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Thèse présentée pour l'obtention du diplôme de

Doctorat LMD

en

Génie mécanique

Spécialité : énergétique

Préparé dans le laboratoire VTRS de l'université d'El oued

Présenté par
Abderrahmane Khechekhouche

Thème :

Amélioration d'un distillateur solaire plan à effet de serre dans la région sud-est de l'Algérie

Devant le jury:

Dr. Djilani Necib	MC.A. Université d'El oued	Président
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Année universitaire 2018-2019

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Summary

Dedications

To my father Talha and mother Saida, may God have mercy on them.

To my Wife Leila and my beautiful kids Manel, Ahmed, Taha and Rami.

To my dear sisters Horia, Monia, Aicha for their constant encouragement, and their moral support,

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Publications list

Publications

1. **A. Khechekhouche**, A. Boukhari, Z. Driss, N.E. Benhissen , Seasonal effect on solar distillation in the El-Oued region of south-east Algeria, international journal of energetica, Vol 2, n° 1, 2017. pp 42-45.http://www.ijeca.info
2. **A. Khechekhouche**, B. Ben Haoua, Z. Driss, Solar distillation between a simple and double-glazing, revue de mécanique. Vol 2, n° 2. 2017. DOI : 10.5281/zenodo.1169839. http://www.cuniv-tissemsilt.dz/RDM/
3. **Abderrahmane Khechekhouche**, Benhaoua Boubaker, Mruthu Manokar, Ravishankar Sathyamurthy, Abd elnaby Kabeel. Exploitation of an insulated air chamber as a glazed cover of a conventional solar still. Heat Transfer - Asian Research. Doi:10.1002/htj.21446
4. **Abderrahmane Khechekhouche**, Boubaker Benhaoua, Abd elnaby Kabeel, Mohammed El Hadi Attia, Wael M. El-Maghlany. Improvement of solar distiller productivity by a black metallic plate of Zinc as a thermal storage materials. 2019, Journal of Testing and Evaluation.https://doi.org/10.1520/ 9 JTE20190119
5. **Abderrahmane Khechekhouche**, Boubaker Benhaoua, Zied Driss, Mohammed El Hadi Attia, Mokhtar Ghodbane,Muthu Manokar, Zied Driss. Polluted Groundwater Treatment in Southeastern Algeria by Solar Distillation. Algerian journal of Environmental and Sciences. 2019
6. **Abderrahmane Khechekhouche**, Boubaker Benhaoua, Muthu Manokar, Ravishankar Sathyamurthy, Abd Elnaby Kabeel, Zied Driss. Sand dunes effect on the productivity of a single slope solar distiller. Heat and Mass Transfer Journal. 2019. https://link.springer.com/journal/231
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1. **A. Khechekhouche,** Z. Driss B. Ben Haoua, A**.** Guerdouhet A. Allal, Study of Double-Glazing on the solar sill with a simple effect, International Conference on Mechanics and Energy, ICME’2016, Hammamet, Tunisia**.**(Poster)
2. **Abderrahmane Khechekhouche,** Boubaker Benhaoua, Zied Driss, Ali Boukhari, Mohammed El Hadi Attia, Solar Distillation Between Heat Transfer and Productivity, First Arab Conference on Mechanical Engineering (ARCME’17), December 10-11, 2017, Biskra, Algeria. (Poster)
3. **Abderrahmane Khechekhouche**, Zied Driss, Boubaker Benhaoua, Mohammed El Hadi Attia, CFD simulation of the solar distiller improvement (Preheating),

International Conference on Mechanics and Energy (ICME'17), December 18-20, 2017, Sousse, TUNISIA. (Oral communication)

4. **Abderrahmane Khechekhouche**, Mohammed El Hadi Attia, Ali Boukhari, Mruthu Manokar, Boubaker Benhaoua, Zied Driss, Mokhtar Ghodbane, Effect of cover thickness on the yield of a solar distiller under the El oued climate, Algeria. International Symposium on Technology & Sustainable Industry Development, ISTSID'2019, Algeria, 2019. (Oral communication)
5. **Abderrahmane Khechekhouche**, D. RA Rajendran, A. Muthu Manokar, Kritika Gupta. Application of solar energy in excess agricultural production. Conference: International Conference on Advancements in Mechanical Engineering (ICAME 2019) At: Jyothi Engineering College, Kerala, India. 2019.
6. **Abderrahmane Khechekhouche**, Donia Djaballah, Ali Sadoun, Imad Kemerchou, Abderlkader Hima, Zied Driss, Effect of fins on the conventional solar still productivity. Fifth International Conference on Mechanics and Energy "ICME'2019", Tunisia. (Poster).

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5. **Abderrahmane Khechekhouche**, Benhaoua Boubaker, Zied Driss, Technical and process for the production of distilled water. Study Day on Green Chemistry and Bioactive Substances - JECVSB 18. Algeria. (Poster)
6. **Abderrahmane Khechekhouche**, Benhaoua Boubaker, Zied Driss, Mohammed el hadi Attia, Nabil Elsharif, Solar distillation and water treatment, Valorization and sustainable management of water resources (VGDRH'2018), 2018, Algeria
7. **Abderrahmane Khechekhouche**, Boubaker Benhaoua, Zied Driss, Mokhtar Ghodbane, A. Muthu Manokar, Energy balances in solar distillation, National symposium on green energies NSGE'19, Algeria (Poster).
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Nomenclature

	Nomenclature	Units
Q_{rw_gi}	Thermal radiation flux between the water film and the glazing	W/m^2
$Q_{cv.w\_gi}$	Thermal flow by convection between the water film and the glazing	W/m^2
Q_{evap}	Evaporative-condensation heat flux between the water film and the glazing	W/m^2
$Q_{cd.gi\_ge}$	Heat flow lost by conduction through the glazing	W/m^2
$Q_{cd.ge\_gi}$	Heat flow lost by conduction through the glazing.	W/m^2
$Q_{r.g.\_a}$	Thermal radiation flux between the water film and the outside	W/m^2
$Q_{cv.g.\_a}$	Thermal flow by convection through the glazing	W/m^2
$Q_{cv.b\_w}$	Convective heat flow between the bottom and the water	W/m^2
$Q_{cd.b\_i}$	Thermal flow by conduction between the bottom and the insulation	W/m^2
$Q_{cd.i\_a}$	Thermal flow by conduction between the insulation and the outside	W/m^2
$Q_{r.w\_g}$	Thermal radiation flux between the water and the glazing.	W/m^2
Q_{rg_sky}	Thermal radiation flux between the glass and the sky.	W/m^2
$Q_{cv.g\_a}$	Thermal flux by convection between the glass and outside	W/m^2
$Q_{cv.b\_g}$	Thermal flow by convection between the bottom and glass.	W/m^2
$h_{cv.w.\_g}$	Coefficient of heat exchange by convection water/glass	$W/m^2.°K$
$h_{r.w\_g}$	Radiation heat transfer coefficient water/glass.	$W/m^2.°K$
$h_{e.w\_g}$	Coefficient of heat exchange by evaporation water/glass.	$W/m^2.°K$
h_{evap}	Coefficient d'échange thermique par évaporation	$W/m^2.°K$
h_{rg_sky}	Coefficient of heat exchange by radiation water/sky	$W/m^2.°K$
$h_{cv.g\_a}$	Coefficient of heat exchange by convection glass/outside	$W/m^2.°K$
$H_{cv.b\_w}$	Coefficient of heat exchange by convection bottom/water	$W/m^2.°K$
G	Global solar radiation	W/m^2
A_g	Glass area	m^2
A_w	Water area	m^2
A_b	Bottom area	m^2
A_i	Insulation area	m^2
M_g	Mass of glass	Kg
M_w	Mass of water	Kg
M_b	Mass of bottom	Kg
M_i	Mass of insulation	Kg
C_{pg}	Mass thermal capacity of glass	J/kg K
C_{pw}	Mass thermal capacity of water	J/kg K
C_{pb}	Mass thermal capacity of bottom	J/kg K

C_{pi}	Mass thermal capacity of insulation	J/kg K
T_{ge}	Uitside glazing temperature	°K
T_{gi}	Inside glazing temperature	°K
T_w	Water temperature	°K
T_b	Botton temperature	°K
T_i	Insulation temperature	°K
P_w	Partial pressure of water	N/m^2
P_{gi}	Partial pressure of saturated water vapor at temperature T_{gi}	N/m^2
V	The wind speed	m/s
M	The production of the distiller	Kg/s
L_{fg}	latent heath	KJ/kg
$L_{T\,w}$	The latent heat of vaporization of water at the considered temperature	KJ/Kg
λ	Thermal conductivity of the fluid	W /m.K
δ	Thickness	M
σ	Constant of Stefan Boltzmann, $\sigma = 5.67\times10^{-8}$	W /m^2 K^4
θ	Inclination of the Dificap	°
M_{ew}	Hourly condensate production	Kg/m^2 h
η_{th}	Thermal efficiency	%
$\eta_{pe:}$	Passive exergy efficiency	%
Ex_{output}	The hourly exergy output efficiency	W/m^2
Ex_{input}	The hourly exergy input efficiency	W/m^2
L	Length of the basin	m
t	Time	s
α_g	Coefficient of glass absorption	
$\alpha_{\mathbf{w}}$	Coefficient of water absorption	
$\alpha_{\mathbf{b}}$	Coefficient of bottom absorption	
τ_g	Coefficient of transmission of the glass	
τ_w	Coefficient of transmission of the water	
τ_b	Coefficient of transmission of the bottom	
ρ_w	Coefficient of reflection of water	
F	Form factor	
ε_g	Glass emissivity	
Nu	Nusselt	
Gr	Number of Grashof	
Pr	Number of Prandtl	

General introduction

General introduction

At the global level, the demand for good quality drinking water is increasing. The population is actually growing rapidly and industry and agriculture's water needs are increasing. To meet this demand, in many countries in the Middle East, North Africa, the South and West of the United States and Southern Europe, desalination is now successfully practiced for domestic and industrial needs. For most parts of the world, drinking water supply is a growing problem. These days, solar distillation systems are being implemented in a number of countries, including West Indian, Bahamas, Kuwait, Saudi Arabia, Mexico, and Australia.

At the local level, Algeria has the largest solar capacity in the Mediterranean basin and is prone to adverse physical and hydro-climate conditions, accentuated by cycles of prolonged drought. The climate changes witnessed and the drought that has existed in Algeria for several decades have had a negative impact on water resources. Algeria has generally adopted two desalination processes in the face of this problem: membrane processes and processes of distillation involving phase change, evaporation / condensation. Where, the latter subject is important in our research. El Oued city is situated in the southeast of Algeria with an area of 54573 square kilometers and over 700,000 inhabitants. The geographical coordinates in decimals are latitude 33.3683 ° and longitude 6.8674 ° with an average altitude of 60 m. The area is very rich in groundwater, but this water is contaminated unfortunately. The National Institute of Public Health has prolonged the exposure of drinking water to excessive fluoridated intoxication in our region with levels exceeding 3.16 mg/l and in some locations which is much higher than the 0.7 mg/l norm. This excess causes diseases in the kidneys, bones and teeth, and most people suffer from these diseases. Solar distillation is currently the subject of several research laboratories around the world and each research team is trying to improve the performance of distillation systems by playing on the temperature gradient between the water in the basin and the glass cover. The problem of this system is the low production of pure water and it is a general problem for all researchers in this field. Our work is to find creative ways to manage this gradient, either by reducing the condenser temperature (glass cover) or by increasing the pool's water temperature or both simultaneously.

This thesis will be the subject of a study to improve and classify the various techniques used in a conventional solar distillery. But how much will our solar distillation techniques improve? We also established a research plan to achieve the goals of this report, which outlines the following six chapters:

Chapter I: Bibliographic study. We addressed the issue and the amount of water in Algeria and the world in this chapter, the various distillation modes most known rely much more on solar distillation and finally, we present the studies aimed at improving solar distillery productivity through several techniques.

Chapter II: Methodology. In this section, we present the introduction of the experiments performed on a conventional solar distiller's productivity improvement techniques. We also present a new temperature measurement technique by an electronic card called Card Ardunio and finalized by solar distillation activity energy balances.

Chapter III: Effect of solar radiation and temperature gradient between glass / water on distillation. In this chapter, we show experimentally that the main factors in solar distillation are solar radiation and the temperature gradient between the water of the pond and the glass interior.

Chapter IV: Effect of different techniques improving the productivity of pure water. The final findings obtained from this fourth part are graphical results with their explanations on refraction tests, plastic fins, aluminium balls, glazing with different thicknesses, a black metallic absorber and a solar collector connected to a solar distiller (hybrid systems).

Chapter V: Sand dune effect has the productivity of at single slope solar distiller. The sand dunes of our region are very abandon and the concept is use of this free material as a factor of improvement in the solar distillation. This section describes in detail the experience of a solar distiller with dune sand.

Chapter VI: Exploitation of an insulated air chamber. The last chapter represents the use of a well-closed and well insulated glass chamber on all four sides; the air is perfectly trapped inside. This piece is used in our system as a condenser. Since this technique improves the efficiency of a solar collector, hence the idea of using the same technique to see the effect of this process on the productivity of a solar still.

Finally, this work is closed by a general conclusion summarizing the main results obtained and classifying them according to their productivity rates.

Chapter I

Bibliographic study

I.1. Introduction

In all scientific research, a literature review is essential to acquire an idea of the previous work. This chapter presents the water problem and position in Algeria and especially in the region of El Oued, located in the south-east of Algeria. This area is suffering from a high concentration of fluoride in its groundwater. It also offers an exhibition. It also provides a general exhibition on the most well-known forms of desalination modes and a detailed documentary study on the processes for improving the output of greenhouse distillers. At the end of this chapter you will find our rationale for the option of solar distillation.

I.2. Water in Algeria

The strong pressure of human activities on irrigation water resources, mainly drinking water has become a global problem especially in the Mediterranean region which is characterized by a high proportion of the population with less than 1000 m^3/inhabitant [1]. In our continent, more than 200 million people are living in a water deficit and by 2025 this number could reach 700 million [2]. In Algeria there are 75 dams with a total capacity of 6.5 billion m^3 [3]. The amount of water in the order of 7.3 x 110^9 m^3 that flows into the sea is very interesting. Surface water is polluted by the discharge of urban and industrial waste, causing enormous ecological and environmental problems. Groundwater is also irreversibly polluted and impaired by the introduction of salt water; the overexploitation of aquifers impairs its ability to retain water, resulting in the accumulation of underlying materials.

The water problem has been exacerbated in recent years by a drought that has affected the entire territory of our country and has shown how necessary it is to pay particular attention to water. Algeria will also have a water deficit of 1 billion m^3 by 2025, despite the construction of a new dams and the use of desalination [3]. The Algerian experience in desalination dates back to the 1960. By the end of the 2018, there were 10 desalination stations with a treatment capacity of 1.610.000 m^3 per day [4]. The table I.1 summarizes the distillation stations in Algeria.

