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Présentée par

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الإهداء

بسم لله الرحمن الرحيم

(قل اعملوا فسيرى لله عملكم ورسوله والمؤمنون)

صدق لله العظيم

من هذا المنطلق القويم نهدي هذا العمل المتواضع:

إلى المُكرَّمان والمُحمولان على الأعناق، اللذان قدَّما لي يد العون في مسيرتي دون مُقابل...

إلى والدي الكريمين

إلى من بها أعلو، وعليها أرتكز، إلى القلب المعطاء

أُمِّي الحبيبة: **خنوس فاطمة**

أُمِّي الغالية، التي جعلتني أتمسَّك بالأمل وأتجاوز الصعاب بكل ثبات..

حفظكِ الله لنا، وجعلكِ ذخرًا لنا، وقلبًا نابضًا أستلهم منه طاقتي الإيجابية..

إلى من شجعني على المثابرة طوال عمري، إلى الرجل الأبرز في حياتي

لن تستطيع كلماتي أن تصف مدى شعوري بالامتنان لصاحب الصدر الرحب والدي.

أبي المبجل: **تمار بشير**

إلى من بذلوا جهدًا في مساعدتي وكانوا خيرَ سندٍ، الذين لم يبخلوا عليَّ بالجُهد الوفير..

إخوتي وأخواتي**: محمد ريان، عبد الواحد، فردوس، ريحان، عبدا لباري.**

أصدقائي وأهلي المُبجَّلون الذين أُكِنُّ لهم كل الاحترام، الذين يُشاركونني الفرح والحزن

أساتذتي الكرام أصحاب الفكر المُستنير...

إلى كل هؤلاء: أهديكم خلاصة جُهدي العلمي، الذي أسال الله تعالى أن يتقبله خالصًا

تمار سوسن

شكر وتقدير

فإني أشكر الله تعالى على فضله حيث أعانني على إنجاز هذا العمل، فله الحمد أولا وآخرًا.

تيمنا بسنة الحبيب المصطفى صلى الله عليه وسلم الذي قال (من لم يشكر الناس لم يشكر الله عزوجل) فانه يشرفني أن أتوجه بالشكر لأولئك الأخيار الذين مدوا لي يدَ المساعدة، خلال هذه الفترة، وفي مقدمتهم أساتذتي الكرام البروفيسور **خلف عبدالحميد** والبروفيسور **سلامي محمد حسان** اللذان لم يدّخرا جهدًا في مساعدتي طيلة فترة الدكتوراه ، حيث كانا يحثانني على البحث، ويقوّيان عزيمتي عليه فلهما من الله الأجر ومني كل التقدير حفظهما الله ومتّعهما بالصحة والعافية، كما أدعو الله أن تتجلى نيتهما الخالصة في رؤية فلذة كبدهما في أعلى المراتب .

وأرفع شكري وتقديري إلى أساتذتي الموقرين في لجنة المناقشة رئاسة وأعضاء ولتفضلهم قبول مناقشة

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إلى صديقتي الغالية: **بن عمر إلـهام**

إلى كل من نسيه الذكر وحفظه القلب.

وأختم شكري وعظيم امتناني إلى من رافقتني دعواتهما أناء الليل وأطراف النهار، ضياء عيني وفجر أيامي والدي العزيزين حفظكما الله ووفقني إلى بركما.

تمار سوسن

Abstract

Many people who live in remote desert areas struggle to find fresh water because they have limited access to natural water sources. However, there are a variety of contemporary technologies that could potentially address this problem .Among them all, solar still might be the best choice for making drinking water because it is simple to operate and doesn't damage the environment.

The goal of the research described in this thesis is to use various types of carbon to enhance the efficiency of a single-slope solar still. The production of distillate has grown as a result of these modifications' significant improvement in evaporation rates.

In the first part of the experiments four distinct types of carbon were added separately to each absorber with a weight of 100g, or 0.4167kg carbon/m^2 of absorber area. These carbon types were activated carbon, graphite, coal, and wood charcoal.The results obtained during experiments at Ouargla University show that the various types of carbon enhance water absorption to solar irradiation. Moreover, placing carbon powder inside the fixed black cloth led to the stability of the carbon particles on the base of absorber avoiding them to float above the water, which contributed to the increase of the daily yield. Activated carbon, graphite, coal and wood charcoal improve the output by: 79.39%, 57.58%, 50.30% and 18.18% respectively relative to the baseline case.

In the second part of the experiments three different mixture types of carbon were used with the same mass of 100 g of each one, i.e, (0.834kg/m^2 of absorber area).The presence of different carbon mixtures namely :(charcoal + activatedcarbon), (charcoal +graphite) and (graphite + activated carbon) has improved distillate output; the modified unit's productivities are higher than the baseline instance by 42,01% , 66,38%, and68.9%, respectively.

Keywords: Activated carbon, graphite, coal, wood charcoal, absorbent materials, solar desalination, Southern Algeria.

ملخص

يعاني العديد من الأشخاص الذين يعيشون في المناطق الصحراوية النائية للعثور على المياه العذبة بسبب محدودية إمكانية الوصول إلى مصادر المياه الطبيعية، ومع ذلك هناك مجموعة متنوعة من التقنيات المعاصرة التي يمكن أن تعالج هذه المشكلة، من بين كل هذه التقنيات، يعد التقطير الشمسي هو الخيار الأفضل لإنتاج مياه الشرب لأنها سهلة التصنيع ولا تضر بالبيئة.

الهدف من البحث الموصوف في هذه الأطروحة هو استخدام أنواع مختلفة من الكربون لتعزيز كفاءة المقطر الشمسي أحادي المنحدر وقد زاد ت نواتج التقطير نتيجة للتحسن الكبير الذي حققته هذه التعديلات في معدلات التبخر.

في المرحلة الأولى من التجارب، تمت إضافة أربعة أنواع مختلفة من الكربون بشكل منفصل إلى كل ماص بوزن 100 غ، أو 0.4167 كغ كربون/م^2 من مساحة الماص ، وكانت أنواع الكربون هذه هي الكربون المنشط، والجرافيت، والفحم الحجري، والفحم الخشبي . وتظهر النتائج التي تم الحصول عليها خلال التجارب بجامعة ورقلة أن الأنواع المختلفة من الكربون تحسن امتصاص الماء للإشعاع الشمسي، كما أن وضع مسحوق الكربون داخل القماش الأسود الثابت أدى إلى ثبات مسحوق الكربون على قاعدة الماص ومنع طفوه فوق الماء مما ساهم في زيادة الإنتاج اليومي،حيث يعمل الكربون المنشط والغرافيت والفحم الحجري والفحم الخشبي على تحسين الإنتاج بنسبة: 79.39 % و 57.58 % و 50.30 % و 18.18 % على التوالي مقارنة بالمقطر الشاهد .

في الجزء الثاني من التجارب تم استخدام ثلاثة أنواع مختلفة من خليط الكربون بنفس الكتلة 100 غرام من كل نوع كربون أي (0.834 كغ/م^2 من مساحة الماص)، وجود خليط كربون مختلف وهو: (فحم خشبي + كربون منشط) ، (فحم + غرافيت) و (غرافيت + كربون منشط) أدى إلى تحسين نواتج التقطير؛ حيث كانت إنتاجية المقطرات المعدلة أعلى من إنتاجية المقطر الشاهد بنسبة 42.01 % و 66.38 % و 68.9 % على التوالي.

الكلمات المفتاحية : الكربون المنشط، الغرافيت، الفحم الحجري، الفحم الخشبي، المواد الماصة، تحلية المياه بالطاقة الشمسية، جنوب الجزائر

Rsumé

De nombreuses personnes vivant dans des zones désertiques isolées ont du mal à trouver de l'eau douce car elles ont un accès limité aux sources d'eau naturelles. Cependant, il existe une variété de technologies contemporaines qui pourraient potentiellement résoudre ce problème. Parmi elles, l'énergie solaire pourrait encore être le meilleur choix pour produire de l'eau potable, car elle est simple à utiliser et ne nuit pas à l'environnement.

L'objectif des recherches décrites dans cette thèse est d'utiliser différents types de carbone pour améliorer l'efficacité d'un distillateur solaire mono-pente. La production de distillat a augmenté grâce à l'amélioration significative des taux d'évaporation grâce à ces modifications.

Dans la première partie des expériences, quatre types de carbone ont été ajoutés séparément à chaque absorbeur avec un poids de 100 g, soit 0,4167 kg de carbone/m^2 de surface d'absorbeur. Ces types de carbone étaient le charbon actif, le graphite, le charbon et le charbon de bois. Les résultats obtenus lors d'expériences à l'Université d'Ouargla montrent que les différents types de carbone améliorent l'absorption de l'eau lors de l'irradiation solaire. De plus, le fait de placer de la poudre de carbone à l'intérieur du tissu noir fixe a permis de stabiliser les particules de carbone sur la base de l'absorbeur en les évitant de flotter au-dessus de l'eau, ce qui a contribué à l'augmentation du rendement journalier. Le charbon actif, le graphite, le charbon et le charbon de bois améliorent respectivement la production de 79,39 %, 57,58 %, 50,30 % et 18,18 % par rapport au distillateur conventionnel.

Dans la deuxième partie des expériences, trois types de mélanges différents de carbone ont été utilisés avec la même masse de 100 g de chacun, soit (0,834 kg/m^2 de surface absorbante). La présence de différents mélanges de carbone, à savoir : (charbon + charbon actif), (charcol+graphite) et (graphite + charbon actif) ont amélioré le rendement du distillat ; les productivités de l'unité modifiée sont supérieures à celles de l'instance de référence de 42,01 %, 66,38 % et 68,9 %, respectivement.

Mots clés : Charbon actif, graphite, charbon, charbon de bois, matériaux absorbants, dessalement solaire, Sud Algérien.

List of abbreviations

A	surface area of the sensor (m^2).
B	Albedo coefficient
C	is the speed of light ($m.s^{-1}$)
Cp	specific heat of the fluid in(J/kg.K)
CT	Civil Time (h)
D	diameter of the conduit(m)
E	The thickness of the transfer layer in (m).
FPB	The amount of water produced in 24 hours/ the amount of energy input in 24 h.
FPH	The amount of water produced after one hour / the amount of energy input at the end of one hour.
G	Global solar energy incident per m^2on a horizontal surface for one day.(W/m^2)
Gdif (s)	Le rayonnement solaire diffus horizontal sur le plan incliné.
h	Thermal convection exchange coefficient (W/m^2 K)
hevp	Evaporation enthalpy (j)
k	Thermal conductivity of the milieu (W/m.°C)
L	is the longitude of the location (°).
Lv	latent heat of vaporization($j.Kg^{-1}$)
L(Tw)	The latent heat of vaporization of water at the temperature Tw (J /kg).
M	The dynamic viscosity of the fluid in (kg/ms).
MST	Mean solar time (h)
md	The distillate flow (kg /m^2 .h)
qw	The heat flux used for water evaporation(J /s).
S	The contact surface with the fluid in (m^2).
Tamb	AmbientTemperature (°C)
Te	The indoor temperature (K)
Tg	Temperature of glass cover (°C)
Ts	The outlet temperature (K)
Tw	Temperature of brackish water in the bassin (°C)

TDS	Total Dissolved Solidsmg/L
T.S.T	True Solar Time (h)
(T.L)	Legal Time
U	The kinematic speed of the fluid in (m/s)
UT	Universal Time (h)
ν	The frequency in s^{-1}
W.H.O	world health organisation
α	inclination of the capture in(°)
α t	the thermal absorption coefficient
α f	absorption coefficient of the bottom of the still.
αe	water absorption coefficient.
ρ	the density of the fluid in(kg /m^3) ;
τe	water transmission coefficient.
τv	glass transmittance coefficient
σ	Stefan-Boltzmann constant (W m^{-2} K^{-4})
λ	the wavelength in nm.
β_T	Fluid expansion coefficient for ideal gases in (K^{-1})
ϕ	Heat flow transmitted by conduction(w).
η	Overall efficiency(%).
ηi	Internal efficiency (%) .

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GENERAL INTRODUCTION

General introduction

ALLAH said in the Holy Quran, Surah of the Prophets, Aya 30, “And we made from water every living thing." The holy book affirms that water, by divine will, is the sole basis of the appearance of life. This invigorating property, as well as other characteristics of water are found in many Quranic verses [1].The availability of drinking water is decreasing day by day, while the need for drinking water is increasing rapidly [2].While most of the earth's surface is water, fresh water is very limited.Therefore, obtaining clean drinking water is one of the great problems facing humanity[3]. By 2030, there will be a major concern about providing drinking water to more than half of the world's population due to population growth, overexploitation, and global warming [4].

Many regions around the world suffer from a shortage of freshwater, including arid and desert regions. Despite significant progress, the problem of drinking water remains a major technical, economic and political issue [5] .

Among the solutions being developed to address the problem of water resources are the reuse of wastewater in agriculture and the desalination of seawater and brackish water [6] . Africa is currently the region with the highest levels of water stress, affecting up to 31% of the population, followed by Asia (25%), America (7%), and Europe (2%)[7].

Indeed, there are many places, even in urban areas, where water is polluted and not always completely safe to drink. According to a study by the World Health Organisation (WHO),Eighty percent of diseases that cause temporary or permanent disability are caused by water that is polluted and poor sanitation[8].

It is estimated that around 500 million people suffer from illnesses caused by contaminated water.Fresh water is one of the necessities not only for drinking but also in all aspects of life [9].

Water covers approximately 70% of the earth's surface.However, more than 97% of the planet's water is salty or brackish (ocean and sea water). Available fresh water is less than 3% of total water, including lakes, rivers, and groundwater[10].

Uneven distribution of fresh water is less than 1% within human reach and 2% remains frozen. To resolve these problems, and to better preserve the future in terms of releasing and mobilizing water resources,It makes more sense to rethink the planning of conventional water resources as part of an overall vision that also integrates the use of unconventional water resources, notably the desalination of seawater and brackish water[11].

Indeed, desalination in general has an increasing role to play in meeting the demand for fresh water. Several methods of desalination of sea and/or brackish water have been implemented; these include thermal distillation and membrane distillation[12].

Energy for desalination can be obtained from fossil fuels or alternative energy sources such as biomass, geothermal energy, wind energy, and solar energy [13].Among the different solar desalination methods, solar stills have several advantages, including simplicity, low cost, ease of maintenance, and low environmental impact. However, they also have drawbacks, such as low performance, which hinder their commercial adoption [14].

Algeria is considered one of the dry countries due to the serious scarcity of its water resources, especially with regard to precipitation, which is the most important factor in the assessment of water resources. It varies from more than 2000 mm/year along the Mediterranean Sea to less than 100 mm/year north of the Sahara. These differences in average annual precipitation determine the different climatic regions of Algeria.Sparsely populated areas in southern Algeria lack fresh water. Fortunately, these regions have a significant potential for very promising solar energy due to the high intensity of sunshine, the duration of sunshine, which can reach 3500 hours/year and enormous groundwater resources. The quantity of water in the south is estimated at 60,000 billion m^3 containing 2000 to 5000 ppm of salts in most places [15].

The immense wealth of renewable energies in our country constitutes an asset for developing desalination technologies while working to make them competitive. For this reason, we must try to improve the efficiency of conventional solar still . With this in mind, the main objective of this experimental work is to improve solar distillation techniques in order to obtain a significant production of distilled water that can meet the drinking water needs of the Saharan community.During this experimental period, different parameters were the subject of a series of measurements, namely:solar radiation, ambient temperature, the temperature of the different parts of the installation (condenser, interior air, pool's water), as well as the quantity of distilled water.

In this context, this thesis manuscript includes four chapters, which are preceded by a general introduction.

- The first chapter presents the problem of drinking water, a bibliographic study concerning the different desalination processes and also a general presentation on solar distillation.
- The second chapter provides a theoretical study contains a brief on solar energy, the different modes of heat and mass transfer, followed by a basic notion necessary for the description of different types of carbon and their applications.
- The third chapter will focus on the design of a chosen prototype of a solar still as well as the description of the equipment and experimental methods that allowed the practical realisation of this study.
- The fourth chapter is devoted to the exploitation of experimental results in the form of graphs with their interpretations, then this thesis is completed with a general conclusion and a series of appendices.

Reference

[1] M. Jandra, M. Shofyullah, Quranic Verses and Sources of Ocean Energy, UMRAN-International Journal of Islamic and Civilizational Studies 5 (2018).

[2] M. Salehi, Global water shortage and potable water safety; Today's concern and tomorrow's crisis, Environment International 158 (2022) 106936.

[3] W. Musie, G. Gonfa, Fresh water resource, scarcity, water salinity challenges and possible remedies: A review, Heliyon (2023).

[4] A.K. Makarigakis, B.E. Jimenez-Cisneros, UNESCO's contribution to face global water challenges, Water 11 (2019) 388.

[5] W.A. Jury, H.J. Vaux Jr, The emerging global water crisis: managing scarcity and conflict between water users, Advances in agronomy 95 (2007) 1-76.

[6] V.G. Gude, Desalination and water reuse to address global water scarcity, Reviews in Environmental Science and Bio/Technology 16 (2017) 591-609.

[7] Y. Wada, L. Van Beek, D. Viviroli, H.H. Dürr, R. Weingartner, M.F. Bierkens, Global monthly water stress: 2. Water demand and severity of water stress, Water Resources Research 47 (2011).

[8] W.H. Organization, Safer water, better health, (2019).

[9] W.H. Organization, Protecting surface water for health: identifying, assessing and managing drinking-water quality risks in surface-water catchments, (2016).

[10] A.N. Angelakis, M. Valipour, K.-H. Choo, A.T. Ahmed, A. Baba, R. Kumar, G.S. Toor, Z. Wang, Desalination: From ancient to present and future, Water 13 (2021) 2222.

[11] J. Williams, Desalination in the 21st century: a critical review of trends and debates, Water Alternatives 15 (2022) 193-217.

[12] A.P. de Nicolás, Á. Molina-García, J.T. García-Bermejo, F. Vera-García, Desalination, minimal and zero liquid discharge powered by renewable energy sources: Current status and future perspectives, Renewable and Sustainable Energy Reviews 187 (2023) 113733.

[13] J. Bundschuh, M. Kaczmarczyk, N. Ghaffour, B. Tomaszewska, State-of-the-art of renewable energy sources used in water desalination: Present and future prospects, Desalination 508 (2021) 115035.

[14] M. Sellami, T. Belkis, M. Aliouar, S. Meddour, H. Bouguettaia, K. Loudiyi, Improvement of solar still performance by covering absorber with blackened layers of sponge, Groundwater for Sustainable Development 5 (2017) 111-117.

[15] D. Bechki, H. Bouguettaia, J. Blanco-Galvez, S. Babay, B. Bouchekima, S. Boughali, H. Mahcene, Effect of partial intermittent shading on the performance of a simple basin solar still in south Algeria, Desalination 260 (2010) 65-69.

ChaptreI:Water and desalination processes

Chaptre I: Water and desalination processes

I.1Water

I.1.1Introduction

Water is the primary source of life on Earth, as it is required for all biological processes. Due to its abundant nature and physico-chemical characteristics, water is not only important for life but also for industry and agriculture. Thus, life without water would be impossible[1].The circulation of water between the different reservoirs is described by the water cycle (Figure I.1).Water is found in oceans, seas, lakes, rivers, groundwater,… etc.In the atmosphere, water is in the vapour state, and then, under the cooling effect, it passes into the liquid (rain) or solid (snow) state. The engine of this cycle is solar energy, which is responsible for this change of state[2].

The consumption of water is increasing day by day due to the improvement in the standard of living of mankind. Some regions of the globe are under severe stress from water scarcity and pollution. The scarcity of fresh water is a major threat to the prosperity of humanity. Today, in many parts of the world, freshwater resources for the production of drinking water are nonexistent or insufficient due to the effects of global warming and the growth of the world's population[3].

Humans were guided towards research and development of various processes to make them available from seawater, brackish water, and wastewater under technically and economically acceptable conditions[10] .

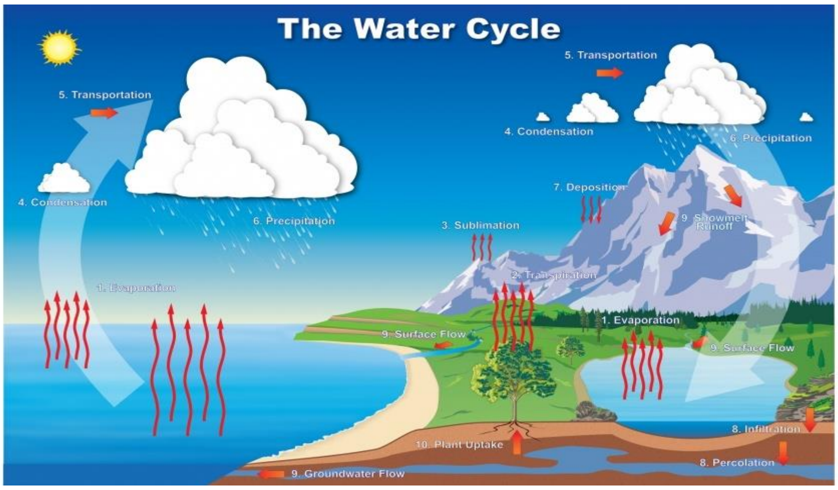

Figure I.1 Water cycle

I.1.2 water reserves on the planet

The amount of water on earth is 1.4 108 km^3.It represents a cube on his side that is more than 1000 kilometres across.This volume is 400 times largerthan the MediterraneanSea's.

However

- 97% of the world's water is found in the oceans, but it is regarded as salted water.
- The atmosphere retains only 1/105 of fresh water, but it plays a rolekey in the hydraulic cycle because it can ensure rapid circulation
- The polar ice caps, in particular those of Antarctica, store ¾fresh water from the earth. Unfortunately, the storage area is notaccessible.
- The water used comes mainly from lakes and rivers representing only less than 3% of fresh water.
- Groundwater is a very important resource that should not be underestimated.Their extraction has already started and faces the same risks as using fossil fuels because the supply cannot be replenished by human activity.

it may also become useless. Due to the salt's incursion (for example, the Eocene aquifer of Aquia)or due to the pollution(for example, the présence of NO−3 nitrates and / or NO−2 nitrites) [2].Table .I .1 presents the water reserves in the ground with its distributions.eart

TableI.1 Global Water Reserves[4, 5].

Reservoir	Volume ($10^{15}m^3$)	Total %	Residence time
Oceans	1350	97.0	2500years
Glaciers (ice cap)	33	2.4	100 à 10000 years
UndergroundWater	8	0.6	1500 years
Lakes	0.1	<0.01	17 years
SoilMoisture	0.070	<0.01	1year
Water in The atmosphere	0.013	<0.001	8 days
Rivers	0.0017	0.0001	16 days
water in livingmatter	0.0011	0.0001	a few hours
Total	1391	100	/

I.1.3.Waterqualitycriteria :

Depending on the use (human, agricultural or industrial use), Water has to conform by several norms. In order to show the diversity of these parameters, some characteristics are collected for potable water and other types of water in the following paragraphs .

I.1.3.1.Potable water

Drinking water is colourless, fresh water. odourless and tasteless, which does not contain toxic products, but some inorganic salts need to be adjusted in concentration. For the World Health Organisation (WHO), drinking water is considered such if the total salinity of the water is between 100 and 1000 mg. $l^{-1.}$ There are other characteristics that water intended for human consumption must meet in addition to this general parameter.

Table I.2presents some of theguide values concerning the physico-chemical characteristics of drinking water.The proportion of fresh water is less than 2.5% of all water on earth, of whichLess than 1% is in liquid form and available for human use.

TableI.2 – Some physical and chemical properties according to water standardsdrinkable[6].

Ions	mg/l
Sodium	200
Chlorides	200
Sulphates	250
Nitrates	50
PH	6.5-9

I.1.3.2.Brackish water :

Brackish water is undrinkable water with a salinity less than that of sea water. The water in some surface or underground aquifers can be salt water with different salinities.The pond water is more or less connected to the sea and can have a high salinity. Saltwater lakes have also beenfound in the interior of the continent [7]. They are divided into three categories based onsalinity. The first two categories of Table 1.3 are found in particular.in North Africa, the Middle East, and the United States of America.

Table 1.3Classification of water according to salinity [8].

Type of water	Salinity (mg/l)
Pure water	<500
Slightlybrackish water	1.000- 5.000
Slightlybrackish water	5.000 - 15.000
Very brackish water	15.000- 35.000
Sea water	35.000- 42.000

I.1.3.3.Sea water

Sea water is a liquid whose composition is extraordinarily varied, since there are about fifty simple bodies. The enumeration of these simple bodies is hydrogen, oxygen, and the content of seawater salts is greatest whose predominant salt is sodium chloride (about 27 g/l), There is also magnesium chloride (about 3.8 g/l), magnesium sulphate (about 1.7 g/l), calcium sulphate (about 1.3 g/l), potassium sulphate (about 0.8 g/l) and calcium carbonate (about 0.1 g/l); the latter being also in the form of bicarbonate subjected to carbon equilibrium. There is also magnesium bromide (about 0.08 g/l). By adding the above contents, we find that seawater has an average salinity of 35 g/l, but in reality, it must be considered that seawater generally contains 35 to 42 g/l of salts. Dissolved minerals and the salinity are different according to the seas [7]. The salinity of the seas and oceans are summarized in Table I.3.

Table I.4 : Degree of salinity of sea water (Data2017) [9].

Seas	Salinity (g/l)
Baltic sea	7
Caspiansea	13.5
Black Sea	20
AdriaticSea	25
Pacific Ocean	33.5
IndianOcean	33.8
Atlantic Ocean	36
MediterraneanSea	39

Arabian golf	43
Red Sea	43
Dead Sea	270

I.1.3.4.Groundwater

Rainwater seeps into the ground and produces groundwater.

There are two types of groundwater, also called aquifers:

- groundwater close to the ground surface
- captiveaquifers, which are deeper

This water is then collected and treated in treatment plants.to produce drinking water for human consumption.

In northern Algeria, these resources are estimated at 1.8 billion cubic metres.The potentialities of the South are estimated at 60,000 billion m^3. These latter aredifficult to exploit and renew; 4 to 5 billion m^3 are exploitable annually [10].

I.1.3.5.Rainwater :

Water on earth circulates constantly, and it operates in a closed loop that has remained unchanged for billions of years. When the sun's rays heat up the surface of the earth, water from oceans and lakes evaporates into the atmosphere (evapotranspiration), where it forms a cloud that will move according to the movementof the wind. Under the action of gravity, the water droplets that make up the cloud become heavy and fall to the ground in the form of precipitation (rain, hail, or snow). 79% of precipitation falls on the ocean, and the remaining 21% falls on dry land, which then supplies water to the water table by infiltration or runoff.

Rainwater is used to top up groundwater underground,The groundwater level will supply water to the waterway, and the water will flow again into the sea. so that the cycle can be restarted again and again[11].

I.1.4. Water consumption around the world

The survival of the human species depends closely on the availability of water resources.At present, this constraint of water scarcity is a source of conflict intersectoral requiring complicated choices.Thus, it makes it difficult to achieve sustainable development goals for several countries.

On a global scale, the uses of water are divided into 70% for agriculture and 20% for industrial production (using water as a process fluid or as an input).in products) and energy (hydroelectricity, thermal, and nuclear energy), and 10%for home consumption [12].

These numbers represent a global average point of evolution in time and space.

It develops differently from one continent to another and between countries, but it tells us about the predominant consumption of the agricultural sector. A sector that consumes almost three quarters of the water resources of the majority of countries. This cannot be only to the detriment of other users and, in particular, the populations [12],as shown in the table (I.5).

Table I.5: World water consumption per capita (data 2010) [12].

Zone	Consumption in (m^3/habitant/year)	Consumption in (L/habitant/day)
Africa	17	47
Asia	31	87
Europe	122	334
USA, Japan	210	578
World average	50	137

The renewable water resources offered by nature can be estimated from the flow of the water cycle and, more particularly, from the circulation flows of continental waters at around 40 km^3/year.

The average quantity of renewable water available on our planet is of the order of: 42×10^{12} m^3/year taking into account the current population of the planet, which is approximately 7.1 billion inhabitants, this quantity represents 5.9155×10^3 m^3/inhabitant/year, i.e., approximately 16.2 m^3/inhabitant/day [13].

The planet's population continues to grow while resources remainconstant; in some cases, these resources are even decreasing as a result of pollution problems. Water resources and needs vary greatly depending on the region. There are deserts and sub-arid areas (30% of the land surface) that have little or no water. There are also certain equatorial or tropical zones that record severalmetres of rain[14].

I.1.5 Water consumption in Algeria

In Algeria, the needs for drinking water and water for industrial use are increasingly more felt, especially in the Saharan regions whose area is around two million km^2 and where groundwater is available in large quantities about 60×10^3 billion m^3. These are difficult to exploit and difficult to renew.; however, only 4 to 5 billion m^3 can be exploited annually despitethat most of these waters are brackish. In northern Algeria, groundwaterare estimated at 1.8 billion m^3 in their natural state, these waters are unusable sothat they can constitute an important factor in the development and improvement ofliving conditions in these regions [15].

Algeria is located, like the 17 African countries affected by water stress, inthe category of the poorest countries in terms of water potential, i.e., belowthe theoretical scarcity threshold set by the World Bank at 1,000 m^3 per inhabitant per year. If iIn 1962, the theoretical water availability per inhabitant per year was 1500 m.

she was not more than 720 m^3 in 1990, 680 m^3 in 1995, 630 m^3 in 1998, 500 m^3 in 2000. Estimated at around 430 m^3 at present, and would be further reduced in 2025 by around 378 m3 and it will only be 309 m^3 in 2050.

I.1.6 Water resources in Algeria

In this part of the territory, surface water resources are very low and essentially limited to the part of the northern flank of the Atlas; on the other hand, underground resources are abundant there but are very weakly renewable (aquifers of the northern Sahara).

The potential for renewable water resources is located in the North of Algeria, which includes the tributary basins of the Mediterranean and the closed basins of the highlands[16].

On high steppe plateaus, there is an annual rainfall range of 200 millimetres (mm), but on the Tell Atlas reliefs along the Mediterranean, there is 1600 mm.In addition to this North-South variation, there is also an increase in precipitation from West to East.

The country's water potential is estimated at just under 20 billion cubic metres, of which only 75% is renewable (60% for surface water and 15% for groundwater). Non-renewable resources concern the aquifers of the Sahara north, which would be exploited as deposits and therefore result in a continuous lowering of the level of these aquifers[15].

Water resources depend on the climate which in the case of Algeria is arid to semi-arid.They are therefore scarce and correspond overall to 12.4 billion cubic meters for surface water and 2.8 billion cubic meters of groundwater, including 800 million cubic meters in the south (renewable water resources).

Schematically, surface water resources decrease from North to south as groundwater resources grow.In the north of the country, 55.3% of total mobilized resources are intended for irrigation (2.1 billion cubic meters), 34.2% for drinking water supply (1.3 billion cubic meters), and 10.5% for industry (0.4 billion cubic meters).

At the level of the high plateaus and the Sahara, which are poor in surface water, correspond underground resources; vast deep aquifers with complex circulations have been highlighted there, but they have the disadvantage of not being renewable in the Sahara[16, 17].

I.2.Different desalination techniques

Seawater contains 35 g/L of dissolved salt and some groundwater between 1 and 10 g/L of salt are usually salty, so they are not used directly, but they aregenerally undergo one or more treatments to remove mineral salts and make them drinkable (less than 0.5 g/L of salt). Desalination is the process of water treatment that consists of removing salts from saline water in order to produce drinking water. This technology was actually used for the first time

From the end of the 1940 , the desalination of seawater was developed on a large scale with thermal desalination technologies (Distillation). In the 1950s, the first industrial desalination plants appeared, mainly in the Middle East. In 1970, new technologies, such as commercial membrane processes such as electrodialysis (ED) and reverse osmosis (RO), appeared and began to be used. Electrodialysis (ED) is suitable for desalinating brackish water because it is much more economical than distillation.

While reverse osmosis (RO) has been used to desalinate both brackish water and seawater since 1990, the use of desalination technologies has become commonplace these days. Brackish water is experiencing significant development through different processes. The water desalination processes are divided into two main categories: on the one hand, and among the best known, there is the thermal distillation process (which requires a phase change: evaporation-condensation), and on the other hand, membrane processes (filtration) [18], including reverse osmosis and electro dialysis, which are techniques withenergy-intensive and are only feasible for large freshwater requirements.

En plus, il y a d'autres procédés comme le procédé d'échange d'ions, le procédé de congélationet les procédés de l'humidification.

in addition, there are other processes like ion exchange process, freezing process and humidification processes.

I.2.1Processes using membranes

Membrane processes are processes whose main source of energy is electricity, such as reverse osmosis (Reverse Osmosis [RO]) and Electro Dialysis [ED]. Membrane separation techniques use a membrane through which the water diffuses with a high proportion of salts, which is retained. By using this technique, the salt water is thus filtered under pressure through a selective membrane. Salts and microorganisms are retained by the latter, a very reliable technique that makes it possible to produce very pure water of constant quality.

I.2.1.1 Reverse osmosis

Reverse osmosis is a process where you demineralize or purify water by pushing it under pressure through a semi-permeable reverse osmosis membrane. To understand the purpose and process of reverse osmosis, you should first understand the natural process of osmosis. Osmosis is a natural phenomenon and one of nature's most important processes. It is a process in which a weaker salt solution tends to migrate to a stronger salt solution. Examples of osmosis are when the roots of plants absorb water from the ground.

Reverse osmosis occurs naturally with no energy required; to reverse the osmosis process, you should apply energy to the most saline solution. A reverse osmosis membrane is a semi-permeable membrane that allows water molecules to pass but not the majority of dissolved salts, as well as organic matter, bacteria, and pyrogens. However, you should 'push' the water through the reverse osmosis membrane by applying pressure above natural osmotic pressure to desalinate the water in the process, allowing pure water to pass while retaining the majority of contaminant[19, 20].

