	2400	0.0738	19	61.3	21600	0.17172
4	42.8	3600	0.086176	20	61.8	22800	0.17496

5	45.6	4800	0.09558	21	62	24000	0.1782
6	47.9	6000	0.1053	22	62	25200	0.18144
7	49.8	7200	0.1134	23	63	26400	0.18468
8	51.6	8400	0.11988	24	63.4	27600	0.188406
9	53	9600	0.12636	25	63	28800	0.190512
10	54.3	10800	0.13446	26	64	30000	0.19116
11	55.4	12000	0.14094	27	64.3	31200	0.18306
12	56.5	13200	0.14742	28	64.64399	32400	0.17172
13	57.3	14400	0.15066	29	64.90909	33600	0.162
14	58	15600	0.15552	30	65.15959	34800	0.15552
15	58.9	16800	0.15876	31	65.39665	36000	0.15066
16	59.6	18000	0.16362				

b) Vessel with Dish

$$Q_u = I\zeta_p\, A_V + Q_d - h\, A_s(T - T_a) - \sigma\, \varepsilon\, A_s F\left(T^4 - {T_{sky}}^4\right) - \frac{\rho_{st} V_V C_{st}(T - T_i)}{t} \quad \dots \text{(D.1)}$$

Where:

$$\mathrm{Q_u} = \mathrm{m}(\mathrm{h_4} - C_w \mathrm{T_i})/\mathrm{t} \quad \dots \text{(D.2)}$$

$$\mathrm{h_4} = \mathrm{h_f} + \mathrm{x}\,\mathrm{h_{fg}} \quad \dots \text{(D.3)}$$

Depending on the assumed temperature, getting from the water steam tables the values of (h_f, h_{fg}) and then they are applied in the equation (D.3) to get (h_4). then Substituting it in the equation (D.2).

$C_w \mathrm{T_i} = 4200 \times 30 = 126000$ J/Kg

m= 0.5 Kg

Assume the first guess of temperature= 67 °C

From water steam tables at T= 67 °C to get $h_f = 283\ KJ/Kg, h_{fg} = 2340\ KJ/Kg,$
$v_g = 5.6195 \frac{m^3}{Kg}, v_f = 1.0215\ m^3/Kg$

$$\frac{V}{m_w} = v_{f1} + x(v_g - v_{f2}) = \frac{\left(\frac{\pi}{4}\times 0.08^2\times 0.14\right)}{0.5} = 0.001 + x(5.6195 - 1.0215)$$

$\therefore x = 0.0000886$

$$\therefore h_4 = 283 + 0.0000886 \times 2340 = \frac{283.2KJ}{Kg} = 283.2\times 10^3\ J/Kg$$

By equating the two equations (D.1) and (D.2), then substituting a value of assumed temperature to obtain time,

$$0.5\times(283.2\times 10^3 - 126000)/t$$
$$= 600\times 0.99\times 0.0376 + 7019.711 - 13.3\times 0.0852(35-30)$$
$$- 5.67\times 10^{-8}\times 0.97\times 0.0852\times 1\left((35+273)^4 - (9+273)^4\right)$$
$$- \frac{7865\times 4.54\times 10^{-5}\times 468(35-30)}{t}$$

t = 584.6736 Sec= 600 Sec

and using the water steam tables to find pressure, as shown in the results table below for several chosen values,

No	Time(sec)	T(°C)	P (bar)	No	Time(sec)	T(°C)	P (bar)
1	0	30	0.0425	4	1800	148	4.1955
2	600	67	0.27	5	1980	160	6.2
3	1200	107	1.225				

c) Vessel with Dish and Fresnel Lens

$$Q_u = Q_L + Q_d - h_w A_V (T - T_a) - \sigma\, \varepsilon\, A_V F\left(T^4 - {T_{sky}}^4\right) - \frac{\rho_{st} V_V C_{st}(T - T_i)}{t}$$

$$Q_u = 44689.6 + 7019.711 - 13.3 \times 0.0176\,(104 - 30) - 5.67 \times 10^{-8} \times 1 \times$$

$$((104 + 273)^4 - (9 + 273)^4) - {}^{7865 \times 4.54 \times 10^{-5} \times 468\,(104 - 30)}/_{t}$$