Table I.1. Seawater desalination project in Algeria [5]

N°	Localisation	Wilaya	Capacité installée (m^3/j)	Date de mise en exploitation
01	Arzew/Kahrama	Oran	90.000	Août 2005
02	Hamma	Alger	200.000	Mars 2008
03	Skikda	Skikda	100.000	Mars 2009
04	Chatt El Hillal (Béni Saf)	Ain Témouchent	200.000	Octobre 2010
05	Souk Tleta	Tlemcen	200.000	Avril 2011
06	Cap Djinet	Boumerdes	100.000	Juillet 2011
07	Fouka	Tipasa	120.000	Juillet 2011
08	Honaine	Tlemcen	200.000	Août 2011
09	Mostaganem	Mostaganem	200.000	Septembre 2011
10	Ténès	Chlef	200.000	Juin 2015

I.3. Water quality criteria

I.3.1. Potable water

Drinking water is odorless, colorless and tasteless fresh water that does not contain any toxic products, but contains some minerals with regulated concentrations that must be respected. The World Health Organization has established international standards for drinking water, which include a general statement of bacteriological, physical, chemical, biological and radiological standards. Water intended for domestic purposes must have a salinity of not more than 0.5 g/l, a hardness (TH) between 1.5 and 3 degrees and it must not contain more than 200 mg/l of chlorine, neither more than 75 mg / l of calcium nor more than 50 mg/l of magnesium nor more than 150 mg/l of sulphates [6]. The pH, which depends on the ion content, conditions the physicochemical equilibrium, in particular the calco-carbonic equilibrium and therefore the action of water on the carbonates (attack or deposit). The pH is acidic in the waters of sandy or granitic aquifers. It is alkaline in limestone. The pH is corrected according to the case by removal of dissolved CO_2 in excess or by correction of the carbonate hardness. The concentration of ions in the water is measured with its pH which is generally equal to 7.0.

The content of dissolved gases from the atmosphere (O_2 and CO_2), the content of dissolved mineral substances generally in ionic form: anions (bicarbonates, chlorides, sulphates, nitrates, fluorides) and cations (calcium, magnesium, sodium, potassium, iron, manganese, ammonium). Table I.2 shows in general the salinity of water.

Table I.2. Classification of waters according to salinity [7]

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

I.3.2. 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 [8]. The salinity of the seas and oceans are summarized in Table I.3.

Table I.3. Salinity degree of sea waters [7, 8]

Seas	Baltic sea	Caspian sea	Black Sea	Adriatic Sea	Pacific Ocean	Indian Ocean	Atlantic Ocean	Mediterranean Sea	Arabian golf	Red Sea	Dead Sea
Salinity (g/l)	7	13.5	20	25	33.5	33.8	36	39	43	43	270

I.3.3. Brackish water

Briny water is not potable saline water and has a salinity that is lower than that of seawater. With a great variety of salinities, the waters of some surface or underground aquifers can be salty. The lagoon waters can have a very high salinity, more or less in communication with the sea. Also found in salt water are inland lakes.

They are categorized into three categories:

• Low brackish water 1,000 <salinity <3,000 ppm.

• Moderately brackish waters 8.000 <salinity <10.000 ppm.

• Highly brackish waters 10,000 <salinity <33,000 ppm.

The first two categories are found particularly in North Africa, the Middle East and the U.S.A. [9].

I.3.4. El Oued valley Water

The city of El Oued has a very large groundwater reservoir but with a very high salt concentration, especially fluoride. According to the 2006 WHO study, the acceptable limit for fluoride in water is in the range of 0.7 to 1 mg per liter. Table I.4 shows the various fluoride concentrated cities in the region. This corresponds to the difference between the acceptable value and the acceptable value.

Table I.4. Content of F - in the cities water (W. El Oued)

Cites	Water	Tenor F mg/L	Maximum acceptable tenor in mg / l
El Oued	Pontian	2,17	0,7
Guemar	"	1,91	0,7
Debila	"	2,17	0,7
Hamraya	"	1,97	0,7
Oued Allanda	Groundwater	3,16	0,7
Debila	"	3,09	0,7
Hassani	"	2,91	0,7
Ourmes	"	2,51	0,7
Taghzout	"	2,88	0,7
Bayada	"	3,16	0,7
Hobba			

I.4. Water desalination

Water desalination in general is grouped in thermal distillation (phase change) and desalination membrane (without phase change). The subgroups that are derived are essentially multi-stage flash (MSF), multi-effect distillations (MED), steam compression (VC) and continuous distillation (SD). The main membrane techniques are reverse osmosis (RO) and electrodialysis (ED). Figure I.1 summarizes the different desalination techniques.

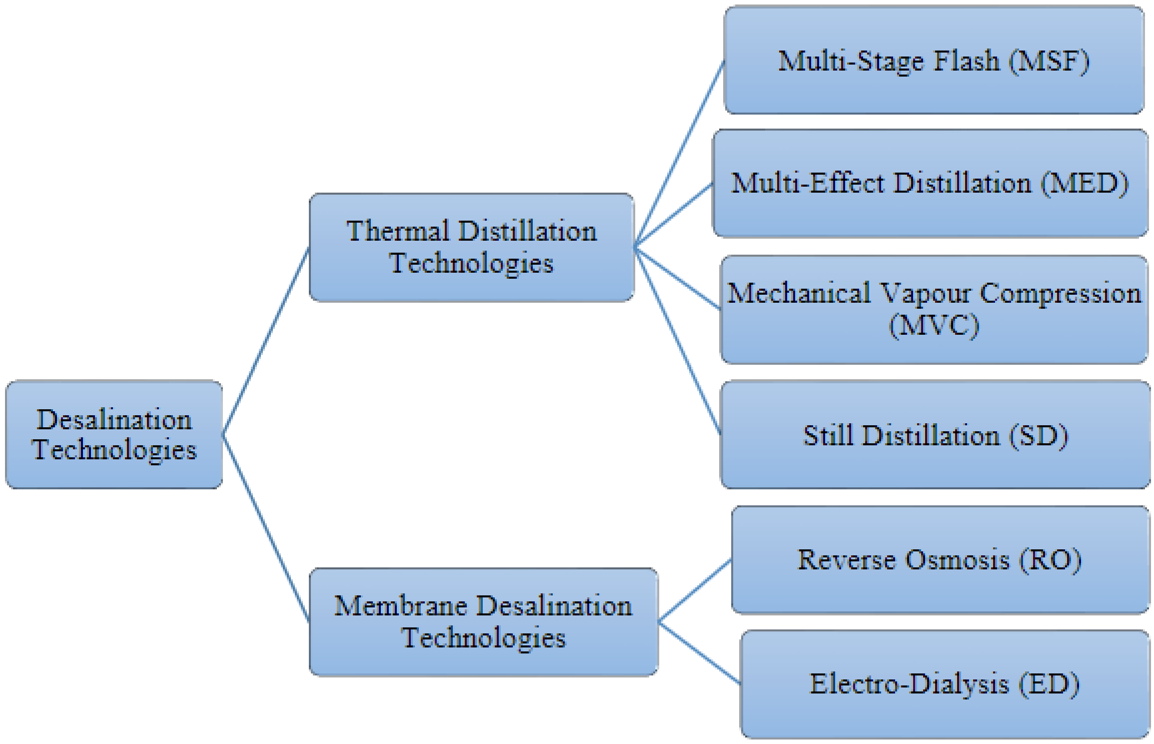

Figure I.1. Desalination classifications [10]

I.4.1. Multi-effect distillation [MED]

The Multi-effect distillation[MED] is a series of evaporation steps or effects in horizontal or vertical evaporators that are maintained at decreasing pressure and temperature levels, from the first warm stage to the last cold stage. Cold seawater is propelled into the top of the beam and sprays on the hot exchangers. This contact creates a pure hot water vapour. The heat of condensation of the vapour produced in the first evaporator is used in the second evaporator which operates at a lower temperature and pressure and the operation is repeated from one evaporator to another. Figure I.2 represents a distillation station MED of three effects.

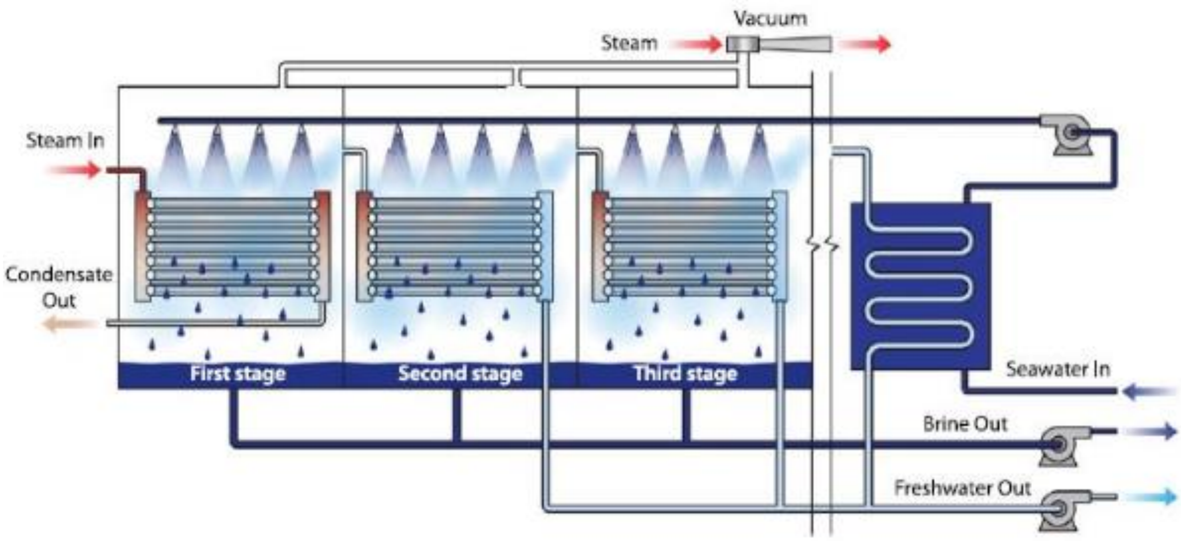

Figure I.2. Multi-effect distillation [10]

I.4.2. Multi-stage flash vapour distillation [MSF]

The water heats up in the various condensers of each stage (from no to 1) before being introduced into a heater which allows the temperature to be further increased. The hot water is led down the first evaporator where the pressure is below the saturation pressure: (instant flash vaporization called Flash). The steam produced condenses on contact with the condenser of the stage concerned and the condensate (fresh water) is collected within each stage. The temperature decreases from stage 1 to n and consequently the pressure, allowing the flow of water between the various stages without the need to use pumps. Figure I.3 shows the multi stage flash vapour distillation.

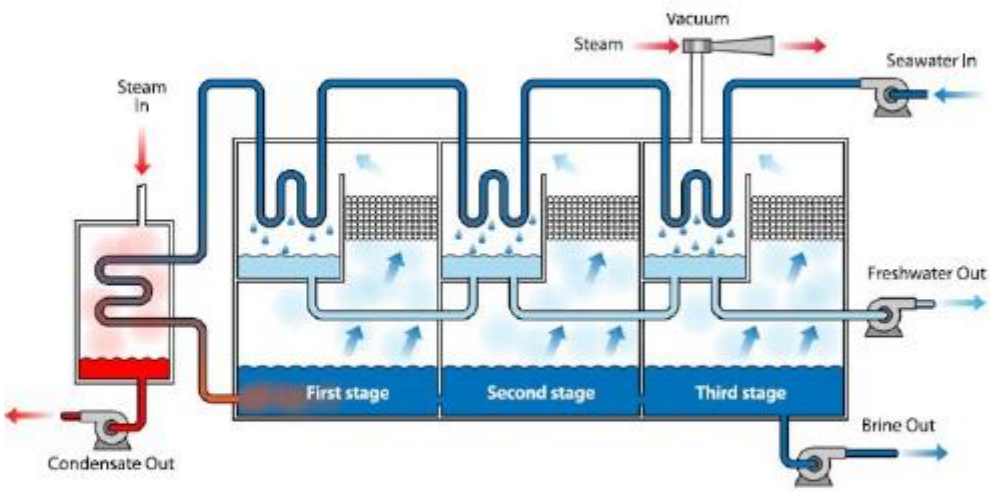

Figure I.3. Distillation Flash [10]

I.4.3. Distillation with vapour compression (thermo compression) [VC]

The water to be treated is vaporized in a thermally insulated enclosure and the steam produced is sucked by a compressor which makes it possible to increase its temperature up to the saturation temperature. From there, the steam passes through a tube bundle at the bottom of the chamber and condenses, causing the water to evaporate due to the heat of condensation.

A concentric tube heat exchanger preheats the salt water to be treated and cools the brine and fresh water. Figure I.4 shows the destination procedure of this mode.

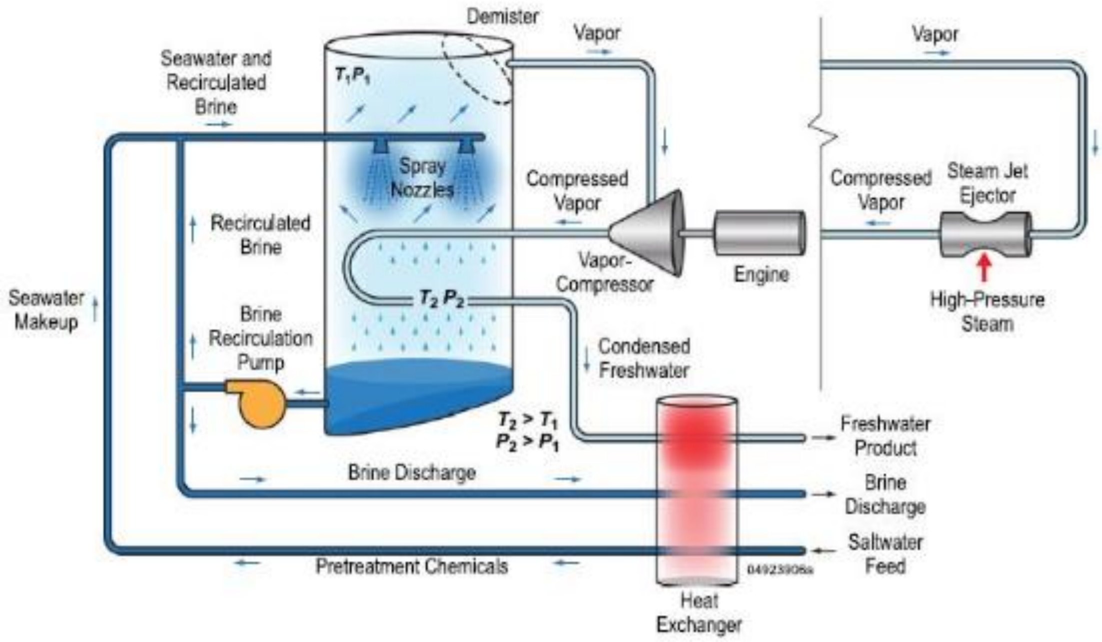

Figure I.4. Distillation with vapour compression [10]

I.4.4 Reverse osmosis [RO]

Osmosis is a natural process: the species move from the diluted medium to the concentrated medium. If pressure is applied at the compartment of the concentrated solution, the transfer between the two compartments will decrease until it is cancelled. When the flow vanishes, the applied pressure is called osmotic pressure. If the applied pressure becomes greater than the osmotic pressure, the flow reverses: the species move from the most concentrated medium to the least concentrated medium → this is the phenomenon of reverse osmosis. Reverse osmosis is thus a form of pressure filtration via a semi permeable membrane that blocks the molecules of salt to pass and this produces pure water. Figure I.5 represents a device of reverse osmosis.