Figure 2 shows the principle of osmosis and reverse osmosis

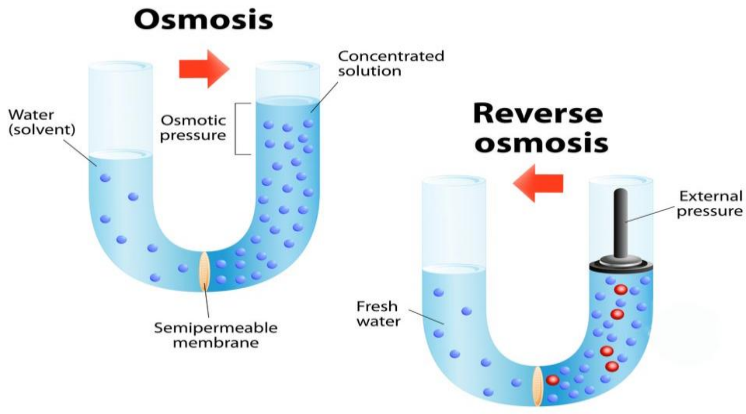

Figure I .2 The principle of osmosis and reverse osmosis.

I.2.1.2Electrodialysis

Electrodialysis (ED) is a membrane process in which ions are transported through a semi-permeable membrane under the influence of an electric potential. Membranes are selective for either cations or anions, which means basically only positive ions or negative ions will pass.

Cation-selective membranes are polyelectrolytes with a negatively charged material that rejects negatively charged ions and allows positively charged ions to flow. By placing multiple membranes in a row that alternately allow positively or negatively charged ions to flow through, ions can be removed from the wastewater.

In some columns, the concentration of ions will take place, and in other columns, the ions will be removed. The concentrated salt water flow circulates until it reaches a value that allows precipitation. At this point, the stream is unloaded. This technique can be applied to remove ions from water.

Particles that do not carry an electrical charge are not eliminated. Cation-selective membranes are made of sulfonated polystyrene, while anion-selective membranes are made of polystyrene with quaternary ammonia.

Sometimes pretreatment is needed before electrodialysis can take place. THESuspended solids with a diameter greater than 10 µm must be removed; otherwise,clog the pores of the membrane. There are also substances capable of neutralising a membrane, such as large organic anions, colloids, iron oxides, and manganese oxide. These disturb the selective effect of the membrane.

Pre-treatment methods which help prevent these effects, are activated carbon filtration (for organic matter), flocculation (for colloids), and filtration techniques[21].

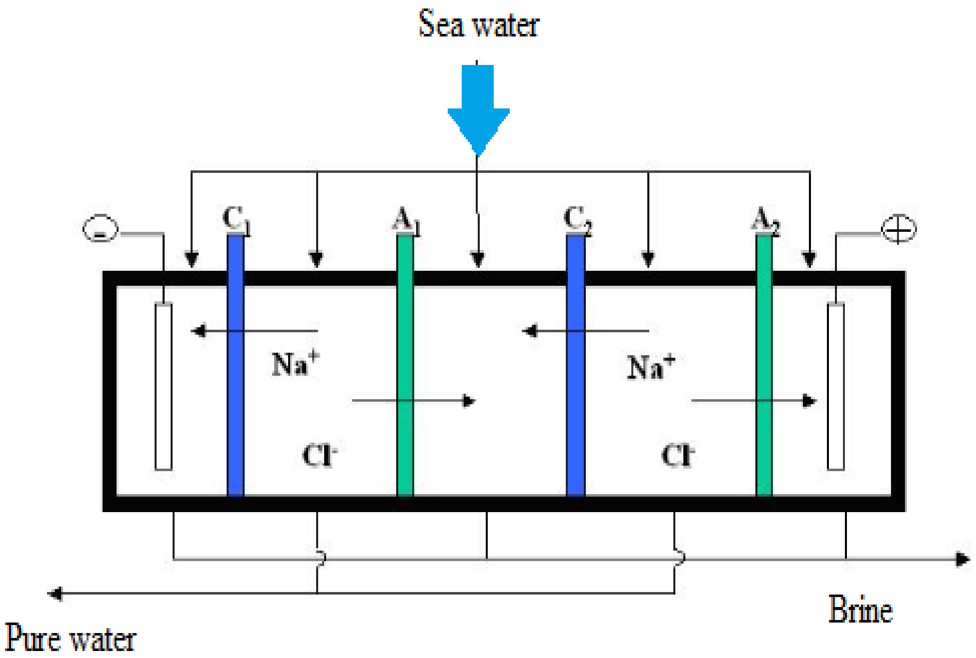

Figure 1.3 Schematic diagram of an electrodialysis unit.

I.2.2Thermal distillation processes

Thermal water desalination processes are mainly distillation processes. Distillation is the oldest and most widely used method of desalination; it is based on heating salt water to produce steam. Which is then condensed to produce fresh water. The various distillation processes used to produce drinking water all generally work on the principle of reducing the vapour pressure of the water inside the unit to allow boiling at lower temperatures, without using additional heat. Distillation units commonly use designs that conserve as much thermal energy as possible by exchanging the heat of condensation and the heat of vaporisation inside the units. The major energy requirement in the distillation process thus becomes the supply of heat for vaporisation of the feed water[22].

1.2.2.1 Simple effect distillation

The principle is very simple, reliable, and requires no maintenance, but its production is relatively low, 4-5 l/d/m^2. Steam circulation heats the brine in the evaporator. The brine evaporates at a pressure slightly above atmospheric pressure. The steam leaving the evaporator can be directly condensed without recovering the heat of condensation, or, on the contrary, the steam can be sent to the condensation to preheat the brine[2].

1.2.2.2Multi-effect distillation [MED]

From the first warm stage to the last cold stage, a sequence of evaporation steps or effects in horizontal or vertical evaporators are maintained at progressively lower pressure and temperature levels. The top of the beam is propelled with cold seawater, which sprays onto the warm exchangers. The result of this encounter is pure hot water vapour. The second evaporator, which operates at a lower temperature and pressure, uses the heat from condensation of the vapour created in the first evaporator, and the process is repeated from one evaporator to the next. A distillation station MED with three effects is shown in Figure I.2.

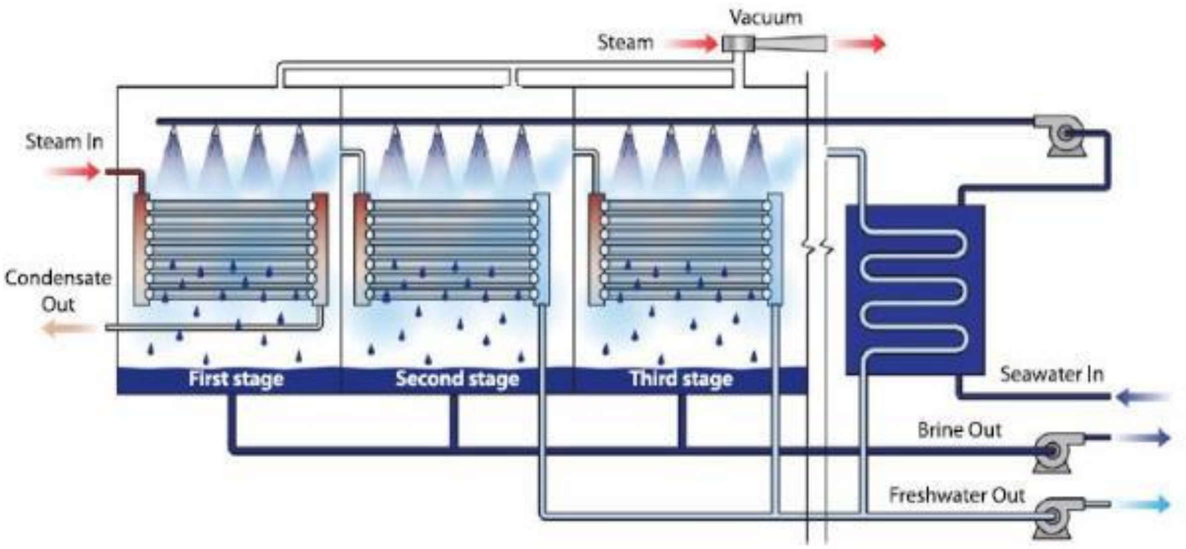

Figure I.4 Multi-effect distillation [23].

1.2.2.3Multi-stage flash vapour distillation [MSF]

Before entering a heater, where the temperature can be raised even more, the water warms up in the numerous condensers of each stage (number 1 through no). In the first evaporator, where the pressure is below the saturation pressure, the hot water is directed to cause instantaneous flash vaporisation, or "Flash." Each stage collects the condensate (fresh water), which is formed when the produced steam comes into contact with the condenser of the relevant stage. Without the need of pumps, water can flow between the different stages as the temperature and pressure both drop from stage 1 to stage n. Flash vapour distillation in many stages is depicted in Figure I.3.

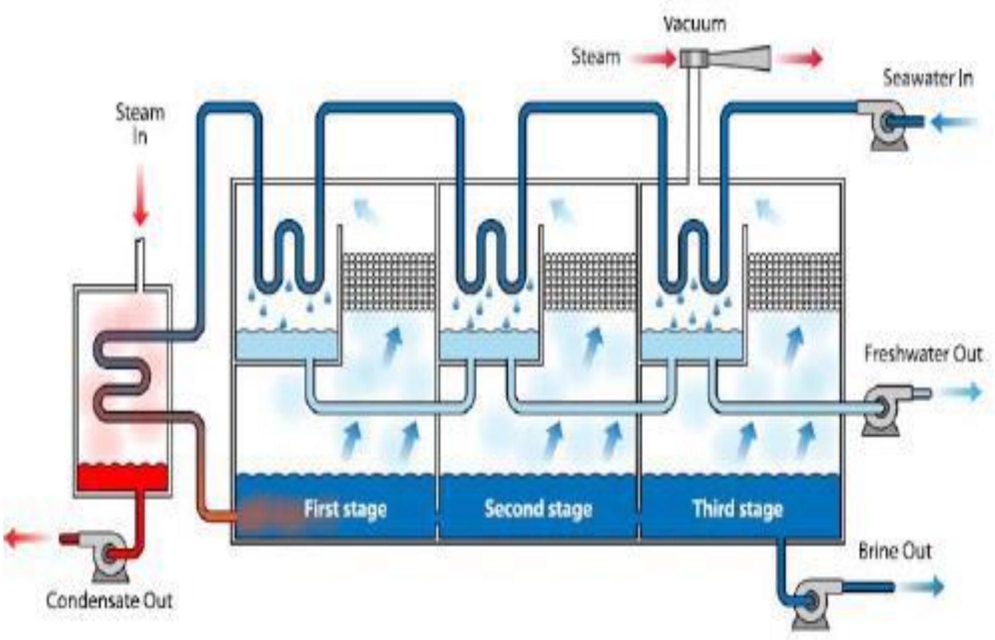

Figure I.5 Distillation Flash [10].

1.2.2.4 Distillation with vapour compression (thermo compression) [VC]

It is feasible to raise the temperature of the treated water up to the saturation point by vaporising it in a thermally insulated container and sucking the steam produced by that process through a compressor. The water then evaporates due to the heat of condensation as the steam continues to flow through a tube bundle at the bottom of the chamber.

The salt water that needs to be treated is warmed in a concentric tube heat exchanger, while brine and fresh water are cooled. The destination technique for this mode is shown in Figure.I.4.

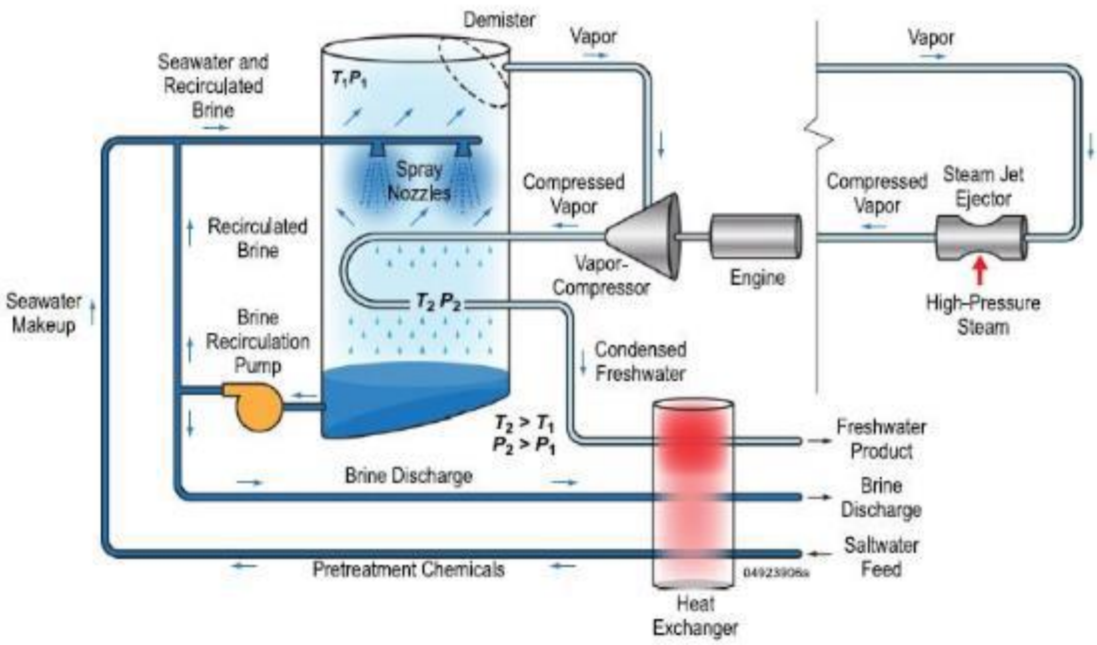

Figure 1.6Vapor Compression Desalination Process[23].

I.2.3. Other desalination processes

There are other water desalination processes such as the ion exchange process,and the freezing process.

Ion exchange :

When brackish water comes into contact with certain insoluble substances, an exchange of ions takes place. These insoluble substances have the particularity of exchanging certain ions with water salts[24].This technology is carried out using cationic and anionic resins. These resins are composed of organic products capable of fixing the salt ions present in salt water by electrostatic attraction. Passing through these resins installedIn series, the water will leave behind these ions (Ca^{2+}, Mg^{2+}, Na^{+}, Cl^{-}, NO^{3-}, SO_4^{2-}...) captured by these resins. Once the resins are saturated, they are regenerated by basic chemicals, and the cycle is repeated if necessary[10].

Distillation by freezing

Freeze desalination is based on the liquid-solid phase change of brine. Salt water solidifies under atmospheric pressure at a temperature below 0°C (according to Raoult's first law). By solidification, salt migrates to the outer surface of solid water, so it can be obtained by simply washing ice (pure water).

The unit operations of a freezing desalination process are:

- pre-treatment of seawater (elimination of suspended solids,removal of dissolved gases for vacuum processes);
- the formation of ice crystals from the saline solution (for theslurry processes, large crystals are desired forfacilitate washing);
- ice crystal washing (for continuous processes,washing in a column with approximately 5% of the water produced);
- the melting of ice crystals[7].

I.2.4.Comparison between desalination processes

Various techniques have been employed in water desalination for purifying groundwater or seawater.

Table I.6 shows the many methods that are most widely used and also provides comparisonsbasedThe investment cost;

- The consumption of energy;
- Effects on the environment.
- The cost of maintenance

Table I.6 shows that solar distillation seems like a good option for dealing with the issues of contaminated or infected water in a remote area.It doesn't use energy and doesn't release harmful pollutants into the environment. ,But on the other hand the limited amount of pure water produced is an unavoidable drawback.which explains why efforts are made worldwide by scientists to increase and improve this productivity as well as our thesis.In the table below, we present a comparative study between the various desalination processes

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Table I.6 present a comparative study between the various desalination processes

Desalination process	The advantages	The disadvantages
Reverse osmosis RO	High production and waterquality	• SignificantcapitalandSignificantexpenses for maintenance • High cost of replacing • membranesand chemicals • excessiveconsumption of energy
Electrodialysis ED	High production and waterquality	• Maintenance of membranes • continuously • The need for multiple pre-treatments
Multi-effect distillation (MED)	High production and water quality	• high level of energy use and gas emissions • required a large area • a corrosion issue.
Multi-stage flashvapour distillation (MSF)	High production and water quality	• high level of energy use and gas emissions • required a large area • a corrosion issue. • required a large area
Distillation with vapourcompression (thermocompression) (VC)	High production and water quality	• significant maintenance and capital expenses. • highlevel of energy use
Ion exchange	Produces water of high quality	• Reduced water output • Expensive process. • Not applicable to sea water.
Distillationby freezing	High productivity of water	• Traces of solvent in water
Solar distillation	• Environmental instrument • Simple for building • Produce water of high quality. • Minimal maintenance and cost effective	• Reduced water output

I.3.Solar Distillation

Simple solar stills are used today for the production of portable water from salt water in several Third World countries. Malik et al maintain that solar distillation is the most economical method for producing fresh water in small quantities[25].

According to Malik et al., Arab alchemists were the first to use solar distillation. The first detailed works published on the subject date back to Harding (1883), where he presents the glass-covered wooden still that the Swedish engineer Carlos Wilson used in Chile. This device could produce an average of 4.9 litres of distilled water per day on a summer day[26].

I.3.1.Principle of operation of a solar still

Solar distillation is a natural phenomenon; it has the same principle as the real phenomenon that takes place in nature, where the solar radiation incident on the sea (the ocean, the lake, or the river...) heats the water, which evaporates and rises above, carried by the wind until it arrives at a colder place where it condenses and gives rain[2].

However, man has reproduced in a miniaturized model, the natural cycle, this model is called solar still.The simple solar still is an insulated basin whose bottom is blackened by a special paint, with adiabatic walls, covered by transparent glass and enclosing a quantity of salt water.

The solar energy entering through the glass roof is absorbed by the water and the basin, and raises their temperature, thus causing evaporation. The temperature of the glass roof, which bathes in the atmospheric air, is generally lower than that of the air-water vapour mixture; there is condensation of the water vapour on the internal surface of the inclined cover. The distilled water produced flows in a thin film that be collected separately.

A large part of solar radiation, direct and diffuse, is absorbed by the black background. Small amounts of energy are lost either by reflection from the surface of the glass and the surface of the water or through the insulation, cover, or support.

The energy absorbed by the base is almost totally transferred to the water, and only a small fraction is lost to the ground by conduction through the support structure. The energy that is transferred from the water to the glass cover is essentially caused by the water vapour evaporating from the surface of the water and losing its heat of vaporisation by condensing.

Heat is also transferred from the water to the lid by the free convection of the air caught under the glass cover[2].

The glass of the cover absorbs part of the heat emitted by the surface of the water and also absorbs a small part of the incident solar rays. This heat absorbed by the cover is lost to the atmosphere by convection and radiation. The simple solar still is characterised by its low efficiency, but from an experience point of view, it is flexible due to the ease of its assembly, disassembly, and maintenance. This is the reason we used it as a test prototype[2].

I.3.2. Different type of solar distillers

All types of solar stills have the same working principle, but it can be different in terms of performance, design, and materials used in their construction.

Basically, solar stills are classified into two groups in terms of energy supply: passive solar stills and active solar stills.

I.3.2.1.Passive solar distillers

Passive solar still systems are conventional solar still systems that use solar energy as the sole source of thermal energy. A solar still is made of a bowl that prevents water from leaking out and is airtightly secured by an inclini glass cover.

Solar irradiation passes through this tilted glass, and more of it is absorbed by the salt water in the bassin. As the water is heated, dissipation occurs. As such, the continuous impact makes the solar energiei look like a heat trapped.There are several types; let's discuss them one by one[23].

I.3.2.1.1.Single effect solar still (EDS)

It is a distiller with a single evaporator, the best known and most used in the world. is the basin type still; generally, this type is simple to build and maintain, but its efficiency remains lower than that of a multiple-effect solar still. There are many such models:

I.3.2.1.2.Single Slope Solar Still

The singleslope solar still tilted at an angle. Can be considered the basic type of passive solar still with which more advanced designs should be compared. Many studies have been carried out on this subject.with variations in parameters such as type of material used, inclination angle of glass cover and cooling, absorbent material inside the solar still, composition of feed water, and type of basin coating. (Figure 1.8) [27].

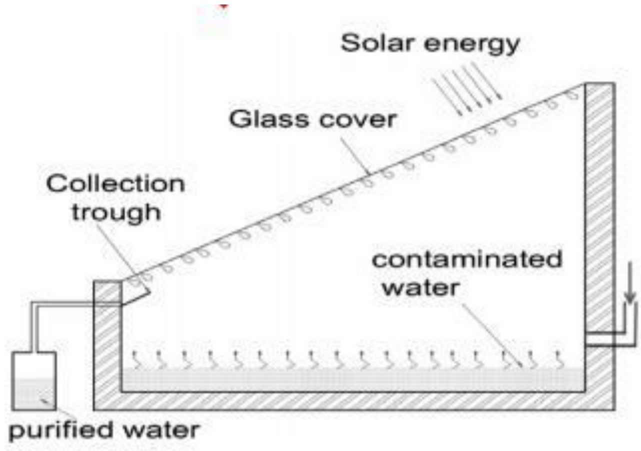

Figure 1.8 Single Slope Solar Still.

I.3.2.1.3.Double Solap solar Still

It is a simple distiller with double glass covers, each of which is inclined at an angle. Its advantage is that it exposes one of its sides to the sun and the other to the shade to accelerate and increase the rate of condensation. (Figure 1.9)[28].

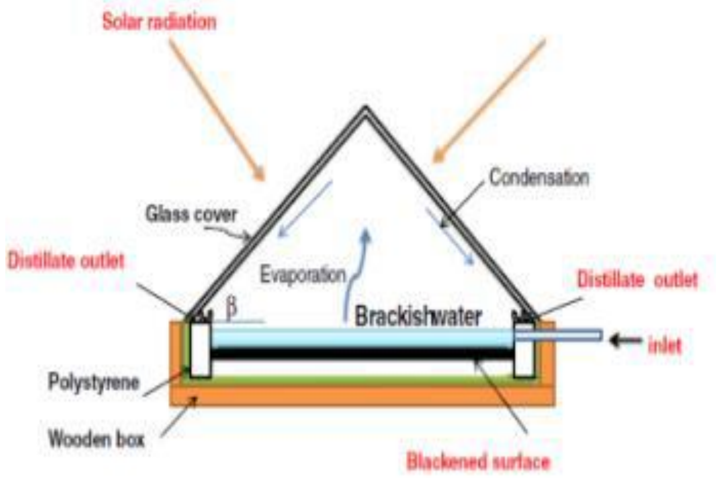

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Figure I.9Double Solap solar Still .

I.3.2.1.4.Multiple-effect solar stills

The solar distiller has many effects, and many evaporators are installed in series and operate at decreasing pressure points ;the head effect and the tail effect. In the following, we will briefly describe the design and operation of a few models, which are as follows:

I.3.2.1.4.1.Multiple basin solar still

The low efficiency of most conventional single-effect solar stills is due to low dissipation of the latent heat of the of the vapor that condenses on the condensing surface.
In the multiple-tank distiller, the latent heat of vaporisation released by the surface of the inside face of the pane is used to heat the water in the upper basin rather than being lost to the outside.Therefore, it increases the rate of evaporation and condensation in this type of double-effect solar still. The basin on the upper part is made of a transparent material (usually glass) to allow the radiation to reach the first basin at the bottom of the distiller.(Figure 1.10) [24].

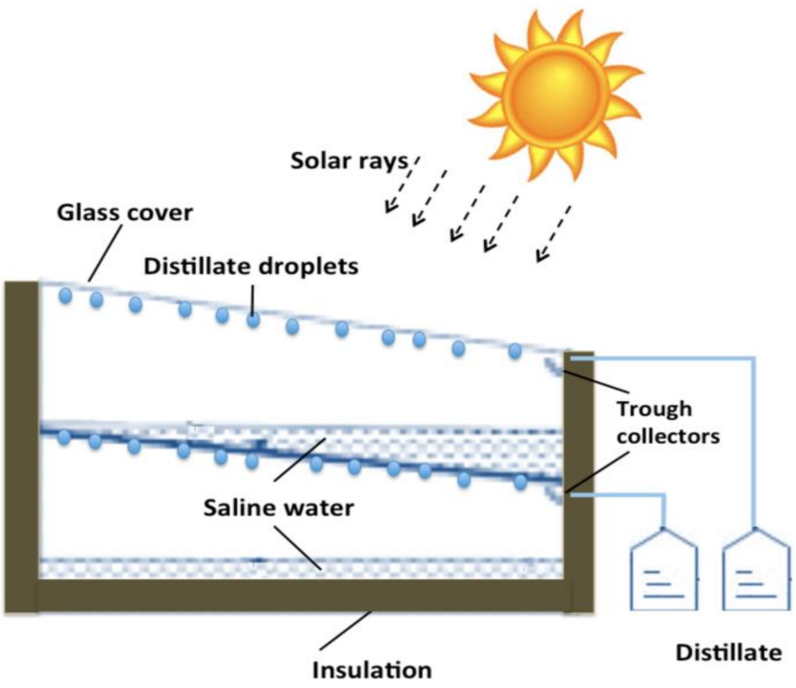


Figure I .10 Multiple basin solar still.

1.3.2.1.4.2..Multiple-effect diffusion solar still

This device mainly consists of two parts: a storage tank connected to a sensor and a series of parallel and vertical metal plates.The hot water coming from the storage tank heats the first plate and causes the evapouration of the water flowing on the right side of it; the water vapour produced condenses on the left side of the second plate; the heat of condensation released will be used to evapourate the water flowing on the right side of the second plate; and so on until the last plate, where the heat of condensation will contribute to the preheating of the salt water supply.(FigureI .11)[9].

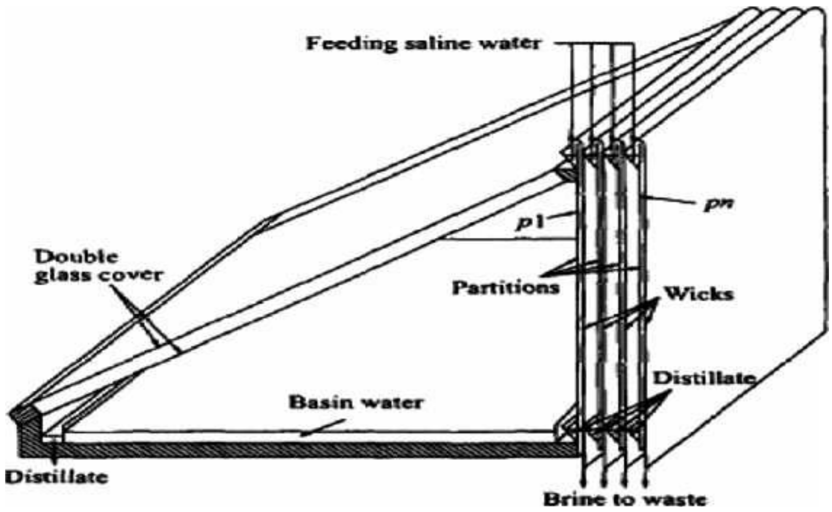


Figure I .11Multiple-effect diffusion solar still.

1.3.2.2. Actif solar still

In active solar stills, additional thermal energy is given to the passive solar still for faster evaporation. This additional thermal energy can be obtained from a solar collector, condensers, chillers, or other equipment added to increase performance. Typically, this equipment requires pumps, fans, or other powered devices for its operation. Thus, the classification is based on the form of the distillation system[25].

There are several models of this type which are as follows:

1.3.2.2.1 Actif solar still with high temperature

The water temperature of the conventional still is increased to provide additional thermal energy to the basin by solar collectors. The temperature is increased by20–50°C to 70–80°C in high-temperature distillation for better evaporation[25].

1.3.2.2.1.1.Solar still coupled with flat platecollector

The solar distiller, coupled with the flat collector, also works with the high-temperature distillation method. The solar still, coupled with a flat plate collector (FPC), operates either in forced circulation or natural circulation mode. In circulation mode forced, a pump is used to supply water. In natural circulation mode, water flows due to the difference in water density. The use of a collector increases the heat supply to the distiller; therefore, it may also be necessary to improve heat production to achieve condensation. This was done using a tower humidifier and condensation cover.

(Figure.1-12) Schematic diagram of a single-slope solar stillcoupled with a flat collector [26].

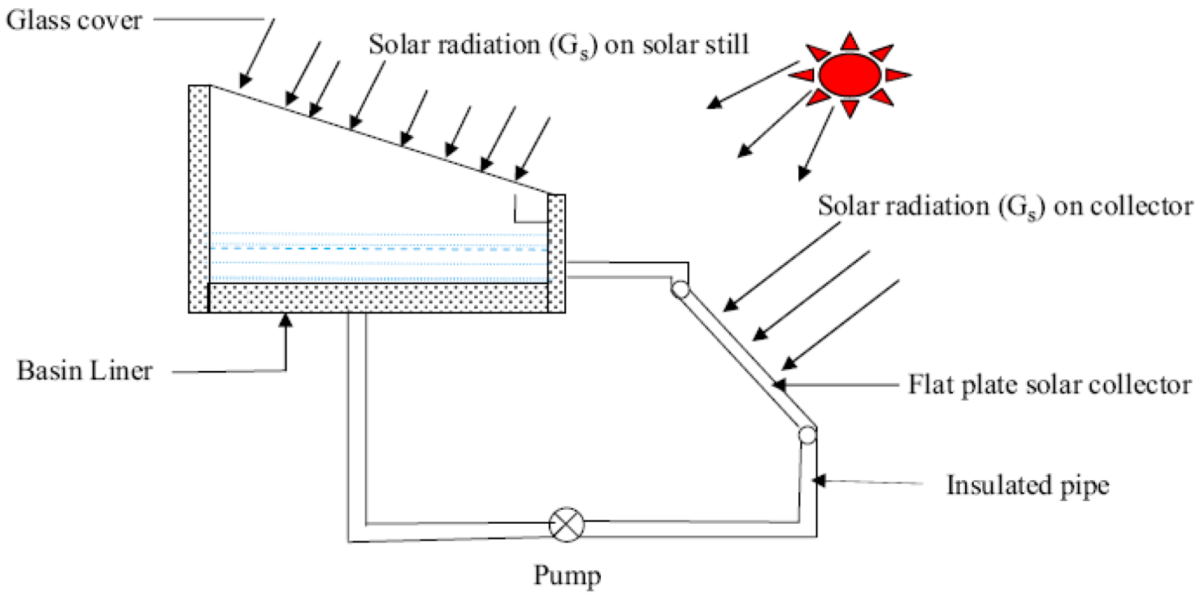
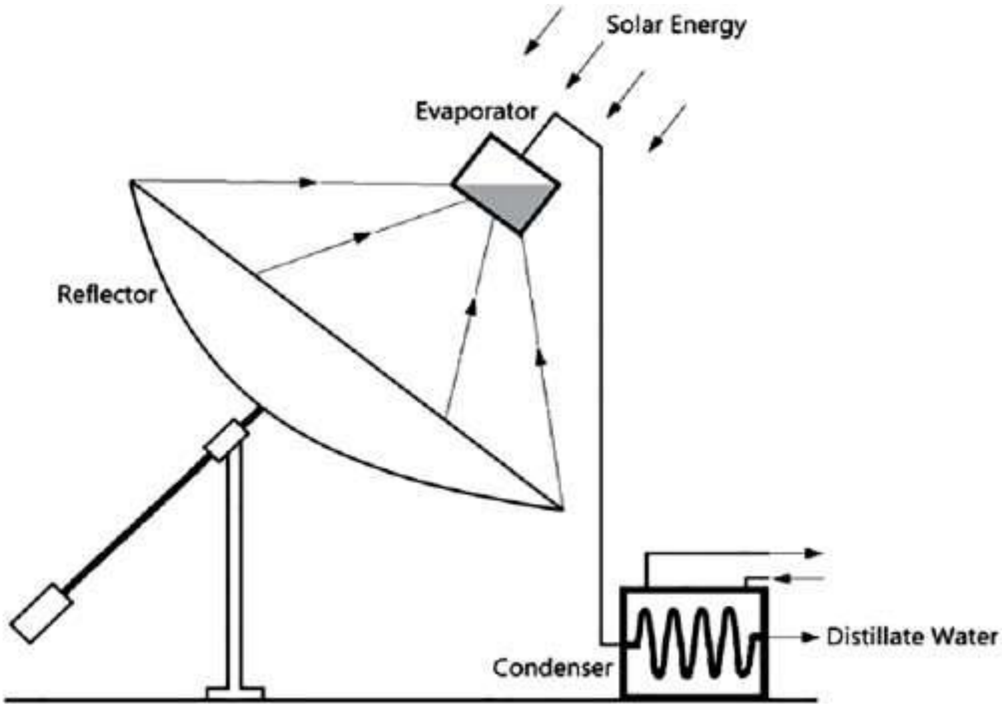


Figure I.12 single-slope solar still coupled with a flat collector.

1.3.2.2.1.2 .Solar still coupled with a parabolic concentrator

The schematic diagram of the solar still coupled with the parabolic concentrator is shown in Figure 1.13. The parabolic shaped concentrator or solar collector concentrates the incident solar radiation on large surfaces and it concentrates on a small absorbing or receiving area. The performance of concentrators is greatly affected by the sun tracking mechanism. The tracking mechanism must move the collectors throughout the day to keep them focused on the solar's rays, achieving higher efficiency.

These types of solar collectors achieve higher temperature compared to flat collectors due to their reduced heat loss area. Different types of concentrators have been used over the years based on applications. To obtain a higher yield, the contractor is coupled to the solar distiller thanks to the increase in the water temperature in the basin. Water will be supplied to the pipe trough receiver by natural circulation mode or forced circulation mode[29].



FigureI.13. Solar still coupled with a parabolic concentrator

I.3.2.2.2. Active solar still with improved condensers

Adding a codenser improves the active distiller and increases drinking water productivity.

I.3.2.2.2.1.Active solar still with internal condenser

Adding an internal condenser increases the condensation rate inside the solar still and increases fresh water productivity. Figure 1-14: Schematic diagram of a single basin double slope solar still with internal condenser[30].