… (D.4)

$$\mathrm{Q_u} = \mathrm{m}(\mathrm{h_4} - C_w \mathrm{T_i})/\mathrm{t}$$

From water steam tables at T= 104 °C to get $\mathrm{h_f} = 440.15\ \mathrm{KJ/Kg}, \mathrm{h_{fg}} = 2243.35\ \mathrm{KJ/Kg}$, $v_g = 1.4415 \frac{\mathrm{m^3}}{\mathrm{Kg}}$, $v_f = 1.048\ \mathrm{m^3/Kg}$

$$\frac{\mathrm{V}}{\mathrm{m_w}} = v_{f1} + x(v_g - v_{f2}) = \frac{\left(\frac{\pi}{4} \times 0.08^2 \times 0.14\right)}{0.5} = 0.001 + \mathrm{x}(1.4415 - 1.048)$$

$$\therefore \mathrm{x} = 0.001035$$

$$\therefore \mathrm{h_4} = 440.15 + 0.001035 \times 2243.35 = \frac{442.47\mathrm{KJ}}{\mathrm{Kg}} = 442.47 \times 10^3\ \mathrm{J/Kg}$$

$$\mathrm{Q_u} = 0.5\,(442.47 \times 10^3 - 4200 * 30)/\mathrm{t} \qquad \text{… (D.5)}$$

By equating the two equations (D.4) and (D.5), to obtain time,

t = 596.33689 Sec ~ 600 Sec

and using the water steam table to find pressure, as shown in the results table below for several chosen values,

No	T(°C)	Time(sec)	P (bar)
1	30	0	0.0425
2	104	600	1.139
3	159	1200	5.468
4	160	1230	6.2

12- Calculations of the temperature and pressure of steam inside the steam sterilization cylinder until achieving 121.1 °C and 2.1 bar with two cases

a) Chamber without Heat Exchanger

$$(Q_{in} - Q_{losses}) = (E_{cy} + E_W + E_{s.e})/t \quad \text{… (D.6)}$$

$$E_{cy} = \rho_{AL}.V.C_{p,AL}(T - T_i)$$

The density of Aluminum, $\rho_{AL}[56] = 2700\ kg/m^3$

The Specific heat for Aluminum [56] = 0.896 KJ/kg. k

As for the volume of the steam sterilization cylinder (Aluminum cylinder), it can be calculated according to its dimensions,

$$V = \pi.D.L.t + 2\{\frac{\pi}{4}(D + 2t)^2.t\} = 0.001802435\ m^3$$

$$\therefore E_{cy} = 4233.6\ (T - 30)\ J \quad \text{… (D.7)}$$

$$E_{s.e} = m\ C_{p,s.e}(T - T_i) = 1.2 \times 468 \times (T - 30) = 561.6\ (T - 30)\ \ J \quad \text{… (D.8)}$$

$$E_W = m_{water}(h_4 - h_i) = 1 \times (h_4 - h_i)$$

$$h_4 = h_f + xh_{fg}$$

Assume the first guess of temperature= 67 °C

From water steam tables at T= 38 °C to get $h_f = 159.2$ KJ/Kg, $h_{fg} = 2411.8$ KJ/Kg, $v_g = 21.60\frac{m^3}{Kg}$, $v_f = 1.007\ m^3/Kg$

$$\frac{V}{m_w} = v_{f1} + x(v_g - v_{f2}) = \frac{\left(\frac{\pi}{4}\times 0.29^2 \times 0.23\right)}{1} = 0.001 + x(21.60 - 1.007)$$

$$\therefore x = 0.00068914$$

$$\therefore h_4 = 159.2 + 0.00068914 \times 2411.8 = \frac{160.862\ \text{KJ}}{\text{Kg}} = 160862\ \ \text{J/Kg}$$