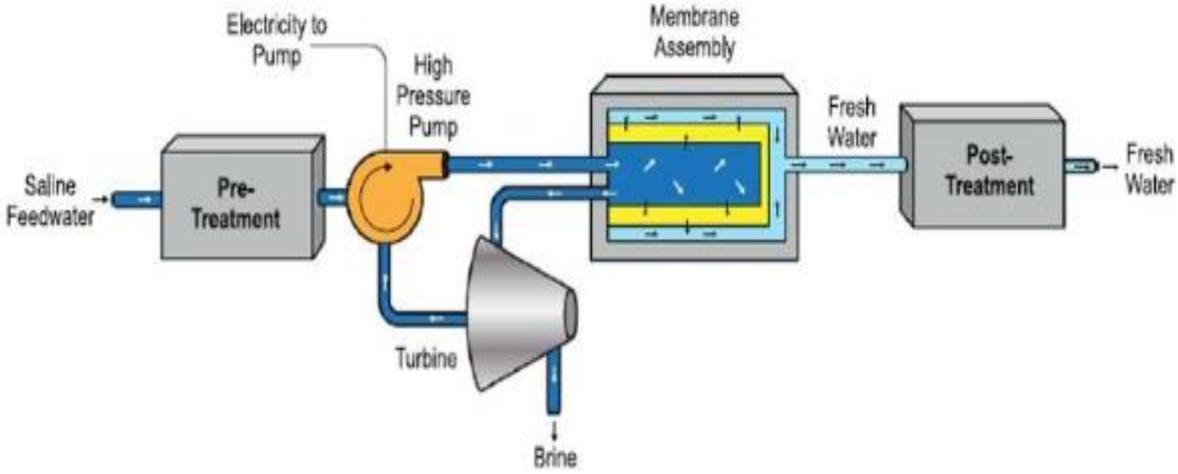

Figure I.5. Diagram of the reverse osmosis process [10]

I.4.5. Electrodialysis [ED]

The compartments are fed with saline solution (generally NaCl: Na + and Cl-). Under the effect of the current, the cations of the saline solution are directed towards the cathode and the anions towards the anode. Blue membranes are permeable to cations and green membranes are permeable to anions. In each compartment, there will be an increase (concentration compartment) or decrease (demineralization compartment) of the ion concentration. And we will get either fresh water or brine. The scheme of the electro dialysis process is shown in Figure I.6.

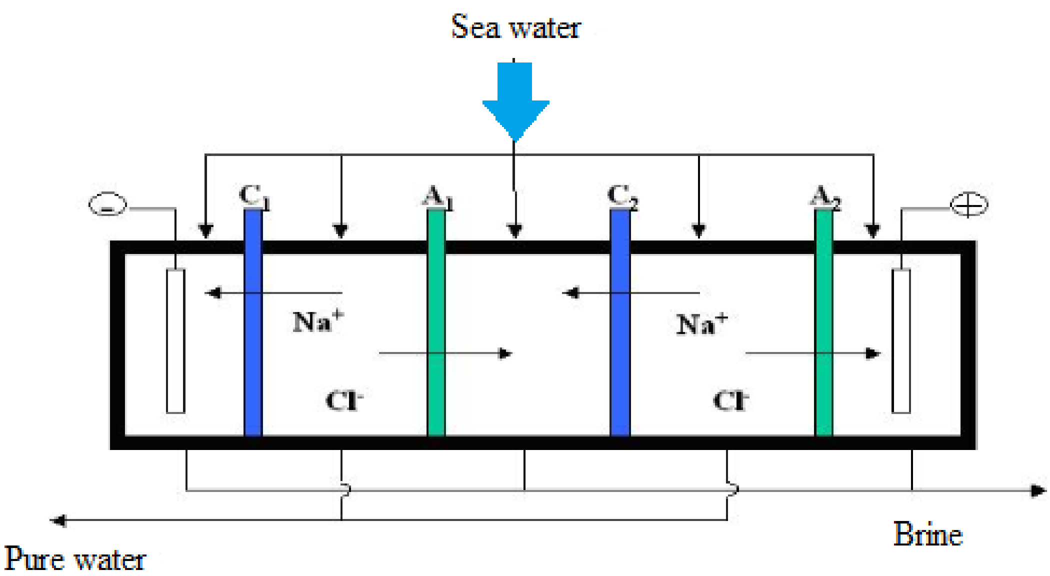

Figure I.6. Diagram of the electro dialysis process [15]

I.4.5. Solar desalination (SD)

The operating principle is based on the greenhouse effect as shown in Figure I.7:

- The sun's rays enter the distiller via the glass cover;
- The water begins to warm up and evaporate;
- The hot water vapour comes back to the glass;
- The hot water vapour condenses (formation of droplets on the inner side of the glass);
- The droplets of pure water slip into the collector and finally driven in the tank.

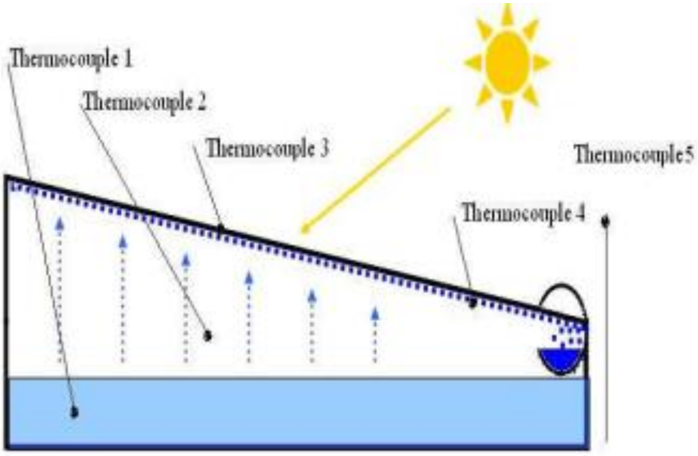

Figure I.7. Solar distiller [16]

I.5. Solar distillation

I.5.1. Solar distillation in Algeria

Algeria is located in the centre of the North Africa along the Mediterranean coast, between the latitudes of 19° and 38 ° North and longitude of 8° West and 12° East. Algeria has the largest solar field in the Mediterranean and also has a huge underground water reservoir in southern Algeria. This water is not usable for the man. A large amount is infected with fluoride, which makes it invaluable. [17,18]. The drought and observed climate changes that have prevailed for many years in North Africa have had a negative impact on drinking water resources [19]. Faced with these challenges, Algeria has adopted the phase change process as a solution. The solar distiller is among the most economical and simple solutions for the production of pure water in isolated, arid and dry Saharan areas. Figure I.8 shows the different types of this technique.

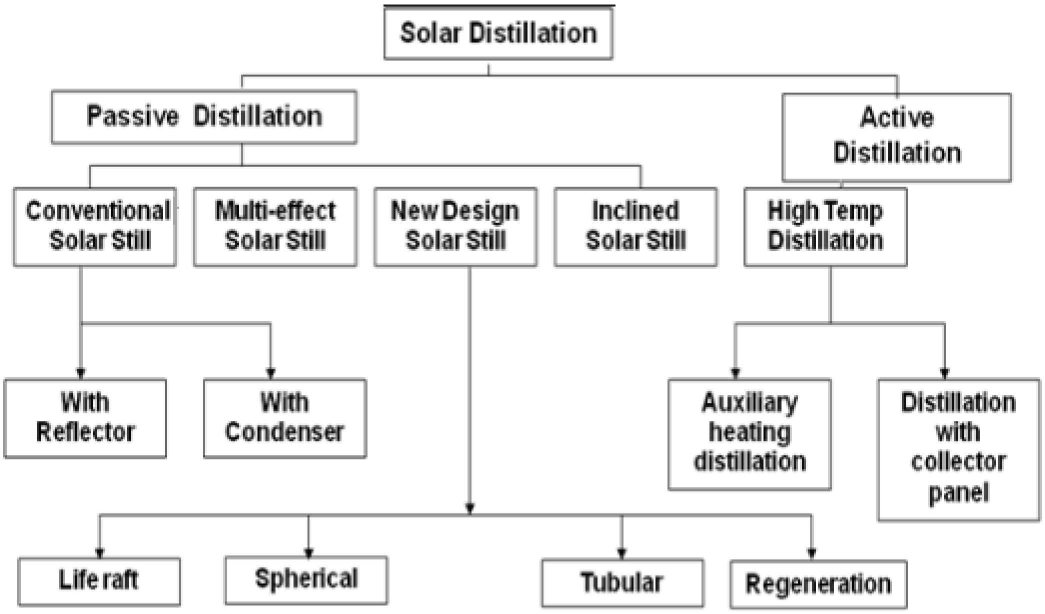

Figure I.8. Different types of solar desalination [20]

The efficiency of this technique is still comparable with other techniques. The advantage of the solar distiller is the low cost, the ease of construction and the ability to make improvements to provide water to communities in remote areas. It can also be used to remove fluoride is the salts [21]. The El Oued region, like all parts of south-eastern Algeria, is catastrophically affected by a high level of fluoride in deep waters, with a concentration of 4.3 mg / l. According to the guide values adopted by the World Health Organization (WHO) this excess cause health problems for many thousands of families [22, 23]. Figure I.9 represents the distribution of groundwater water in the region of El Oued valley, southeast Algeria.

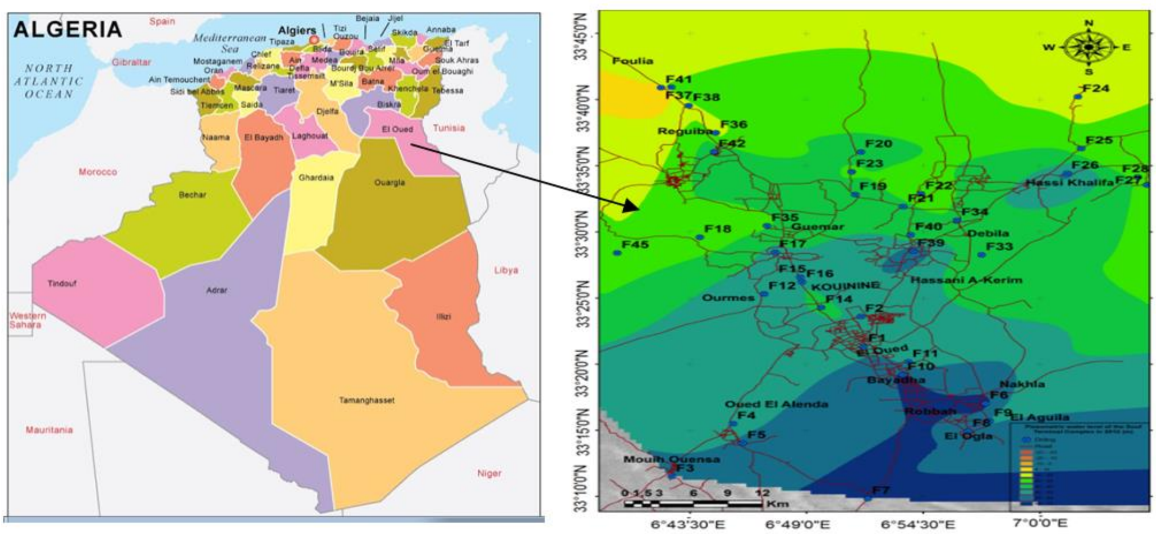

Figure I.9. Water Disposal Map of groundwater in the El Oued valley [24]

This bad situation has led researchers and research laboratories in universities to conduct local studies. The University of Ouargla has been one of the pioneers in the solar energy processing of pure water in southern Algeria [25, 26]. A small solar distillation station under the insulation has been designed for the desalination of underground water from the Ouargla region of south-eastern Algeria. The small station had a daily capacity of more than 15 liters / m^2 of pure water [27]. Since the southeast of Algeria is a very hot region in summer and very cold in winter. Another study was carried out at the University of El Oued to show the influence of the change of seasons on solar distillation. The results show the phenomenon of the more favourable distillation in the summer season than for the winter season [16].

Various studies relating to the realisation and simulation of a solar distiller have been made for the improvement of the productivity of pure water. The results obtained were true between 1.8 and 2.5 liters / day for absorbers of 0.436 and 0.54 m^2 respectively [28, 29]. Another study combining experimentation and simulation yielded an improvement of 17% [30]. Numerical methods are taken into consideration to estimate the results. [31].

In Algeria, as in studies around the world, researchers are playing on cooling the glass cover or on increasing the temperature of pond water. Both methods improve the performance of the solar distiller regardless of its type. The results showed an improvement that varies between 11, 82 and 33.7% for the cover glass cooling [32-34] and they showed an improvement that varies between 33 and 60 % for the on increasing the pond water temperature [35, 36]

I.5.2. Solar distillation in the world

I.5.2.1. Storage materials

Incorporation of sensible heat energy storage materials is an effective method to improve the freshwater yield of the solar still. The location of sponges of different sizes placed in the pool of a solar distiller was studied experimentally by a group of researchers and the results obtained were surprising. An increase in the production of the distiller with the sponges by 273% compared to the distiller identical without the pieces of cubic sponges, it should be noted that the two devices were in the same weather conditions [37]. Experiments have been done on solar distillers to test the impact of different thermal storage hammers on the productivity of pure water. Both units are designed, manufactured and tested under the same climatic conditions. The results showed that daily productivity improved by 42.2%, 15.2%, 20.1% and 17.2% when mica, stainless steel, aluminium and copper are used as floating absorbents [38]. A study comparing the use of wicks in a solar distiller has been studied by researchers. The result shows that the maximum yield is obtained at 4.50 l / m² per day for a distiller with a black cotton wick and a yield of 3.52 l / m² per day for a jute wick at a depth of 2 cm and under the same conditions [39]. A comparison study was carried out between two modified solar distillers and an unmodified third distiller to evaluate the effect of thermal fluids (HP-500) and Increased Frontal Height constituted a sensitive heat storage material. The results for a water depth of 2 cm show that the productivity for images still containing Thermal Fluid and the Increased Frontal Height increased by 11.24% and 23% respectively, compared to a conventional distiller [40]. Four solar stills have been studied experimentally; the D1 is without porous material, the D2 with effect pebbles, the D3 with black granite pieces effect and the D4 with black granite slab effect. The results obtained show that D4 with black granite slab effect has the highest productivity compared to D2 and D3. The material-free distiller D1 is in the last position as shown in Figure I.10. So the porous materials increase the productivity of the solar system [41].