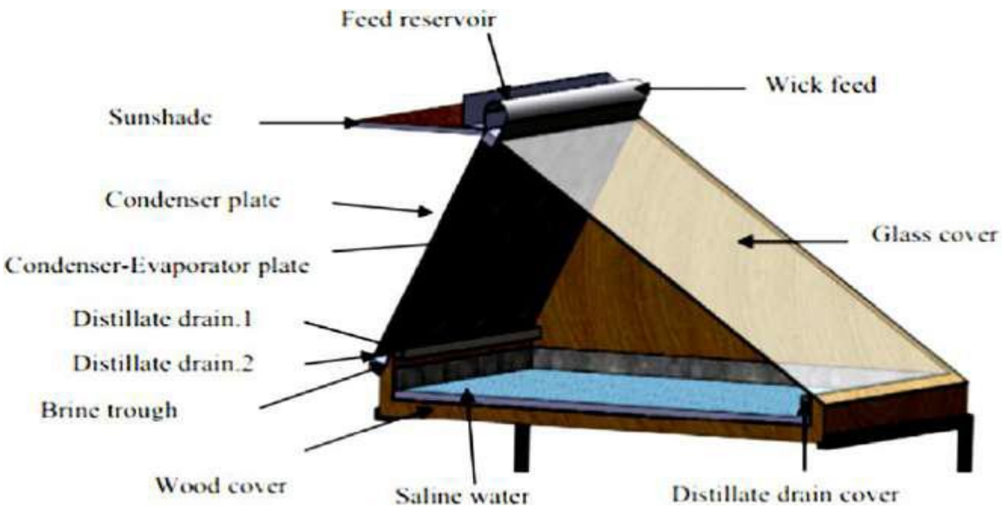


Figure I.14 Schematic diagram of a single basin double slope solar still with internal condenser

I.3.2.2.2.2.Active solar still with external condenser

The external condenser improves the condensation rate of the active distiller, improves the heat transfer properties and evaporation properties, and reduces convection heat loss from the basin to the glass cover. (Figure I .15) Schematic diagram of a single basin single slope solar still with an external condenser[31].

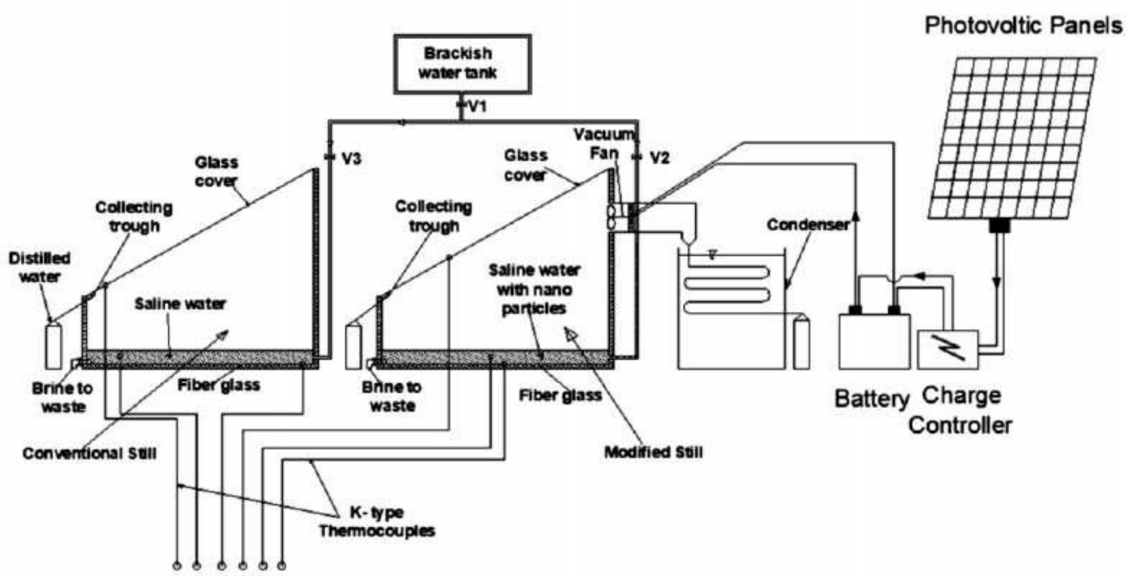


Figure I.15 Schematic diagram of a single basin single slope solar still with an external condenser.

I.3.3.Parameters influence the operation of the solar distiller.

really test a distiller, it must be placed in real-world conditions of functioning. To study the transfer of heat and mass and the flow of distilled water,all you have to do is experiment in the laboratory and master all the key parameters that affect efficiency [29].

Two types of parameters influence the distillation system :

- External parameters (climatic and local).
- The internal parameters of the device (condenser, absorber, saline water depth, etc.).

I.3.3.1.External Parameters

These parameters are related to the experimental location :

- Geographic parameters, such as longitude, latitude, and sun height
- Meteorological (atmospheric) parameters, including the most frequently selected :

A- wind speed

Wind speed is related to the forced convection that occurs at the window panes.It proportionally influences the temperatures of the windows, so it leads to aincrease in the difference between the temperatures of the salt water and those of the glass, whichhelps increase the rate of water evaporation[30].

B-ambiantetemperatur

The production of distilled water increases slightly when the air temperature increases.

C-solar radiation

This is the essential factor in the operation of the solar still.

because it directly influences the temperature of the water to be distilled and increases the difference between it and that of the condenser. Moreover, the distillate flow rates recorded in summer are greater than those recorded in winter or during cloudy weather. High radiation intensities

can now cause internal overheating of the device, leading to a decrease inremarkable production of distilled water This phenomenon is observed, especially whenuses reflective mirrors to increase the energy incident on the absorber[31].

I.3.3.2.Parameters inside

A-The nature of the cover

La couverture intervient essentiellement par :

- the nature of itsmaterial
- Itswettability by water
- positioning and thickness
- Its transparency to solar radiationIts inclination with respect to the horizontal (angle α) (Theangle of the glass cover is equal to the latitude of the experiment's location)

B-The nature of the absorber (basin)

The absorber Its role is to instantly transform the solar radiation it receives into heat and transmit it by conduction to the salt solution.

The absorbent surface can be made of several materials (wood, metal, concrete, synthetic material or ordinary glass)

The following characteristics must be present in a good absorber:

- An absorption factor close to unity
- good thermal conductivity
- good chemical resistance to the solution it comes in contact with
- and good chemical resistance to the solution it comes in contact with.

C-The depth of brackish water in the basin

The greater the depth of the brackish water table, the less its temperature fluctuates during production.

The difference between distillers,with small and big thicknesses of brackish water,
is notable for stills whose base is thermally insulated.

The production is all the more important as the depth is shallow; on the other hand, the greater the depth of the brackish water, the longer the distillation lasts after sunset [32].

D-Thermal insulation :

To decrease the heat losses at the level of the absorber and thus increase the temperature of the brackish water, the base and the sides of the solar still must be thermally insulated. In some cases, the annual water production of a solar still with thermal insulation is 15% greater than that of an uninsulated one.

E-Sealing: The cover must be thoroughly sealed with transparent adhesive to stop steam leakage from the still's interior to the exterior.

F-The gutters: The gutters must be deep enough to reduce the loss of condensate by spillage and narrow to minimize the shadow on the absorber

I.3.4Features and performance of distillers

In order to describe the water production of such distillers, multiple values are defined. The yield of the distillate, internal and external performance, absorption effectiveness, and pressure inside the distiller are all constantly distinguished from one another[33].

I.3.4.1.Production of distilled water

The production of distillate from a solar still represents the quantity of distilled water produced per square metre of evaporation surface and per day. The flow rate of distilled water is given by the following relationship:

$$\mathbf{M = \frac{qw}{L(Tw)}} \qquad \text{(I-1)}$$

where :

q_w: The heat flux used for water evaporation (J /s).

$L(T_w)$:The latent heat of vaporization of water at the temperature Tw (J /kg).

I.3.4.2.Overall efficiency

The overall daily efficiency is the ratio between the amount of heat used for evaporation per unit time and the amount of overall energy incident per unit time, which can be calculated by the following formula**:**

$$\eta = \frac{qev}{G.A} = \frac{md\ Lv}{G.A} \qquad \text{(I-2)}$$

A: surface area of the sensor

G: Global solar energy

Lv: latent heat of vaporization

m_d: the distillate flow

I.3.4.3.Internal efficiency

If overall efficiency relates to the amount of distilled water output due to the solar energy's rays hitting a horizontal surface,It does not mention the amount of energy actually entering the still, especially since a solar still is generally built for a given location and with a fixed cover.A change in slope and locality varies the amount of energy entering the still. We therefore define a so-called internal efficiency, which takes into account

$$\eta i = \frac{qev}{qwater} = \frac{mdLv}{\alpha tG.A} \qquad \text{(I-3)}$$

α t .G.A: The quantity of heat absorbed by the water

α t : the thermal absorption coefficient

For a global intensity G,expression of q_{water} is:

$$\varphi = (\tau\alpha + \tau\tau\alpha) \times G.A$$

where :

$$\alpha = \tau_v\, \alpha_e + \tau_v\, \tau_e\, \alpha_f$$

$Q_{water} = \alpha t\ G.A$

So It results:

$$\eta i = \frac{\eta g}{\alpha t} \qquad \text{(I-4)}$$

α_f : absorption coefficient of the bottom of the still.

α_e: water absorption coefficient.

τ_e : water transmission coefficient.

τ_v:glass transmittance coefficient

The coefficient τt depends on the angle of incidence of the incident radiation with respect to the glass cover

(For the angle of incidence of the radiation between 0° and 30° τt =0.8)

I.3.4.4.Performance

FPB = The amount of water produced in 24 hours/ the amount of energy input in 24 h

.FPH = the amount of water produced after one hour / the amount of energy input at the end of one hour.

The following equation can be used to determine the instantaneous efficiency at a given moment in day :

$$FP = \frac{md}{\alpha t\ G.A} \qquad (I\text{-}5)$$

I.3.4.5.Yield

It is the quantity of water produced per unit of surface area of the absorber per day. The major drawback of this criterion is that it does not mention the solar energy that arrives at the still. The efficiency of a simple still is

$$\eta = \frac{mdhevp}{G} \qquad (I\text{-}6)$$

h_{evp} : Evaporation enthalpy.

m_d: Distillate mass flow.

G: Incident solar radiation power per surface unit

I.3.4.6.The pressure inside the still

The pressure inside the distiller is equal to atmospheric pressure since the distilled water recovery channels are in communication with the internal and external atmospheres

Reference

[1] M. Chandrashekara and A. Yadav, "Water desalination system using solar heat: A review," *Renewable and Sustainable Energy Reviews,* vol. 67, pp. 1308-1330, 2017.

[2] M. Sellami, "Etude et amélioration des techniques de distillation solaire dans la région Sud-Est Algérien (Ouargla)," Thèse de Doctorat: Sciences Physiques, Physiques Energétique. Université …, 2014.

[3] H. Sharon and K. Reddy, "A review of solar energy driven desalination technologies," *Renewable and Sustainable Energy Reviews,* vol. 41, pp. 1080-1118, 2015.

[4] S. AKLI, "Le Dessalement de l'eau de mer ou l'irrigation économie?," 2007.

[5] A. Maurel, "Dessalement de l'eau de mer et des eaux saumâtres et autres procédés," *Chapitre I: Problématique de la disponibilité de l'eau pour l'irrigation dans les zones côtières et arides,* 2006.

[6] M. Brusseau, D. Walker, and K. Fitzsimmons, "Physical-chemical characteristics of water," in *Environmental and pollution science*, ed: Elsevier, 2019, pp. 23-45.

[7] K. Abdenacer and T. Abderachid, "Etude et modélisation de deux distillateurs solaires symétrique et asymétrique à effet de serre," 2017.

[8] R. Tripathi and G. Tiwari, "Performance evaluation of a solar still by using the concept of solar fractionation," *Desalination,* vol. 169, pp. 69-80, 2004.

[9] B. Bouselsal, "Groundwater quality in arid regions: the case of Hassi Messaoud region (SE Algeria)," *Journal of Fundamental and Applied Sciences,* vol. 9, pp. 528-541, 2017.

[10] A. Kettab, "Les ressources en eau en Algérie: stratégies, enjeux et vision," *Desalination,* vol. 136, pp. 25-33, 2001.

[11] A. MOUMEN, H. J. Oulidi, L. Khazaz, and B. El Mansouri, "Système d'Information d'Eau au Maroc: Etat d'art, Problématique, Approche et Prototype," *des Journées Doctorales en Systèmes d'Information, Réseaux et Télécommunications,* pp. 12-13, 2015.

[12] B. Remini, "La problématique de l'eau en Algérie du nord," *LARHYSS Journal P-ISSN 1112-3680/E-ISSN 2521-9782,* 2010.

[13] Q. Aemig, A. Hélias, and D. Patureau, "Impact assessment of a large panel of organic and inorganic micropollutants released by wastewater treatment plants at the scale of France," *Water Research,* vol. 188, p. 116524, 2021.

[14] D. Bechki, H. Bouguettaia, J. Blanco-Galvez, S. Babay, B. Bouchekima, S. Boughali, *et al.*, "Effect of partial intermittent shading on the performance of a simple basin solar still in south Algeria," *Desalination,* vol. 260, pp. 65-69, 2010.

[15] N. BOUBOU-BOUZIANI and S. B.-E. MALIKI, "La crise de l'eau: entre réalité, enjeu et perspectives."

[16] A. M. Hamiche, A. B. Stambouli, and S. Flazi, "A review on the water and energy sectors in Algeria: Current forecasts, scenario and sustainability issues," *Renewable and Sustainable Energy Reviews,* vol. 41, pp. 261-276, 2015.

[17] T. Idder, A. Idder, A. Tankari Dan-Badjo, A. Benzida, S. Merabet, H. Negais, *et al.*, "Les oasis du Sahara algérien, entre excédents hydriques et salinité. L'exemple de l'oasis de Ouargla," *Revue des sciences de l'eau,* vol. 27, pp. 155-164, 2014.

[18] B. Hichem, "Etude et conception d'un distillateur solaire à usage agricole," thèse de doctorat 2012, Université des Frères Mentouri, Constantine-1, 2012.

[19] P. Xu, M. Capito, and T. Y. Cath, "Selective removal of arsenic and monovalent ions from brackish water reverse osmosis concentrate," *Journal of hazardous materials,* vol. 260, pp. 885-891, 2013.

[20] F. Fu and Q. Wang, "Removal of heavy metal ions from wastewaters: a review," *Journal of environmental management,* vol. 92, pp. 407-418, 2011.

[21] T. Sata, T. Sata, and W. Yang, "Studies on cation-exchange membranes having permselectivity between cations in electrodialysis," *Journal of Membrane Science,* vol. 206, pp. 31-60, 2002.

[22] H. M. Qiblawey and F. Banat, "Solar thermal desalination technologies," *Desalination,* vol. 220, pp. 633-644, 2008.

[23] H. Al-Madhhachi, "Solar powered thermoelectric distillation system," Cardiff University, 2017.

[24] D. Bechki, "Etude comparative et optimisation des procédés de distillation solaire en vue de la production d'eau potable dans les zones arides sahariennes," Université de Batna 2, 2011.

[25] M. A. Malik, G. N. Tiwari, A. Kumar, and M. Sodha, "Solar distillation (a practical study of a wide range of stills and their optimum design, construction, and performance)," 1982.

[26] J. Beauséjour, *Conception d'un distillateur solaire pour le traitement des effluents d'une tannerie mexicaine*: École Polytechnique de Montréal, 2003.

[27] H. S. Aybar, "Analysis of a mechanical vapor compression desalination system," *Desalination,* vol. 142, pp. 181-186, 2002.

[28] Y. Mandri, "Étude paramétrique du procédé de dessalement de l'eau de mer par congélation sur paroi froide," Université Claude Bernard-Lyon I; Université Mohammed V-Agdal (Rabat, Maroc …, 2011.

[29] P. Prakash and V. Velmurugan, "Parameters influencing the productivity of solar stills–A review," *Renewable and sustainable energy reviews,* vol. 49, pp. 585-609, 2015.

[30] A. J. N. Khalifa and M. A. Ali, "Indoor tests on the effect of wind speed on still performance," *International Journal of Energy and Environment,* vol. 6, p. 299, 2015.

[31] H. N. Panchal and S. Patel, "Effect of various parameters on augmentation of distillate output of solar still: a review," *Technology and Economics of Smart Grids and Sustainable Energy,* vol. 1, pp. 1-8, 2016.

[32] A. Alaudeen, K. Johnson, P. Ganasundar, A. S. Abuthahir, and K. Srithar, "Study on stepped type basin in a solar still," *Journal of King Saud University-Engineering Sciences,* vol. 26, pp. 176-183, 2014.

[33] A. Deliou, N. Bessas, Z. Belgroun, H. Aburideh, A. Lounis, and A. Chikouche, "Etude expérimentale des caractéristiques d'un distillateur solaire à effet de serre," *Revue des Energies Renouvelables CICME,* vol. 8, pp. 109-118, 2008.

Chapter II: Theoretical study

II.1Solar energy

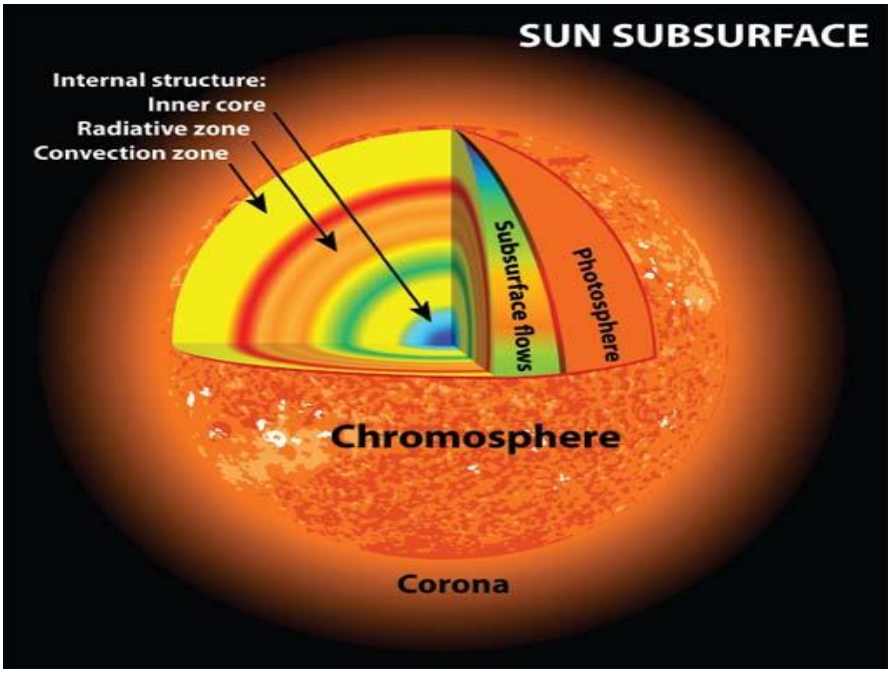
II.1.1 Introduction

Solar energy is the energy transmitted by the sun in the form of light and heat. This energy is virtually inexhaustible on the human time scale, which makes it classified as renewable energy. Solar energy can be used directly by humans for lighting, heating, and cooking (solar water heater, solar oven) or to produce electricity via photovoltaic panels. Indirectly, solar energy is also the source of most renewable energies and fossil hydrocarbons**.** Solar energy is in charge of the water cycle (hydraulic energy), photosynthetic energy (biomass and hydrocarbons), the movements of the water and air masses (marine and ethereal energies), and the water cycle.The potential of this energy source is, therefore, immense. Regarding Algeria, in the north of the country we have 1700 kWh/m^2/year for 2600 hours of sunshine; in the highlands we have 1900 kWh/m^2/year for 3000 hours of sunshine; and in the south is 2200 kWh/m^2/year for 3400 hours of sunshine. Dispersion makes solar energy available; it is an energy source that covers decentralised needs and is within reach of residents of rural areas.

II 1.2 Sun

The sun is a gas sphere composed of helium and hydrogen (80% H_2, 19% He, 1% other elements). Its diameter is 1391000 km (100 times that of the earth), its mass is of the order of 2.1027 tonnes, its age is approximately 4.6.109 years[40]. All the energy in the sun comes from the thermonuclear reactions that occur there. They transform 564.106 tonnes of hydrogen into 560.106 tonnes of helium every second, the difference (4 million tonnes) is dissipated in the form of energy ($E=mc^2$), which represents a total energy of 36.1014 kW.The earth being at a distance of 150.106km from the sun, it receivesapproximately 1.8.1014 kW[1].

The sun is not a homogeneous sphere; we can distinguish three main zones[1].As shown in the Figure II.1

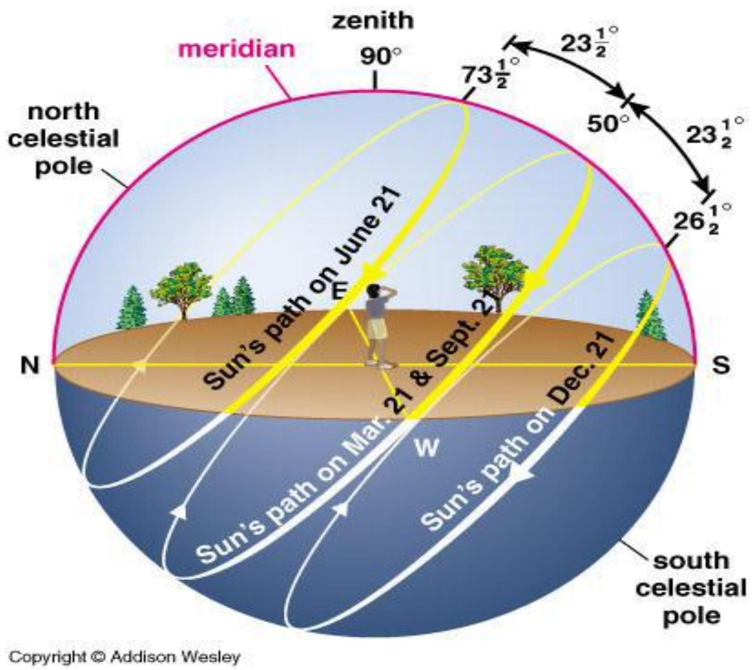


FigureI1.1 The layers of the Sun

- The interior: where the energy is created by thermonuclear reactions and is inaccessible to investigations because the radiation emitted in this region is totally absorbed by the outer layers. The temperature reaches several million, and the pressure is one billion atmosphere.
- The photosphere: the thickness is approximately 300 km, is responsible for almost all of the solar radiation that we receive.
- Chromosphere and solar corona: where the matter is very diluted, a fact which explains that although the temperature there is very high (1 million degrees), the radiation emitted is very weak.

II.1.3.Astronomical data

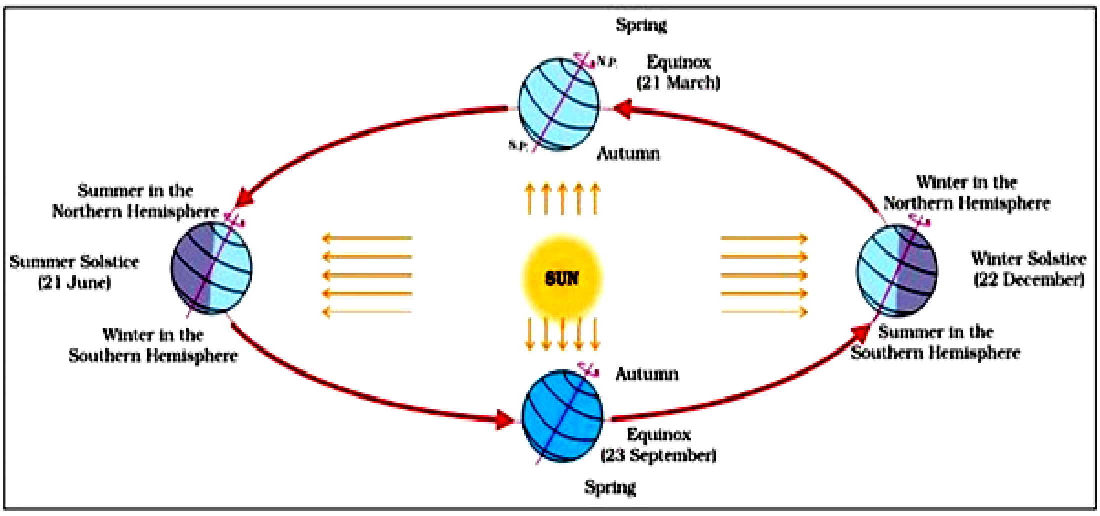
The earth revolves around the sun in (one revolution/year) in an elliptical trajectory with the sun as its focus and rotates around itself in relation to a north-south axis.The equator is inclined to the horizon at an angle between -23° 27' in winter and +23° 27' in summer, while at the spring and autumn equinoxes it changes to 0°.The apparent movement of the sun in the celestial sphere constitutes an important event [2].



FigureII.2Sun's apparent movements.

II.1.3.1.Movement earth-sun

It is important to study the movement of the earth and the sun because it is the direct result of the sequence of the four seasons and the succession of night and day, which have a great influence on solar energy captured at ground level. In FigureII.3 , we present a diagram relating to the earth-sun movement and some axes and orientations allowing us to identify the main periods of the year[3].



FigureII .3Movements of the earth around the sun

II.1.3.2 Earth movement

One of the foci of the ellipse formed by the earth's orbit around the sun is the sun. The earth-sun distance only varies by ±1.7% because of the tiny eccentricity of this ellipse, whose plane is known as the ecliptic.compared to the average distance. The circumference of the sun takes place in a sidereal year of 365 days, 6 hours, 9 minutes, and 10 seconds.This revolution causes the relative durations of day and night to vary according to the rhythm of the seasons limited by the two equinoxes and the two solstices. The earth also rotates around an axis called the pole axis in a sidereal day of 23 hours, 56 minutes and 4 seconds. The plane perpendicular to the axis of the poles and passing through the centre of

We refer to the earth as the equate. The equator and the ecliptic form an angle known as inclination, which is worth 23°27', because the axis of the poles is not perpendicular to the ecliptic.[4].

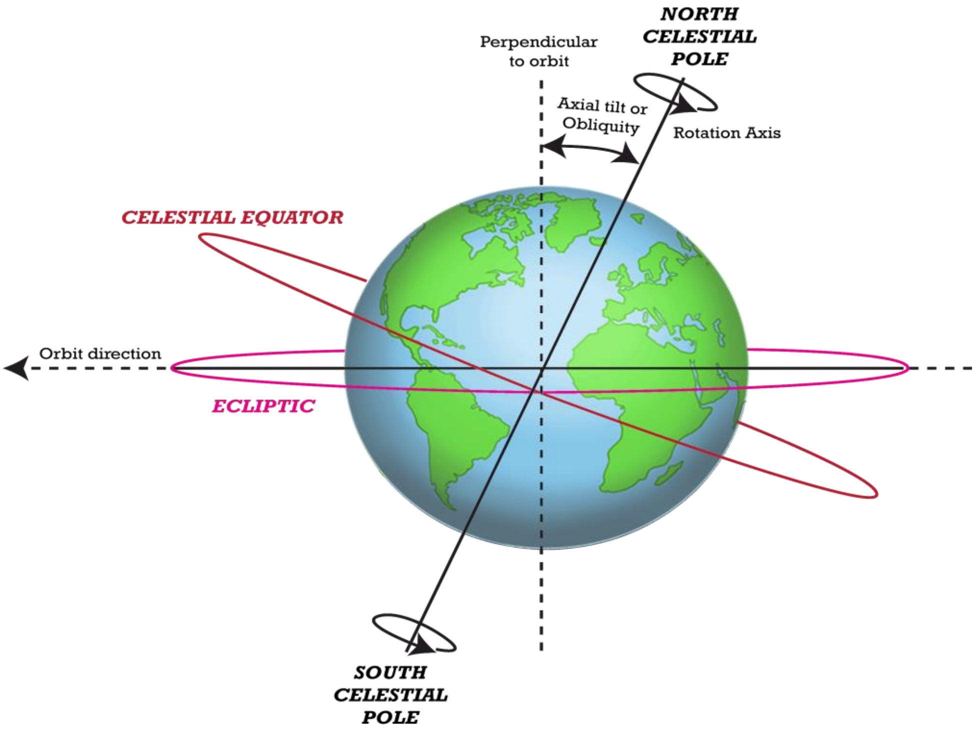


Figure II.4 Earth Movements

II.1.3.3 Sun-earth base angles

Any point on the terrestrial sphere is identified by two angular coordinates, called terrestrial coordinates [5]. As can be seen in the figure below :

Latitude (φ): It allows you to identify the angular distance of any point from the equator; it varies from 0° at the equator to 90° at the north pole. It is positive in the northern hemisphere and negative in the southern hemisphere.

Longitude (λ): This is the measuremenrepresents the angle formed by the location's meridian and the longitudes' origin meridian (Greenwich, England).The + symbol is used to indicate the number of locations that are to the east. The prime meridian is the wide segment of a circle that connects Greenwich, the south pole, and the north pole.The 24 time zones are created by the 15° separation of 23 meridians.

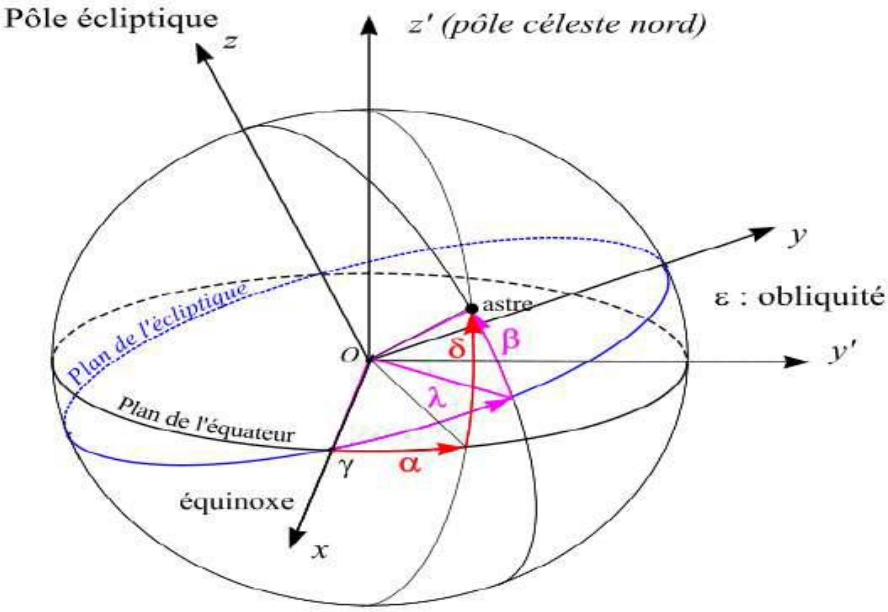
Longitude is counted positively in the west and negatively in the east based on the prime meridian which is the Greenwich meridian.

Zenith angle (θz): It is the angle between the solar radiation and the line perpendicular to the horizontal plane, the zenith z is the complementary angle of the altitude to form an angle of 90°.

Altitude (α): This is the angle between solar radiation and a horizontal plane such that:

$$\alpha = 90 - \theta z$$

Angle of inclination (β): It is the angle formed between the flat surface and the horizontal one. It is considered positive for a south-inclined surface and negative for north-inclined surfaces.



FigureII .5 Sun - Earth Base Angles

II.1.4 Solar radiation

Thermal radiation is electromagnetic radiation emitted in all directions by any body whose temperature is greater than 0 K. Solar radiation is the raw material for solar energy. It's the propagation of a wave whose length varies between 0.2 and 4.10^{-6} m. Without the need for a physical medium to move around[6].

II.1.4.1 Ground-level solar radiation

Two components make up the solar radiation that reaches the earth: direct solar radiation, which originates from the sun directly, and diffuse solar radiation, which is scattered by the atmosphere. In addition, pure radiation exists on Earth and in the atmosphere. By understanding these different radiations, a radiative equilibrium in the earth-atmosphere system can be established.[7].

II.1.4.1.1 Direct radiation (G_{dir})

It is the radiation that crosses the atmosphere without undergoing modifications; it is received directly from the sun without diffusion by the atmosphere, and its rays are parallel to each other .

$$G_{dir} = G_{dir(s)} .cos\theta \qquad \text{(II-1)}$$

G_{dir} **:**Normal solar radiation received per unit area.

$G_{d(s)}$:Horizontal diffuse solar radiation on an inclined plane

θ :angle of a surface inclined to the horizontal and oriented to the south.

II.1.4.1.2 Diffuse radiation (G_{dif})

This is the amount of solar energy that gets duffused by liquid or solid airborne particles that are floating in the atmosphere and include things like aerosols, nebulosity, and air. It is not directed in any way[8].

$$G_{dif} = \frac{G_{dif(s)}(1+\cos\alpha)}{2} \qquad \text{(II-2)}$$

α**:**inclination of the capture in(°)

$G_{dif\,(s)}$ **:** Le rayonnement solaire diffus horizontal sur le plan incliné.

II.1.4.1.2.1Albedo

In reality, the earth is not a black body; part of the incident solar radiation is reflected by the atmosphere (mainly by clouds) and by the earth's ground. This quantity is called the albedo flux. Albedo is generally defined as the ratio of solar energy reflected from a surface to incident solar energy.We use a graduated scale from 0 to 1, corresponding respectively to black, for a body with no reflection, and to the perfect mirror, for a body that diffuses in all directions without absorption of all the visible radiation it receives. Table II.1 groups together the albedo values (β) for some materials [9].

$$G_{alb}= \frac{\beta(1-\cos\alpha)}{2(G_{dif(s)}\sin s+G_{dif(s)})} \qquad \text{(II-3)}$$

S : The height of the sun (°).

β : Albedo coefficient

Table II.1 The coefficient (β) of albedo for some materials [61].