$$h_1 = C_w T_i = 4200 \times 30 = 126000\ \ \text{J/Kg}$$

$$E_W = 1 \times (160862 - 126000) = 34862\ \text{J}$$

$$E_{s.e} = 561.6\ (38 - 30) = 4492.8\ \ \ \text{J}$$

$$E_{cy} = 4233.6\ (38 - 30) = 33868.8\ \ \text{J}$$

To calculate amount of heat losses to the surrounding environment through the walls of the sterilization chamber:

$$Q_{losses} = U.A_s\ (T - T_{amb})$$

$$U = \frac{1}{\sum R}$$

$$\sum R = R_{conduction} + R_{convection,out}$$

$$R_{convection,out} = \frac{1}{h_w}$$

Calculation of the convective heat transfer coefficient at the outer surface of the heat sterilization chamber wall:

$$h_w = 13.3\ W/m^2K$$

$$R_{conduction} = \frac{t_{st}}{K_{st}} + \frac{t_{g.w}}{K_{g.w}} + \frac{t_{alu}}{K_{alu}}$$

Where:

$t_{st} = 0.6$ mm , $t_{g.w} = 75$ mm, and $t_{alu} = 6$ mm: Thickness of steel layer, glass wool, and alucobond, respectively.

$K_{st}, K_{g,w}$, and K_{alu}: Thermal conductivity of steel, glass wool, and alucobond (W/m. K).

$K_{st} = 16.3$ W/m. K

$K_{g,w} = 0.038$ W/m. K

K_{alu} for 6mm thickness $= 0.35$ W/m. K

$$U = \frac{1}{\frac{t_{st}}{K_{st}}+\frac{t_{g.w}}{K_{g.w}}+\frac{t_{alu}}{K_{alu}}+\frac{1}{h_w}} = \frac{1}{\frac{0.6\times10^{-3}}{16.3}+\frac{0.075}{0.038}+\frac{6\times10^{-3}}{0.35}+\frac{1}{13.3}} = 2.334\ W/m^2K$$

The result is that the value of the heat loss lost to the external environment is

$$Q_{losses} = 2.334(T - T_{amb}) = 2.334(38 - 30) = 18.672 \text{ Watts}$$

$$Q_{in} = I\ \zeta_p A_g \tau_g = 600 \times 0.99 \times (0.5 * 1) \times 0.9 = 273.24\ W$$

By use equation D.6 to get time

t = 1138.633 Sec =1200 Sec

And using the water steam tables to find pressure, as shown in the results table below for several chosen values,

No	T(°C)	Time(sec)	P(bar)	No	T(°C)	Time(sec)	P(bar)
1	30	0	0.0425	6	76	6000	0.3636
2	38	1200	0.0563	7	88	7200	0.5783
3	46	2400	0.0738	8	102	8400	1.01
4	55	3600	0.1576	9	115	9600	1.698
5	65	4800	0.2401	10	121	10800	2.1

b) Chamber with Heat Exchanger

The same steps and values used in the previous section (a) above will be adopted with an additional amount of heat to the input heat quantity. The additional heat input is the amount of heat added by the heat exchanger, which was calculated (Appendix C).Therefore, the results were as shown in the table below.

No	T(°C)	Time(sec)	P(bar)	No	T(°C)	Time(sec)	P P(bar)
1	30	0	0.0425	6	87	300	0.62012
2	40	60	0.08706	7	100	3600	1.01
3	51	120	0.1235	8	112	4200	1.73398
4	63	180	0.22485	9	121	4800	2.1
5	74	240	0.369542				

13- Calculations of the temperature of the air inside the dry, hot air sterilization chamber until achieving 160 °C with two cases as follows: -

a) Chamber without Heat Exchanger

$Q_{in} - Q_{losses} = Q_{A.S.Ch}$ … (D.8)

The same calculations are shown above

$Q_{in} = 273.24\ W$

$Q_{A.S.Ch} = (E_{box} + E_{air} + E_{s.e})/t$ …(D.9)

Where:

E_{box} is the energy absorbed by the sterilization box (Where the surgical equipment is located inside it) and can be found by the equation as follow: -

$E_{box} = \rho_{st}.V_{box}.C_{p,st}(T - T_i)$

Where:

V_{box} is the volume of the sterilization box material, and according to figure (3.16), it can be calculated by the following equation as follow: -

$$V_{box} = 2t_b\{H_bL_b + (W_b + L_b)H_b\}$$

$$\forall_{st,box} = 2[(0.6 * 0.3) + (0.6 + 0.3) * 0.12] * 0.5 * 10^{-3}$$

$$V_{box} = 2.88 * 10^{-4}\ m^3$$

$$\therefore E_{box} = 7865 * 2.88 * 10^{-4} * 468\ (T - T_i)$$

$$\therefore E_{box} = 1060\ (T - T_i)\ \mathrm{J}$$

And E_{air} does the air inside the sterilization box absorb the heat, and it can be found by the next equation as follow: -

$$E_{air} = \rho_{air} V_{space} C_{v,air}(T - T_i)$$

Where the volume of the hot air sterilization chamber space

$$V_{space} = (0.5 \times 0.3 \times 0.5) + (0.5 \times 0.3 \times 0.43 \times 0.5) = 0.10725\ m^3$$

$$E_{air} = \frac{P}{RT} V_{space} C_{v,air}(T - T_i) = \frac{1 \times 10^5}{287\ T} \times 0.10725 \times 718(T - T_i)$$

$$E_{air} = \frac{34899(T - T_i)}{(T + 273)}$$

$E_{s.e}$ and Q_{losses} are the same as in section (11).

The table below shows the results for using above equations

No	Time (sec)	T(°C)	No	Time(sec)	T(°C)
1	0	30	8	8400	132
2	1200	47	9	9600	146
3	2400	60	10	10800	158
4	3600	75	11	12000	171
5	4800	88	12	13200	180
6	6000	103	13	14400	189
7	7200	118	14	15600	196

b- Chamber with Heat Exchanger

The same steps and values used in the previous section (a) above will be adopted with the addition of an input heat quantity.

The amount of additional heat input is the amount of heat added by the heat exchanger, which is obtained as shown in Appendix C: -

The obtained results are shown in the table below.

No	T(°C)	Time (Sec)
1	30	0
2	45	60
3	59	120
4	74	180
5	89	240
6	106	300
7	122	360
8	139	420
9	154	480
10	166	540
11	177	600
12	186	660

Appendix E

Studies and Patents

Republic of Iraq
Ministry of Higher Education
and Scientific Research
University of Karbala
Scientific Affairs Department

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة كربلاء
قسم الشؤون العلمية

No :
Date :

العدد : ع.ش.ع / 3163
التاريخ : 2021/8/4

الى / وزارة العلوم والتكنلوجيا / دائرة بحوث الطاقة المتجددة
م / تأييد أستفادة من دراسة علمية

تحية طيبة ...

نرسل اليكم كتاب كلية الهندسة ذي العدد ع/2069/6 بتاريخ 2021/7/28 والمتضمن الطلب المقدم من قبل (**أ.م.د.محمد حسن عبود**) و(**أ.م.د.فرحان لفته رشيد**) التدريسيين بجامعتنا واللذان يرومان فيه تأييد مدى الأستفادة من الدراسة الموسومة (**تصميم وبناء مجمع شمسي مزدوج الأداء لتعقيم المعدات الطبية الجراحية**) نود اعلامكم عدم ممانعتنا من تقدم الطلب اعلاه ، راجين تفضلكم بالاطلاع وبيان الرأي .

*** مع التقدير ***

المرفقات
- اصل الكتاب .
- دراسة علمية .

أ.د نجم عبدالحسين نجم
مساعد رئيس الجامعة للشؤون العلمية
2021/8/4

قسم الشؤون العلمية – جامعة كربلاء – Department of Scientific Affairs

فارس 8/2

نسخة منه الى///
- مكتب السيد رئيس الجامعة المحترم ..للتفضل بالاطلاع ..مع التقدير .
- مكتب السيد المساعد العلمي المحترم .. للتفضل بالاطلاع .. مع التقدير .
- كلية الهندسة / كتابكم اعلاه للتفضل بالاطلاع وابلاغ الموما لهم ..مع التقدير .
- قسم الشؤون العلمية .
- الصادر