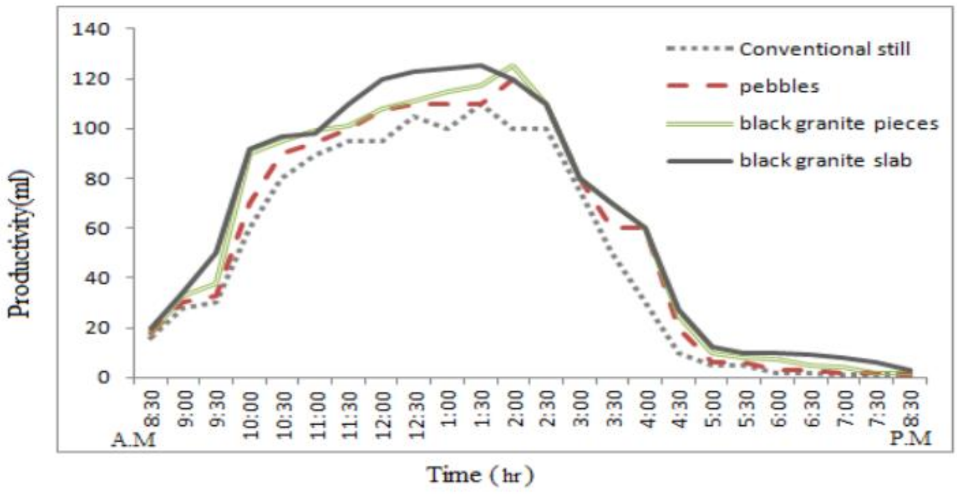

Figure I.10. The variation of the productivity of the solar distillers [41]

I.5.2.2. PCM storage materials

The Phase change material, or PCM, is any material capable of changing physical state in a temperature range roughly between 10 °C and 80 °C. These temperatures are naturally accessible and they are in the hot water of a solar still. The introduction of materials such as graphite (PCM) into the pond of a solar distiller has a positive effect because the high thermal conductivity of graphite has an improvement of up to 75-80%. Researchers have an idea of using materials with high thermal conductivity. They are introduced graphite into the basin of a solar still to see its effect on the productivity of pure water. The results obtained were very positive and an improvement of up to 75-80% was obtained at the end of their studies. Experimental results have shown that the production of pure water is also improved by hybrid or mixed storage materials [42, 43]. Storage materials in solar distillers have been developed to arrive at phase change materials or PCM. The use of PCM increases productivity in freshwater by 17 to 25%. A very important result shows that the reduced PCM makes a 400% improvement during the night and a 7% decrease during the day [44, 45]. A comparative investigation has been made between the various PCMs on the performance of conventional solar distillers. The results show that PCM A-48 increases productivity by 92% compared to solar convection still [46]. One study used a single-slope passive solar distiller with a tank filled with PCM (stearic acid). The result obtained from this experiment is a 28% improvement in distillate production compared to a similar non-PCM solar still. After sunset and without pumping systems or operators to go into night mode, the still with PCM produced more than 12% of total water production during the night [47]. Figure I.11 shows the basin filled with stearic acid (PCM) and the other picture shows the production of pure water on the day.

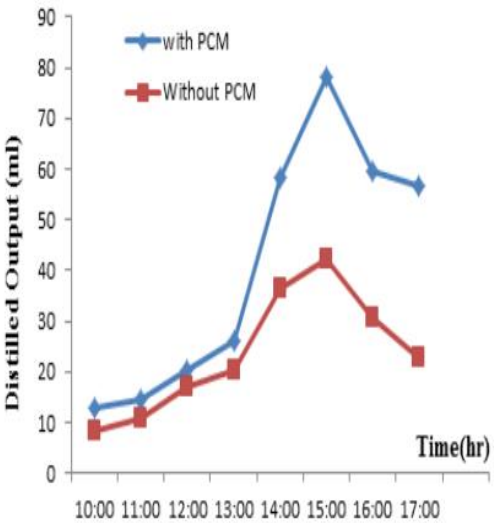

Figure I.11. Productivity graph and PCM photo [47]

I.5.2.3. Nanofluids

A nanofluid is a fluid containing particles of nanometric size, called nanoparticles and they are generally made of metals, oxides, carbides or carbon nanotubes. Common base fluids include water, ethylene glycol and oil. Nanofluids have novel properties that make them potentially useful in many heat transfer applications such as solar distillation. A recent study showed that different concentration of magnetic nanofluids in a solar distiller increased the efficiency of water evaporation from 24.91% to 76.65% [48]. A study on different types of nano-fluids Al_2O_3, CuO, Cu_2O, ZnO, SnO_2, TiO_2, SiO_2, Cu, Fe_2O_3, Sic and multi-walled carbon nanotubes. The results showed that the smaller size of the nano-fluids has the best conductivity and the best amount of pure water produced by the system. The results also show that MWCNT, SiC, Cu, graphite flakes, Cu20 and Al_2O_3 improved the productivity as well as the thermal efficiency of the distiller [49]. Experimental research on modified solar distillers using nanoparticles and a sprinkler accessory was performed to see the influence of nanoparticles on the productivity of pure water. The distiller with the nanoparticles produced 3,445 ml / m² / day which is more compared to the distiller without nanoparticles which produced 2,814 ml / m² / day [50]. The application of micro-flakes of graphite and copper oxide with different depths of pond water and different concentrations has been studied experimentally in order to improve the productivity of a solar distiller. The results show that the productivity is improved by 44.91% and 53.95% respectively by using micro-flakes of copper oxide and graphite [51]. An investigation work clearly shows the role of nanofluids in passive solar distillation. The benefits of using nanofluids have been highlighted by the improved thermal performance of solar distillations [52]. The effects of using two types of nanomaterials (cuprous oxides and aluminum) on the productivity of pure water from a solar distiller were studied and the results show that the use of cuprous oxide nanoparticles increased the productivity by distillation of 133.64% and 93.87%, respectively with and without fan and in the same way the nanoparticles aluminium oxide improved the distillate by 125.0% and 88.97%, respectively with and without a fan compared to a similar conventional solar still. The graphical results of Figure I.12 show us the variations of fresh water productivity for the modified and the conventional still when using Al_2O_3 and Cu_2O at weight fraction concentration of 0.06% without operating the fan [53].

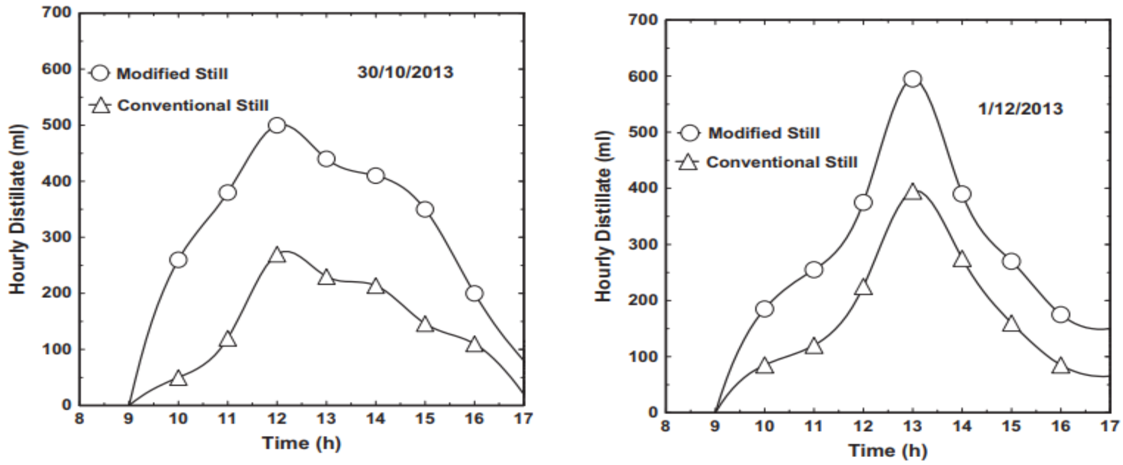

Figure I.12. Productivity for the two distillers with and without Cu2O and Al2O3 [53]

I.5.2.4. Solar and cooling systems integrate with solar distillation

An experimental study has been done on the performance of a double basin solar still with vacuum tubes. The results confirmed that there is an increase in the production of distilled water by 225% compared to a conventional solar reference distiller [54]. The coupling of a parabolic trough collector (PTC) with a solar distiller has been studied experimentally. The solar energy incident on the PTC is transferred to the distiller via an oil line connected to a finned loop heat exchanger in the solar distiller basin. In these conditions, the pure water productivity of the solar distiller with PTC is about 142.3% compared to the conventional solar still [55]. A study has grouped different conception designs to improve the productivity of a solar distiller. The technique is to integrate an external or internal condenser and see its effect on the device [56, 57]. The thermal and productivity yields of solar distillers were evaluated by a study that tested the cooling of transparent glazing. The experimental results revealed that the productivity of the distiller cooled in pure water is 10.06 l/ m^2.day as well as its internal thermal efficiency and 80.6% compared to solar distiller. Therefore, reference productivity is 7.8 m^2.day with 57.1% of internal efficiency of course under similar conditions of 1 cm deep brine and 3 mm thick glass cover [58]. Increasing the difference between water and glass temperatures is the basis for improving the productivity of solar distillers. The use of fans, thermal storage materials, internal and external reflectors and glass cover cooling are methods for maintaining the temperature difference between glass and high water. The results show that the improvement varies between 15.5 to 59% [59]. A study on the effect of cooling the glass cover of an inclined solar still has been made in a very hot region where the ambient temperature exceeds 45 °C. This temperature affects the glass and the productivity of pure water. The cooling of the glazing by a continuous flow of a film of water on the glass was used as solution. The consequence of this technique gave an improvement of 58.98% [60]. Figure I.13 compares the cumulative hourly production rate for distillers and notes the offset of the ISWD-WF distiller. This distiller was associated with a system of cooling by a flow of a water film (WF) on the glass.

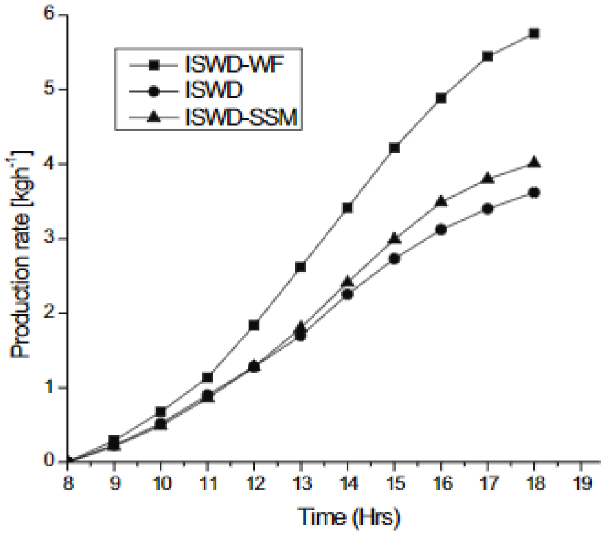

Figure I.13. Hourly cumulative productions of the systems

I.5.3. Comparison between desalination methods

Water desalination has used several modes to purify water, either seawater or groundwater. Table I.5 presents the various best known techniques and also shows a comparison based on:

- the quality and quantities of water produced;
- the investment price;
- the maintenance cost;
- the energy consumption;
- the impact on the environment.

According to table I.5, solar distillation appears as an acceptable solution to solve the problems of infected or polluted water in an isolated region because the investment price are low, the device is portable, easy to build, it does not consume energy and finally there is no emission of gases that pollute the environment. But on the other hand, the small amount of production of pure water is an inevitable disadvantage, which is why efforts of researchers in the world work to strengthen and improve this productivity as well our thesis.

Table I.5. Comparison of destination modes

Type	Advantages	Disadvantages
Multi-effect distillation MED	High water quality and productivity	Large space needed High energy consumption and gas emissions High capital and high maintenance costs Corrosion problem
Multi-stage flash vapor distillation MSF	High water quality and productivity	Large space needed High energy consumption and gas emissions High capital and high maintenance costs Corrosion problem.
Distillation with vapor compression VC	High water quality and productivity	Small space needed High energy consumption High capital and high maintenance costs
Reverse osmosis RO	High water quality and productivity	Higher costs for chemical and membrane replacement High energy consumption High capital and high maintenance costs
Electrodialysis ED	High water quality and productivity	Multi Pre-treatments are required Continuous maintenance of membranes
Solar distillation SD	High water quality Low cost and low maintenance Easy to build An environmental device	Low water production

1.6. Conclusion

Solar distillation is an economic and environmental solution for excess fluorine concentration in sub-terrestrial waters. Simple and low-cost, this solution is possible. Water quality is very good and very low maintenance. All its advantages drive us towards this approach despite the low efficiency, but this drawback will be dealt with in the next chapters in order to increase. All its advantages push us towards this solution despite the low productivity. The next article will deal with measurement methods and theory of distillation.

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Chapter II

Methodology

II.1. Introduction

Before any experiment, a theoretical study is necessary to understand the mathematical modelizations applied in this field and it is also necessary to take also the influential factors on the solar distillation. This chapter proposes to analyze the factors that affect the performance of solar distillers such as solar radiation, ambient temperature, insulation, wind speed, dust and cloud cover, depth, nature and temperature of the water. Other design factors may also affect performance such as passive / active systems, slope and thickness of cover, distance between water surface and condensation cover, choice of materials, storage materials, reflectors. A series of experiments will be cited which take into account the factors of influence as object of study. The energy balances governing solar distillation will be present at the end of this chapter.

II.2. Factors influence distillation

A solar distiller is influenced by geometric factors such as the shape, surface, inclination and position of the condenser, the depth of the pond water ... etc. These factors are more or less controllable by the manufacturer or the user. There are other uncontrollable climatic parameters such as solar radiation, wind speed, ambient temperature.

II.2.1. Climatic factors

II.2.1.1. Solar radiation

Solar radiation is the set of electromagnetic waves emitted by the Sun. A small portion of the radiation reaches the Earth's surface where a portion is reflected and other parts are absorbed. Solar radiation is the most vital factor. The effect of solar radiation on distillation has been of interest to many researchers. The results showed that the increase in productivity strongly depends on incident solar radiation [1-4]

II.2.1.2. The Wind

Wind is the mass movement of gas on the surface of a planet. Winds are generally caused by unevenly distributed global warming from stellar radiation (solar energy), and by planet rotation. Effect of wind on solar still performance based on surface temperatures of the glass cover, the difference in temperature between glass and water widens with decreasing coverage temperature, which has improved productivity. The forced convective heat transfer from the cover to the atmosphere increases with the wind, resulting in increased heat transfer by evaporation and convection of the pond water [5, 6].

II.2.1.3. Ambient temperature

Temperature is an indirect measure of the degree of microscopic particle agitation, measured in our work in °C. This temperature has an effect on solar distillation; several researchers have studied the effect of varying ambient temperatures on the productivity of a solar distiller. The results have shown that an increase in ambient air temperature improves the production of pure water from a solar still. A study has even given values an increase of the ambient temperature of 10 °C it will be followed by an improvement of 8.2 % [7].