Material type	Albedo
Bareearth	0.17
Freshsnow	0.85
Dry grass	0.30
Freshgrass	0.20
Freshgrass	0.22
Aluminium	0.90

II.1.4.1.3. Global Radiation (Gg)

It is all solar radiation that reaches a horizontal surface on the globe. It therefore includes thevertical component of direct solar radiation and diffuse solar radiation (see Figure II.2) [10].

$$G_g = G_{dif} + G_{dir} \qquad \text{(II-4)}$$

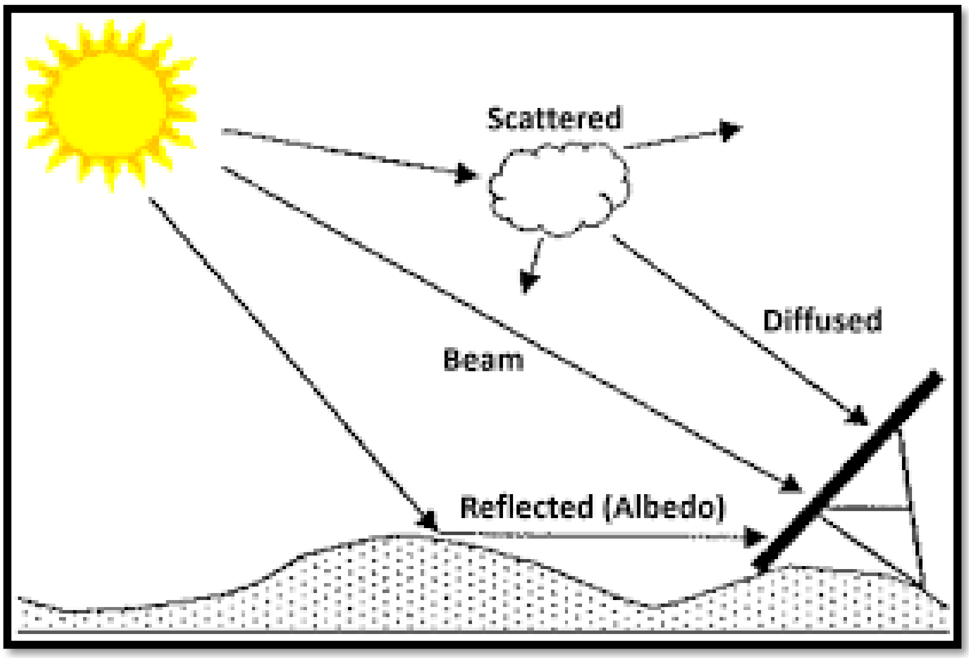


Figure II.6 Components of solar radiation

II.1.5 Spectrum of solar radiation

The spectral distribution of solar radiation is determined by the temperature of its surface, namely 5900 K.The spectral distribution of real solar radiation outside the atmosphere (the spectral illumination is defined as the power received by a surface for a given wavelength; it is expressed in W/m^2 nm; compared to that of the black body at 5900 K, we see that the sun behaves approximately like a black body.

These spectra show that the sun emits electromagnetic radiation within a band of length varying from 0.2 µm (ultraviolet) to 10 µm (infrared). This solar radiation breaks down into bands as follows (see figure II.3) [11]:

- 6.4% in the ultraviolet (UV) band: $\lambda \leq 0.4$ µm.
- 48.0% in the visible band: 04 <$\lambda \leq 0.8$ µm.
- 45.6% in the infrared (IR) band: λ> 0.8 µm.

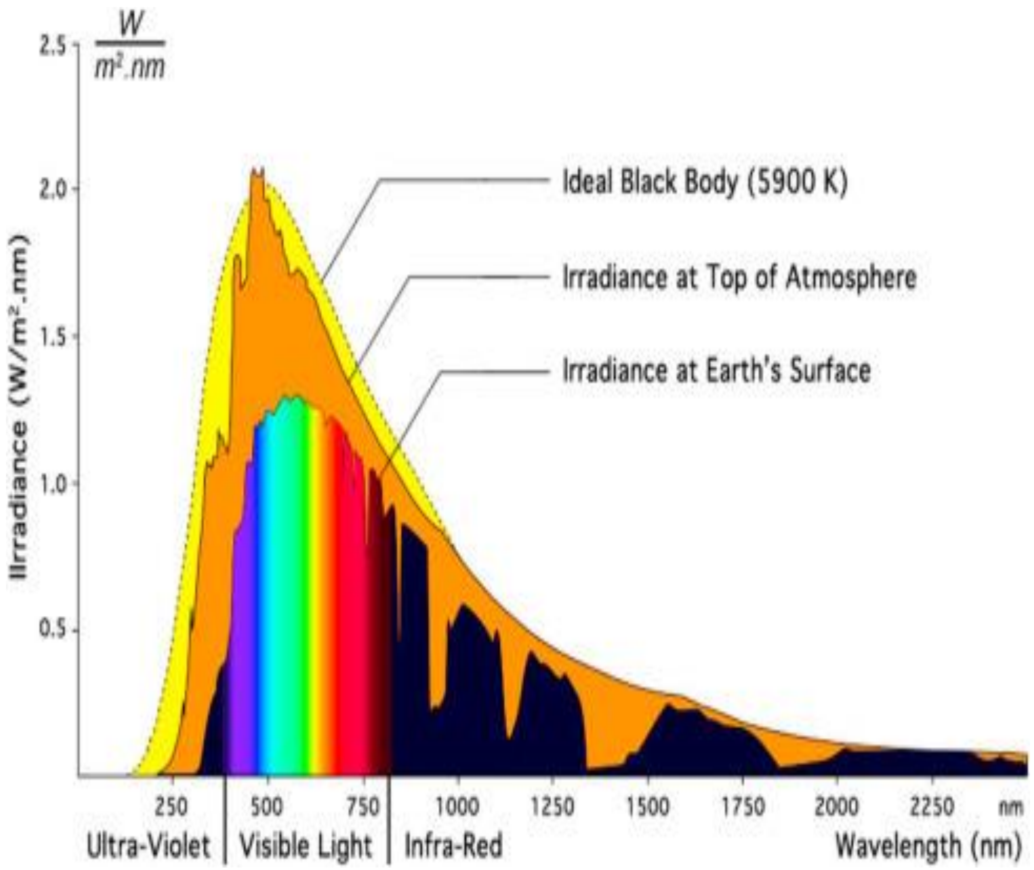


Figure II.7: Spectrum of solar radiation.

Electromagnetic radiation is made up of "grains" of light called photons. The energy of each photon (Ep) is directly linked to the wavelength λ[12].

$$Ep = \hbar \times \nu = \hbar \times \frac{c}{\lambda} \qquad \text{(II-5)}$$

Where :

$\hbar$:isPlanck's constant 6.624×10^{-34} J.s.

c :is the speed of light 3×10^{8} m.s^{-1}.

ν :The frequency in s^{-1}

λ:the wavelength in nm.

II.1.6 Solar times

II.1.6 .1Length of day

This is the time between sunrise and sunset. Two particular moments of the day that give zero sun height h are sunrise and sunset. At the time of sunrise and sunset, the value of the height of the sun, h = 0, The relationship giving the height of the sun can be written:

$$\text{Sin h} = \cos\delta \times \cos\theta \times \cos\omega + \sin\delta \times \sin\theta = 0 \qquad \text{(II-6)}$$

And also :

$\sin h = \cos\delta \text{ x } \cos\theta\ (\cos\omega + \text{tg}\delta\text{tg}\theta) = 0$

We can write:

cos (ω) C, L = - tgδ* tgθ avec : ωc 0, ωL < 0 ; ωc = - ωL

The length of the day (Ld) is given in hours by the equation:

$$\text{Ld} = \omega c - \frac{\omega L}{15} \qquad \text{(II-7)}$$

Knowing that :

$$\text{Ld} = \left(\frac{2}{15}\text{tg}\emptyset\text{Arco}(-\text{tg}\emptyset)\right) \qquad \text{(II-8)}$$

II.1.6.2. True Solar Time (T.S.T)

True solar time (T.S.T.) represents the hour angle (ω) formed by the meridian plane passing through the centre of the sun and the vertical meridian plane of the middle: It is given in the following form[13]:

$$\text{TST} = 12 + \frac{\omega}{15} \qquad \text{(II-9)}$$

ω is expressed in degree.

If $\omega = 0$, TST=12h. 00

If $\omega < 0$, the morning.

If $\omega > 0$, in the afternoon

II.1.6.3 Mean solar time (MST)

We introduce the notion of Mean Solar Time (T.S.M.), which varies in relation to (T.S.T), where the corrective term (ET) designates the equation of time:

$$T.\ S.\ M = T.\ S.\ T - ET \qquad \text{(II-10)}$$

With:

ET : the equation of time, which corrects the T.S.T. in relation to the T.S.M.

$Et = 9.87 \sin(2N') - 7.53 \cos(N') - 1.5 \sin(N')$ [min]

$N' = (N - 81) \times 360/365$

N : is the number of days in the year.

II.1.6.4 Civil Time (CT)

Civil time (C.T.) is the time which originates at midnight:

$$C.T = T.S.M + 12 \qquad \text{(II-11)}$$

II.1.6.5 Universal Time (UT)

Universal time is the mean civil time of the Greenwich meridian (primary meridian).

$$TU = TSM - \frac{L}{15} \qquad \text{(II-12)}$$

Where :

L: is the longitude of the location (°).

L > 0, for towns located east of Greenwich

L < 0, for towns located west of Greenwich

TU = TSM, for the Greenwich meridian

II.1.6.6Legal Time (T.L)

This is the official time of a state, it is given by:

$$TL = TU + \Delta H \qquad \text{(II-13)}$$

Where :

ΔH: the time difference between the Greenwich meridian and the state considered.

ΔH = 1 hour for Algeria [44].

II.2 Heat and matter transfer

II.2.1 Heat transfer

Among the main phenomena involved in the thermal conversion of energy using solar systems, the mechanism of heat transmission is very appropriate for modelling and evaluating the nature and quantity of the energy involved.It is agreed that heat transfer is one of the most common modes of energy exchange

A temperature gradient causes heat to transfer from a high to a low point. The heat flux density is the quantity of heat transferred per unit area and per unit time of the isothermal surface[14].

Heat transfer within a phase, or more generally, between two phases, can be distinguished into three transfer modes:

- By radiation
- By conduction
- By convection.

Each of these modes is linked to a specific physical process. In fact, the thermal energy of a material medium corresponds to the sum of the kinetic energies of its constituents having a certain freedom of movement (molecules or atoms).

II.2.1.1 Radiation

However, the heat from the sun reaches our planet even though there is no solid support, liquid, or gas beyond the Earth's atmosphere. This, therefore, means that thermal energy can cross the void. This mode of transfer is called radiation.It corresponds to a flow of electromagnetic waves emitted by any body, whatever its temperature. As we think, the higher the temperature, the higher the electromagnetic radiation.As for conduction, these are the interactions between atoms and molecules that are at the origin of this radiation. The radiation emitted is made up of radiation whose wavelengths depend on the body temperature.The total radiated power increases as the fourth power of the temperature, following Stephan Boltzman's law[15].

$$\mathbf{E = \sigma T^4 (W/m^2)} \qquad \text{(II-14)}$$

σ (W m^{-2} K^{-4}) : Stefan-Boltzmann constant.

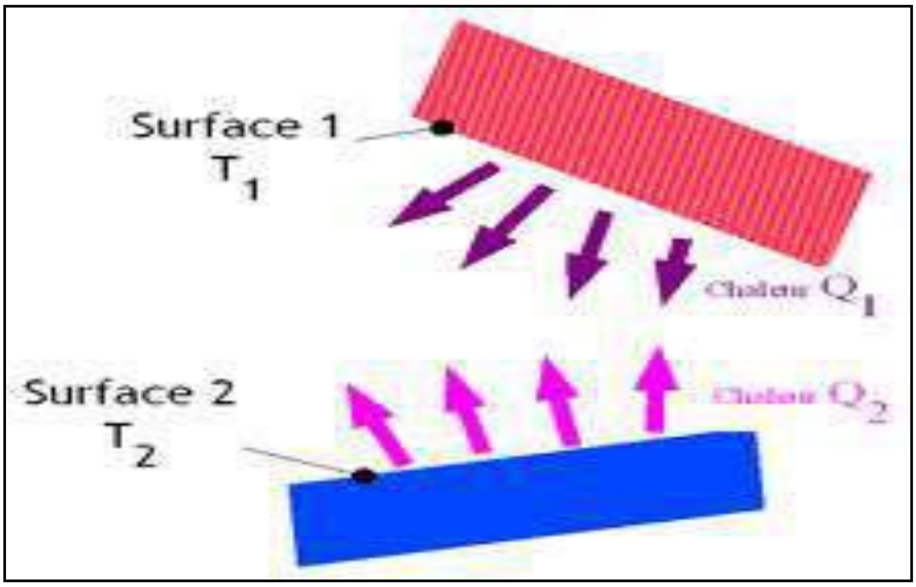


Figure II.8Heat Transfer by Radiation

II.2.1.2 Conduction

Transfer by conduction is an exchange of energy occurring without the displacement ofmatter; it therefore concerns immobilised solids and fluids. This transfer can take place within a single object or through direct contact between two objects.There are two different ways that heat can spread through a body by conduction: through the vibrations of atoms or molecules, or through free electrons[16].

In the simplest case of a solid wall of thickness **e** whose two surfaces of area **S** have a difference ofhomogeneous temperature $T_1 – T_2$, the heat flow depends on the thermal conductivity of the material (W m^{-1} K^{-1}): Fourier's law is the main law that describes the heat release process. The relationship is provided as follows:

$$Q = -\mathrm{grad}\,T \qquad \text{(II-15)}$$

grad (T): represents the temperature gradient($c°.m^{-1}$).

Or in algebraic form:

With :

$$\emptyset = \frac{d\varphi}{dt} = -\text{k. S.}\frac{dT}{dX} \qquad \text{(II-16)}$$

$\boldsymbol{\phi}$:Heat flow transmitted by conduction($\boldsymbol{W}$).

$\boldsymbol{k}$: Thermal conductivity of the milieu (W/m. °C)

S : Area of the heat flow passage section ($\boldsymbol{m^2}$).

x : Space variable in the direction of flow ($\boldsymbol{m}$)

The minus sign (-) on the right-hand side of the relationships indicates that the transfer of heat occurs in the direction of decreasing temperatures. That is to say, the heat flow goes from higher temperatures to lower temperatures (see figure II.8).

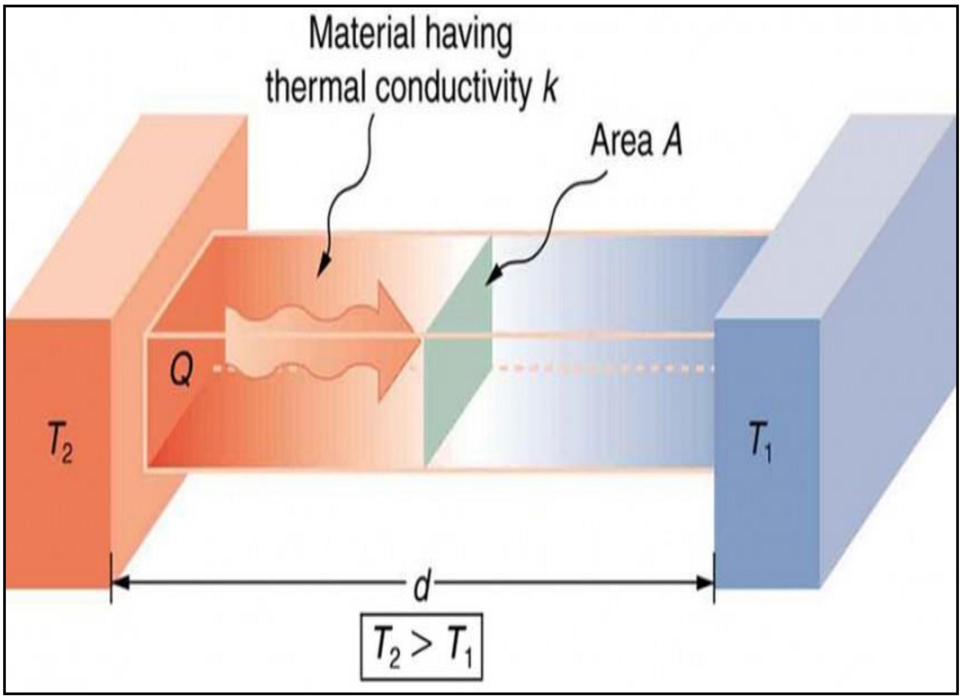


Figure II.9 Heat transfer by conduction

Table II.1 Thermal conductivity of some materials [46]

Material	K (W/m. °C)	Material	K (W/m. °C)
Silver	419	Plaster	0.48
Copper	386	Wood	0.12-0.23
Aluminum	204	Extrudedpolystyrene	0.028
Nickel (métal pur)	237	Foamedpolystyrene	0.030-0.045
Mildsteel	45	Glass	1.0
Stainless steel	15	Air	0.026
Graphite	100-150	Water	0.60

II.2.1.3 Convection

The movement of matter in a material medium causes heat to be transferred by convection. As a result, this technique of transfer exclusively deals with fluids or the exchange of one solid for another.

This transfer mechanism is governed by Newton's law. Heat transmission by convection is designated, depending on the mode of fluid flow, by free convection and forced convection[17].

When currents occur within the fluid simply due to temperature differences, we say that the convection is natural or free. On the other hand, if the movement of the fluid is caused by an external action, such as a pump or a fan, the process is called forced convection[17].

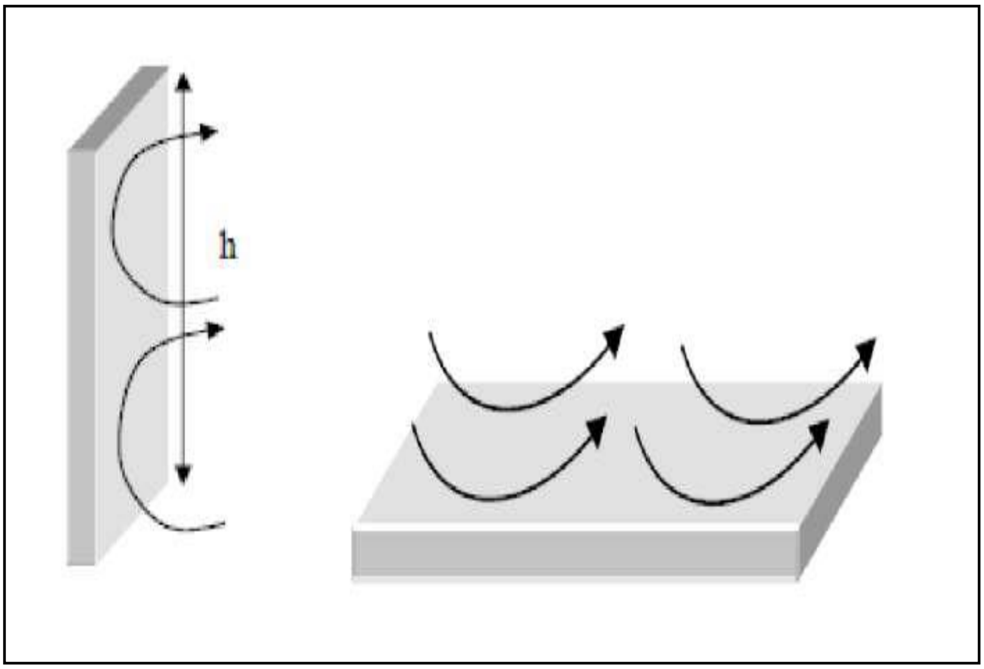


Figure II .10 Heat transfer by convection between a solid and a fluid

The heat flow transmitted by convection between a wall at temperature T1 and a fluid at temperature T2 can be written in the form (Newton's law)[18].

$$Q = h\ S\ (T_s - T_e) \qquad \text{(II-17)}$$

h : Thermal convection exchange coefficient (W/m^2 K) ;

Ts: The outlet temperature in(K) ;

Te: The indoor temperature in (K) ;

S :The contact surface with the fluid in (m^2).

In practice, the value of the convective exchange coefficient (h) is determined from experiments. The results of these experiments are translated into terms of correlation involving laws dimensionless quantities.

II.2.1.3.1 Dimensionless numbers

The technique of convection is based on the principles of energy conservation, the quantity of movement, and the fluid mass. is related to some important parameters: fluid characteristics, flow regime, temperature, and the format of the surface changes**.**Several dimensionless numbers exist and are used as appropriate, as follows [19].

II.2.1.3.1.1Reynolds number

This number plays a fundamental role in characterising the flow of the fluid and is defined by the following expression[20]:

$$Re = \frac{\rho U D}{\mu} \qquad \text{(II-18)}$$

R e > 2300 the regime is turbulent;

R e < 2300 the regime is laminar.

Where :

ρ : the density of the fluid in(kg /m^3) ;

U : The kinematic speed of the fluid in (m/s) ;

D : diameter of the conduit(m) ;

μ: The dynamic viscosity of the fluid in (kg/ms).

II.2.1.3.1.2 Nusselt number

This number relates to heat transfer; it can be interpreted as the ratio of the average convection coefficient of the wall and the thermal conductivity coefficientcorresponding. It is defined by the relation[17]:

$$Nu = \frac{h\,e}{\lambda} \qquad \text{(II-19)}$$

λ : Thermal conductivity in (W/m.K)

e : The thickness of the transfer layer in (m).

II.2.1.3.1.3 Prandtl number

It is the ratio between dynamic viscosity and thermal diffusivity and is defined bythe relationship[17]:

$$Pr = \frac{\mu Cp}{\lambda} \qquad \text{(II-20)}$$

Cp : specific heat of the fluid in(J/kg.K)

λ: Thermal conductivity in(W/m.K)

II.2.1.3.1.4 Grashoff number

In free convection, the movement of the fluid is due to the variation in density under the effect of of the variation of temperature or concentration, and is defined by[21]:

$$\mathrm{Gr} = \frac{\mu\rho g \beta_T (Te - Ts)\, e^3}{\mu^2} \qquad \text{(II-21)}$$

β_T :Fluid expansion coefficient in (K^{-1}) for ideal gases, and it is equivalent tothe inverse of the absolute temperature: β=1/T

e: characteristic thickness of the cell

II .2.1.3.1.5 Rayleigh number

This number is the product of the Grashof number and the Prandtl number; it provides a criterion for transition between laminar free convection and turbulent free convection, and it is defined by the relation[22] :

$$\mathrm{Ra} = \mathrm{Gr.\ Pr} \qquad \text{(II-22)}$$

II .2.1.3.1.6 Schmidt number (Sc)

It is the ratio between the kinematic diffusivity and the mass diffusivity, i.e. :

$$\mathrm{Sc} = \frac{\upsilon}{\mathrm{D}} = \frac{\mu}{\rho \mathrm{D}} \qquad \text{(II-23)}$$

II.2.1.3.1.7 Sherwood number (Sh)

This number relates to the transfer of matter. It is the ratio between the overall flow of matter (k ΔC) and the flow of matter which would exist if only diffusion intervened: (DΔC/e), hence Sherwood's number[17]:

$$\mathrm{Sh} = \frac{Ke}{D} \qquad \text{(II-24)}$$

II.3Carbon

II.3.1 Introduction

With an estimated crustal concentration of 180–270 parts per million, carbon is the fourth most abundant element in the solar system and ranks between 12th and 17th in terms of abundance in the Earth's crust [23].

The fact that carbon stores exist and fluctuate across rock, sediment, atmosphere, biosphere, and ocean reservoirs makes it challenging to estimate the amount of carbon in Earth's crust. The form that carbon takes during its geochemical cycle affects how that carbon behaves.

About 80–90% of the carbon in the crust of Earth is found in carbonate minerals, which are found in carbonate rocks. The majority of the carbon left in the Earth system is found in organic matter, both living and fossil, as well as in carbon dioxide (CO_2), which is either dissolved in the ocean or found in the atmosphere. The carbon cycle is dominated by these residual carbon types[23]**.**

Group IV of the periodic table contains carbon, which has an atomic number of 6. Graphite, diamond, and fullerene are the carbon forms that are allotropic. Because they can chemically mix with other carbon-based materials and form strong covalent bonds with a variety of different elements, carbon-based compounds have a wide range of applications. They thus possess exceptional qualities like great hardness, high density, and high strength.

Carbon materials are an excellent choice for many advanced technology applications due to their remarkable properties.Advanced carbon monoliths have been applied in photovoltaic, environmental, energy, thermal, and electronic fields because of their exceptional physical qualities.

II.3.2.Carbon Types

Carbon comes in a variety of types, and each has unique properties. The most common types of carbon include[24]:

II.3.2.1Graphite

Graphite is a material with a hexagonal crystal structure made up of layered sheets of carbon atoms.Its hue ranges from grey-black to black.It is a pliable, soft mineral with a greasy appearance and a metallic sheen. Its low density (2.1–2.3) and extremely high melting point (3500 °C) are its defining characteristics.In typical settings, it is the most stable form of pure carbon[24].

Carbon is compacted into graphite by high temperatures and pressures, which is why graphite occurs naturally in igneous and metamorphic rocks.

Moreover, carbon-rich materials can be heated to produce synthetic graphite. A temperature of between 2500 and 3000 degrees Celsius is applied to the carbon-rich material, which is hot enough to "purify" the material of impurities and enable the carbon to form its hexagonal sheets[25].

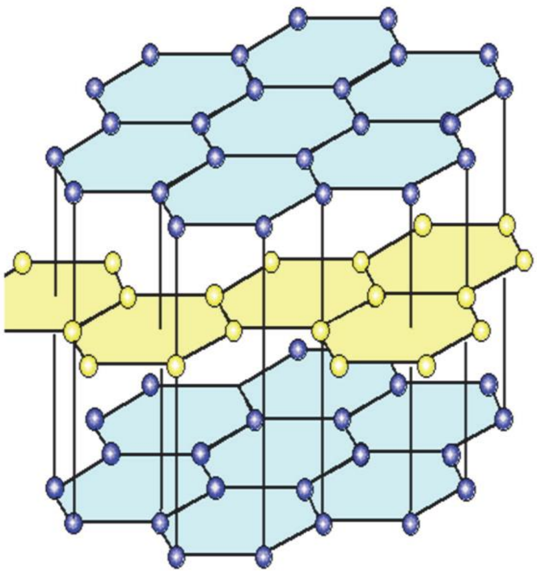
Graphite is highly electrically and thermally conductive, very soft, and has a low specific gravity. It is also comparatively non-reactive.Because of its excellent conductivity, it can be found in electronic devices including solar panels, electrodes, and batteries.

China, India, and Brazil are the three countries that produce the majority of the world's natural graphite, which is exported. As the world's largest exporter, China sets global prices for natural graphite, accounting for over 67% of global output.

II.3.2.1.1 Graphite-structural

The "honeycomb-structure" of graphite is a layer structure characterised by a hexagonal arrangement of C atoms bearing covalent bonds. The secondary bonding type, or Van der Waals interactions, which gauge graphite's poor shear strength, stacks the layers together. Because of this, graphite becomes anisotropic—its properties rely on the direction of applied force—when a modest shear stress is applied, causing structural deformation. Because each C atom in structural graphite is covalently linked to three nearby C atoms, each atom leaves a spare free electron**.**

The primary cause of graphite's excellent electrical conductivity along each layer is the delocalized cloud of free electrons that these electrons form that is weakly bound to the layers[26].The graphite structure is shown in Figure II.11.



FigureII.11Structure of graphite

II.3.2.1.2The physical characteristics and practical applications of graphite

Because of its unique combination of metal and nonmetal qualities, graphite is the perfect material for a wide range of industrial and technological applications. High electrical and thermal conductivity are among the metallic qualities (table J2). Among the nonmetallic characteristics are excellent cleavage and lubricity (slipperiness), high heat resistance, low thermal expansion, and inertness to the majority of chemical reagents (strong acids, bases, solvents, and fluxes). Above 3,000 °C, graphite is stable in an environment that is not oxidising. Graphite is very soft since it has a Mohs hardness of 1 to 2[27].

Refractories, steel manufacturing, and brake linings are a few of the primary end uses for graphite. Graphite's other end uses include batteries, fuel cells, brushes for electrical motors, foundry materials, and high-temperature lubricants. When alkali metal vapours, often potassium, lithium, rubidium, and cesium, fit between the planar carbon sheets of graphite, graphite forms intercalation compounds with them. These substances find use in various technologies as well as the energy industry. The properties and crystallinity of the mined graphite determine its industrial applications and related commercial worth (table II .2).

Table 3.II Selected physical properties of graphite.

Property	Description
Composition	Carbon
Color	Gray to black, metallic luster
Density (g/cm3)	2.09 to 2.26
Thermal conductivity (watt/cm °C)	a axis: 4.0 c axis: 0.8
Electricalresistivity (Ω- cm×104)	aaxis: 1 to 100 c axis: 10,000

II.3..22 Activated carbon

Activated carbon (AC) is a rough, poorly organised type of graphite, sometimes referred to as activated charcoal. Its pores range widely in size, from visible cracks and fissures to molecular diameters.Due to its large surface area, air conditioners (AC) are widely used for a number of applications, such as purging water and air of pollutants. AC has small, low-volume pores that increase the amount of surface area available for chemical reactions like adsorption, which is not the same as absorption. Charcoal has a specific surface area of 2.0 to 5.0 m^2 g^{-1} prior to activation, which rises to 1000 m^2 g^{-1} after activation. According to gas adsorption study, the high level of microporosity in AC can provide a high activation level for practical applications, meaning that one gramme of AC has a surface area of more than 3000 m2. Molecule adsorption is strengthened on AC[28].

II.3..22.1.Activation Reaction or Activation of Carbon

Activation increases the surface area of raw carbon by converting it into a porous material. The two types of activation—chemical and physical—are discussed in the sections that follow[29]:

- **Physical Activation**

  AC is produced from source materials using hot gases.Air is then used to help burn off the gases, producing a filtered, polished, and brushed version of AC (Figure 1.3). a single or many of the subsequent[30].

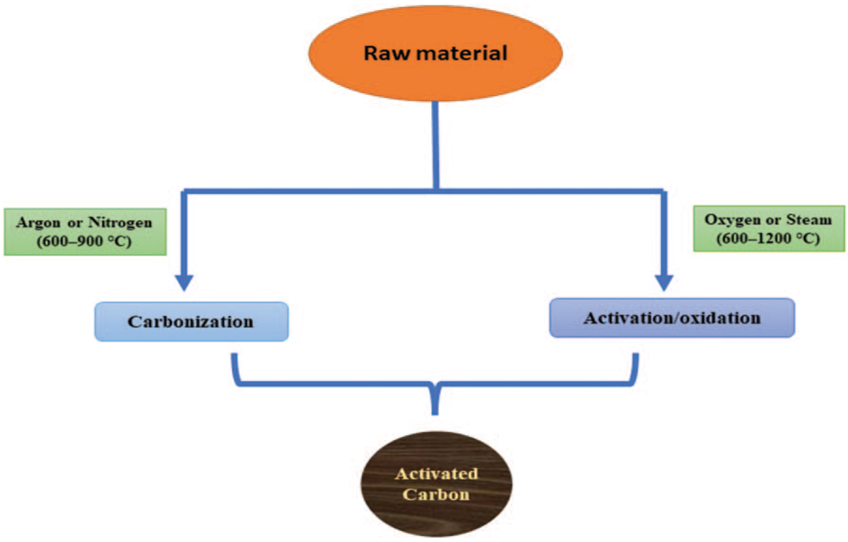


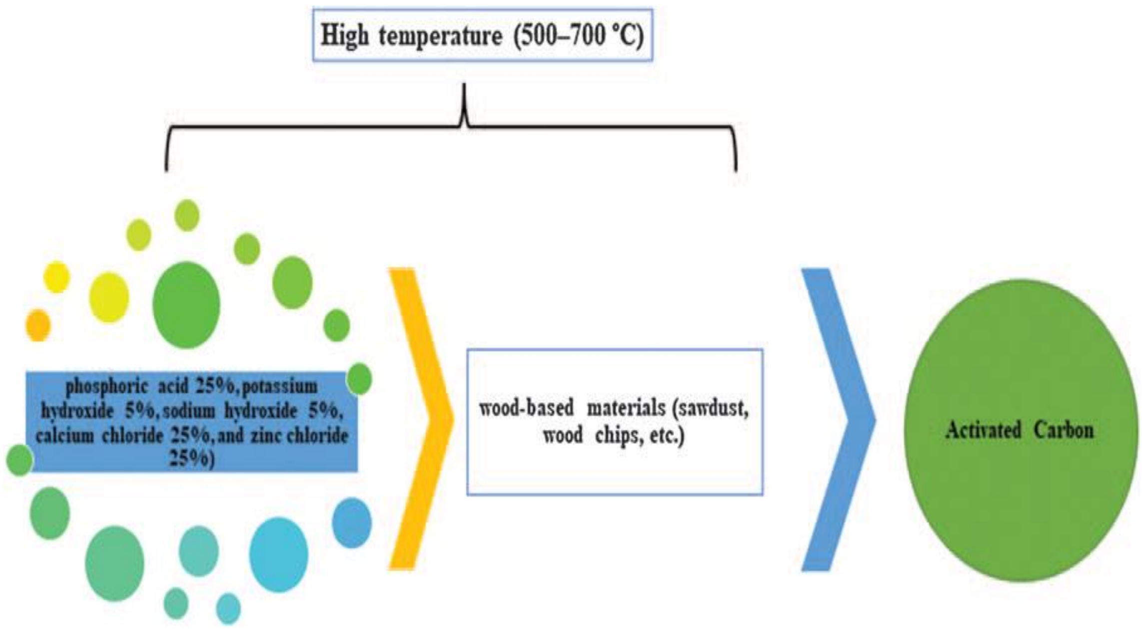
Figure II .12Illustration of the carbon's physical activation process.

This is usually accomplished by the steps listed in the following list:

The process of carbonisation involves pyrolyzing carbon-containing materials at temperatures between 600 and 900 °C while in the presence of gases such as argon and nitrogen in an inert environment.