العراق- كربلاء المقدسة – جامعة كربلاء - مجمع فريحة ص.ب 1125 - الشؤون العلمية
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ايميل مدير القسم sci.affairs.manager@uokerbala.edu.iq

قناتنا على التليكرام — موقع تدوني

REPUBLIC OF IRAQ
MINISTRY OF SCIENCE & TECHNOLOGY
RENEWABLE ENERGY DIRECTORATE

وزارة العلوم و التكنولوجيا
Ministry Of Science & Technology

جمهورية العراق
وزارة العلوم والتكنولوجيا
دائـــرة الطاقات المتجددة
العـــدد: ط.م/ ٨٤٦
التاريخ: ٥/ ١٠/ ٢٠٢١

الى / وزارة التعليم العالي والبحث العلمي / جامعة كربلاء / قسم الشؤون العلمية

م / تأييد الاستفادة من دراسة علمية

تحية طيبة ..

إشــــــارة إلى كتابكم العدد ٣١٦٣ في ٢٠٢١/٨/٤ ،

نود إعلامكم بقبول وتأييد الدراسة موضوع كتابكم أعلاه وإمكانية الاستفادة منها في مجال عمل دائرتنا.

.. مع التقديــــــــــــــــــــــر .

د . فلاح إبراهيم العطار
معاون المدير العام
٥ / ٢٠٢١/١٠

وزارة العلوم والتكنولوجيا دائرة الطاقات المتجددة

نسخة منه إلى :
-قسم التخطيط .. مع الأوليات .

جمهورية العراق

وزارة التخطيط
الجهاز المركزي للتقييس والسيطرة النوعية

العدد : ٧٧٦
التاريخ م : ٢/ ٣/ ٢٠٢٢
هـ : / /

رئاسة الجهاز
مديرية براءات الاختراع والنماذج الصناعية
القسم الاداري/ شعبة التدقيق

الى / جامعة كربلاء / كلية الهندسة / قسم الهندسة الميكانيكية

م/ تــأييــد

يهدي الجهاز أطيب تحياته ....
نؤيــد استلام طلب براءة الاختــراع المرقم (٤٢٥/ ٢٠٢١) في ٢٠٢١/٨/١٧
والموســوم : (**تصميم وبناء مجمع شمسي مزدوج الأداء لتعقيم المعدات الطبية الجراحية**)
والمودع من قبل السادة المدرجة اسمائهم في ادناه :
١- ا٠م٠د٠ محمد حسن عبود
جامعة كربلاء / كلية الهندسة / قسم الهندسة الميكانيكية
٢- ا٠م٠د٠ فرحان لفتة رشيد
جامعة كربلاء / كلية الهندسة / قسم هندسة النفط
٣- المهندس محمد محسن جاسم
محافظة كربلاء المقدسة / مديرية شباب ورياضة كربلاء المقدسة منتدى الرعاية العلمية

وحالياً قيد اجراءات الفحص والتقييم، وبناء على طلبهم زودناهم بهذا التأييد

مــــع التقــــدير

نعيم أحمد اسماعيل
مدير القسم الاداري
ع/ مسجل براءات الاختراع والنماذج الصناعية
٢٠٢٢/٣/

جمهورية العراق - وزارة التخطيط
الجهاز المركزي للتقييس والسيطرة النوعية
C.O.S.Q.C
مديرية براءات الاختراع والنماذج الصناعية
القسم الاداري
شعبة الصادر والوارد

صورة منه الى /
- المهندس محمد محسن جاسم / محافظة كربلاء المقدسة / مديرية شباب ورياضة كربلاء المقدسة منتدى الرعاية العلمية ٠٠٠مع التقدير
- مديرية براءات الاختراع والنماذج الصناعية/ القسم الفني / للحفظ في اضبارة الطلب اعلاه

العراق - بغداد - الجادرية - ص . ب (١٣٠٣٢) - البريد الالكتروني : www.cosqc.gov.iq
هاتف ٨٤ / ٨٣ / ٨٢ / ٨١ / ٧٧٨٥١٨٠ تليفاكس ٧٧٦١٩٨١ cosqc@cosqc.gov.iq