II.2.2. Geometric factors

II.2.2.1. Surface, thickness and positioning of the condenser

To receive a maximum of solar radiation and to have maximum productivity, we must play on the orientation and thickness of the glass cover (condenser), this confirmation has been confirmed by a study of a researchers group, and they are also confirmed that the angle of the glass cover must be equal to the latitude of the place of the experiment [8, 9]

II.2.2.2. The condenser cooling system

To cool the glass cover of a solar still, that is to say to widen the difference of temperature between the water and the glass; this has the consequence of increasing the productivity. Some researchers have adapted this solution and they are creating a weak and continuous flow of a film of water on the cover. This technique has led to improvements in the productivity of pure water [10].

II.2.2.3. The water heating system

The heating of the pond water can be done via solar systems integrated in the solar still such as the flat solar collector, the parabolic solar collector or parabolic cylinder or other systems, not to mention to play on the variation of the depth of the water in the basin. The use of thermal storage materials is present in solar distillation; this technique is widely used to ensure the continuity of production after sunset. The solar reflector is one of the easiest ways to increase the efficiency of a solar still. Studies have developed the use of this useful to move to external and internal refractors at a time. This plus has given more improvement [11, 8].

II.3. Different type of solar distillers

There are dozens of types of solar still such as wicked still, cascading distiller and many others but we want to choose the solar stills that look a lot like the conventional distiller with a water basin that occupies the bottom of the device as shown in Figure II.1. We notice different modifications on the condenser (glass) but the basin remains the same.

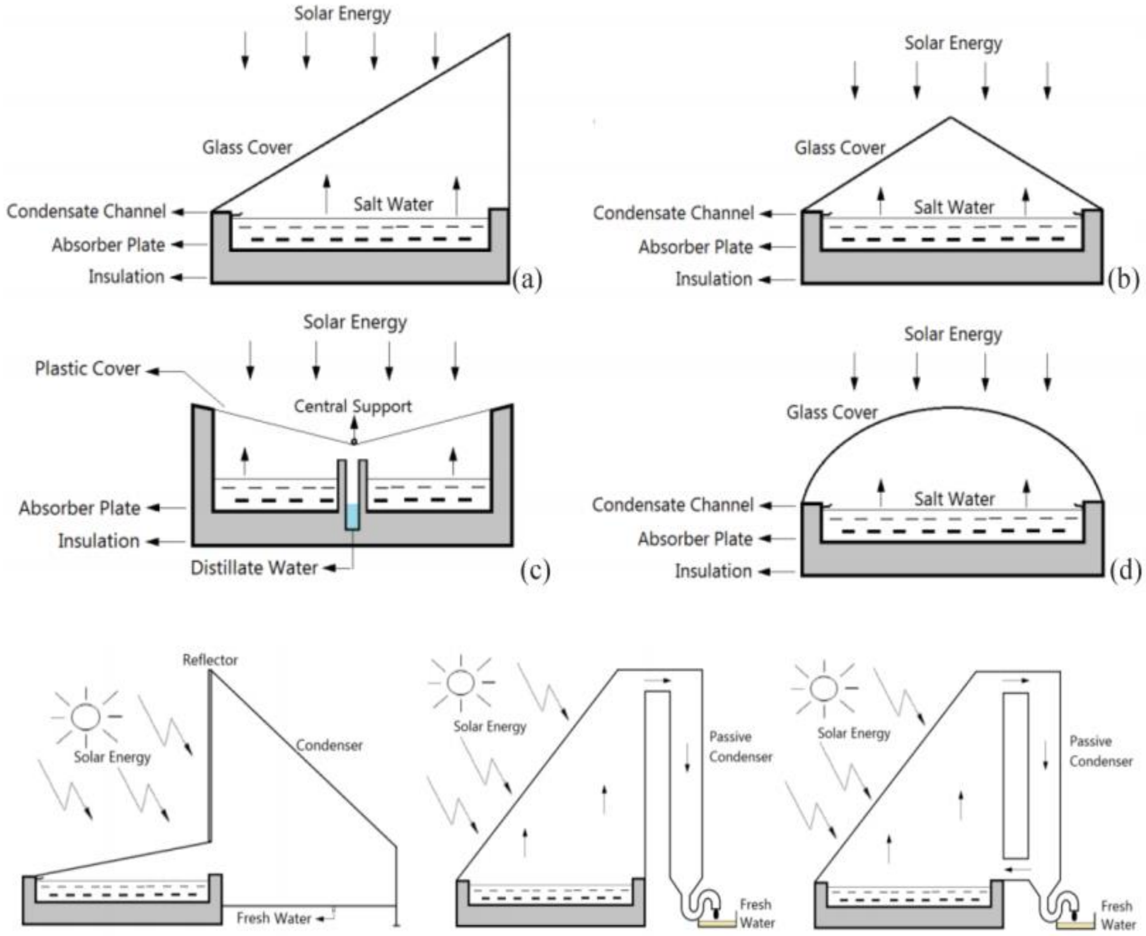

Figure II. 1. Different types of distillers

II.4. Measurement instrumentation

II.4.1. Card Arduino

It is an open-source platform or a programmed electronic board that is based on a simple microcontroller board and software, a true integrated development environment, to write, compile and transfer the program to the microcontroller board. The Arduino board as shown in Figure II.2 can be used to develop interactive objects that can receive inputs from a wide variety of switches or sensors, and can control a wide variety of lights, motors, or other hardware outputs. The idea is to use the Arduino board as a macro component in electronic prototyping applications. The designer only has to develop interfaces and program the macro-component to realize its application. The Arduino programming language is an implementation of Waring, a similar development platform, which is based on the Procession multimedia programming environment.

Figure II. 2. The Arduino board

II.4.2. LM35 thermal sensor

Figure II.3 shows an analogical temperature sensor manufactured by Texas Instruments, which is extremely popular in electronics because it is very simple to use. It is capable of measuring temperatures ranging from 55c C ° to 150 C ° in this most accurate version and with the fitting can also measure from -40 C ° to +110 C °.

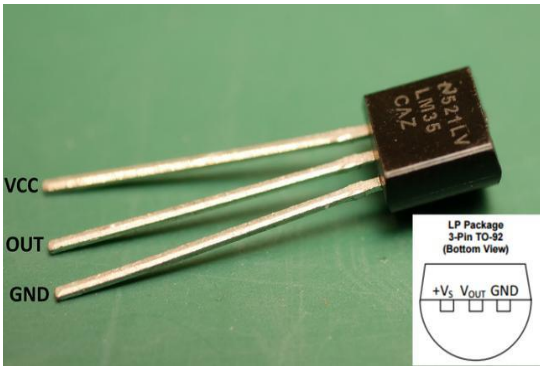

Figure II. 3. LM 35 thermal sensor

II.4.3. Pyranometer

The Figure II.4 shows pyranometer (Kipp & Zonen CMP-11) that measures solar radiation with Accuracy of +/- 1W/m^2, range 0 to 5000 W/m^2 and error of 0.153 %.

Figure II. 4.. Pyranometer Kipp & Zonen CMP-11

II.4.4. PHM210 Standard Device

The Figure II.5 shows PHM210 Standard pH Meter from the VTRS laboratory of the El Oued University, helps to give the distilled water PH of each distiller.

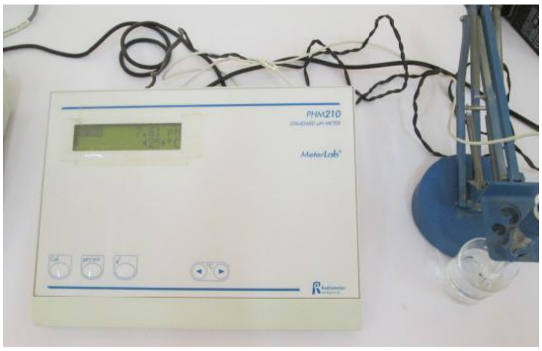

Figure II. 5. PHM210 Standard

II.4.5. Device CDM210 Conductivity Meter

The Figure II.6 shows CDM210 conductivity meter of the VTRS laboratory, helps to give the electrical conductivity of the distilled water of each distiller.

Figure II. 6. CDM210 conductivity meter

II.4.6. Graduated beaker

The Figure II.7 shows graduated beaker facilitates the measurement of the quantity of distilled water collected in order to know the quantity of distilled water produced in each hour.

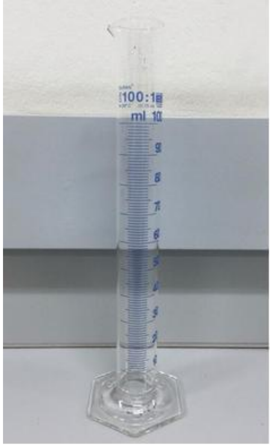

Figure II. 7. Graduated beaker

II.5. Energy balances in the solar still

The mathematical modelling of a single-slope solar distiller illustrates the different heat exchanges that occur in a solar still. It is based on four points: the glazing balance, the water balance, the insulation balance and the condensate flow rate. [12]

II.5.1. Balance of glazing

The quantities of total heat exchanged between the glass and the atmosphere are subdivided into two modes, convection and radiation. Figure II.8 shows the thermal balance of the glass recapitulated from heat exchanges at the two faces coming from the body of water and towards the environment.

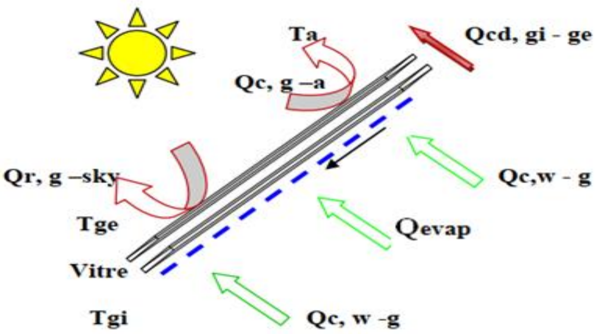

Figure II. 8. Energy balance of the glass

Glazing balance is represented by [13]:

- On the outside:

The quantity of heat received by the glass is evacuated by the conductivity through it:

$$\frac{M_g Cp_g}{A_g}\frac{dT_{ge}}{dt} = \alpha_g G + Q_{c.ge\_gi} - Q_{r.g.w\_a} - Q_{c.g.\_a} \tag{2.1}$$

- On the inside:

$$\frac{M_g Cp_g}{A_g}\frac{dT_{gi}}{dt} = Q_{r.w\_gi} + Q_{c.w\_gi} + Q_{evap} - Q_{c.gi\_ge} \tag{2.2}$$

Q_{rw_gi}: Thermal radiation flux between the water film and the glazing.

Q_{cw_gi}: Thermal flow by convection between the water film and the glazing.

Q_{evap}: Evaporative-condensation heat flux between the water film and the glazing.

Q_{cgi_ge}: Heat flow lost by conduction through the glass to the outside.

II. 5.2. Water balance

The Figure II.9 shows the exchange of heat between the body of water and the inside of the glass, the same amounts of heat are found by convection, radiation and evaporation, respectively.

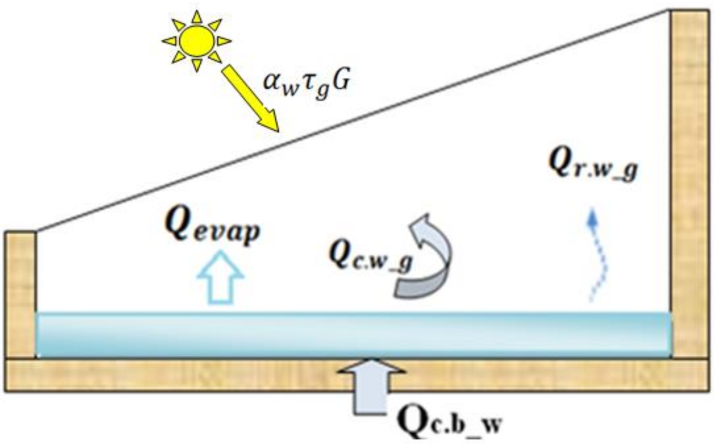

Figure II. 9. Energy balance of water

$$\frac{M_w Cp_w}{A_w}\frac{dT_w}{dt} = \alpha_w \tau_g G + Q_{c.b.\_w} - Q_{c.w.\_g} - Q_{evap} - Q_{r.w.\_g.i} \tag{2.3}$$

$Q_{c.b\_w}$: Convective heat flow between the bottom of the distiller and the water film.

II. 5.3. Bottom balance sheet (the absorber)

The bottom balance is represented by:

$$\frac{M_b Cp_b}{A_b}\frac{dT_b}{dt} = \alpha_b \tau_g \tau_w G - Q_{c.b\_w} - Q_{c.b\_i} \qquad (2.4)$$

Figure II.10 shows the black metallic absorber at the bottom of the distiller.

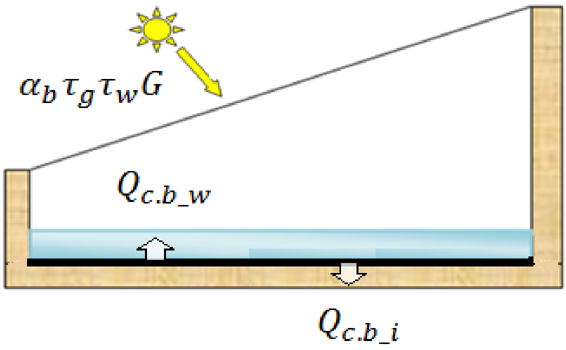

Figure II. 10. Energy balance of Bottom (abdorber)

II.5.4. Balance sheet insulation

We use thermal insulation to reduce heat loss of the solar distiller. The Figure II.11 shows the energy balance of insulation and the equation 2.25 represents this balance [13]:

$$\frac{M_i}{A_i}\frac{C_{pi} dT_i}{dt} = \alpha_i \tau_g \tau_w \tau_b G + Q_{c.b\_i} - Q_{c.i\_a} - Q_{r.i\_a} \qquad (2.5)$$

$Q_{c.b\_i}$: Thermal flow by conduction between the tank and the thermal insulation.