Activation/oxidation: the raw material is subjected to an oxidising environment (steam or oxygen) at temperatures between 600 and 1200 °C. In an air-filled muffle furnace, the sample is heated to 450 °C for one hour in order to activate it.

- **Activation via Chemical Process**
  The carbon substance is mixed with a variety of substances. One of the following is usually infused: zinc chloride (25%), sodium hydroxide (5%), potassium hydroxide (5%), calcium chloride (25%), and phosphoric acid (25%).[31]carbon is burned at high temperatures (500–700 C) once the air is blocked (Figure I.12). It is believed that the temperature at this moment activates the carbon, causing the substance to split open and produce more tiny pores. Chemical activation is preferred over physical activation due to lower temperatures, better quality uniformity, and shorter material activation durations.



FigureII .13demonstration of the carbon's chemical activation process.

II.3.2.2.2.Applications of Activated carbon

Among the various industrial and residential applications of activated carbon are:

- the removal of pollutants from power plants and landfills
- the process of filtering drinking water
- the retrieval of precious metals.
- the treatment of municipal water supplies and groundwater

In addition, activated carbon finds application in the following processes: solvent recovery, decaffeination, hydrogen storage, air purification, medicine, metal extraction, sewage treatment, gold extraction, and capacitive deionization.

Figure II.14 Applications of activated carbon.

II.3..23.Graphene

With its hybridised Sp2 bonding, graphene is the first known 2-D allotropic form of carbon and has sparked new developments in science and technology. The single layer of this material's enigmatic electrical, structural, electrochemical, and physicochemical properties are a major source of concern for material scientists[32, 33].

Large surface areas were made possible by the highly porous substance of the monoatomic carbon layer that stretched between the two, indicating its powerful absorption capacity. Scientists might so conclude that it is a highly suitable candidate for adsorption[34].

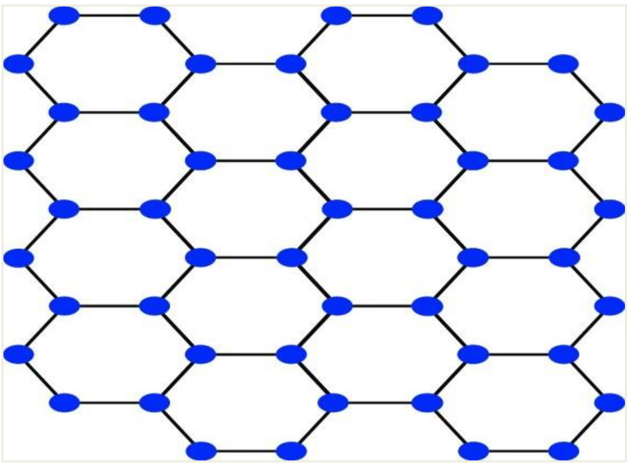


Figure II.15structures of graphene.

II.3..23.1.Practical uses for materials based on graphene

Graphene's exceptional physical properties make it a versatile material. It has been applied widely in both the environment and industry. The following are some uses for graphene components.[35, 36].

• Solar energy and energy storage.

• Photo detectors, memory, transistors, and sensors.

• Electronics that are stretchable, foldable, and flexible.

• Biotechnology and pharmaceuticals

II.3..24.Carbon nanotubes (CNTs)

A layer of carbon atoms bound together in an ahexagonal (honeycomb) mesh forms a carbon nanotube. A carbon nanotube is created by joining this one-atom-thick sheet of carbon, known as graphene, in the form of a cylinder.Nanotubes can be formed of several walls (cylinders inside other cylinders of carbon) or they can have a single exterior wall made of carbon. The physical structure of carbon nanotubes can alter their spectrum of electrical, thermal, and structural characteristics.

There are two different kinds of carbon nanotubes:

- single-walled carbon nanotubes (SWCNTs)
- multiple-walled carbon nanotubes (MWCNTs).

Thestructures of single wall and multi wall nanotubes are shown in
Figure .II.15 and Figure .II.16

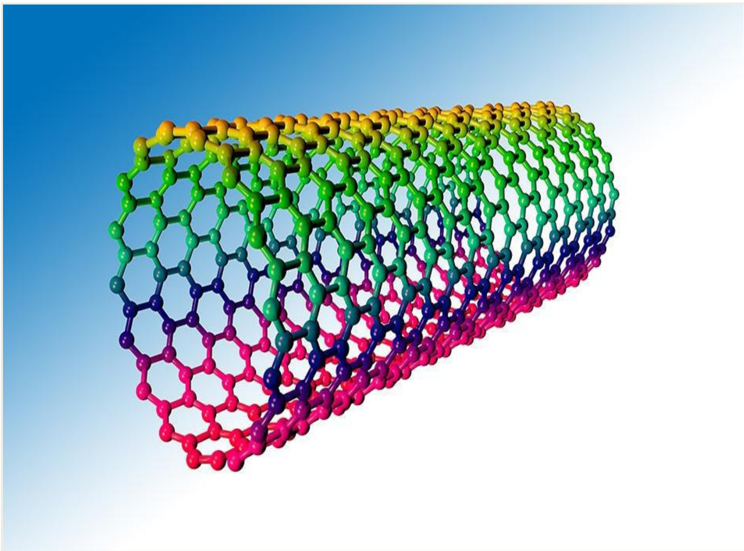


Figure II.16Single walled carbon nanotubes.

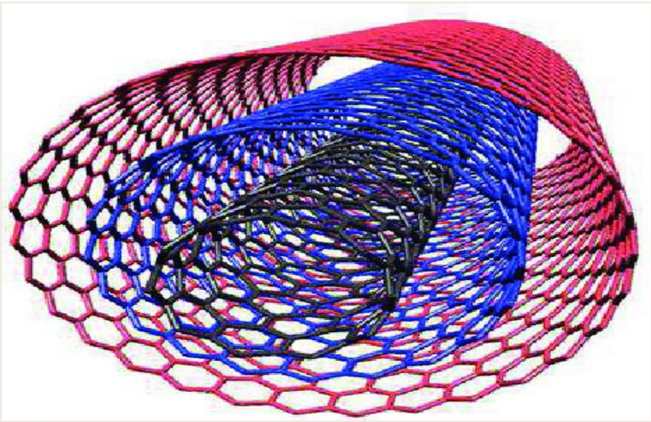


Figure .II.17 Multiple walled carbon nanotubes.

II3.2.4.1Applications and physical characteristics of carbon nanotubes :

Sp2 C-C bonding ability allows carbon nanotubes to exhibit an excellent combination of outstanding mechanical, electrical, and thermal capabilities. These qualities have made their way into several industrial application fields.some of themare listed below[37].

TableII.4 Some applications and characteristics of carbon nanotubes :

Properties	Areas of application
• Strongchemicalandenvironmentalreliability • efficientthermal-conductivity	These materials may find use in the aircraft industry if the lightweight characteristics of carbon-based materials are combined with the features of carbon nanotubes.[26].

• Electricalconductivity	Electronics employ carbon nanotubes because of their high electrical conductivity, which is on par with copper's[38].

II.3..25.Fullerene

The scientific community has been revolutionised by the 1985 discovery of fullerene. In applications related to physics, biology, and chemistry, it has been frequently used. The fullerene family actually includes C60, which has amazing physical features.When carbon atoms are added to the C60 ball's equator, oblong molecules with the formulae C70, C76, C84, etc. result (Fig. 1.4). The fullerenes are employed in drug delivery systems as lubricants, catalysts, and transporters[39].

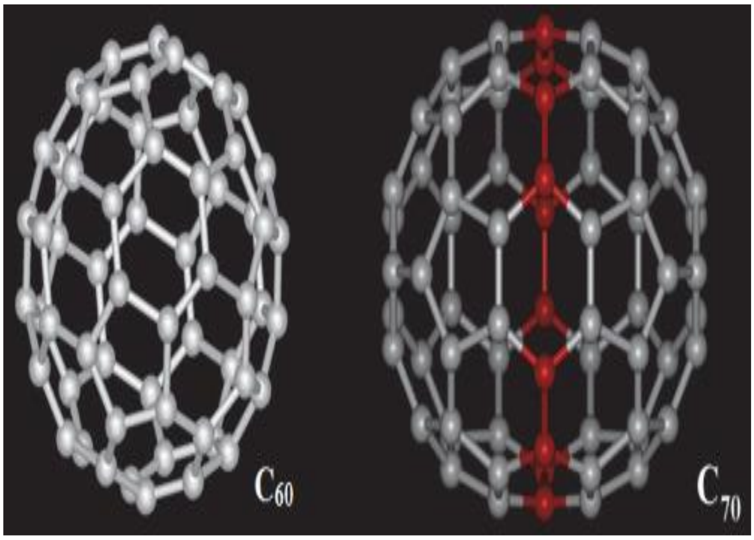


Figure II.18 Comparing the structures of the molecules C60 and C70

II.3.3Study the effect of carbon types in solar distillations

These days, there is concern over solar water evaporation due to its many uses, particularly in the fields of electric generation and water desalination. Using a light particle as an absorber will increase the efficiency of evaporation because water is a poor absorber. Attia et al. looked at how coal and charcoal affected solar distillers' performance[40].

Both compounds enhanced the thermal performance of the solar still.Abd El Kawi and Naim employed little bits of charcoal as an absorbent material to increase the distillation yields. The system's thermal inertia was lowered by the charcoal's capillary action, rough surface, black colour, and partial submersion in water. Charcoal really accelerated the distillation process significantly[41].

Kumar, B. Selva, et al. investigated An approximate measure of the amount of distilled water collected and the thermal efficiency of a "V" shaped solar still equipped with a charcoal absorber are made. Both exterior and interior heat transport modes are investigated. Estimating the still's efficiency can be done in four ways. The still's overall efficiency is 24.47% when it doesn't have charcoal, 30.05% when it has, 11.92% when it does, and 14.11% when it has both charcoal and boosting mirror[42].

Another combination of fibres and materials have used in [43]When the employment of cotton textiles, floating coal, and nanoscale carbon black particles improved the thermal performance, Three scenarios (coal alone, coal coated in cotton fabrics, and modified solar still-C with carbon black nanoparticles scattered on top of the coal/cotton combination) were examined using the suggested materials. In comparison to the reference solar still, the modified solar still-C achieved the highest gains in cumulative output, average energy efficiency, and average energy efficiency, at 59.33, 75.12, and 142.7%, respectively. In this case, cutting production costs by 25.32% and increasing the reduction of carbon emissions by 127.5% are also feasible.

Ali et al. offered a numerical analysis and modelling of a solar still. The results showed that adding granular activated carbon to a solar still enhanced its functionality[44].

Activated carbon is one of such materials for this use. Hota and Diaz (2019) discussed its desired qualities as an excellent absorber. For low volume fractions (about 0.01%), the coefficient of sun absorption was found to vary from 0.98 to 0.9.

Furthermore, their findings demonstrated that, in comparison to pure water, the evaporation performance improved by 57.3 % and 38.2 % at the previous volume fraction for the sizes of 80 nm and 8 m, respectively. For decontamination and water treatment applications, AC is one of the most sought-after materials.

An experimental investigation using AC fibres produced a higher evaporation rate (approximately 1.22 $kg/m^2.h$)[45].

One of the most in-demand materials for desalination and water treatment is activated carbon.In a recent experiment with activated carbon fibres, an evaporation rate of 1.22 $kg/(m^2•h)$ and a photo-thermal conversion efficiency of 79.4% were noted[46, 47].

To increase the productivity of the solar still, Sharshir et al. conducted an experiment wherein they added micro-flakes of graphite and copper oxide at concentrations ranging from 0.125% to 2%. The water levels in the many basins varied from 0.25 to 5 cm, and different masses of water flow over the glass cover to keep the condenser cold. The results show that using CuO nanoparticles increases production by approximately 44.91%, and using graphite microflakes increases production by approximately 53.95%[48].

Experimental research on the effects of 28 graphite on still production was undertaken by Kabeel et al. The production of still 29 is found to be improved by 74.89–80.05 percent when graphite is used[49].

Because of the exceptional mechanical, thermal, optical, and electrical capabilities of nanomaterials like carbon nanotubes (CNTs) and graphene (Gr), composite materials containing these materials have found extensive application[50, 51].

For example, due to their high specific heat, high thermal conductivity, and strong optical and thermal absorptivity, particularly at low temperatures, nanomaterials have been used in thermal applications[52, 53].

For instance, experimental measurements of the specific heat and thermal conductivity of individual multi-walled CNTs revealed that the former was approximately 0.75 J/g K while the latter was 3000 W/mK[54].

In an experimental study conducted by Gnanadason et al., carbon nanotubes were utilised.

The result was improved by 50% by increasing the efficiency of a solar distiller integrated with a vacuum pump and different water depths[55].

References

[1] J. M. Vaquero and M. Vázquez, *The Sun recorded through history* vol. 361: Springer Science & Business Media, 2009.

[2] D. G. De Paor, M. M. Dordevic, P. Karabinos, S. Burgin, F. Coba, and S. J. Whitmeyer, "Exploring the reasons for the seasons using Google Earth, 3D models, and plots," *International Journal of Digital Earth,* vol. 10, pp. 582-603, 2017.

[3] D. Baker, "Effects of the Sun on the Earth's environment," *Journal of Atmospheric and Solar-Terrestrial Physics,* vol. 62, pp. 1669-1681, 2000.

[4] A. Berger, "A brief history of the astronomical theories of paleoclimates," in *Climate change: inferences from paleoclimate and regional aspects*, ed: Springer, 2012, pp. 107-129.

[5] A. Tartaglia, E. Lorenzini, D. Lucchesi, G. Pucacco, M. Ruggiero, and P. Valko, "How to use the Sun–Earth Lagrange points for fundamental physics and navigation," *General Relativity and Gravitation,* vol. 50, pp. 1-21, 2018.

[6] A. Dumas, A. Andrisani, M. Bonnici, G. Graditi, G. Leanza, M. Madonia, *et al.*, "A new correlation between global solar energy radiation and daily temperature variations," *Solar energy,* vol. 116, pp. 117-124, 2015.

[7] M. Lefevre, A. Oumbe, P. Blanc, B. Espinar, B. Gschwind, Z. Qu, *et al.*, "McClear: a new model estimating downwelling solar radiation at ground level in clear-sky conditions," *Atmospheric Measurement Techniques,* vol. 6, pp. 2403-2418, 2013.

[8] H. Xie, J. Zhao, K. Wang, and H. Peng, "Long-term variations in solar radiation, diffuse radiation, and diffuse radiation fraction caused by aerosols in China during 1961–2016," *PloS one,* vol. 16, p. e0250376, 2021.

[9] G. L. Stephens, D. O'Brien, P. J. Webster, P. Pilewski, S. Kato, and J. l. Li, "The albedo of Earth," *Reviews of geophysics,* vol. 53, pp. 141-163, 2015.

[10] L. Wald, "Basics in solar radiation at Earth surface," 2018.

[11] C. W. Brown, "Ultraviolet, visible, near-infrared spectrophotometers," in *Ewing's Analytical Instrumentation Handbook, Fourth Edition*, ed: CRC Press, 2019, pp. 117-128.

[12] M. A. Heald and J. B. Marion, *Classical electromagnetic radiation*: Courier Corporation, 2012.

[13] A. Oudrane, B. Aour, B. Zeghmati, X. Chesneau, and H. Massaoud, "Study and Simulation of the Density of the Incident Solar Flux on the Walls of a Building in

Adrar, Algeria," *Engineering, Technology & Applied Science Research,* vol. 7, pp. 1940-1945, 2017.

[14] K. M. Armijo and S. L. Shinde, "Heat Transfer Phenomena in Concentrating Solar Power Systems," Sandia National Lab.(SNL-NM), Albuquerque, NM (United States)2016.

[15] T. Ming, W. Liu, and S. Caillol, "Fighting global warming by climate engineering: Is the Earth radiation management and the solar radiation management any option for fighting climate change?," *Renewable and Sustainable Energy Reviews,* vol. 31, pp. 792-834, 2014.

[16] L. M. Jiji and A. H. Danesh-Yazdi, *Heat conduction*: Springer Nature, 2024.

[17] L. M. Jiji and L. M. Jiji, *Heat convection*: Springer, 2006.

[18] R. J. Ribando, *Heat Transfer Tools*: McGraw-Hill New York, 2002.

[19] P. R. de Souza Mendes, "Dimensionless non-Newtonian fluid mechanics," *Journal of non-Newtonian fluid mechanics,* vol. 147, pp. 109-116, 2007.

[20] J. Happel and H. Brenner, *Low Reynolds number hydrodynamics: with special applications to particulate media* vol. 1: Springer Science & Business Media, 2012.

[21] A. Ede, "Advances in free convection," *Advances in heat transfer,* vol. 4, pp. 1-64, 1967.

[22] E. D. Siggia, "High Rayleigh number convection," *Annual review of fluid mechanics,* vol. 26, pp. 137-168, 1994.

[23] A. Yaroshevsky, "Abundances of chemical elements in the Earth's crust," *Geochemistry International,* vol. 44, pp. 48-55, 2006.

[24] H. O. Pierson, *Handbook of carbon, graphite, diamonds and fullerenes: processing, properties and applications*: William Andrew, 2012.

[25] T. W. Clyne and D. Hull, *An introduction to composite materials*: Cambridge university press, 2019.

[26] S. Sharif, S. Arbab, A. Saeed, K. Shahzad, M. A. Iqbal, A. K. Durrani*, et al.*, "Introductory Chapter: Introduction to Advanced Carbon Materials and Innovative Engineering Applications," *21st Century Advanced Carbon Materials for Engineering Applications: A Comprehensive Handbook,* p. 3, 2021.

[27] E. Solfiti and F. Berto, "A review on thermophysical properties of flexible graphite," *Procedia Structural Integrity,* vol. 26, pp. 187-198, 2020.

[28] H. Marsh, *Activated Carbon*: Elsevier Ltd, 2006.

[29] Z. Heidarinejad, M. H. Dehghani, M. Heidari, G. Javedan, I. Ali, and M. Sillanpää, "Methods for preparation and activation of activated carbon: a review," *Environmental Chemistry Letters*, vol. 18, pp. 393-415, 2020.

[30] F. Rodriguez-Reinoso and M. Molina-Sabio, "Activated carbons from lignocellulosic materials by chemical and/or physical activation: an overview," *Carbon*, vol. 30, pp. 1111-1118, 1992.

[31] R. Ganjoo, S. Sharma, A. Kumar, and M. Daouda, "Activated Carbon: Fundamentals, Classification, and Properties," 2023.

[32] X. Zhou, W. Wang, and Z. Liu, "Graphene overview," *Graphene: Energy Storage and Conversion Applications*, vol. 6, pp. 1-1, 2014.

[33] S. Singhal, M. Gupta, M. S. Alam, M. N. Javed, and J. R. Ansari, "241 Carbon Allotropes-Based Nanodevices: Graphene in Biomedical Applications," in *Nanotechnology: Device Design and Applications*, ed: CRC Press, 2022, pp. 241-269.

[34] A. Armano and S. Agnello, "Two-dimensional carbon: a review of synthesis methods, and electronic, optical, and vibrational properties of single-layer graphene," *C*, vol. 5, p. 67, 2019.

[35] F. Perreault, A. F. De Faria, and M. Elimelech, "Environmental applications of graphene-based nanomaterials," *Chemical Society Reviews*, vol. 44, pp. 5861-5896, 2015.

[36] V. B. Mohan, K.-t. Lau, D. Hui, and D. Bhattacharyya, "Graphene-based materials and their composites: A review on production, applications and product limitations," *Composites Part B: Engineering*, vol. 142, pp. 200-220, 2018.

[37] M. J. O'connell, *Carbon nanotubes: properties and applications*: CRC press, 2018.

[38] V. Sivasubramaniyam, S. Ramasamy, M. Venkatraman, G. Gatto, and A. Kumar, "Carbon Nanotubes as an Alternative to Copper Wires in Electrical Machines: A Review," *Energies*, vol. 16, p. 3665, 2023.

[39] F. Giacalone and N. Martin, "Fullerene polymers: synthesis and properties," *Chemical reviews*, vol. 106, pp. 5136-5190, 2006.

[40] M. E. H. Attia, Z. Driss, A. M. Manokar, and R. Sathyamurthy, "Effect of aluminum balls on the productivity of solar distillate," *Journal of Energy Storage*, vol. 30, p. 101466, 2020.

[41] M. M. Naim and M. A. Abd El Kawi, "Non-conventional solar stills Part 1. Non-conventional solar stills with charcoal particles as absorber medium," *Desalination*, vol. 153, pp. 55-64, 2003.

[42] B. S. Kumar, S. Kumar, and R. Jayaprakash, "Performance analysis of a “V” type solar still using a charcoal absorber and a boosting mirror," *Desalination,* vol. 229, pp. 217-230, 2008.

[43] S. W. Sharshir, M. Ismail, A. Kandeal, F. B. Baz, A. Eldesoukey, and M. Younes, "Improving thermal, economic, and environmental performance of solar still using floating coal, cotton fabric, and carbon black nanoparticles," *Sustainable Energy Technologies and Assessments,* vol. 48, p. 101563, 2021.

[44] M. I. Ali, R. Senthilkumar, and R. Mahendren, "Modelling of solar still using granular activated carbon in matlab," *Bonfring International Journal of Power Systems and Integrated Circuits,* vol. 1, p. 5, 2011.

[45] G. B. Abdelaziz, E. M. El-Said, A. G. Bedair, S. W. Sharshir, A. Kabeel, and A. M. Elsaid, "Experimental study of activated carbon as a porous absorber in solar desalination with environmental, exergy, and economic analysis," *Process Safety and Environmental Protection,* vol. 147, pp. 1052-1065, 2021.

[46] S. Ma, W. Qarony, M. I. Hossain, C. T. Yip, and Y. H. Tsang, "Metal-organic framework derived porous carbon of light trapping structures for efficient solar steam generation," *Solar Energy Materials and Solar Cells,* vol. 196, pp. 36-42, 2019.

[47] H. Li, Y. He, Y. Hu, and X. Wang, "Commercially available activated carbon fiber felt enables efficient solar steam generation," *ACS applied materials & interfaces,* vol. 10, pp. 9362-9368, 2018.

[48] S. Sharshir, G. Peng, L. Wu, N. Yang, F. Essa, A. Elsheikh*, et al.*, "Enhancing the solar still performance using nanofluids and glass cover cooling: experimental study," *Applied thermal engineering,* vol. 113, pp. 684-693, 2017.

[49] A. Kabeel, M. Abdelgaied, and A. Eisa, "Enhancing the performance of single basin solar still using high thermal conductivity sensible storage materials," *Journal of cleaner production,* vol. 183, pp. 20-25, 2018.

[50] N. Mohd Nurazzi, M. M. Asyraf, A. Khalina, N. Abdullah, F. A. Sabaruddin, S. H. Kamarudin*, et al.*, "Fabrication, functionalization, and application of carbon nanotube-reinforced polymer composite: An overview," *Polymers,* vol. 13, p. 1047, 2021.

[51] Z. Ali, S. Yaqoob, J. Yu, and A. D'Amore, "Critical Review on the Characterization, Preparation, and Enhanced Mechanical, Thermal, and Electrical Properties of Carbon Nanotubes and Their Hybrid Filler Polymer Composites for Various Applications," *Composites Part C: Open Access,* p. 100434, 2024.

[52] L. Yang, W. Jiang, W. Ji, O. Mahian, S. Bazri, R. Sadri, *et al.*, "A review of heating/cooling processes using nanomaterials suspended in refrigerants and lubricants," *International Journal of Heat and Mass Transfer*, vol. 153, p. 119611, 2020.

[53] D. Coetzee, M. Venkataraman, J. Militky, and M. Petru, "Influence of nanoparticles on thermal and electrical conductivity of composites," *Polymers*, vol. 12, p. 742, 2020.

[54] R. Sadri, G. Ahmadi, H. Togun, M. Dahari, S. N. Kazi, E. Sadeghinezhad, *et al.*, "An experimental study on thermal conductivity and viscosity of nanofluids containing carbon nanotubes," *Nanoscale research letters*, vol. 9, pp. 1-16, 2014.

[55] M. K. Gnanadason, P. S. Kumar, S. Rajakumar, and M. S. Yousuf, "Effect of nanofluids in a vacuum single basin solar still," *International Journal of Advanced Engineering Research and Studies*, vol. 1, pp. 171-177, 2011.

ChapterIII:Experimental Study

Chapter III :Experimental Study

III .1Introduction

Solar distillation in arid and desert regions is one of the best solutions to solve the problem of lack of drinking water. The aim of our study is to improve the production of the greenhouse single slope solar still.Five single basin single slope solar stills were installed at the University of Ouargla where the experiments were carried out to compare the performance of the still with and without absorbent material (carbon).

This work was carried out at the engineering laboratory Processes (LGP)/faculty of applied sciences and laboratory for the development of new and renewable energies in arid and Sahara zones (LENREZA)/faculty of mathematics and material sciences. KasdiMerbah University/Ouargla.

The experiment takes place at the same time, in the same position, and of course in the same weather conditions. All this to avoid any doubts that could negatively influence our results.

III .2 General presentation of the experimentation location :

III .2.1 Geographical location:

The city of Ouargla is the capital of the third largest wilaya in Algeria in terms of surface area, it is located in the south-east of Algeria, at the bottom of a very wide basin in the OUED M'YA valley. It covers a total area of 163,233 km^2.

Its geographic coordinates are :

— Altitude : 164 m

— Latitude : 31°57 North

— Longitude : 5°19 East

III .2.2 Climate Studies :

Ouargla is one of the hottest regions of Algeria (and the world). It has a Saharan climate, characterized by low temperatures in winter, very high temperatures in summer, low atmospheric humidity, low precipitation and an average annual wind speed of 3.70 m/s. There is considerable sunshine in Ouargla, as there are approximately 138 days of clear skies per year. On the other hand, Ouargla is characterized by the frequency of storms sand, especially in spring (February to May) [1].It also has one of the highest annual average solar radiation values in the world.The photovoltaic energy potential of Algeria and the Ouargla region is presented in the figure III 1.

The climatic parameters (temperature, evaporation, humidity, wind speed…) are the most determining factors for the production of distilled water, the values of these parameters are available to the national meteorological office of Ouargla presented by Table III .1

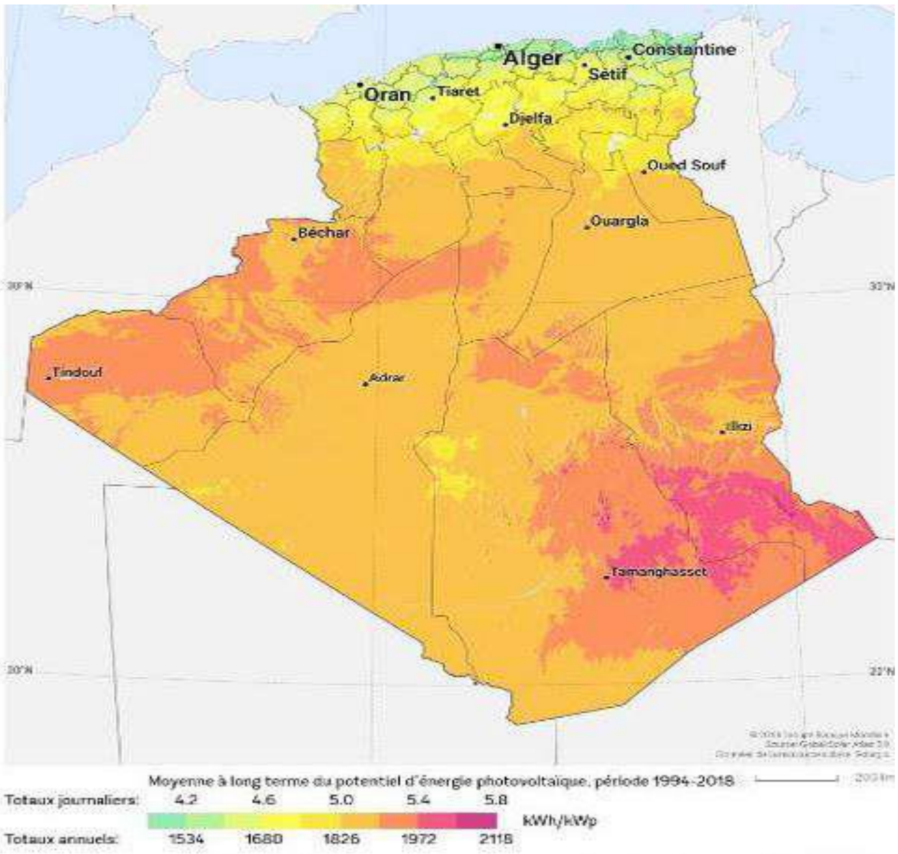


Figure III .1Photovoltaic potential of Algeria and the Ouargla region [2].

Table III .1 Climatic study of the city of Ouargla [112].

Settings	Value
Temperature	(5-44°C)
Evaporation	26-36%
Humidity	24-62%
Wind	3.7m/s
Rainfal	20-60mm
Insolation	138 jours/année

III.3 Material and equipment

III.3.1 Description of the greenhouse solar still:

III.3.1.1 The operating principle of the greenhouse solar still:

The single-basin, single-slope solar still is made of a wooden support as insulation; its basin is a galvanised metal tray; and the basin is blackened to ensure maximum absorption of solar rays.

Salt water is poured into the basin and then exposed to the sun's rays. Therefore, the water vapour produced from a salt solution is transported by convection to a transparent glass condenser, where it is condensed. The glass cover has been sealed with silicone to prevent any steam leakage, and a horizontal angle is provided to facilitate the flow of condensed water down the wall to a distilled water collector.

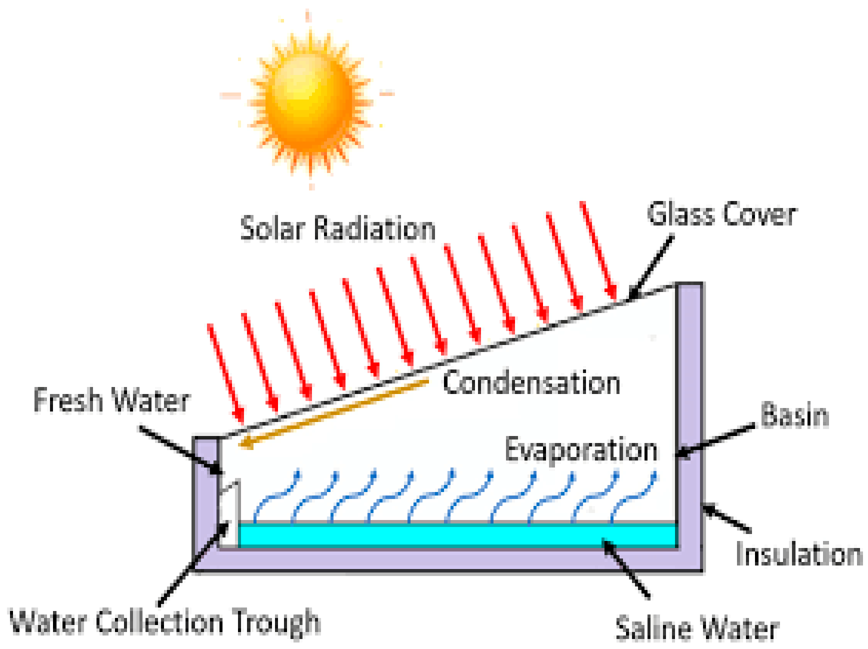


Figure III.2 Principle diagram of operation of the greenhouse solar still.

III.3.1.2 Creation of the solar still

The distillers used in our experiments have a very simple design. They are simple solar distillers, which have the advantage of being easy to build and, especially, to maintain. They have the same dimensions; one was taken as a conventional distiller (witness), and the others are used to the subject of study.

Each distiller consists of:

- **Absorbing basin (black plate)**

The absorbing basin is the most important part of the single-slope solar distiller. It is designed to absorb as much of the overall solar radiation as possible and transfer the heat generated by this absorption to the brine. This is why it is painted matte black. It is obtained by welding and essentially made from galvanised iron.

❖ The dimensions of the surface of the absorber are:

- Length: 0.6m;
- Width: 0.4m;
- Heights: 0.07;
- Thickness: 0.004mm;
- Base area: 0.24m

- **The transparent cover**

The transparent cover (glass) is a very important element of the still and plays a vital role in creating the greenhouse effect inside the solar still.In addition, it serves as the condensate transporter and steam condenser for the recovery of distilled water.

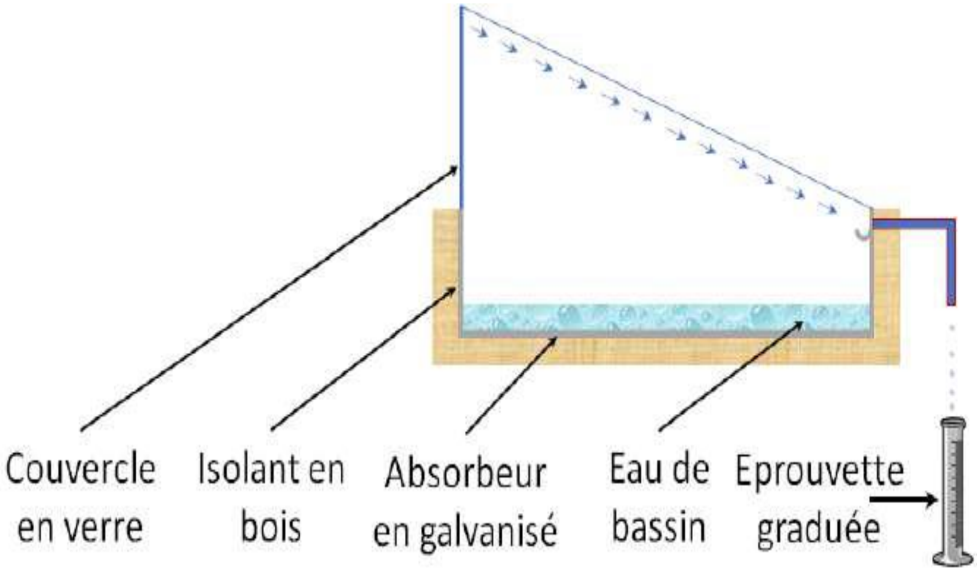
- **Thermal insulation**

The chosen insulation is polystyrene, covering the absorbent. To reduce heat loss, the products used must be resistant to operating temperatures. Containing a 2 cm-diameter hole at the bottom from the centre for drainage. It is airtight and removable for easy changing and cleaning.