Appendix F
Published Papers

Int. J. Nonlinear Anal. Appl. 13 (2022) 1, 2535-2547
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http://dx.doi.org/10.22075/ijnaa.2022.5955

Design and construction solar steam sterilizer

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(Communicated by Madjid Eshaghi Gordji)

Abstract

Doctors, especially surgeons in remote areas, need help to overcome the problem of transmission of infection resulting from the repeated use of surgical instruments without sterilization, and that is why researchers sought to find solutions. This study presented a design and model made for a low-cost solar sterilizer. It relied on benefits from the glasshouse properties to generate the wet steam that was required for sterilization at a temperature of $121.1°C$ and a pressure of 2.1 bar inside an aluminum pressure cylinder that was placed inside an insulated chamber, whose dimensions were 50 cm wide, 30 cm high, and 93 cm deep. Its front face was made of 10 mm-thick thermal glass. The top face was used as a frame for fixing the cylinder. The outer surface of the cylinder was coated with a matte black paint to increase heat absorption. The model was tested in the absence of surgical equipment using half a liter of pure water, and it took 128 minutes to achieve a steam with the properties necessary for sterilization. The test started when the temperature of the water inside the cylinder was 56.1°C. In climatic conditions in which the average intensity of solar radiation was 903 W/m^2 and the average ambient temperature was 34°C. Then the performance was tested with the presence of 1.2 kg of instruments. The presence of the surgical instruments increased the time required to achieve the temperature and pressure required for sterilization by 25.78%. And to increase the thermal enablement of the system, reflective panels were placed to reflect the solar radiation towards the surface of the cylinder. This procedure achieved a 6.2% reduction in the time required for the sterilization requirement for steam. The tests were conducted over several days and under different conditions, each achieving the necessary steam for sterilization.

Keywords: Solar energy, Solar autoclave, Solar steam sterilization.

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5th International Conference on Engineering Sciences

ICES2021

ICES

ID-Code: ICES-104

Authors: Mohammed Hassan Abbood, Farhan Lafta Rashid, Mohammed Mohsen Jassim

Dear Authors,

I am pleased to inform you that your manuscript entitled "**Design and Construct An Efficient Solar Collector to Sterilize Surgical Medical Equipment**" has been accepted for publication in the conference proceeding of the 5th International Conference on Engineering Sciences: ICES2021. The conference proceeding will be published in a Scientific Journal which is indexed in the Scopus database. The 5th ICES will be held on 28-29 December 2021 at Engineering College / University of Kerbala.

Thank you for your participation to the 5th ICES.

Best Regards,

L.Sh.Rasheed

University Of Kerbala
Dean Office
College Of Engineering

Assistant Prof. Dr. Laith Sh. Rasheed
Chair of the Organizing Committee -ICES
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https://sites.google.com/view/ices2021/home?authuser=2&read_current=1

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Advancing the World of Information and Engineering

International Journal of Heat and Technology
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Journal homepage: http://iieta.org/journals/ijht

Design and Construction Solar Oven Sterilizer

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Keywords:
solar energy, solar autoclave, solar sterilization, solar oven

ABSTRACT

Researchers are seeking to help doctors, especially surgeons, in remote areas overcome the problem of diseases transmission by using non-sterile surgical equipment. This study presented a design and model of a low-cost solar sterilizer to sterilize surgical equipment with hot dry air. Sterilization with dry hot air requires a temperature 160°C for 60 minutes. The design includes a stainless steel box with dimensions of 60 cm×30 cm×12 cm in which the surgical equipment is placed. This box is placed inside a chamber with insulated walls, except for the front and top. The front and top are a layer of tempered thermal glass. This chamber rests on an iron base that rotates around an axis in its center to follow the sun from east to west. Placed reflective sheets arranged in a cone shape around the surgical equipment box to increase the thermal enablement of the box. The system was tested in several variants. With and without surgical equipment and with and without reflective plates. The system achieved 160°C hot air in 121 minutes. This period increased by 23.9% when surgical equipment weighing 1.2 kg was placed. The presence of reflective plates reduced the time required to achieve the required heat by 9%.