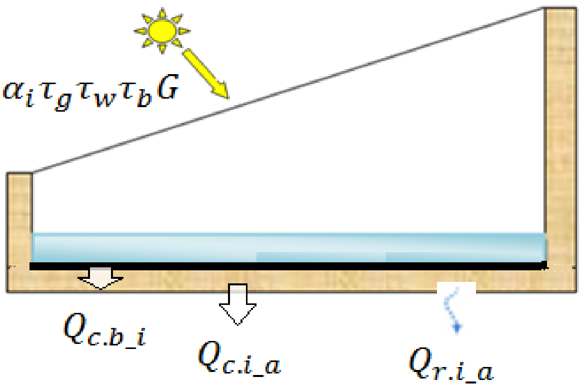

Figure II. 11. Energy balance of insulation

II.6. Heat exchange coefficients

II.6.1. By water-glass radiation

The radiation heat exchange flux between the brackish water and the glass is given by [13]:

$$Q_{r.w\_g} = F.\sigma.\left(T_w^4 - T_{g.i}^4\right) \quad (2.6)$$

F: is the form factor, F = 0.8
σ: Constant of Stefan Boltzmann, σ = × 5.67 10^{-8} *W /m*^{2} *K*^{4}

$$Q_{r.w\_g} = h_{r.w\_g}\,(T_w - T_{g.i}) \quad (2.7)$$

So

$$h_{r.w\_g} = h_{r.w\_g}\,(T_w - T_{g.i}) = 0.8.\sigma.\left(T_w^2 - T_{g.i}^2\right).\left(T_w + T_{g.i}\right).(T_w - T_{g.i}) \quad (2.8)$$

Hence the coefficient of radiation heat transfer between the water film and the glass is:

$$h_{r.w\_g} = 0.8.\sigma.\left(T_w^2 - T_{g.i}^2\right).(T_w + T_{g.i}) \quad (2.9)$$

II.6.2. By convection water-glass

The heat flow between the water and the glass is given by the expression [12, 13]

$$Q_{c.w\_g} = h_{c.w\_g}\,(T_w - T_g) \quad (2.10)$$

The convective heat exchange heat flux between the brackish water and the glass is defined by Dunkle in the case where the surface of the water and the glass are parallel [13]

$$Q_{c.w_g} = 0.884\left[T_w - T_{gi} + \frac{(P_w - P_{gi})(T_w + 273.15)}{268.9 \times 10^3 - P_w}\right]^{\frac{1}{3}}(T_w - T_{gi}) \quad (2.11)$$

In the case of a solar still, the glass makes an angle θ with the surface of the water so the equation of Dunkle became [13]

$$Q_{c.w_g} = 0.884\left[T_w - T_{gi} + \frac{(P_w - P_{gi})(T_w + 273.15)}{268.9 \times 10^3 - P_w}\left(\frac{1 + \cos\theta}{2}\right)\right]^{\frac{1}{3}}(T_w - T_{gi})$$

The coefficient of heat transfer by natural convection between the water film and the glazing is:

$$h_{c.w_g} = 0.884\left[T_w - T_{gi} + \frac{(P_w - P_{gi})(T_w + 273.15)}{268.9 \times 10^3 - P_w}\left(\frac{1 + \cos\theta}{2}\right)\right]^{\frac{1}{3}} \quad (2.12)$$

II.6.3. By vaporization

The heat flux transported by evaporation is [12]

$$Q_{evap} = h_{evap}\,(T_w - T_{g.i}) \tag{2.13}$$

Dunkle offers [13]

$$Q_{evap} = 16.273 \times 10^3 Q_{c.w\_g}\,\frac{(P_w - P_{g.i})}{(T_w - T_{g.i})} \tag{2.14}$$

According to the formulation presented by Ouahid [14], the pressure of the water vapor is estimated by the following relation:

$$P = 133.32 \exp\left(18.6686 - \frac{4030.1824}{T + 273.15}\right) \tag{2.15}$$

$$P = 0.148\,.T - 0.3653 \times 10^{-2}.T^2 + 0.11242 \times 10^{-3}\,.T^3 \tag{2.16}$$

II.6.4. By radiation: glass - ambient environment

$$Q_{r.g\_sky} = h_{r.g\_sky}\,(T_{g.w} - T_{sky}) \tag{2.17}$$

The coefficient of the heat transfer by radiation from the window to the outside is wortten as follows [12, 13].

$$h_{r.g\_sky} = \varepsilon_g.\sigma\left(T_{g.w}^2 - T_{sky}^2\right).(T_{g.w} + T_{sky}) \tag{2.18}$$

Where:

T_{sky} : Sky temperature

In general, we use the expression proposed by Whillier [12, 13]:

$$T_{sky} = 0.0552\,.(T_a^{1.5}) \tag{2.19}$$

$$T_{sky} = T_a - 12 \tag{2.20}$$

Where:

T_{sky} and T_a are measured in Kelvin and $\varepsilon_g = 0.9$.

II.6.5. Flow by convection: glass - ambient

The convective heat loss between the glass and the outside is given by [12, 13]:

$$Q_{c.g\_a} = h_{c.g\_a} (T_{g.e} - T_a) \tag{2.21}$$

The coefficient of convection exchange between the external face of the glass and the air is given by the following relation.

$$h_{c.g\_a} = 5.7 + 3.8\, V \tag{2.22}$$

Where:
V: the wind speed (m / s).
$T_{g.e}$: external temperature of the glass.

II.6.6. Flow by convection: basin – glass

The heat flow transferred by convection from the basin (absorber - evaporator) to the glass is given by the relation:

$$Q_{c.b\_g} = h_{c.b\_w} (T_b - T_g) \tag{2.23}$$

The coefficient of heat transfer by convection between the bottom of the tank and the water film is given by the relation:

$$h_{c.b\_w} = \frac{Nu\,.\lambda}{\delta} \tag{2.24}$$

Where:
λ: Thermal conductivity of the fluid (in our case it is water).
δ: thickness

Nusselt's expression takes the following relation for angles greater than 60° between the horizontal and the outer face of the pane [13]. This angle is equal to 160° in our device.

$$Nu = A \left(\frac{\delta}{L}\right)^m (Gr_T.Pr.\sin\theta)^n \tag{2.25}$$

With
Gr: Number of GRASHOF
Pr: Number of PRANDTL

$$h_{c.b\_g} = \frac{\lambda}{\delta} A \left(\frac{\delta}{L}\right)^m (Gr_T.Pr.\sin\theta)^n \tag{2. 26}$$

In the experiments, a heat and mass transfer appears. In these conditions, λ become λ ', Pr becomes Pr' and have the sum of GrT + GrM. The equation 2.25 becomes:

$$h_{c.b\_g} = \frac{\lambda'}{\delta} A \left(\frac{\delta}{L}\right)^m \left((Gr_T + Gr_M) +. Pr'.\sin\theta\right)^n \tag{2. 27}$$

The exponents m, n and the coefficient A have been determined experimentally in the case of the thermal convection. In the case of natural thermal and material convection, A = 0.271, m = 0.21 and n = 0.25 as mentioned by Inaba [15].

II.7. Main characteristics of a solar distiller

II.7.1. Yield of a solar distiller

This is the production of the distiller, which represents the amount of distilled water produced per m^2 of evaporation surface. According to Bechki [13], it is given by the following relation:

$$M = \frac{Q_{evp}}{L_{Tw}} \tag{2.28}$$

Where:

q_e: The heat flux used for the evaporation of water.

$L_{T\,w}$: The latent heat of vaporization of water at the considered temperature

II.7.2. The hourly exergy output

According to Manokar et al [16], the hourly exergy output is calculated as:

$$Ex_{output} = \frac{m_{ew}L_{fg}}{3600} \times \left[1 - \frac{T_a}{T_w}\right] \tag{2.29}$$

II.7.3. The hourly exergy input

According to Manokar et al [16], the hourly exergy input is calculated as:

$$Ex_{input} = A_w G(t) \times \left[1 - \frac{4}{3}\left(\frac{T_a}{T_s}\right) + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4\right] \tag{2.30}$$

II.7.4. Solar distiller efficiency

II.7.4.1. Global efficiency

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

$$\eta_g = \frac{Q_{evp}}{G}\ (\%) \tag{2.31}$$

II.7.4.2. Thermal efficiency

According to Manokar et al [16], the thermal efficiency for a passive solar distiller is estimated as following:

$$\eta_{passive} = \frac{\sum \dot{m}_{ew} L}{\sum I(t) A_s x 3600} x100 \quad (2.32)$$

II.7.4.3. Fxergy effectiveness

The exergy effectiveness of the passive solar distiller is given by [16]:

$$\eta_{averall,exe} = \frac{\sum Ex_{output}}{\sum Ex_{input}} \quad (2.33)$$

II.9. Performance

The characterization of a solar distiller in a general is by the ratio between the quantities of distilled water produced by the distiller and the energy received by the distiller. It is led to define the factors of raw performance (G.P.F) and hourly (G.P.H) like [13]:

$$GPF = \frac{Quantity of produced water produced after\ 24\ hours}{Quantity of energy entered after\ 24\ hours} \quad (2.34)$$

$$GPH = \frac{Quantity of water produced after one hour}{Quantity of energy to enter after one hour} \quad (2.35)$$

II.10. Experience series

The solar distillers were designed by local materials and the dimensions chosen are (50 x 50 cm) and this to be able to compare our results with the literature. Figure II.12 shows the dimensions of the solar distiller.

A series of experiments has been done to study the parameters for improving the productivity of pure water. The first experiment aims to choose two similar distillers that produce almost the same amount of pure water under the same conditions. This gives credibility to our results. The 10 experiments were done at the Faculty of Technology of Hamma Lakhdar University of El Oued, south-east of Algeria. All experiments are done by two or three distillers one is a reference (witness) and the other for improvement. The experiment takes place at the same time, in the same place, with the same position, with the same nature of water and of course in the same meteorological conditions.

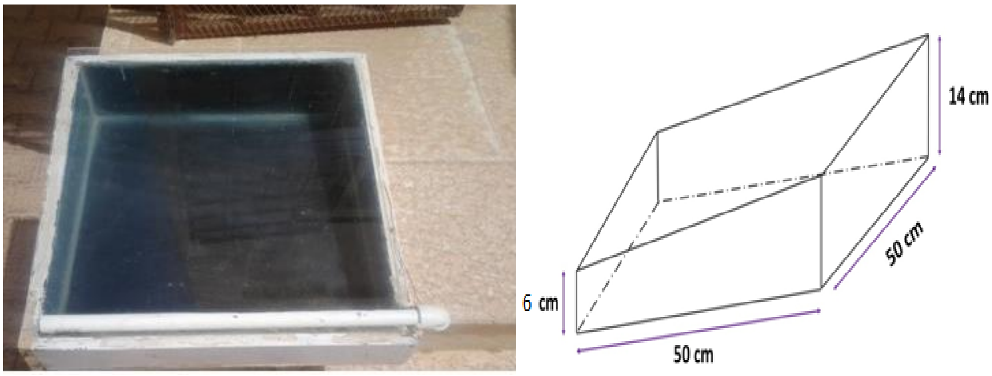

Figure II. 12. Dimensions of the solar distiller

II.10.1. Experiment nº1: Choosing Distillers

Four similar solar stills were exposed to the sun on the same table, with the same position, filled with the same amount of water, measuring with the same instrumentation. The aim of this experiment is to choose two very similar distillers for use in future experiments, one will be a referenced distiller and the other will be the subject of an improvement study. Figure II.13 shows the 4 stills on the same table before the experiment.

Figure II. 13. The four stills on the same table

II.10.2. Experiment nº2: Effect of radiation

The experiment was done by a single solar distiller. The distiller was placed on a table in the cold period in the winter for a day and it was once placed on the same table and the same position but in the hot summer period. The goal is to see the effect of solar radiation on the distiller. Table 2.1 shows the weather conditions of the two experiments

Table II. 1. Experience conditions

Meteorological conditions	January 2017	May 2017
Sunrise	07 :38 am	05:41 am
Sunset	05 :46 pm	07:19 pm
Ambient temperature	11-17 °C	26-35°C
Atmospheric pressure	1031 mb	1013 mb

II.10.3. Experiment nº3: Effect of temperature difference between pond water-glass

Two similar solar distillers were tested under the same conditions. A distiller D1 is retained as a reference and the distiller D2 with two covered glass covers separates by an isolated air space of the quads quoted. The aim of this experiment is to concretely touch the effect of temperature gradient between water and glass on the destination. Figure II.14 schematizes the temperature gradient between the pond water and the inside face of the glazing in the solar still.

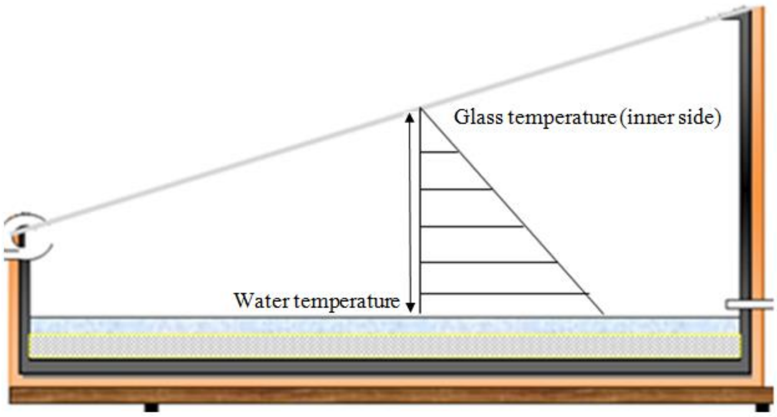

Figure II. 14. Schematization of the temperature gradient

II.10.4. Experiment nº4: Effect of a metal absorber on distillation

A black metal plate has been used as an absorber in the solar still D2 as shown in Figure II.15 and another still D1 receiver remains as a reference. Both distillers have been testing for a day under the same conditions. The purpose of this experiment is to influence the effect of a metal absorber on the productivity of pure water.

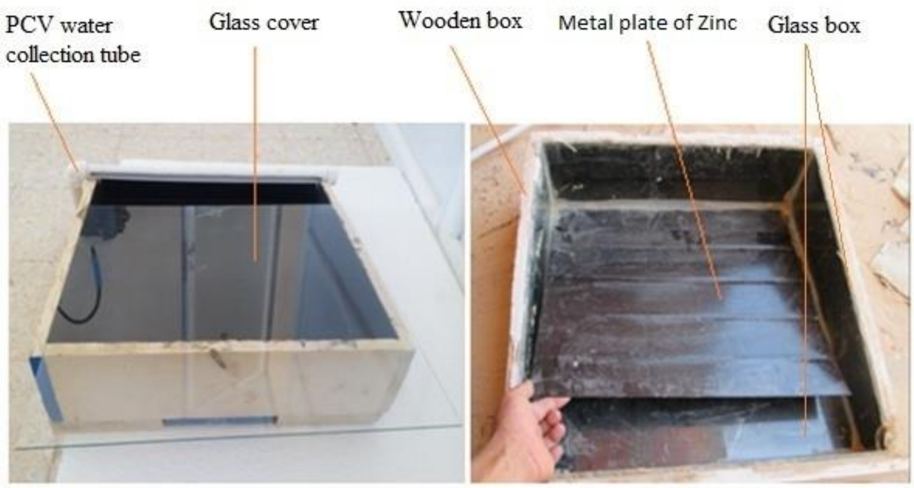

Figure II.15. Metal plate absorber

II.10.5. Experiment nº 5: Effect of an external refractor on distillation

Figure II.16 shows a commercial mirror was used as a refractor on the distiller D2 and the second distiller D1 and taken as a reference. Both distillers are tested under the same conditions for one day. The purpose of this experiment is to see the impact of an outdoor refractor on the solar destination.

Figure II. 16. Distiller with external refractor

II.10.6. Experiment nº6: Effect of glass cover thickness

In this experiment we use three recipients with three different glass covers. The distiller D1 has a thickness of 3 mm, the distiller D2 has a thickness of 5 mm and the distiller D3 has a thickness of 6 mm. The purpose of this experiment is to see the effect of the thickness of courage on the productivity of pure water. Figure II.17 shows the three stills on the test table.