❖ The dimensions of the thermal insulation are:
  - Length: 0.6m;
  - Width: 0.4m;
  - Thickness: 0.04m;
  - Base area: 0.24m^2

- **Exterior cover**

A wooden support as insulation for the distiller has a thickness of 0.04 m; the distiller's chest contains the different active elements. It must therefore provide effective protection against atmospheric agents. Who serves to reduce heat loss from the absorber base.



FigureIII.3Diagram of different components of the solar still[3].

- **Piping and connectionlines**

The piping used is plastic, with a diameter ranging from 15 to 20 mm, to connect the different parts of the distiller in order to transport the brackish and distilled water.

- **Distilated water collector**

For the recovery of distilled water which is located at the level of the wooden cover and the basin, which is linked by a plastic tube to collect the distilled water outside the distiller.

- **Graduated test tubes**

These are graduated tubes used to measure the volume of distilled water every hour. We then calculate the volume flow rates of the distillate.

III.3.2 Measuring instruments

- **Instruments for measuring wind speed (Hot wire anemometer).**

We heat a metal wire by passing a weak electric current through it. Electrical resistance increases with temperature.The wire is cooled by the wind. The stronger the wind blows, the more the wire is cooled, and the electrical resistance decreases. An electronic device linked to this wire will show the degree of cooling that has been done by the air in the form of two readings: the first expresses the wind speed, and the other expresses the air temperature. (Figure .A1-Annex)

- **Instruments for measuring global solar radiation (Solari meter)**

It consists of a part placed on the window and an electronic instrument that transformsthe radiation in a direct reading on a small digital screen, and gives a real value of the ray incident on the window in (W/m^2) as well as the quantity of energy.in (Wh/m^2.day). . (Figure .A 2-Annex)

- **Instruments for measuring ambient temperature and humidity. (hygrometer)**

It is a multifunctional diagnostic device that monitors environmental values. which is installed in the open air at a height between (1 – 1.5 m on the earth's surface to measure the following three quantities: ambient temperature, relative humidity and the dew point. (Figure .A 3-Annex)

- **Instruments for measuring atmospheric pressure (Barometer).**

To measure atmospheric pressure, we used a Barometer which measures pressure.absolute atmospheric pressure in the region where the experiment was carried out (the pressure of the atmosphere on the surface of the Earth), its measurement is optional and expresses it in mbar.

- **Temperature-measuring instruments (thermocouples)**

Is there an association of two metal wires of different types, welded at one of their ends.called“measuring weld” when the junction of the two metals is heated or cooled, a tension is produced, which can be transcribed into temperature. Alloys Thermocouple connectors are usually available in wire form. Each a thermocouple is linked to a device (special millivoltmeter) containing a screen .digital. This device transforms the temperature into an electric current, from which we can subsequently read the temperature value at the location where the thermocouples have been put. (Figure A.4-Annex-)

- **Graduated test tube**

Graduated tubes to facilitate measuring the quantity of distilled water obtained each hour. (Figure A.5-Annex-)

Precision and error of experimental analysis for various measuring instruments. The accuracies, range, and analysis errors for various measuring instruments are given in Table III.1 :

Table III.2 Precision and Error of measuring instruments

Instruments	Precision	Range	Error
Hygrometer	±1 °C	0-100°C	3.33
Thermocouple	±0.1°C	0-100°C	0.33
Pyranometer	±1 W/m²	0-2500 W/m²	22.5
Graduated tubes	±0.1 ml	0-100 ml	10

III.3.3. The thermocouples' placement

The measurement of essential temperatures by thermocouples is type K, carefully fixed using silicone on the parts of the distiller as follows:

- ✓ Temperature of the inner surface of the face (T1) ;
- ✓ Temperature of water in the bassin (T2) ;
- ✓ Temperature of vapour (T3) ;
- ✓ Ambient temperature (T4) ;

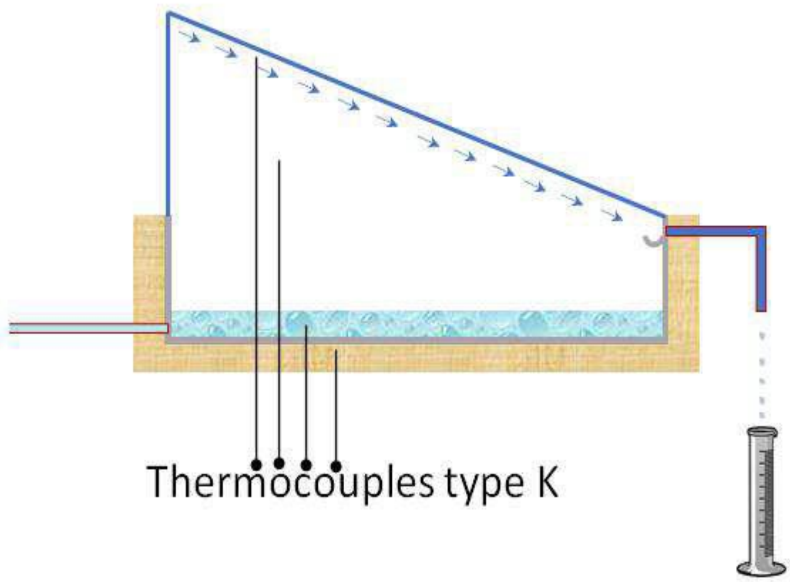


Figure III.4 Placement of thermocouples.

III.3.4 Measured quantities

From these experiments, and during each hour, and during eight hours: from 9:00 a.m. to 5:00 p.m., we measured the quantities as following :

- Ambient temperature.
- Global solar radiation;
- The different temperatures relating to the solar still: (the glass cover,the temperature of the vapour trapped inside the distiller,brackish water in the basin)
- Wind speed.
- Hourly productivity of the distillated water.

We have mentioned and represented in our study that the key parameters and other parameters, such as relative humidity and atmospheric pressure, are arbitrary because their influence on the distillation is almost negligible.

III.3.5 Experiments

The production of the distiller depends on the temperature gradient that exists between the water temperature inside the basin and the transparent cover (condenser). However, several techniques are tested and adopted for increasing the distiller's production.Water temperature in the bassin.

The use of additives is a technique applied to increase the performance of heat and mass transfer in the still tank. Among them is the addition of different types of carbon as an absorbent material, which has a significant effect on the heat transfer process and water purification.

The importance of our experimental work lies in the application of different types of carbon in solar distillation, using four types of carbon separately as an absorbent material.

Our experiments are carried out in three parts, as follows:

III.3.5.1 Preliminary tests

This chapter begins with preliminary tests (see figure III.5) with the aim of evaluating the performance of the solar still. To calibrate our systems, we use five identical solar stills installed and tested at the University of Ouargla, in a place where the stills are exposed to solar rays so that they can capture the maximum amount of solar radiation without any obstruction.

Distillers facing south have an inclination angle of 30° and the same depth of water. Firstly, in order to find the best yield.

All experiments started at 9:00 a.m. and ended at 5:00 p.m. local time. During the operations, we measured the different temperatures, and the volume of distilled water every hour was also monitored. The reproducibility of the results in all tests was checked by repeating each experiment twice in the following two days.

The results of each experimental series were recorded for comparison of yield between the five test distillers.

Figure III-5: Preliminary test.

After the preliminary tests, the following notes were recorded:

- ✓ equal hourly and daily productivity in the five distillers;
- ✓ good thermal insulation;
- ✓ good sealing in different components of the distiller.

III.3.5.1.1 Effect of depth of brackish water

This study aims to improve the performance of the solar still. So it is necessary to evaluate some important parameters affecting the productivity of the system.Three identical distillers were used to evaluate the effect of the water depth in the basin on the perfermance of the solar still quantity of distillate. The different depths of brackish water used (1 cm, 2 cm, and 3 cm) .

were tested at the same time during the day in December 2021, from 9:00 a.m. to 5:00 p.m., and under the same climatic conditions (see figureIII.6). At the University of Ouargla During this experiment, we measured the ambient temperature, the solar intensity, and the hourly and daily quantities of distilled water produced by each distiller.

Figure III.6.Water depth effect.

III.3.5.1.2 Effect of Stabilisation of Carbon Particles (Cloth Effect)

For a better study of the effects of carbon types,we try to stabilise the carbon particles on the base of the absorber, preventing them from floating above the water. For this experience, we use three similar single slopes still installed at the laboratory level (LENREZA). One distiller remains as a witness. The other two distillers were used to test the experiment by adding the same weight of charcoal to each of them, separately within each absorber with the same weight of 100 g, i.e., 0.4167 kg of carbon per m2 of absorber area. In the third solar still,the carbon powder was placed inside the fixed black cloth,(as display in the Figur III**-7)**which led to the stability of the carbon particles on the base of the absorber, avoiding them from floating above the water. The cloth used in this experiment is very thin and black to absorb the greatest amount of solar radiation .The experience was from 09:00 to 17:00 until the end of the day, February 2022.

During this experiment, we measured the ambient temperature, the solar intensity, and the hourly and daily quantities of distilled water produced by each distiller.

The photograph and the installation plan for solar distillers. are displayed in figures III.7 andIII.8, respectively.

Figure III.7placed carbon pouder in the fixed black cloth.

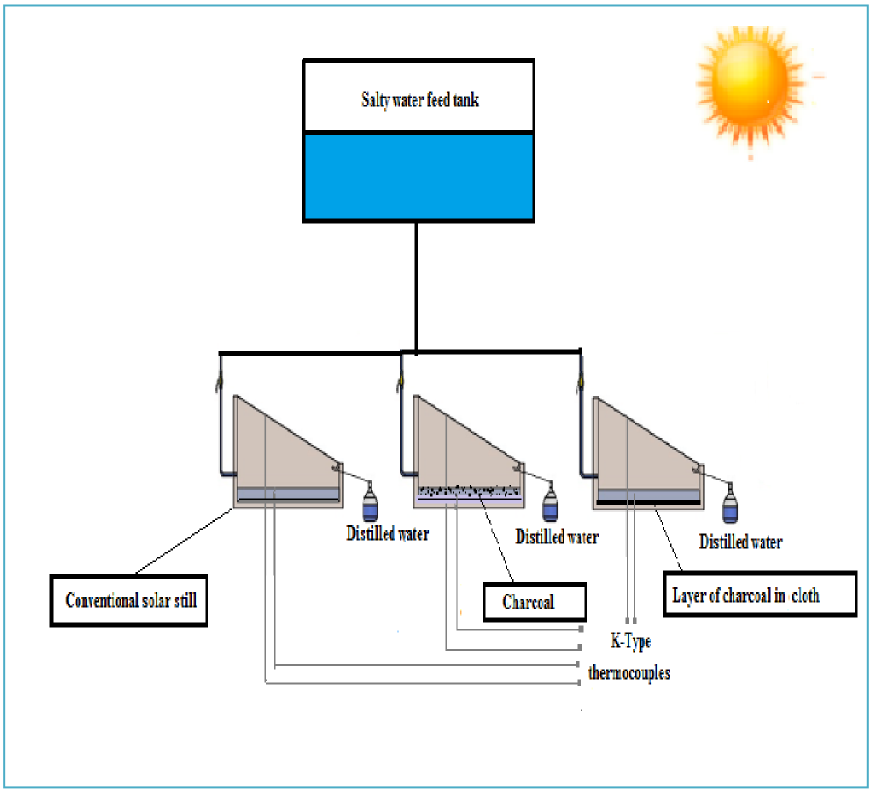


Figure III.8Effect of Stabilisation of Carbon Particles (Cloth Effect).

III .3.5.2. First experience

The five solar stills were constructed and tested at Ouargla University. The stills' long axes are oriented south-north and the inclination of the glass cover is at an angle of 30° ,that is Almost equal to the latitude of the wilaya of Ouargla ,to take high solar radiation and to facilitate the descent of condensed droplets.

In order to find the best performance, we tested the five distillers with constant water depths; after the tests preliminary, the optimal depth of brackish water is 1 cm.

The first solar still was used as a witness, while the four types of carbon were added separately to the other four solar stills. The different types of carbon have been placed inside the fixed black cloth, which led to the stability of the carbon particles on the base of absorber and avoiding them to float above the water. To allow a better study of the effects of carbon types and to eliminate the effect of the cloth, we fixed the same cloth in the absorber of the witness as well.

In this experiment, four different types of carbon were used: activated carbon, graphite, coal, and wood charcoal separately with the same mass of 100 g of each one, i.e, (0.4167 kg/m^2 of absorber area); this is enough to cover the entire absorber area. Particles' diameters are the same (0.080 mm); the particles should be small as possible to maximise the heat exchange area. As display in figurIII-9

All tests were conducted from 9:00 AM to 5:00 PM local time ,During the month of march 2022.

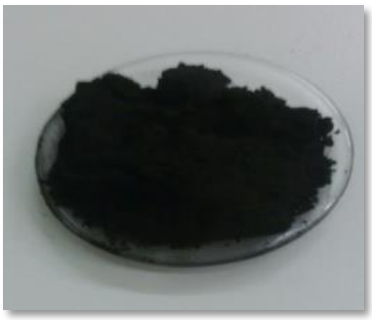
During the various tests we measured :

- the temperature of the inner of glass cover
- the temperature of brakich water in the basin.
- The solar radiation,
- Ambient temperature,
- Wind speed,
- the volume of distilled water

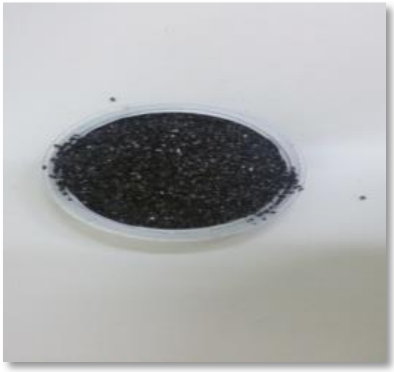
The reproducibility of the results in all experiments was confirmed by carrying out each experiment twice over the course of the following two days. The yield comparison between the witness and test units was used to normalise the experiment's results in the form of a productivity factor.

III .3.5.2.1.carbon types used in the experiments

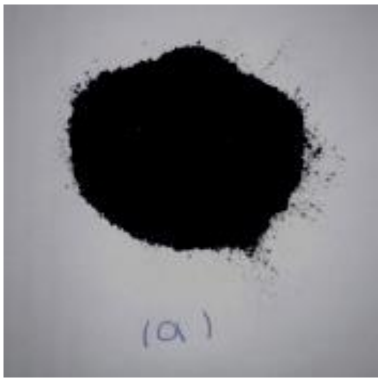
In our case, we chose carbon ,according to the criteria cited above, and according to the availability




Activated carbon **Graphite**



Coal



wood charcoal

FigureIII.9 different types of carbon used in the experiments

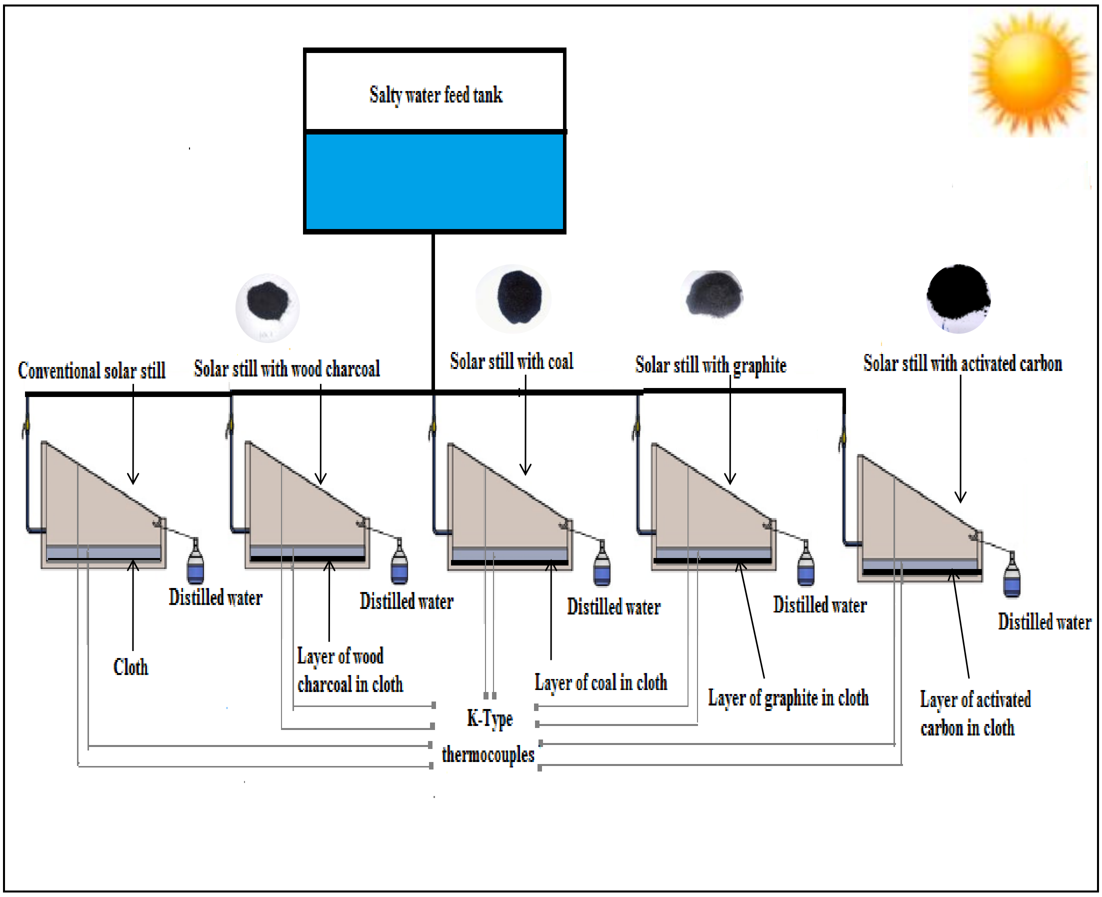


Figure III.10 Scheme of first series of experiments.

III.3.5.3.Second experiment

The three distillers and the entire system were erected and tested simultaneously under the same weather conditions at the Process Engineering Laboratory (LGP) of the University of Ouargla, southeast of. During the month of November 2022, from 9:00 a.m. to 5:00 p.m., the installation diagram of the second experiment is shown in Figure III-11.

The experimental configuration is placed in the direction of the sun to receive maximum solar radiation for a long period of time during the test. It consists of four conventional single-slope solar still .

The first solar still was used as a witness, while the different mixture types of carbon were added separately to the other three solar stills. The different mixture types of carbon have been placed inside the fixed black cloth, which led to the stability of the carbon particles on the base of absorber and avoiding them to float above the water. To allow a better study of the effects of carbon types and to eliminate the effect of the cloth, we fixed the same cloth in the absorber of the witness as well. In this experiment, three different mixture types of carbon were used: (charcoal+activated carbon), (charcol+graphite), (graphite+activated)with the same mass of 100 g of each one, i.e, (0.834kg/m^2 of absorber area);the particles should be small as possible to maximise the heat exchange area.
All tests were conducted from 9:00 AM to 5:00 PM local time.

The reproducibility of the results in all experiments was confirmed by carrying out each experiment twice over the course of the following two days. The yield comparison between the witness and test units was used to normalise the experiment's results in the form of a productivity factor.
During the various experiments, we measured the following quantities:

- The temperatures of the water and glass cover
- Ambient temperature
- solar radiation
- Hourly production of distillate.
- Wind speed
- humidity

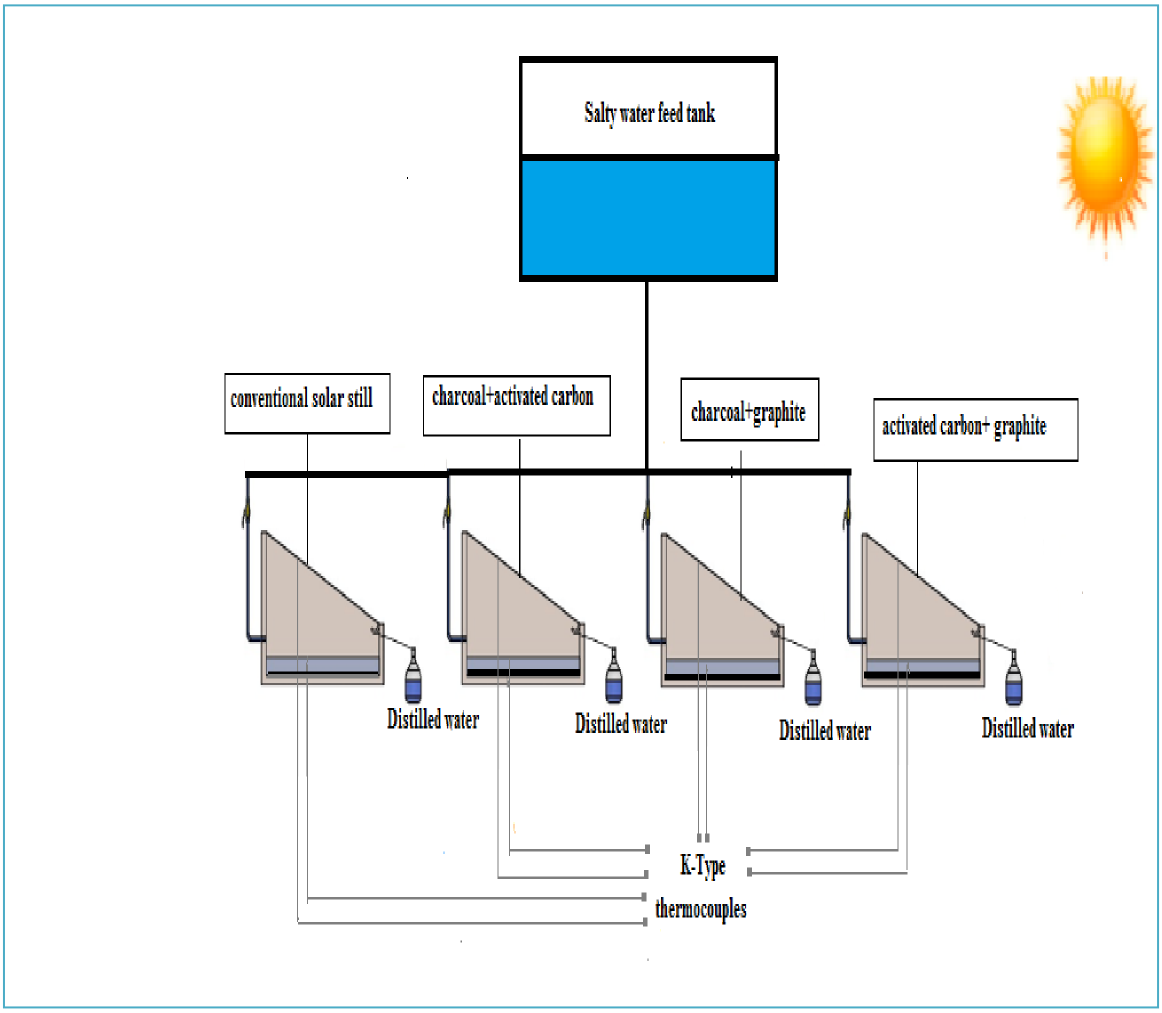


Figure III.11 Scheme of the second series of experiments.

References

[1] M. Y. Rachedi, D. Bechki, Y. Marif, S. Boughali, and H. Bouguettaia, "A novel model for optimizing tilts of four reflectors on a flat plate thermal collector: Case study in Ouargla region," *Case Studies in Thermal Engineering*, vol. 32, p. 101872, 2022.

[2] A. Gougui, A. Djafour, M. Danoune, and N. Khelfaoui, "Field experience study and evaluation for hydrogen production through a photovoltaic system in Ouargla region, Algeria," *International Journal of Hydrogen Energy*, vol. 45, pp. 2593-2606, 2020.

[3] P. K. Ithape, S. B. Barve, and A. R. Nadgire, "Climatic and design parameters effects on the productivity of solar stills: a review," *Int. J. Curr. Eng. Sci. Res*, vol. 4, pp. 17-23, 2017.

Chaptre IV : Results and discussion

Chapter IV: Results and discussions

The main objective of this work is to produce distilled water through the phenomena of evaporation and condensation at a low cost. The device had to use only solar energy and simple, less expensive equipment. Evaporation and condensation results have each been optimised to obtain the maximum possible distillate. These results essentially concern the solar intensity, the hourly and daily production of distillate, and the variation of the different temperatures of the device as a function of the local weather during the days of the experiments. The results are presented in the form of graphs.

IV.1.Water depth effect

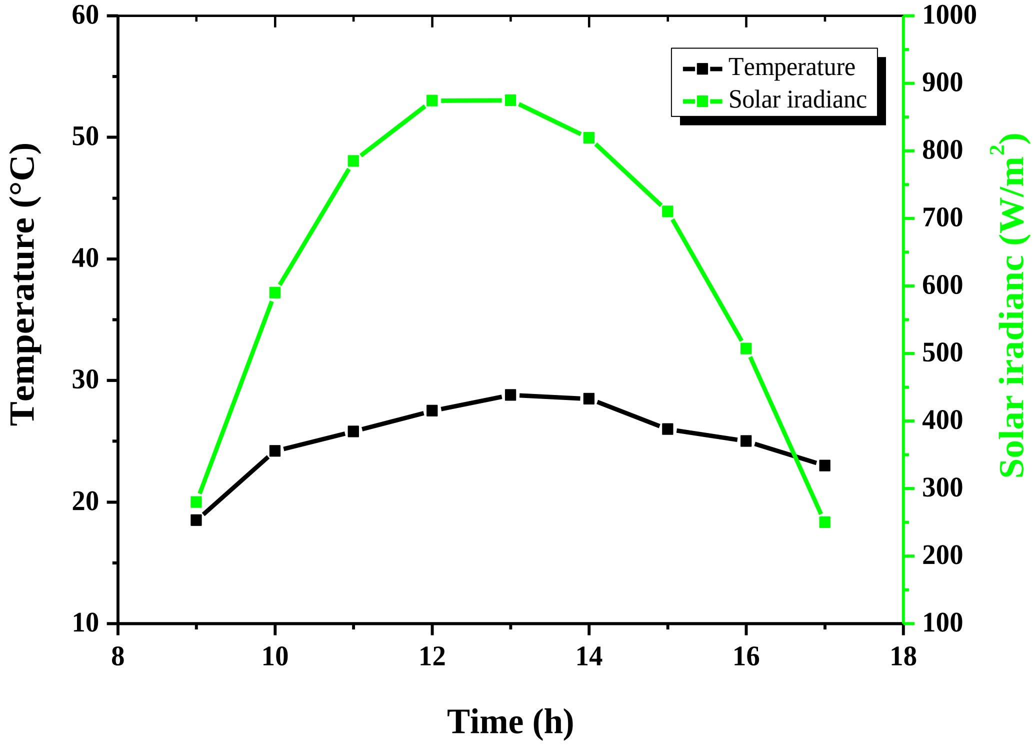


Figure IV.1Solar intensity and ambient temperature versus local time

We chose December 29, 2021, which is characterised by a clear sky all day. FigureIV.1: presents the evolution of the ambient temperature and solar radiation as a function of time. We notice that temperatures increase as solar radiation increases.We notice that temperatures increase as solar radiation increases. The distillation system will not be in operation before 8:00 a.m. or after 5:00 p.m.given that solar radiation is either zero or too weak. The intensity of solar radiation begins to increase in the morning and reaches its maximum value of 875W/m^2 at 1:00 p.m.then it decreases again,It is less intense at the end of the day. The ambient temperature follows almost the same variation, with a maximum value of 28.8°C at 1:00 p.m.

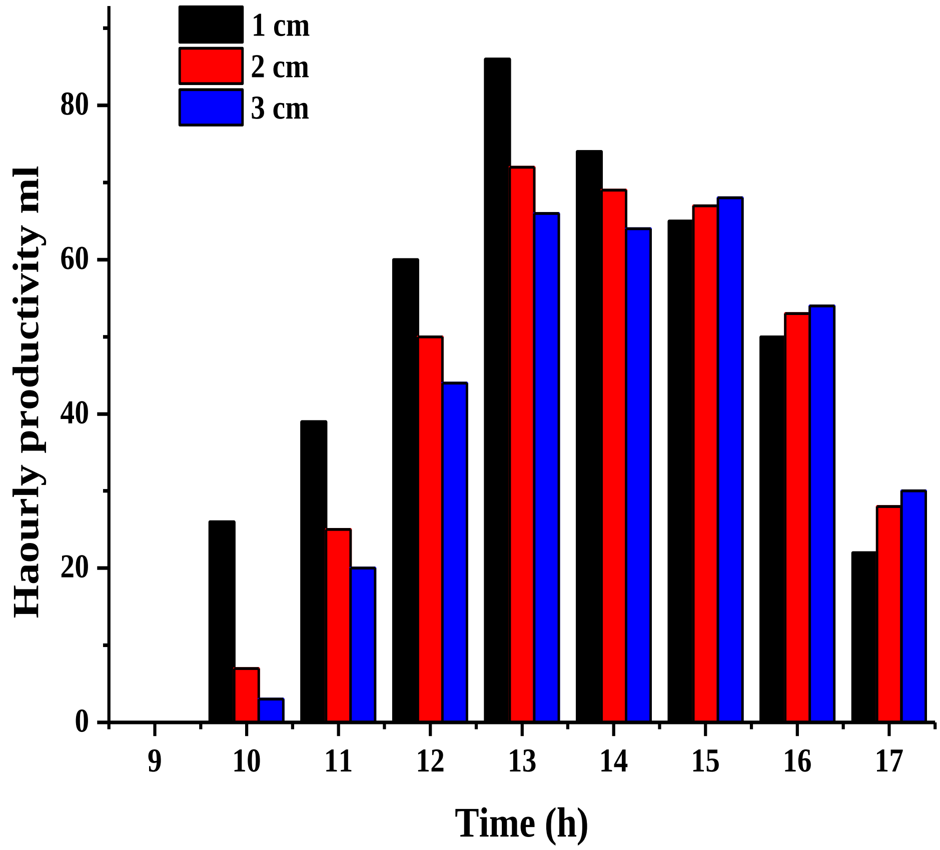


Figure IV.2 Hourly productivity of the three depths versus local time

Figure IV.2 displays hourly productivity versus local time for distillers with different water depths of 1cm, 2 cm, and 3 cm.The trend of the curves indicates that the hourly output is directly proportional to the solar radiation.We notice that for a depth of 1 cm, the productivity increases more under the effect of the faster evaporation rate due to the small quantity of water existing inside the basin.On the other hand, for the highest water depths (2 and 3 cm), the productivity of distilled water is less intense.In addition, when using higher water depths, this water needs more time to be heated and generate steam.The maximum value of hourly production recorded at 1:00 p.m. for each distiller was 86 ml, 72ml, for the units at water depths of 1cm, 2 cm,respectively,and 68 ml at 3 :00 pm for the units at water dethof 3cm

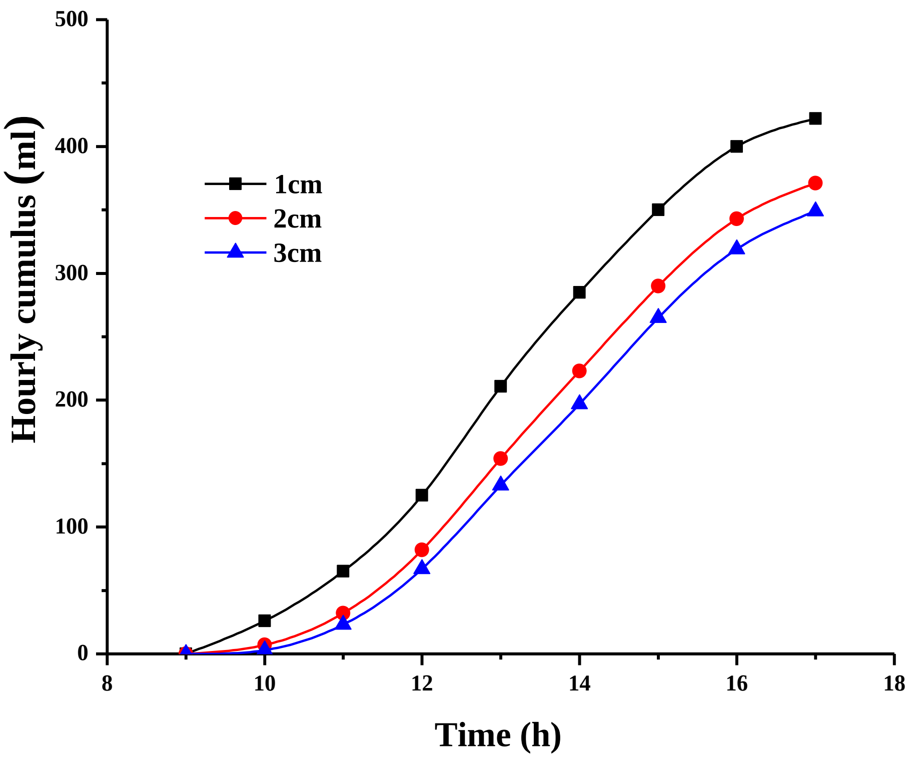


Figure IV.3 The hourly accumulation as a function of time by the three depths

Figure IV.3 :displays the hourly accumulation of distillate per unit area of absorber for distillers with different water depths (1cm, 2 cm, and 3cm) to compare the accumulation of the distiller, In other words,we should find the water depth.optimal in the basin.As expected, the lowest depth gives the best production and daily cumulative values.The daily accumulations recorded are: 1.76, 1.55 and 1.45 L/(d.m^2) for the distillers with water depths: 1cm, 2cm and 3cm respectively.The results obtained showed that decreasing the water depth had a significant effect on increasing the productivity of distilled water.According to these results we can take a depth of 1cm as constant depth for all our experiences.