1. INTRODUCTION

Sterilization of medical surgical equipment is one of the basics in preserving human life. Sterilization is the process of eliminating all microorganisms present on the surface of a substance or liquid to prevent the transmission of harmful organisms through repeated use of these materials and liquids, and thus the transmission of infection from one person to another. The sterilization process is carried out in several ways [1], physical and chemical. Sterilization is done by physical methods using steam or hot dry air. The steam sterilization process requires steam at a temperature of 121.1°C and a pressure of 2.1 bar for 15 minutes. The dry hot air sterilization process requires air at 160°C for 60 minutes. As for sterilization by chemical methods, it uses ethylene oxide (EtO) sterilization, formaldehyde sterilization, plasma gas (H_2O_2), and acetic acid sterilization. There are some effective chemicals that perform the sterilization process for all surgical equipment, but these materials are very expensive. The type of sterilization method is selected based on the type of surgical equipment [2], to be sterilized. Some surgical equipment is affected by humidity and cannot be sterilized by steam. Sharp and microscopic metal equipment, powders, and glass are affected by moisture, so steam sterilization is not recommended. Also, some organisms are active in moisture. Some equipment, such as rubber and textile equipment, cannot withstand high temperatures, so it cannot be sterilized with hot dry air. The autoclave was manufactured for the purpose of steam sterilization and the oven for the purpose of sterilization with dry hot air. These devices have contributed to some extent in reducing the problem of cross-infection with surgical equipment. The problem of transmission of infection was not completely resolved, as it was impossible to use sterilization devices in remote areas where there is no electricity. Researchers and scientists had to use alternative energy sources, such solar energy, to produce the heat needed for sterilization. But all the researchers focused on the method of steam sterilization without the sterilization by hot dry air because steam sterilization does not need high temperatures as in needed with the method of sterilization with dry hot air. The methods of generating steam from solar energy differed among researchers, some of them used parabolic reflectors to generate steam, as Lawrence et al. [3]. They used a box with a length of 2 m, coated on the inside with a reflector and in the form of a parabola, and closed with a glass panel on the side opposite the sun, while the box was thermal insulated on the other sides. In the center of the parabola, a tube made of galvanized steel passes, through which water passes to take the heat that the inverter concentrates on the tube to gradually turn into steam, which in turn is rushed into the pressure chamber (autoclave). The system achieves temperatures of 118°C and pressures of 18 psi, respectively. These results were close to what was required due to the heat loss from the walls of the autoclave and tubes.

Sunny et al. [4] Four convex lenses, 65 mm in diameter and 250 mm in focal length, were arranged in a circular frame to focus heat onto a 1.5 mm thick mild steel rectangular parallelepiped tank. The water is passed through 6 mm in diameter and 762 mm long copper tubes from the water tank to be converted into steam by the action of concentrated heat. The steam is then forced into a pressure chamber where surgical instruments are sterilized. Steam generation was achieved at a temperature of 132°C.

Harikrishnan et al. [5] came up with a design and construction of a solar collector to feed the steam sterilizer drum along with a water purification system. It consists of a

Appendix G
Calibration of Devices

REPUBLIC OF IRAQ
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جمهورية العراق
وزارة العلوم والتكنولوجيا
دائرة الطاقات المتجددة
العدد: ط م ٢٠٩
التأريخ: ١٩ / ٤ / ٢٠٢١

وزارة العلوم و التكنولوجيا
Ministry Of Science & Technology

إلى/ جامعة كربلاء-كلية الهندسة

م/ معايرة أجهزة قياس

تحية طيبة

إشارة إلى كتابكم المرقم بالعدد (د.ع/٦/١١٤٦ في ٢٠٢١/٤/١٥)، بخصوص إبداء المساعدة لطالب الدراسات العليا / الماجستير (محمد محسن جاسم)، تم إجراء المعايرة للأجهزة والمعدات المدرجة تفاصيلها في أدناه في مختبراتنا بتاريخ ٢٠٢١/٤/١٩ وهي جاهزة للاستخدام.