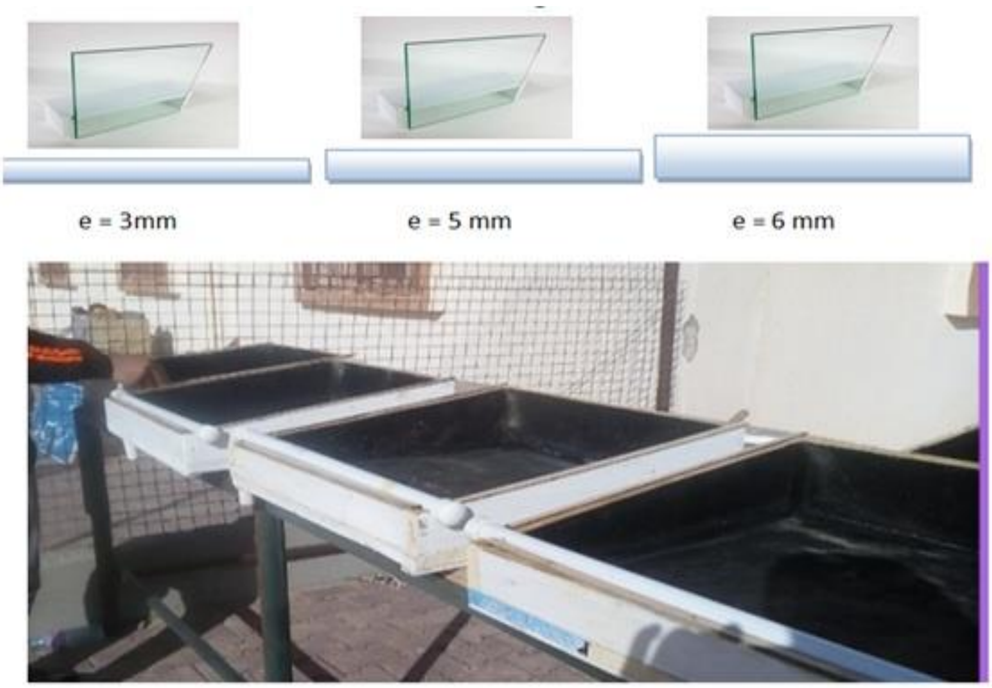

Figure II. 17. Distiller with different glass covers

II.10.7. Experiment nº 7: effect of cylindrical plastic fins

This experiment was done with two similar distillers during a clear day without wind. The distiller D1 is taken as a reference and the destination D2 has cylindrical plastic fins of d = 0.5 cm. The figure II.18 shows the two distillers side by side before the experience. The purpose of this experiment is to see the effect of the fins on solar distillation.

Figure II. 18. Distiller with plastic fins

II.10.8. Experiment n^o 8: effect of aluminium balls

Balls were made from the aluminium foil and were placed in the bottom of a solar still D2 as shown in Figure II.19 and another distiller D1 is retained as a comparison reference. The two distillers were placed on the same table for a day of experience. The purpose of this experiment is to see the effect of aluminium balls on solar distillation

Figure II. 19. Distiller with plastic aluminium balls

II.10.9. Experiment n^o 9: effect of a flat solar collector

Figure II.20 shows two distillers of the same dimension exposed to the sun for a day. The distiller D1 and plays the role of a witness or reference while the distiller D2 is the subject of our study. The latter is linked to a flat solar collector, the distiller-sensor system works together. The purpose of this technique is to heat up more of the pond water via the solar collector.

Figure II. 20. Distiller with flat solar collector

II.10.10. Experiment nº 10: The choice of hot water outlet hole

The Figure II.21 shows the geometry of the solar distiller designed by Gambit and it also shows the flow lines from the hot flow water into the water basin. The flow is from the sensor outlet to the sensor inlet as shown in the figure. This experiment was done by a single solar still that is linked to a flat solar collector. The hot water comes out of the sensor and gets into the distiller's water basin through a hole in the corner. The goal of this experiment is to find the best position of the output hole water using the CFD

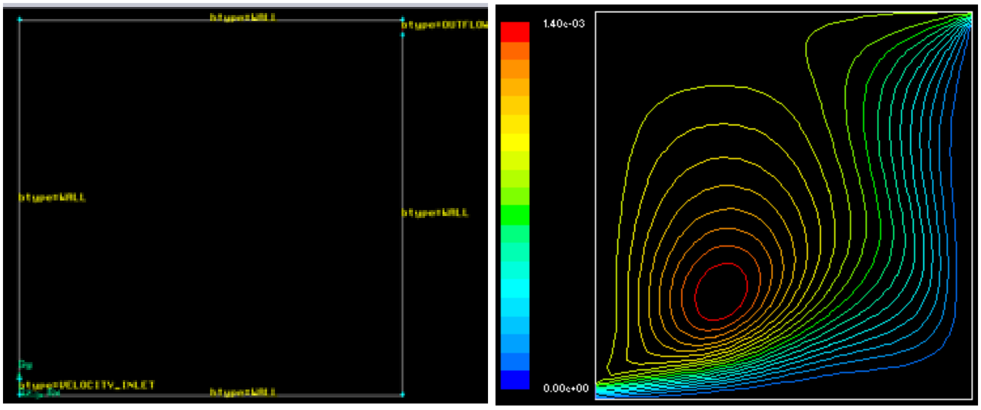

Figure II. 21. The hot flow lines in the distiller

II.10.11. Experiment nº 11: effect of sand dune

The Figure II.22 shows a solar still with dune sand, this D1 still is the object of our study, next another distiller D2 is taken as a reference to facilitate the comparison between the two distillers and to see the effect better sand in the distillation and that's exactly the purpose of this experiment.

Figure II. 22. Distiller with dune sand

II.10.12. Experiment no 12: effect of an insulated air chamber as a glazed cover

The insulated air chamber increases the efficiency of a solar collector and other solar systems that use glass as cover, hence the idea of using the same technique for a solar distiller and seeing the effect of an insulated air chamber as a glazed cover. Figure II.23 shows a schematic of an insulated air chamber on the experience table links to the thermal sensors and all connected to the Arduino board. The results are retrieved in the portable PC connected to the system.

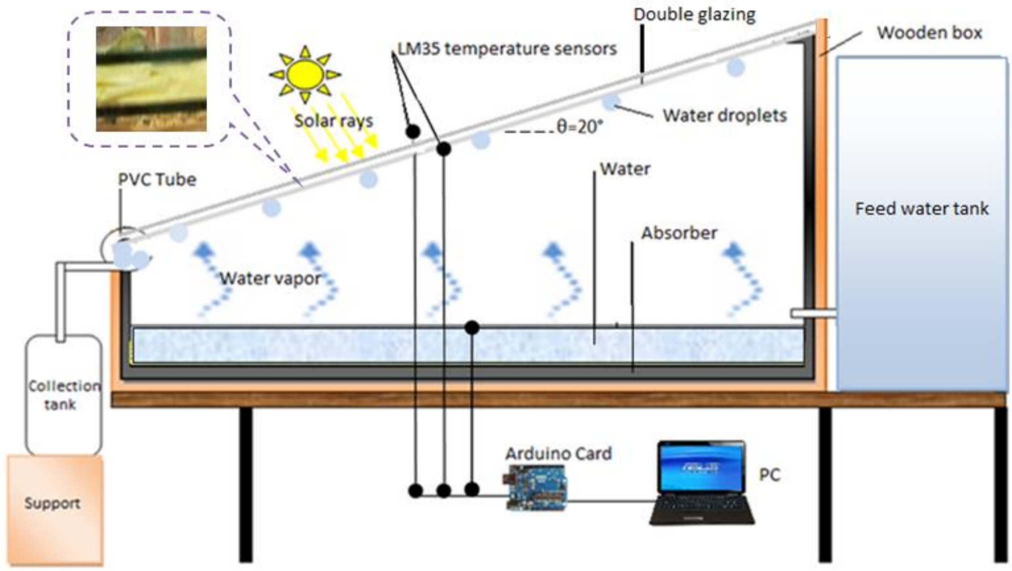

Figure II. 23. Distiller with double glazing

II.11. Conclusion

This chapter is a platform for solar distillation because it encompasses all the information needed to work in this field starting with the parameters that influence solar distillation, the measurement instruments used in this field, the energy balances governing the distillation and finally the preparation of 10 experiments to test 10 different factors that can improve or slow down the distillation. In the next chapters, each experiment will be treated apart to show the effect of each factor on the productivity of pure water.

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Chapter III

Effect of solar radiation and temperature gradient between glass and water on distillation

III.1. Introduction

The lack of drinking water has become a huge global problem. Algeria, like the countries of the Great Maghreb, is not immune to this problem and has adopted two types of distillation (membrane processes and solar distillation processes). Solar distillation is the simplest and most economical of all techniques. Despite its low efficiency compared to other technologies in which a membrane distillation or multi-effect distillation were used. The solar distillation has a great advantage due to the use of free solar radiation [1, 2] without another source of energy. As well known any variation in radiation, during the different seasons, influences the productivity of distillation. So there is a great relationship between the productivity and radiation. The relationship between the intensity of solar radiation and the volume of distilled water has been the subject of scientific work in the results show that any increase in solar radiation will be followed by an increase in the productivity of pure water and note the maximum intensity of solar radiation occurred at 13:00, or 950 W / m², and the maximum volume of distilled water at 14:00, up to 1400 ml / m^2.hour. It usually takes about one hour for the solar distiller to change the temperature of the water from 20 ° C to 45 ° C [3]. Then this technique is done outdoors; meteorological factors also have an influence on distillation. For instance, the wind has an influence on the glass cover. It forces the convection and causes an increase of the productivity. The output of a solar distiller increases from 2.75 to 3.25 L/m^2 when the wind speed increases from 1 to 3 m/s [4, 5]. Geometric factors affect productivity in a rather remarkable way. The angle inclination and thickness of the glazing influence the procedure of the distillation. The best angles are between 10-20°C, but if the thickness of the glass increases, the resistance to heat flow increases too. This resistance is inversely proportional to productivity[6, 7]. The improvement of this technique is the object of several researchers, especially in developing countries. Use of preheating by a solar collector or a solar concentrator and new forms of distiller have been developed recently [8]. Using CFD Fluent, the simulation was made for a transient state to validate the results experience for known climatic conditions [9]. Finally, in the developed laboratories, the use of nano fluid as a potential heat transfer fluid with superior thermo physical properties is an effective method for improving the thermal performance of the solar distiller [10-13].

This work shows that the change of seasons, that is to say the change of solar rays has a direct influence on the productivity of a solar distiller and that the temperature gradient between the water of the basin and the inner face of the glass also has a great influence on the distillation of water.

III.2. Method and Experience

III.2.1. Description of the solar distiller

Solar distillers are simple black-bottomed containers filled with water and topped with glass or clear plastic. Sunlight absorbed by the black material accelerates the rate of evaporation. Figure III.1 shows schematically the elements of a conventional solar distiller. The system consists of:

- a wooden box of size 50 x 50 cm. The thickness of the wood is 2.5 cm;
- the cover is made of commercial glass having 0.4 cm thick (playing the role of the condenser);
- the collector of distilled water (in which the glass is emerged) having 3 cm in diameter and 0.55 cm in length;
- Tank for distilled water.

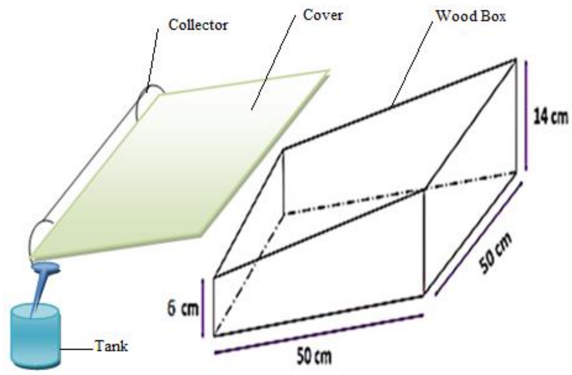

Figure III. 1. A single-slope solar distiller description

III.2.2. Principle of operation

The solar distillers are generally used in arid and insulated areas where access to freshwater is limited. The basic principle of solar distillation is simple, but effective, because distillation reproduces the way nature makes rain. A solar distiller always works on two scientific principles: evaporation and condensation. Salts and minerals do not evaporate with water. However, you still need a certain amount of energy for the water to turn into water vapor. Although a certain amount of energy is needed to raise the temperature of one kilogram of water from 0 ° C to 100 ° C, it takes five and a half times more energy for water to change from liquid to 100 ° C with water vapor at 100 ° C. Virtually all this energy is delivered when the water vapor condenses. The operating principle of a distiller is presented in the form of points: The sun's rays enter the distiller via the glass cover:

- the water begins to warm up and evaporate;
- the hot water vapor comes back to the glass;
- the hot water vapor condenses (formation of droplets on the inner side of the glass);
- The droplets slip into the collector and finally driven in the tank.

III.2.3. Location of thermocouples

Type K Thermocouple (Nickel-Chromium / Nickel-Aluminum): Type K is the most commonly used type of thermocouple. It is inexpensive, accurate and has a wide temperature range. The maximum continuous temperature is about 1100 ° C. Figure III.2 shows the thermocouples location. Temperature samples are taken each hour by type K1 thermocouples. Apart the thermocouple 2, the other ones are used to control the temperature at different places as shown in figure III.2 The latter are linked to controller whereas the thermocouple 2 is used to control the hot water vapor so in this soft work we neglect the temperature measurements of this thermocouple.

Thermocouple is a sensor used to measure the temperature. It consists of two metals of different natures connected to one end. When the junction of metals is heated or refrigerated, a variable voltage is produced, which can then be transcribed in temperature. Thermocouple alloys are generally available in wire.

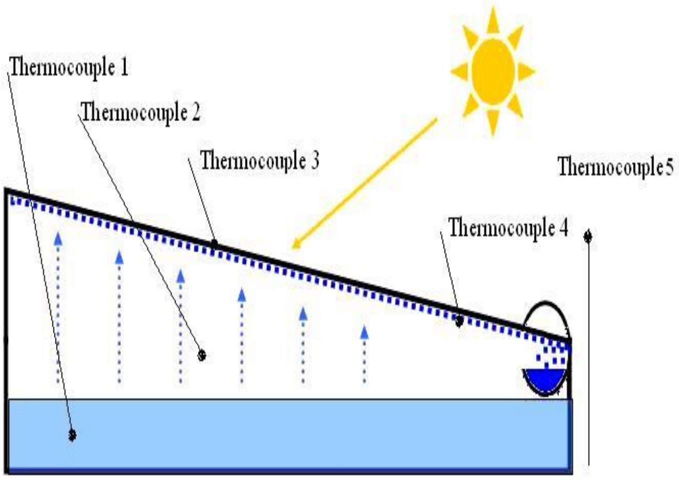

Figure III. 2. Thermocouple location [14]

III.2.4. Treatment data of the first experiment

The experiments are done according to the geographical coordinates of the city of El-Oued located at 33.3676° N latitude and 6.8516° E longitude. The same distiller was exposed to the sun in the same place, same position, same water nature and the same water quantity to be distilled, but in two different seasons. The first experiment was carried out in January 2017 (in winter), while the second in May 2017 (in summer) in order to see the influence of meteorological effects on the phenomenon of solar distillation. Temperature sampling was carried out every one hour during the period from 9:30 am to 4:10 pm for both experiments, so the same period of sunshine was maintained to eliminate any ambiguities in relation to this factor (i.e. sunshine duration).