IV.2.Effect of Stabilisation of Carbon Particles (Cloth Effect)

IV.2.1 Interpretation and discussion of results

In order to further improve the production of distilled water for another technique, And for a better study of the effects of carbon types, we proposed to stabilise the carbon particles on the base of the absorber, wich are covred with fixed black cloth, that prevents them from floating above the waterto absorb the maximum solar rays, resulting in an increase in the productivity of distilled water.We chose the month of Fébrury 2022 , which is characterised by clear skies for the majority of the day

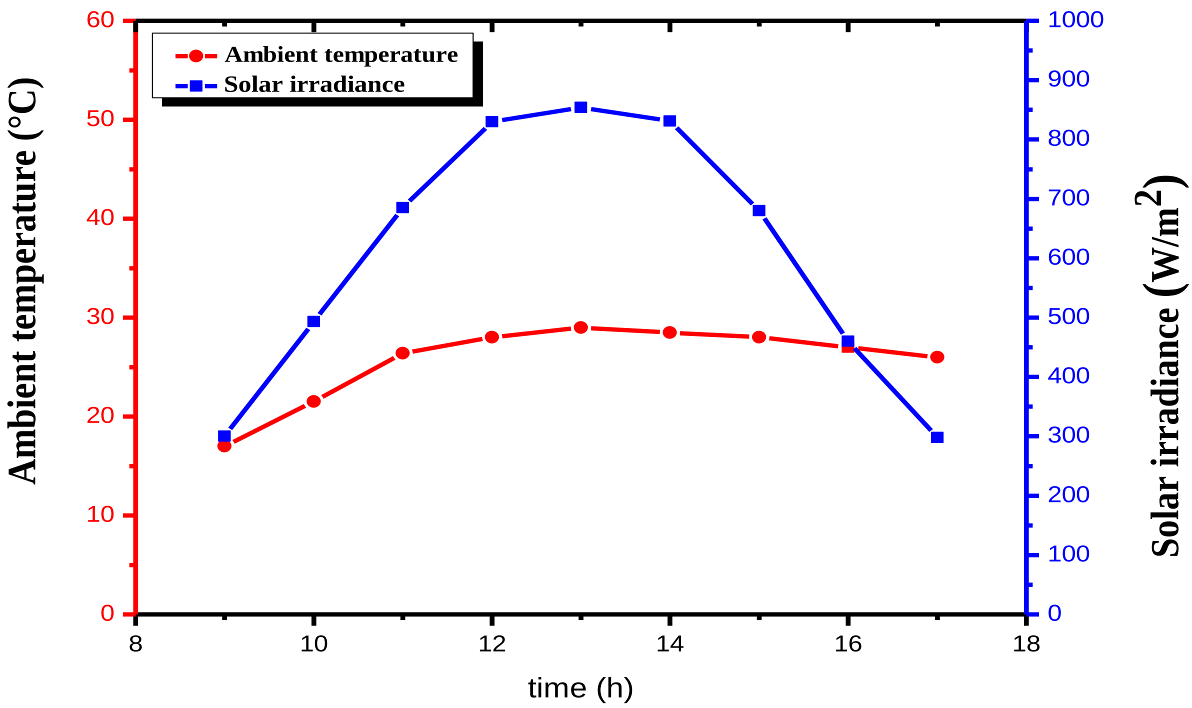
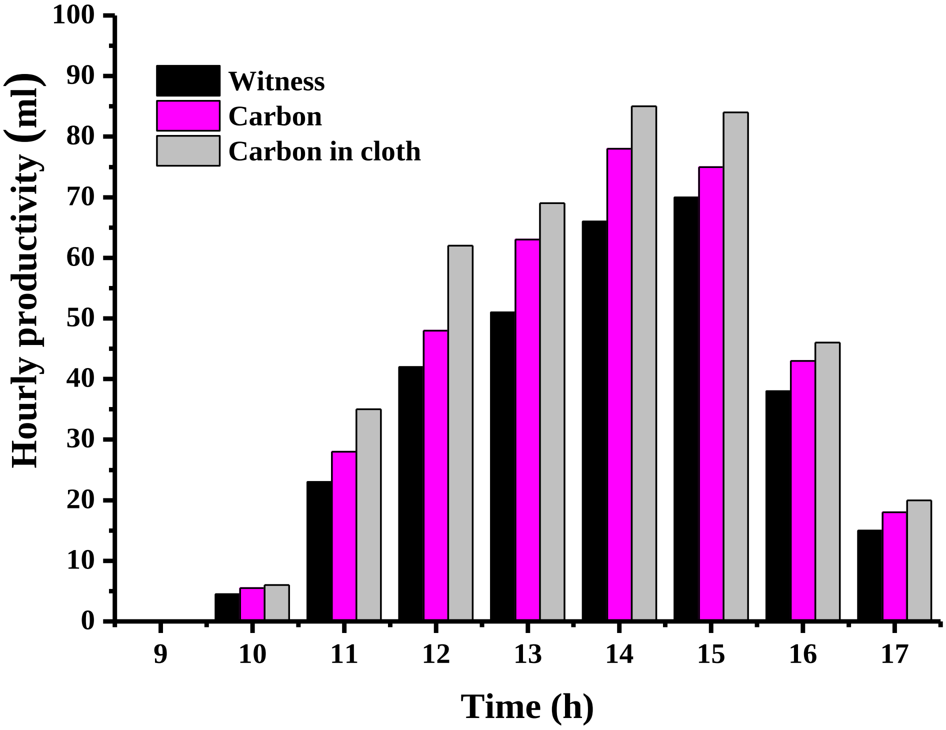


Figure IV.4 Solar intensity and ambient temperaturevs.local time.

Figure IV.4 presents the evolution of ambient temperature and solar radiation versus local time for our experiment location From the results recorded, we note thatThe solar intensity, as usual, begins to increase in the morning until the middle of the day, when it will reach its maximum, which is 854 W/m2, recorded at 1:00 p.m., then decrease again at the end of the day.The path of the ambient temperature curve is similar to that of the intensity (they have the same trend); the maximum recorded temperature is 29 °C at 1:00 p.m.



FigureIV.5The hourly prouductivity of all units versus local time.

FigureIV.5 displays the hourly productivity of the three stills' versuse local time,The result obtained shows that the haourly yield is directly related to the solar intensity.The highest results were recorded between 12:00 AM and 2:00 PM local time.The mean hourly productivity of each unit was calculated at the end of the experiment as folows : 143.29 ,161.13 and188.41 ml.m^{-2}.h^{-1} for the units with carbon, carbon in cloth, and the reference unit, respectively.The unit with the carbon in the cloth was the best,This was explained by the function of the fixed black cloth ,witchit contributes to the stability of the carbon particles on the absorber surface, which allows the water to absorb the maximum solar rays and improves the rate of vaporation of water in the still, resulting in an increase in the productivity of distilled water.

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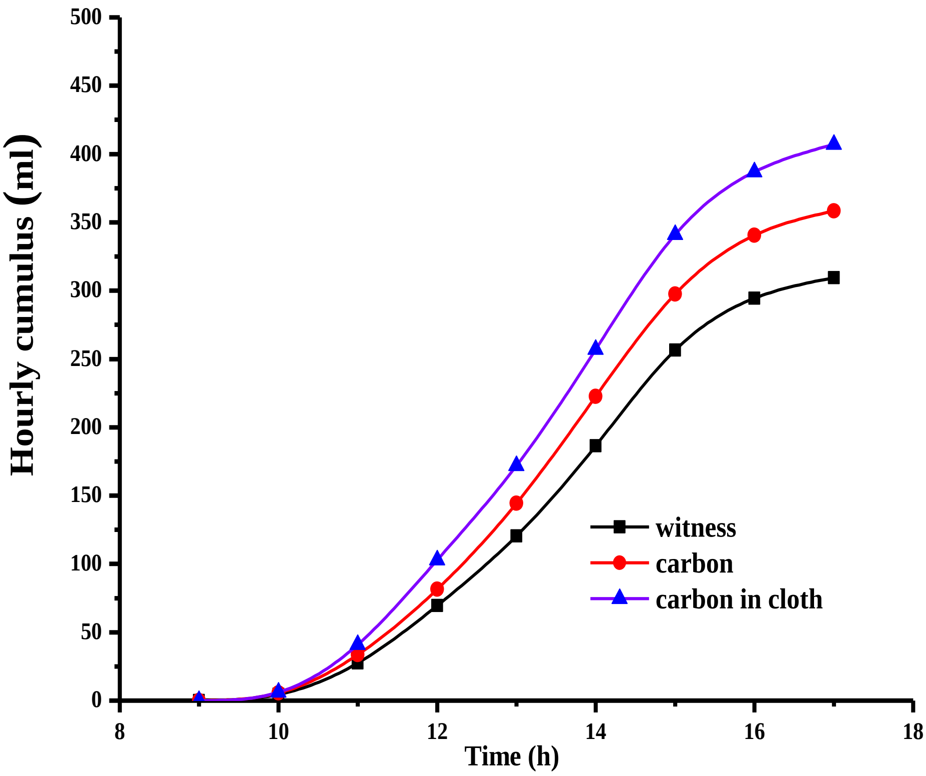


FigureIV.6 Hourly cumulus for each studied unit versus local time.

The daily distillate yield for each unit is displayed in Figure IV.6 ; the modified solar stills have produced more distillate overall at the end of the experiments than the witness recorded. The presence of carbon and its effects are responsible for the improved distillate output; the cumulus for all units is 1.7, 1.49, and 1.29 L/m^2/d produced by various units: with carbon, carbon in cloth, and the conventional still. Lastly, the productivities of the modified unit are increased by 15,83% and 31,5%, respectively, in comparison to the baseline case. Based on this result, we can say that the idea of puting carbon pouder in black cloth is recommended

IV.3.First experience

IV.3.1.Solar intensity and ambient temperature

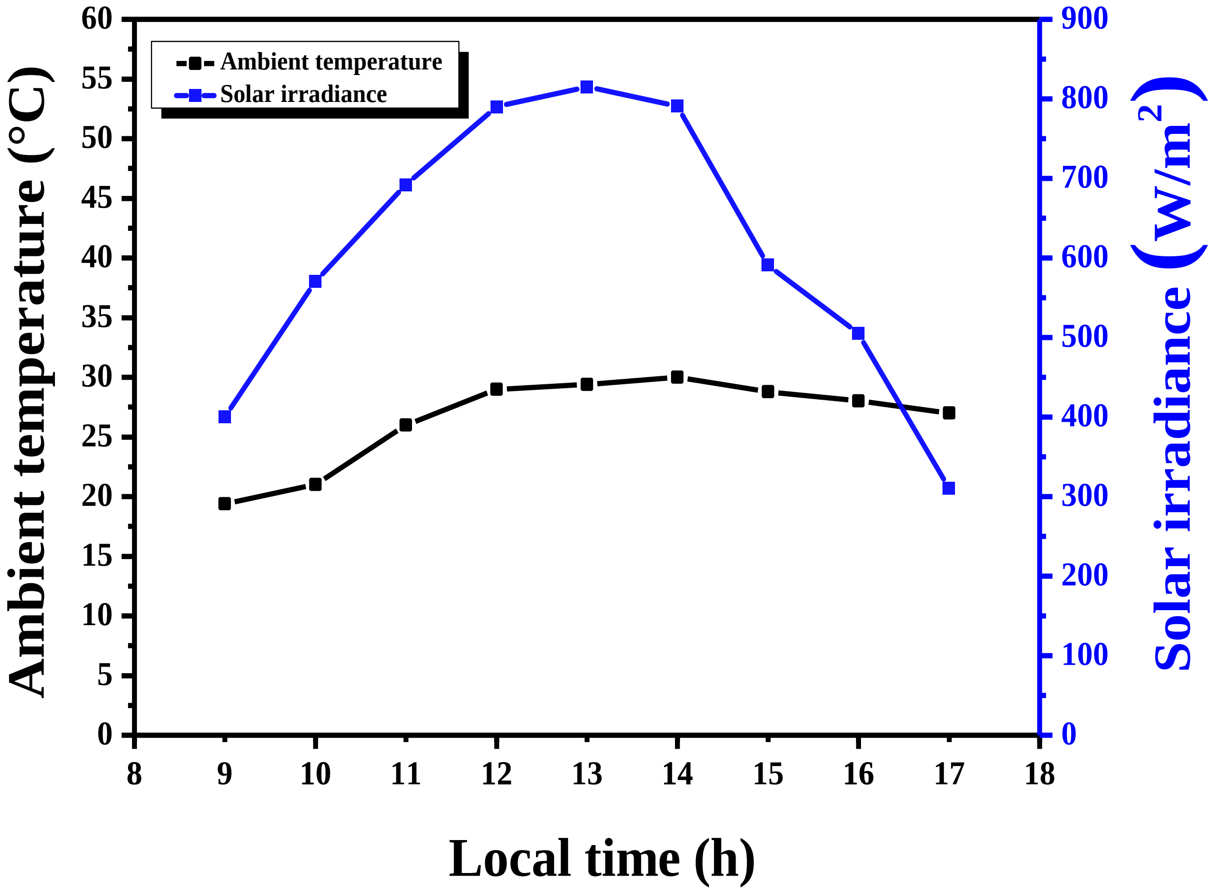
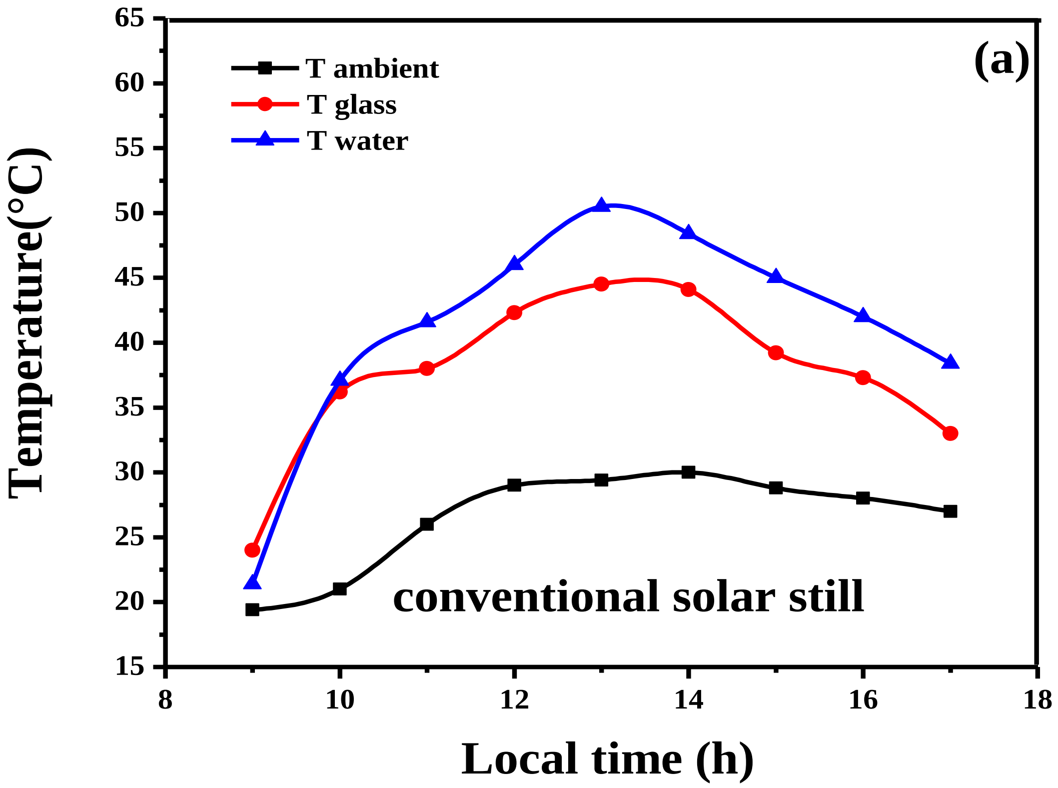
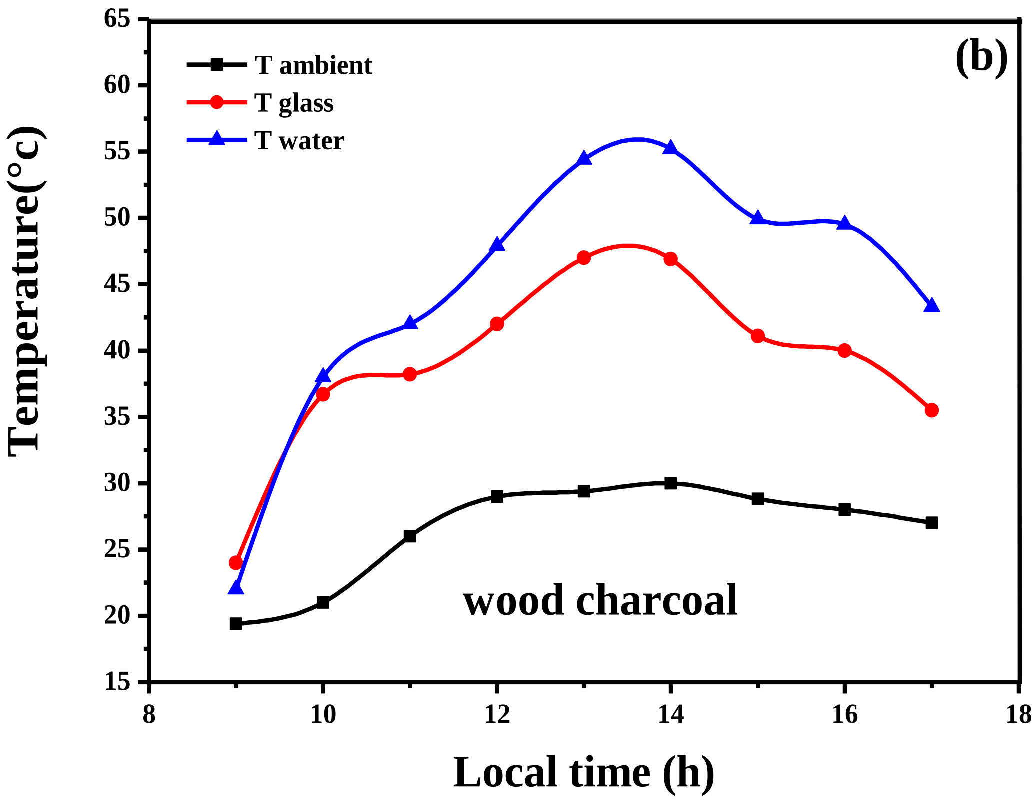


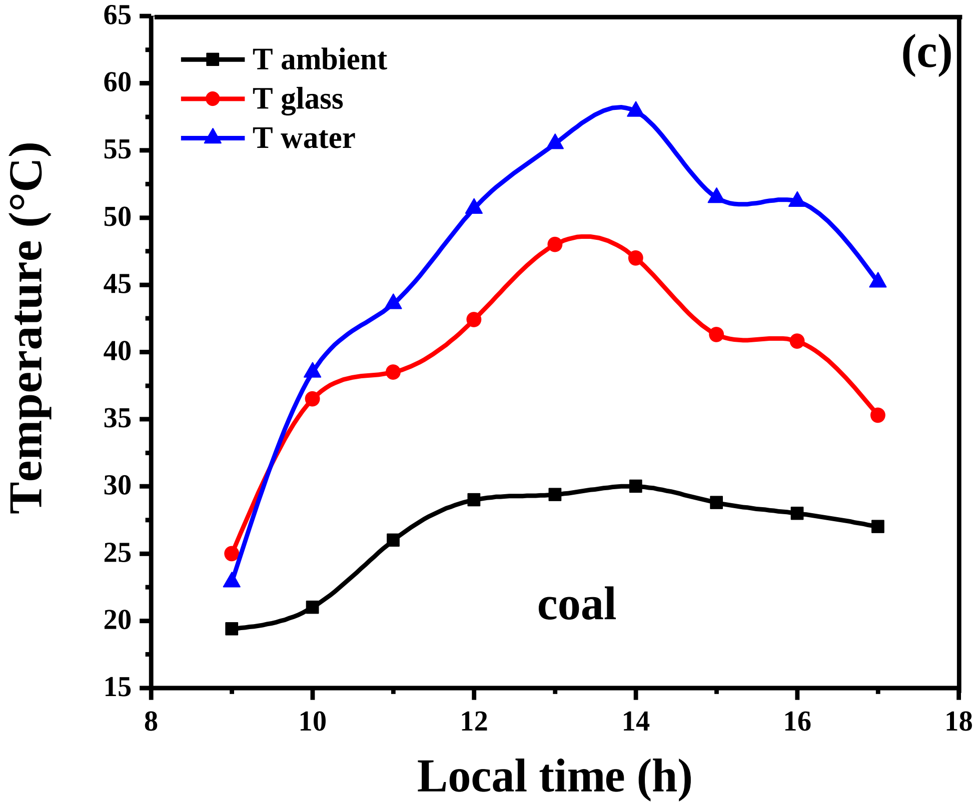
Figure IV.7 Temperature and solar irradiation versus local time

Figure IV.7displays the ambient temperature and solar irradiance measurements for our experiment location as a function of local time. In our trials, solar irradiation increases during the first part of the day and reaches its peak between 12:00 AM and 2:00 PM. After that, it begins to decrease in the afternoon. The highest value measured was 815 W/m^2 at 1:00 p.m. local time. Between 19.4 °C at 9:00 a.m. and 30 °C at 2:00 p.m., the measured ambient temperature fluctuated.

IV.3.2. Variation of different temperatures in solar stills







(c)
T ambient
T glass
T water
coal
Temperature (°C)
Local time (h)
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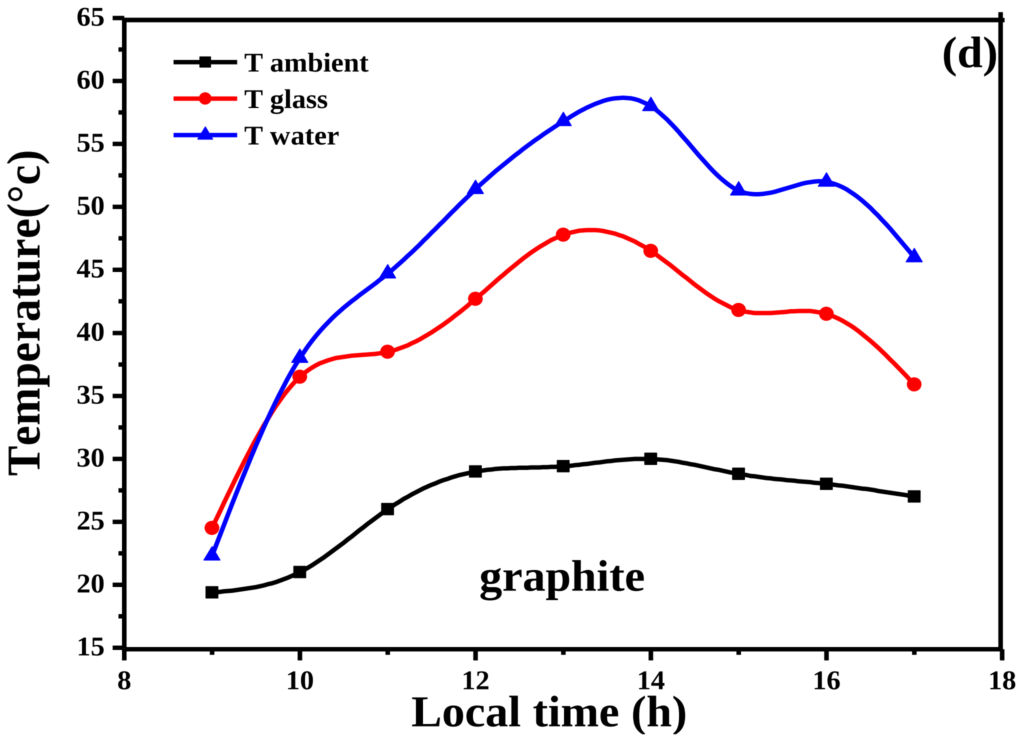

(d)
T ambient
T glass
T water
graphite
Temperature(°c)
Local time (h)
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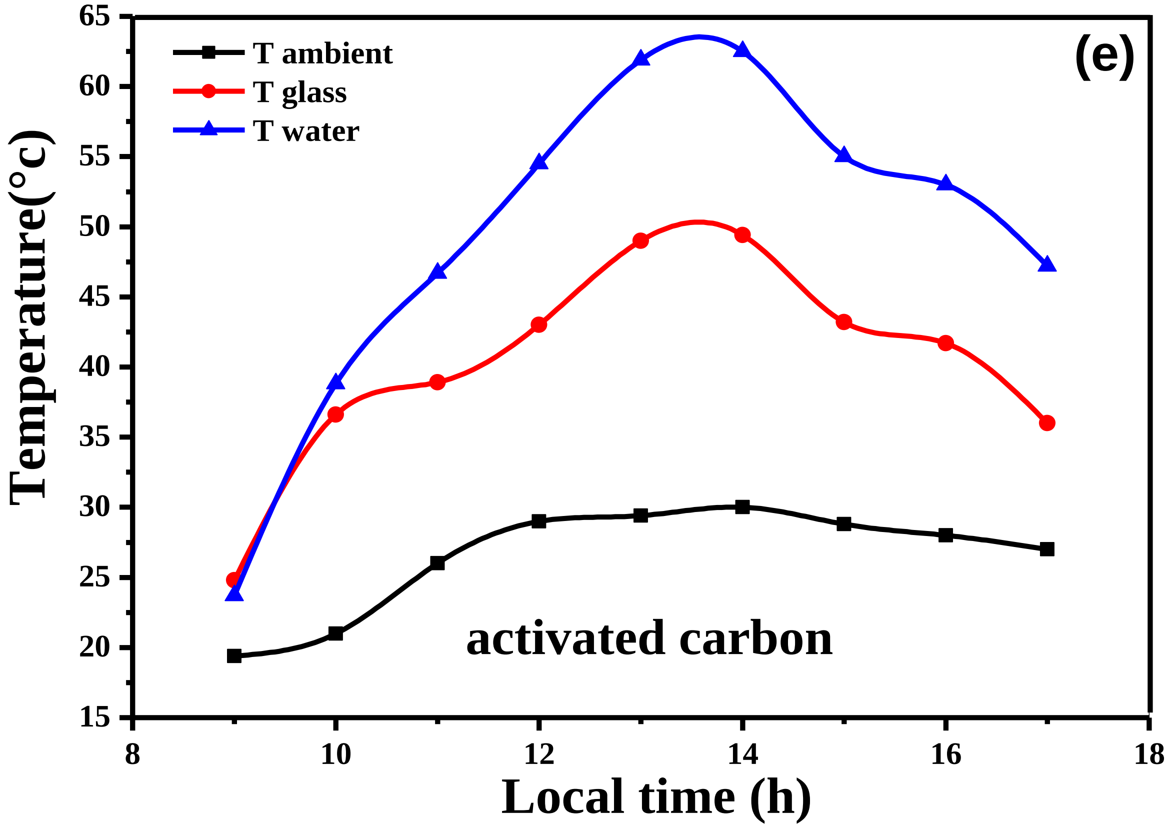


Figure IV.8 : Diverse temperatures for (a) traditional solar still, (b) wood charcoal unit, (c) coal unit, (d) graphite unit, and (e) activated carbon unit.

The temperatures of the various units (ambient, glass cover, and brackish water) are shown in Figures IV.8 (a–e) is vs. local time. The majority of the temperature curves in the test andreference stills show a similar tendency to solar radiation.The greenhouse effect causes stills' interior temperatures to typically be high.

All of the temperatures still reach their maximum values between 1:00 PM and 2:00 PM. The brackish water temperature (Tw) is the highest recorded temperature for the still; this is because the absorber absorbs sun radiation, which raises the temperature of the water in the basin. The temperature of the glass cover came next, and the lowest outside temperature came last. At 2:00 PM, the maximum brackish water temperature ever measured in the activated carbon solar still unit was 62.5°C. The activated carbon unit, the graphite unit, the coal unit, the wood charcoal unit, and the reference unit have recorded average glass-cover temperatures (Tg) of 40.28, 39.5, 39.42, 39.04, and 37.62°C, respectively.

These temperatures show the amount of heat from vapour condensation, which causes the inner surface of the glass cover to get warmer. Overall, we can observe that for every experiment, the water's temperature in the basin (Tw) is higher than the condenser's (the inside surface of the glass cover: Tg) temperature. The value of the space between them usually indicates how much distilled water was collected.

IV.3.3. temperature differential between the condenser and the water in the basin

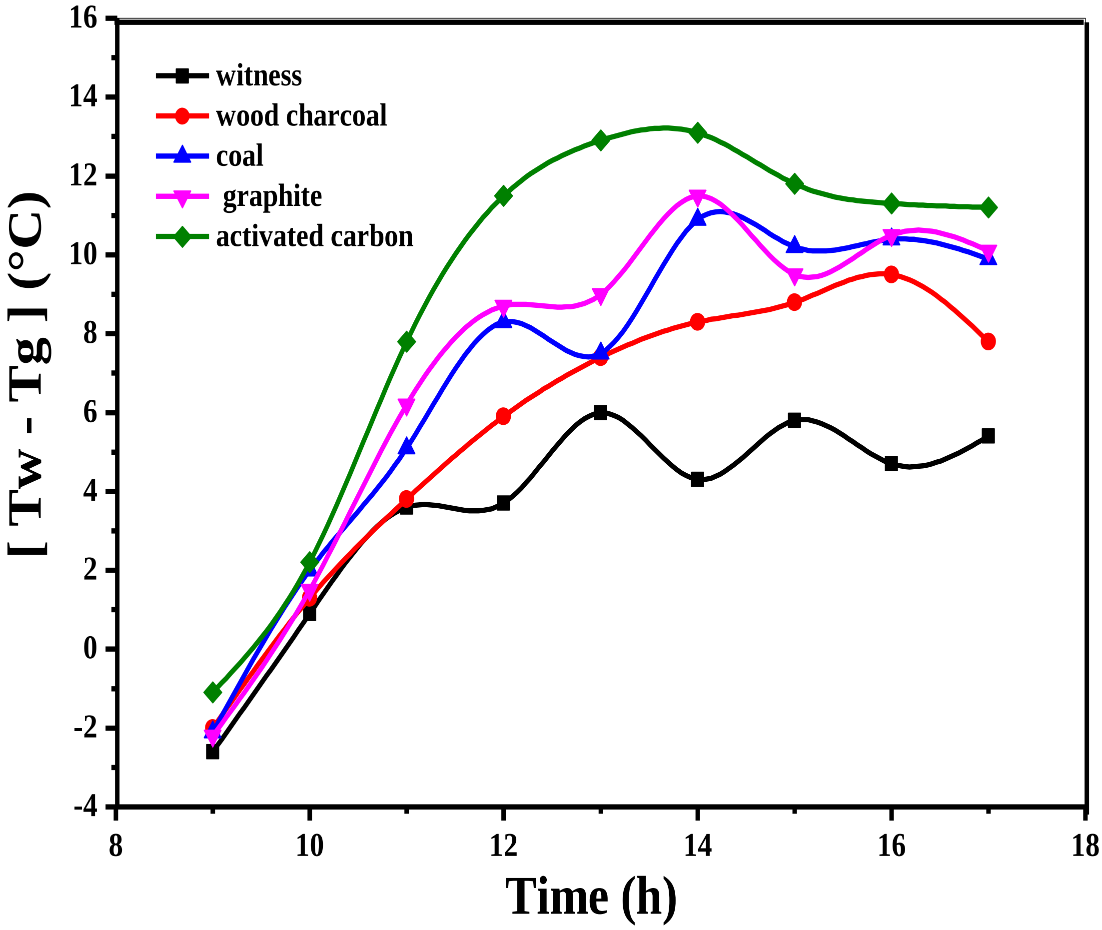


Figure IV.9:The temperature differential between the condenser and the basin's water for each unit.

The temperature differential for each of the five stills—between the water in the basin (Tw) and the condenser (Tg)—is shown in Figure IV.9. In general, for distillation to take place, the temperature of the water in the basin (Tw) needs to be higher than the condenser temperature (Tg). The volume of distilled water directly reflects the difference between them. The maximum value recorded at 2:00 PM for the unit with activated carbon was 13.1 °C, while the gap for same unit was 8.96 °C.The maximum value recorded at 1:00 PM local time is 6 °C, while the rate value of the gap, measured in the witness unit, is 3.53 °C. The observation that the gap for all stills was negative (Tg> Tw) at the start of the experiment is surprising. This could be explained by the fact that, prior to 9:00 AM, the sun's rays strike the glass cover first before reaching the water in the basin. Because of thermal inertia, the water in the basin retains the temperature of the previous night, which is why we see that the glass's temperature is slightly higher than the water's, producing a negative difference that won't be seen later.