شاكرين تعاونكم معنا .. مع فائق التقدير

الأجهزة التي تم معايرتها:

١-جهاز قياس شدة الإشعاع الشمسي العدد / ١
٢-جهاز قياس درجة الحرارة العدد /١
٣-جهاز قياس سرع الرياح العدد /١
٤-متحسس درجة الحرارة T/C k طول ١ متر العدد /١

وزارة العلوم و التكنولوجيا
دائرة الطاقات المتجددة

د. فلاح إبراهيم العطار
ع/المدير العام
٢٠٢١/٤/١٩

Ministry Of Science & Technology

نسخة منه إلى/
مركز تخطيط وادارة الطاقة مع الأوليات .... للتفضل بالاطلاع مع التقدير
قسم التخطيط والمتابعة .... للتفضل بالاطلاع مع التقدير

الخلاصة

تتضمن الدراسة الحالية تصميم وتصنيع نموذج تجريبي لمنظومة شمسية مبتكرة لتعقيم الأدوات الجراحية لأول مرة حيث يتم أستخدام البخار والهواء كمائعي تعقيم بشكل منفصل. وذالك من خلال حجرتي تعقيم إحداهما تحتوي ماء يتم تحويله إلى بخار بدرجة حرارة ١٢١.١ د. س. وضغط ٢.١ بار ليتم أستخدامهُ كمائع تعقيم. والأخرى تحتوي هواء يستخدم كمائع تعقيم بعد تسخينه إلى درجة الحرارة المطلوبة للتعقيم (١٦٠ د. س). وذالك بأستخدام الطاقة الشمسية. أبعاد المنظومة هي ٢.٣ متر طول و١ متر عرض ١.٤و متر ارتفاع وبوزن ٦٥ كغم تقريباً.

تم تطويرهذه المنظومة بتنصيب وعاء أسطواني ماص للأشعة الشمسية بين حجرتي التعقيم الغاية منه هي توليد بخار بدرجة حرارة عالية جداً (١٦٠ د. س.) ليستخدم كوسيط لتسريع أنتاج مائعي التعقيم وبالتالي تسريع عملية التعقيم. وذالك من خلال تنصيب مبادل حراري في كل حجرة تعقيم لغرض التبادل الحراري بين مائع التعقيم والبخار المتولد داخل الوعاء الأسطواني. أيضاً لتعجيل توليد البخار داخل الوعاء الأسطواني تم أستخدام عدسة فرينل وطبق بيضوي عاكس كمركّزات شمسية لتركيز الشعاع الشمسي بأتجاه هذا الوعاء. المنظومة أيضاً تمتلك جهاز تتبع شمسي بمحورين لتعقب الشمس أوتماتيكياً.

تم أيجاد درجة حرارة وضغط سائل التعقيم (بخار أو هواء) والبخار المتولد في الوعاء الأسطواني نظرياً و تجريبياً. هذا لمقارنة نتائج الدراسة الحالية لإظهار دقتها.

أظهرت النتائج أنَّ أستخدام الوعاء الماص للشمس بحالته الأعتيادية (بدون مركزات شمسية) لا يمكنه تحويل الماء الى بخار. بينما بعد تنصيب الطبق العاكس تم الحصول على البخار (١٦٠ د. س. و٦.٢ بار) داخل الوعاء الأسطواني خلال ٣٧ دقيقة تجريباً و٣٣ دقيقة نظرياً. وبعد تنصيب عدسة فرينل مع وجود الطبق البيضوي العاكس تم تقليل هذا الوقت بنسبة ٣٥% تجريباً و٣٦,٤% نظرياً مقارنةً مع نتائج الطبق البيضوي لوحده.

بمقارنة النتائج التجريبية بالنتائج النظرية وجد أن الحد الأقصى للانحراف حوالي ١٧٪. وبحسب الأسعار في العراق ، وجد تقييم الجدوى الاقتصادية للنظام أنه يكلف ٦٦٤ دولارًا.

جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة كربلاء

كلية الهندسة

قسم الهندسة الميكانيكية

تصميم وبناء مكثف شمسي باستخدام عدسات فرينل لتعقيم المعدات الطبية الجراحية

رسالة مقدمة الى كلية الهندسة في جامعة كربلاء كجزء من متطلبات نيل درجة الماجستير في علوم

الهندسة الميكانيكية

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