IV.3.4.Haourly prouductivity of distilated water

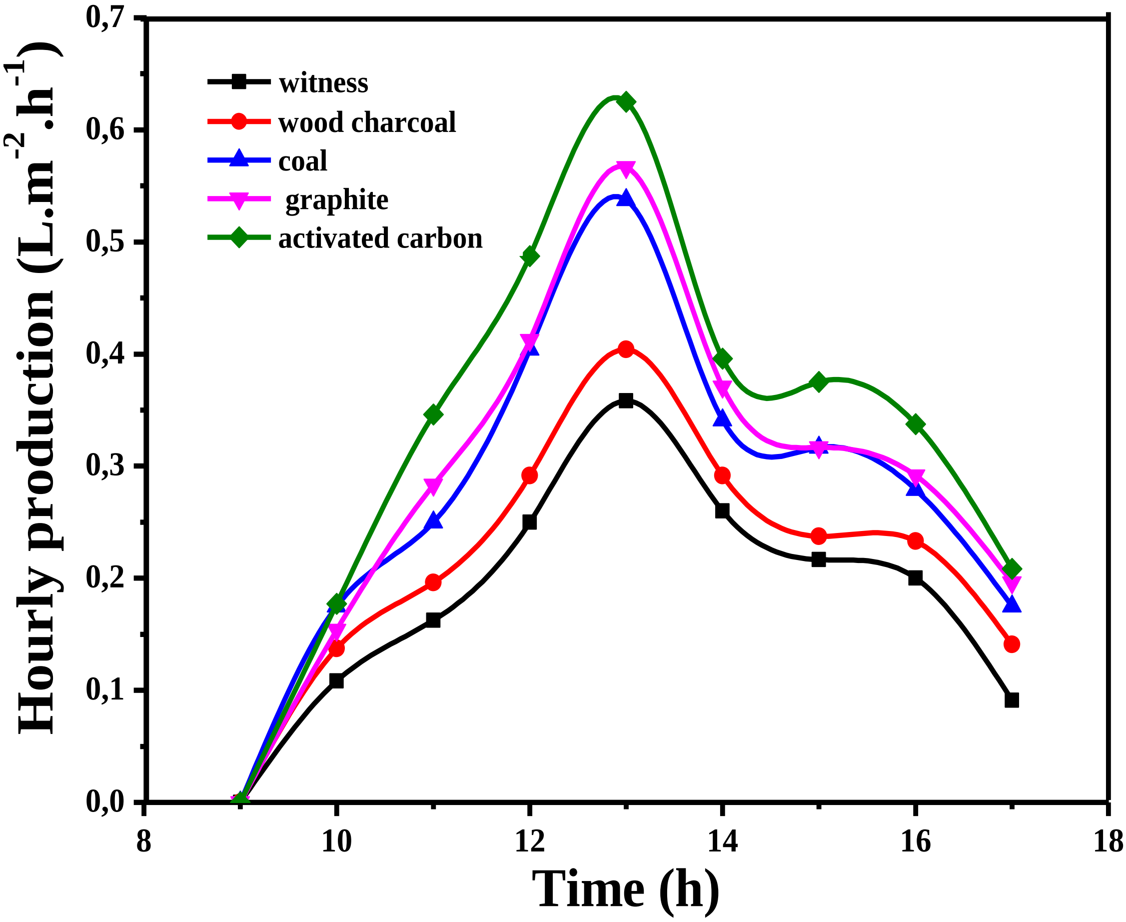


Figure IV.10All units' hourly productivity vs. local time.

The hourly production of the five stills versus local time is shown in Figure IV.10. The hourly production and sun irradiance have a direct relationship based on the tendency of the curves. The highest readings were recorded between 12:00 AM and 2:00 PM local time. The average hourly productivity of each unit was calculated at the conclusion of the experiment and was 0.3690, 0.3239, 0.3097, 0.2243, and 0.2062 L/m2/h for the units that contained activated carbon, graphite, coal, wood charcoal, and the reference unit, respectively.

The unit with activated carbon proved to be the most effective. This can be attributed to the carbon's dual function as a heat-absorbing medium and its higher porous structure than other forms of carbon, which increases surface area and enhances the rate of evaporation. Moreover, graphite is clearly superior to other forms of carbon due to its high thermal conductivity value of 139 W/m/K. Generally speaking, brackish water's temperature, mass, and heat transfer coefficients increase under high irradiance, which aids in explaining the observed increase in output.

IV.3.5.Daily prouductivity of distilated water

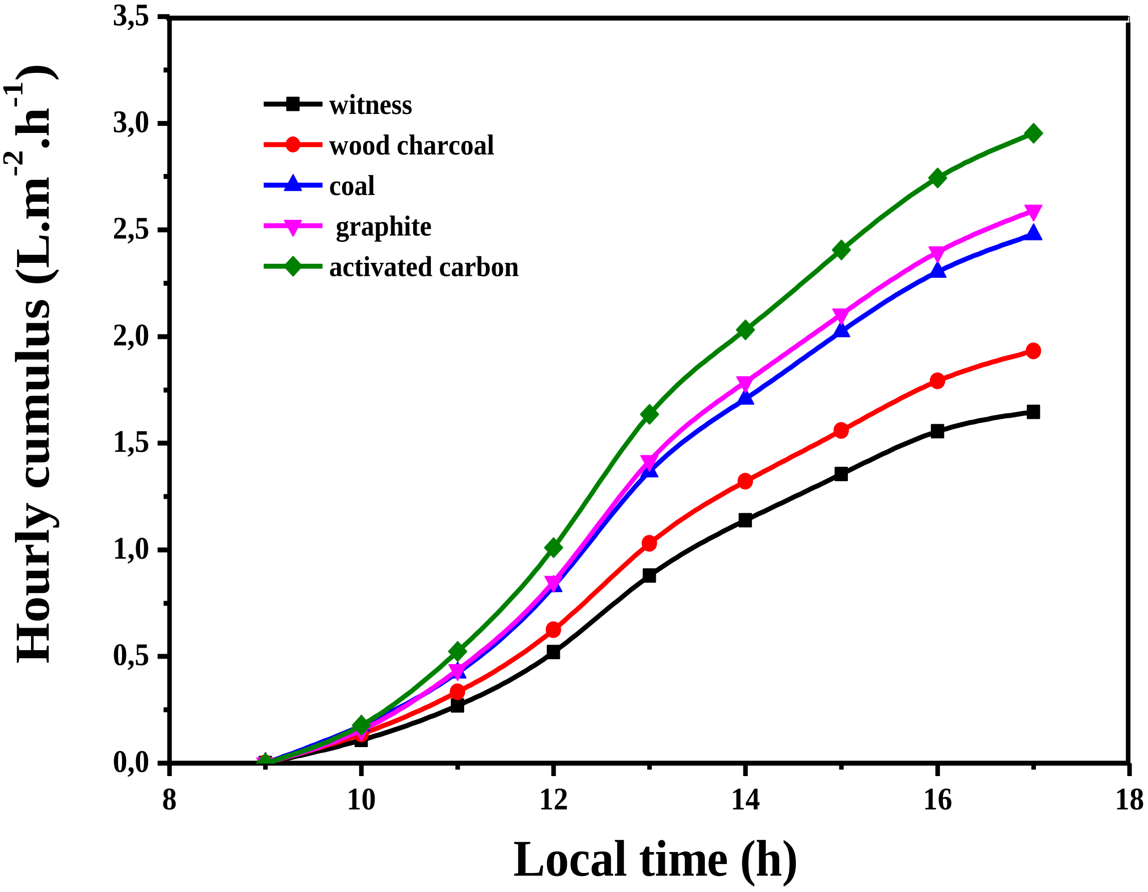


Figure IV.11All units' daily productivity vs. local time.

At the end of the studies, the modified solar stills had more total distillate than the witness recorded; Figure IV.11 shows the daily yield of distillate for all units. Distillate output has improved as a result of the presence of various forms of carbon and their effects. Utilising variety of carbon units, including activated carbon, graphite, coal, wood charcoal, and the traditional still, the cumulus for all units is 2.96, 2.60, 2.48, 1.95, and 1.65 L/m2/d. At last, the modified unit's productivities are higher than the baseline instance by 79.39%, 57.58%, 50.30%, and 18.18%, respectively.

IV.3.6Results of the water analysis

We assessed the quality of brackish and distilled water (with and without different forms of carbon) using salinity, pH, total dissolved solids (TDS), and electrical conductivity measurements. Table 1. provides a summary of the findings from these investigations.

According to this investigation, the inclusion of various carbon types results in an increase in still production as well as an improvement in the quality of distilled water because of carbon's porous structure and other physicochemical features that cause organic and inorganic contaminants to adsorb.

Based on those studies, the distilled water quality conforms with W.H.O.'s permitted value [42]. The unit producing the distilled water with activated carbon had the best quality. This is because activated carbon is primarily employed for water treatment applications.

Table IV. 1 Results of the Water Analysis .

The quality of water	Salinity (%)	Conductivity (µs/cm)	TDS (mg/L)	pH
Brackish water	1.6	3165	1586	8.07
Distilled water (witness)	0.02	35	17	6.92
Distilled water (Wood charcoal)	0.02	49	25	6.8
Distilled water (coal)	0.02	34	17	7.06
Distilled water (graphite)	0.01	35	19	6.51
Distilled water (activatedcarbon)	0.01	16	8	6.6

IV.4.Secondexperience

IV.4.1. Solar intensity and ambient temperature

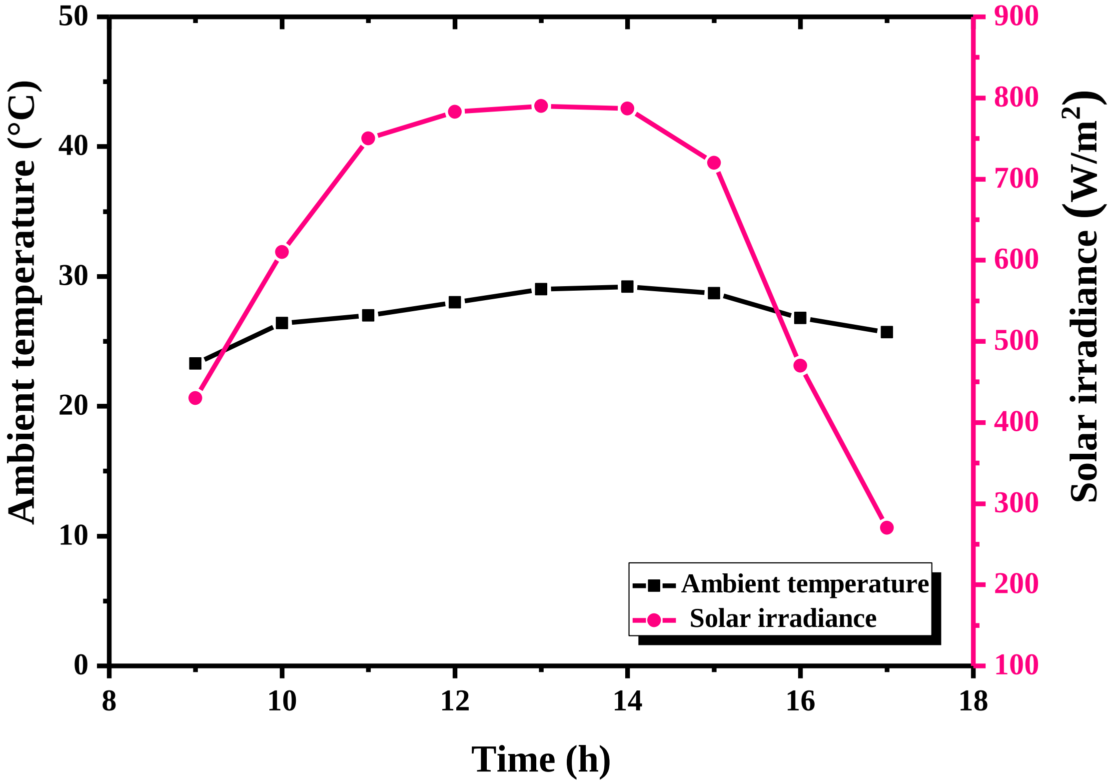
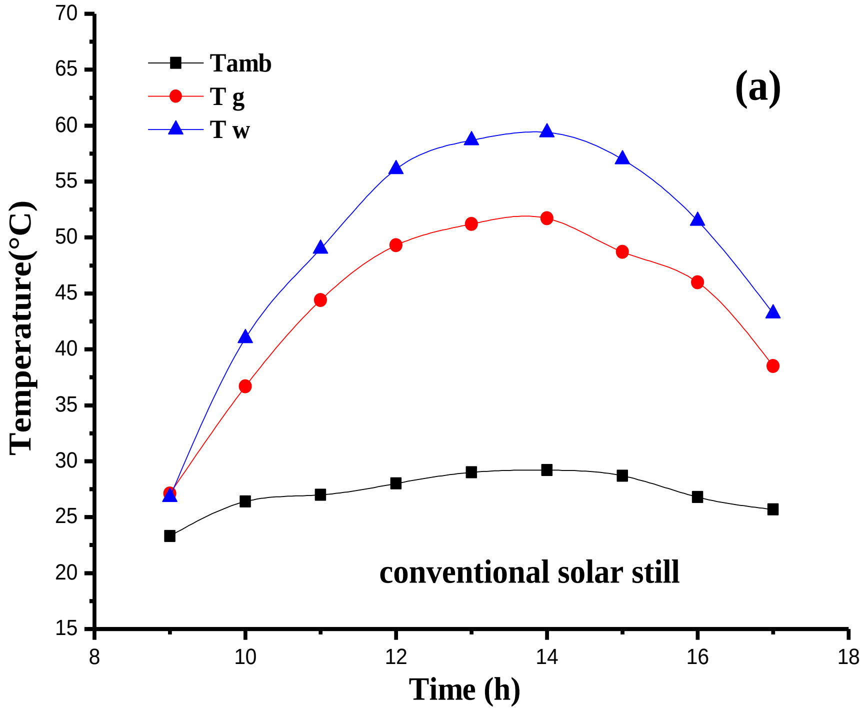
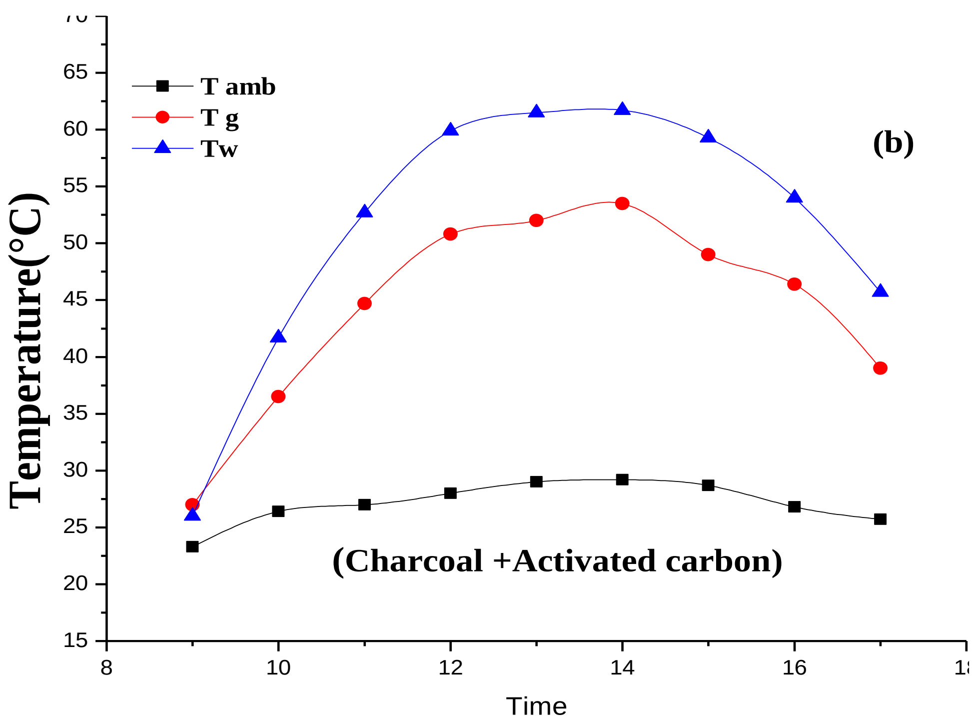


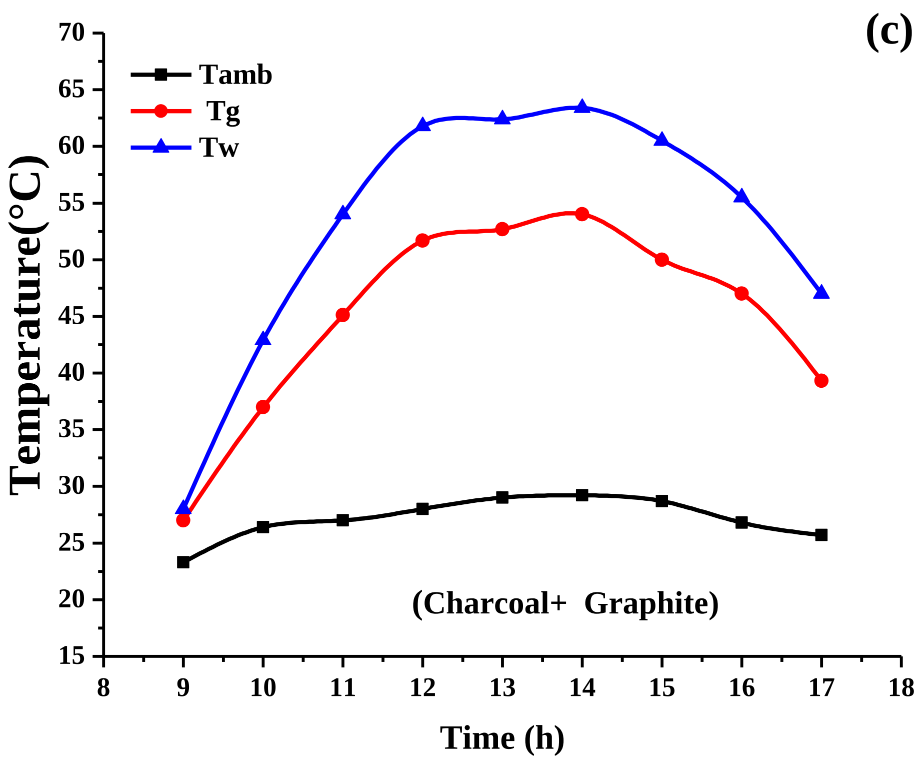
Figure IV.12 Ambient temperature vs. solar radiation during the experimentation.

The progression of solar radiation and ambient temperature versus local time for our experiment location is shown in Figure IV.12 The data show that, as is typical, the solar intensity increases in the morning and continues to do so until midday, when it reaches its maximum of 790 W/m2, which is recorded at 1:00 p.m. The solar intensity subsequently decreases once more at the conclusion of the day.The ambient temperature curve follows a similar course to the intensity curve, exhibiting a similar trend. The highest recorded temperature was 29.2 °C at 2:00 p.m.

IV.4.2. Variation of different temperatures in solar stills







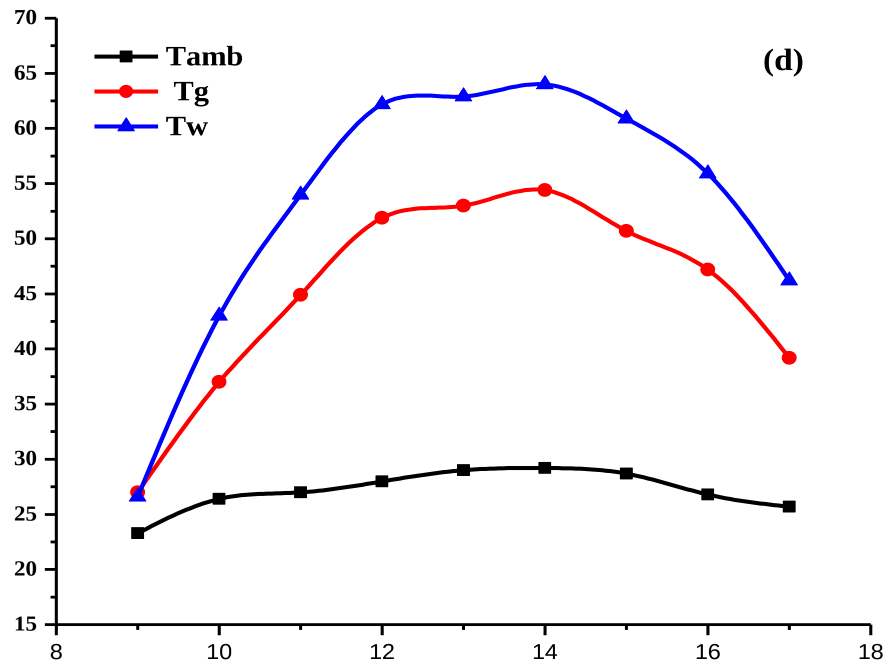


Figure IV.13Diverse temperatures for (a) conventional solar still, (b) (Activated carbon+ charcoal) unit, (c) (Graphite +Charcoal) unit, (d)(Graphite + Activated carbon) unit.

Figures IV.13 (a–d) represent the temperatures of the various units (ambient, glass cover, and brackish water) vs. local time. Most of the test and reference stills' temperature curves exhibit a similar tren trend solar radiation.

Between 12:00 AM and 2:00 PM, all of the temperatures still reach their highest points. The absorber's ability to absorb solar radiation causes the water in the basin to heat up, resulting in the brackish water temperature (Tw) being the highest temperature ever recorded for the still.

The highest brackish water temperature ever recorded in the solar still unit with activated carbon and graphite was 64°C at 2:00 PM.

IV.4.3.temperature differential between the condenser and the water in the basin

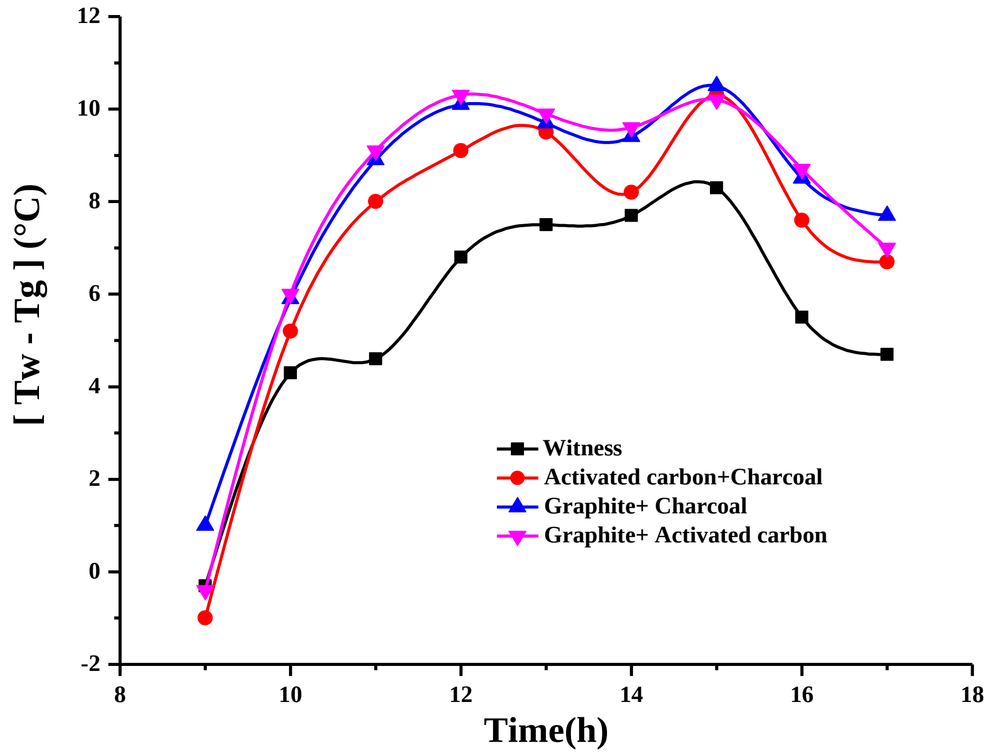


Figure IV.14The temperature differential between the condenser and the basin's water for each unit.

Figure IV.14 displays the temperature differential for each of the four stills, from the water in the basin (Tw) to the condenser (Tg). Generally speaking, the water in the basin (Tw) must be hotter than the condenser (Tg) in order for distillation to occur. The difference between them is directly reflected in the volume of distilled water.

The unit containing graphite and activated carbon recorded a maximum temperature of 10.1 °C at 12:00 AM; the same unit's gap was 7.82 °C.The rate value of the gap, measured in the witness unit, is 5.45 °C, whereas the maximum value, recorded at 2:00 PM local time, is 7.7 °C.

IV.4.4.Haourly prouductivity of distilated water

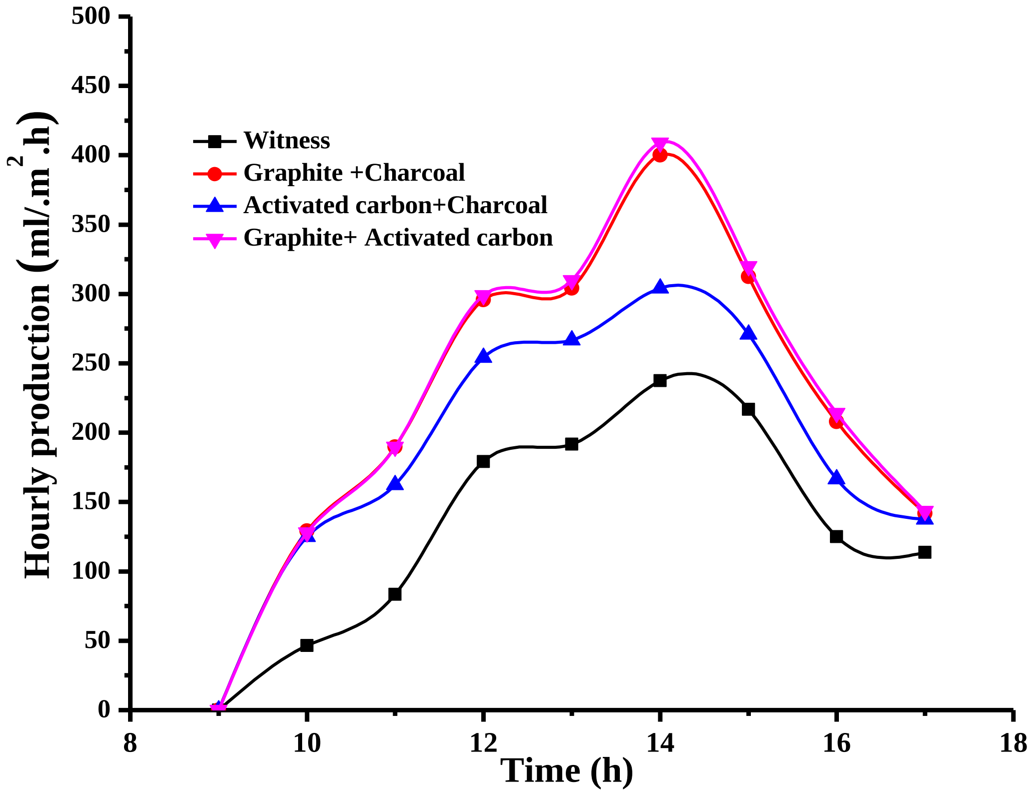


Figure IV.15 All units' hourly productivity vs. local time.

Figure IV.15 displays the hourly production of the four stills versus local time. Based on the curves' tendencies, there is a direct correlation between the solar irradiation and hourly production. Between 12:00 AM and 2:00 PM local time, the greatest readings were noted.

At the end of the experiment, the average hourly productivity of each unit was determined. For the units containing (activated+graphite), (graphite+charcoal), (activated carbon +charcoal), and the reference unit, it was 223,64, 220,1,187,5, and 132,62 mL/m^2/h, respectively.

IV.4.5.Daily prouductivity of distilated water

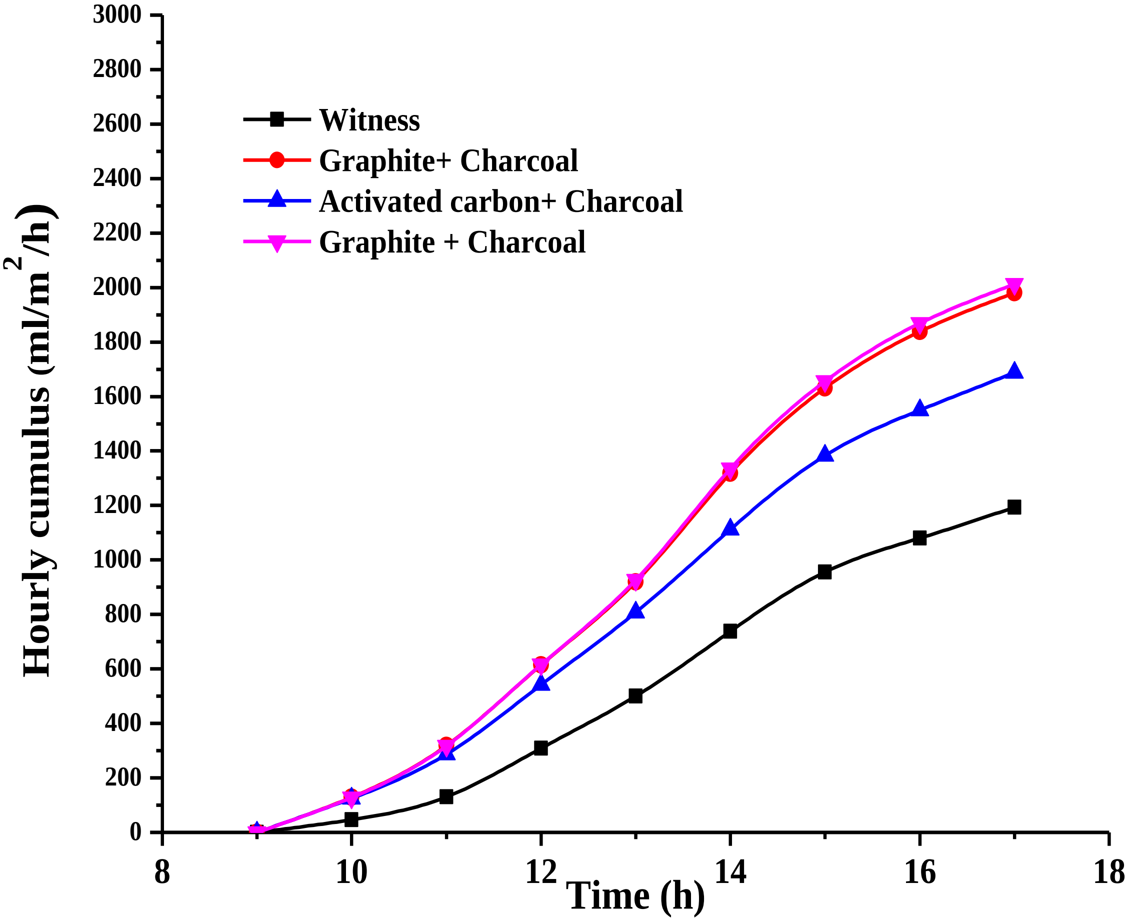


Figure IV.16 Hourly cumulus for each studied unit versus local time.

The modified solar stills produced more distillate overall at the end of the studies than the witness recorded; Figure IV.16 displays the daily yield of distillate for all units. The presence of different carbon mixtures and their effects has improved distillate output; using a variety of carbon units, such as (activated carbon+graphite), (graphite+charcoal), and (activated carbon+charcoal),witness, the cumulus for all units is 2.01, 1.98, 1.69, and 1.19 L/m2/d. Lastly, the modified unit's productivities are higher than the baseline instance by %, 68.9%, 66,38%, and 42,01%, respectively.

GENERAL CONCLUSION

GENERAL CONCLUSION

In Algeria, as in developing countries, the demand for drinking water is expected to increase due to urbanization, population growth and climate change ; the threat ofunsustainable means of supplying drinking water is leading to the examination of various renewable energy sources to create a cleaner and more efficient solution for supplying drinking water. Various modular technologies existed, in which potable water can be produced, but these turned out to be quite expensive because large and very complex designs involved.

It is necessary that the design technology be simple, affordable, and durable. Conventional solar stills are a method of supplying potable water using a free, renewable energy source. The work carried out focuses on the development of solar desalination in order to increase water security in arid and desert regions where solar radiation is generally widely available, as well as groundwater resources.Generally, improving solar still productivity can be achieved by improving evaporation, condensation, and reducing heat loss.

Increasing the rate of water evaporation in solar stills is one of the most efficient techniques. This can be done by several methods including increasing the temperature of the pond water, using additives

The addition of absorbent materials, which are crucial to the field of solar distillation because they improve water absorption to solar irradiation, is one way to improve the productivity of distilled water.

In this research, we study the impact of four different types of carbon namely: activated carbon, graphite, coal and wood charcoal , to improve the efficiency of traditional solar still. The tests were carried at the Ouargla University in southern Algeria

The experiments carried out are divided into two parts as follows:

In the first part we tested using four different types of carbon namely: activated carbon, graphite, coal and wood charcoal which they are added separatelywithin each absorber with the same weight 100g .i.e (0.4167kg carbon/m^2 of absorber area).

After carrying out the set of experiments, we drew the following conclusions:

- The performance of the solar still was improved by using different types of carbon, which raised water absorption for solar radiation and increasing the temperature of the water inside the distiller.

- The carbon pouder helped to improve the rate of evaporation by enlarging the exchange area.

- Activated carbon is one such material with desirable absorption properties for the application of solar distillation wich has highly porous structure increases the coefficient of heat transfer and excellent solar absorption behavior.

- The addition of 100g of each of activated carbon, graphite, coal, and wood charcoal separately within the absorbers of the four separate units increases the solar still's production by: 79.39%, 57.58%, 50.30% and 18.18% respectively relative to the witness.

- The idea of putting carbon powder inside a fixed black cloth on the absorber surface is recommended in the process of solar distillation because it contributes to the stability of the carbon particles on the absorber surface, which allows the water to absorb the maximum solar rays, resulting in an increase in the productivity of distilled water.

- The physical analysis shows that using different types of carbon as absorbent materials produces distilled water of high quality.

In the second part of the experiments concerning the study of the effect of three different mixture types of carbon, namely: (charcoal+activated carbon), (charcol+graphite), and (graphite+activated carbon), we used the same mass of 100 g of each one, i.e., 0.834 kg/m2 of absorbing area.

The results obtained showed that:

The presence of different carbon mixtures (charcoal+activated carbon), (charcoal+graphite), and (graphite+activated carbon) has improved distillate output by 42,01%, 66,38%, and 68.9%, respectively, relative to the baslin case.

Annex A

Measurement tools

Figure A.1 : Hot wire anemometer

Figure A.2 : Solari metre

Figure A.3 : Instrument for measuring ambient temperature and humidity (hygrometer).

Figure A.4 : Temperature-measuring instrument (thermocouples)

Figure A.5 :Graduated test tube