The single slope solar distiller in Figure III.3 is a well-known device with simple design and construction because its components are available in all world's markets.

Figure III. 3. Conventional solar distiller

Two experiments were carried out at the University of El-Oued (south-east of Algeria) with the same distiller. A single difference between the two experiences is that the first one was on January 13, 2017 and the second one was on May 5, 2017 during the hot season. Table III.1 shows the meteorological conditions of the experiments.

Table III. 1. Experience conditions

Meteorological conditions	May 2017	January 2017
Sunrise	**05:41 am**	07 :38 am
Sunset	**07:19 pm**	05 :46 pm
Ambient temperature	**26-35°C**	11-17 °C
Atmospheric pressure	**1013 mb**	1031 mb

III.2.5. Treatment data of the second experiment

The experiments were done at the Renewable Energy Laboratory of El Oued University. Two distillers are used in the experiment, one of them was used as a reference distiller and the other constituted the object of our study. The latter was designed with two glasses superposed with a gap of 1 cm and isolated from the quads side by polyester rods.

The two distillers have worked side-by-side in the same meteorological conditions and they have the same geometric parameters except at the glazing, as shown in Figure III.4 and Figure III.5.

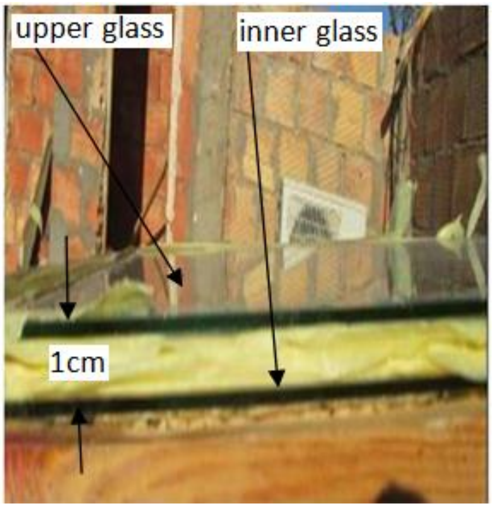

Figure III. 4. Distiller with Double glazing

Figure III. 5. Solar distillers in action

The experience was proceeding on May 5th, 2017. Table III.2 shows the meteorological conditions of the experiments.

Table III. 2. Experience conditions

Meteorological conditions on May 2017	
Sunrise	05:41 am
Sunset	07:19 pm
Ambient temperature	26-35°C
Atmospheric pressure	1013 mb

III.3. Result and discussion

III.3.1 Result of the first experience

Weather factors such as solar radiation and ambient temperature influence the operation of the distiller. Solar radiation is a more important factor in solar distillation and any variation in it results in a variation in productivity. This experiment wants to highlight this factor. Since solar control is impossible then two experiments were planned in two different seasons where the solar radiation is clearly different. The two chosen seasons are summer and winter.

III.3.1.1. Evolution of solar radiation

Figure III.6 shows the solar radiation evolution in W/m^2 during the day time (in hours) for experiments, one in winter and the other in summer. The radiation increases gradually in both cases until reaching a maximum value between noon and 2:00 pm with the only difference that the solar radiation in winter has not exceeded the value of 600 W/m^2 but in summer it has reached the value of 1000 W/m^2. Solar radiation is the key parameter in solar distillation.

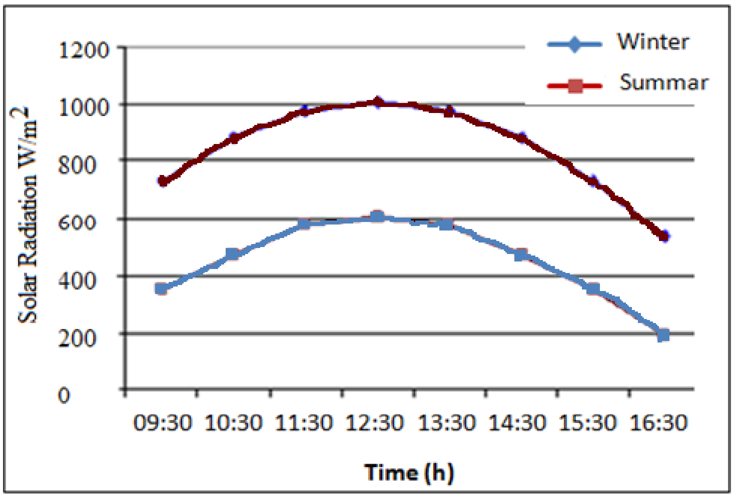

Figure III. 6. Evolution of solar radiations

III.3.1.2. Evolution of ambient temperature

Figure III.7 shows the relationship between the day time (hours) and the ambient temperature for the two experiments. The latter increases gradually until reaching a maximum constant value between 12:00h and 13:00h [7]. Figure III.7 shows also that the ambient temperature is greater in summer where it has exceeded 30 °C, than that in winter which has not reached the value of 18 °C. The ambient temperature is also a crucial factor influencing the phenomenon of solar distillation.

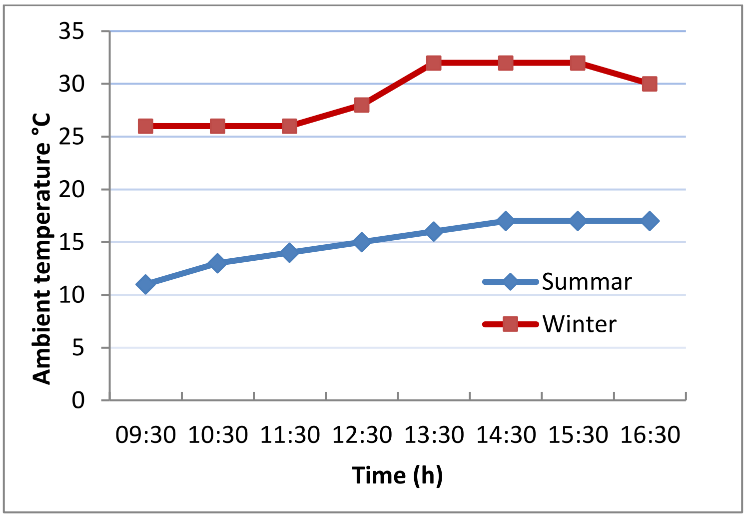

Figure III. 7. Evolution of ambient temperatures

III.3.1.3. Evolution of the inner glazing temperature

Figures III.8 illustrates the evolution between the day time (hours) and the interior temperature of the glazing for water distiller in the experiments. We can see that the temperature difference between the basin water and the inner glazing temperature is also another important factor for the distillation process. The mean temperature difference between the inner glazing and the basin water in the first experiment (carried out in winter) is of the order of 16.25 °C. However, it is of the order of 40.37 °C in the second experiment (carried out in summer). This large difference is favorable for the improvement of the productivity of distilled water due to the evaporation phenomenon of water.

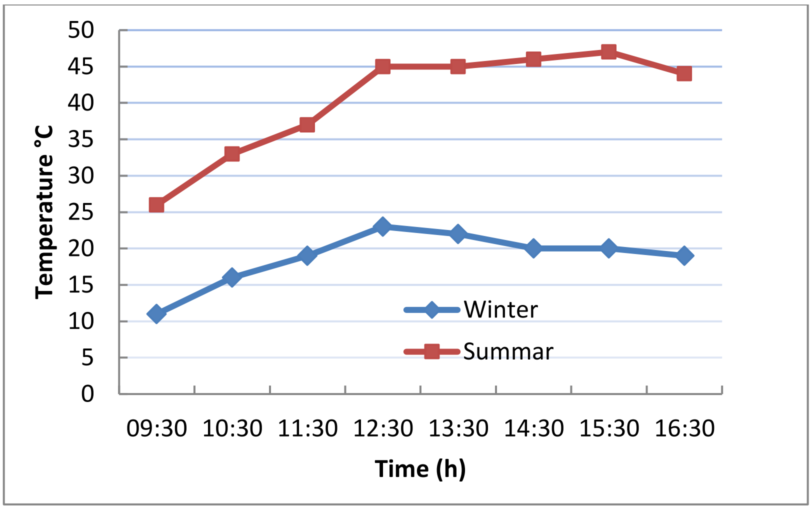

Figure III. 8. Time evolution of the inner glazing temperatures

III.3.1.4. Evolution of water temperature

Figure III.9 shows that the temperature evolution of the basin water in summer is very high, and exceeds the value of 50 °C to reach a maximum temperature of 73 °C at 013:30h. All temperatures in winter are below the value of 40 °C. The temperature of the water to be distilled in the basin is an essential factor in the phenomenon of solar distillation.

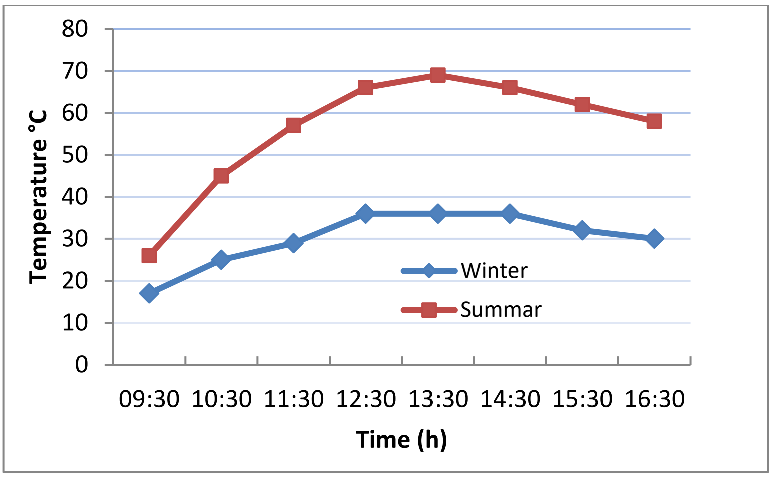

Figure III. 9. Time evolution of the basin water temperature

III.3.1.5. Evolution of water productivity

Obviously, from Figure III.10 we can see the dependence of the productivity of the distilled water on daytime and season for both experiments. Note that the first 4 sunshine hours in the winter did not trigger the distillation, but the first hour of sunshine in the summer triggered the distillation. Consequently, the production of distilled water in summer is more profitable than in winter. The total amount of water produced by the winter experiment was 119 ml, and that in summer was 1127 ml over a period of 6 hours and 40 minutes. The distillate yield increased by 1008 ml / day in the summer.

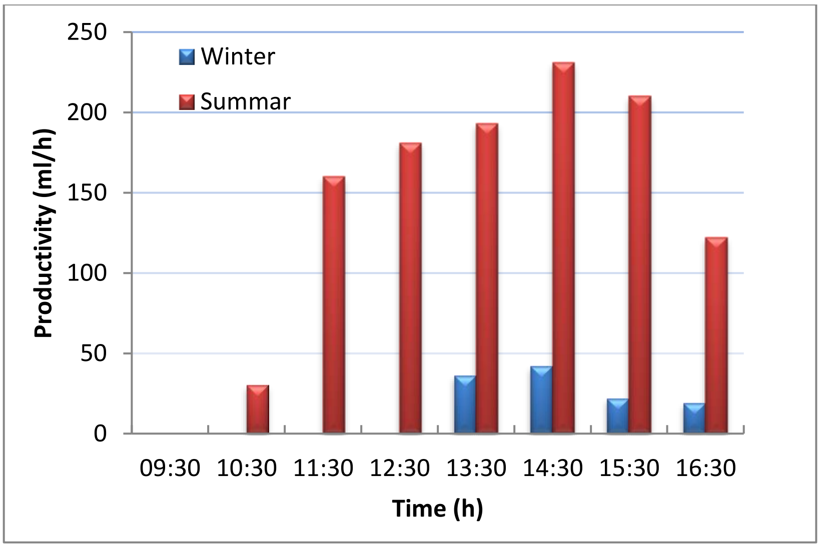

Figure III. 10. Evolution of water productivity

III.3.1.6. Evolution of water accumulation

Figure III.11 represents the accumulation of pure water produced by the solar distillers and it is noted that production of the distiller during the summer season is greater than production of the distiller during the winter season. This figure reinforces figure 3.10. The final production of the distiller in winter is 119 ml and that of the distiller in summer is 1127 ml. It's 9.5 times; it is a big value as a difference. We note that the period from 8:00h to 12:00h the productivity of pure water in the distiller is 0 ml. On the other hand, in the summer season, evaporation was triggered in the first hour. At 12:00h productivity in summer is 371 ml and it is 0 ml in winter. This clearly confirms the great importance of solar radiation in solar distillation.

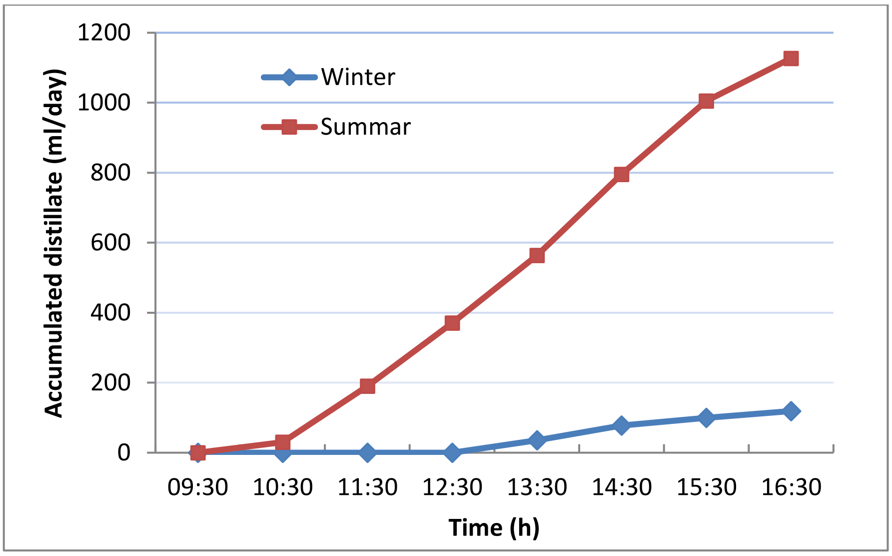

Figure III. 11. Evolution of accumulated water

III.3.2. Result of the second experience

A very important factor in solar distillation and which cannot be neglected is the difference in temperature between the pond water and the inner side of the glass. All the lab researches in the world try to enlarge this difference either by heating the water or cooling the glass. This experiment wants to show that this factor is really of great importance in the distillation, for that we increased the resistance of the glass to slow down its cooling and in this way the temperature difference is decreased.

III.3.2.1. Solar radiation

The experiment was done in the region of El Oued south-east of Algeria in May 2017 dealing with two distillers. The latter are exposed to the sun. The distiller D2 is the object of our study and it has double glazing and the distiller D1 is the reference (the witness).

The temperature samples are taken every hour. Figure III.12 shows the evolution of solar radiation (in W/m^2) during the day. An electronic radiation meter, by which every hour the solar radiation is taken, is placed next to the solar distiller. The curve has a normal shape as it was found in literature and having its maximum radiation between 11:00h and 14:00h which is the most important factor in solar distillation.

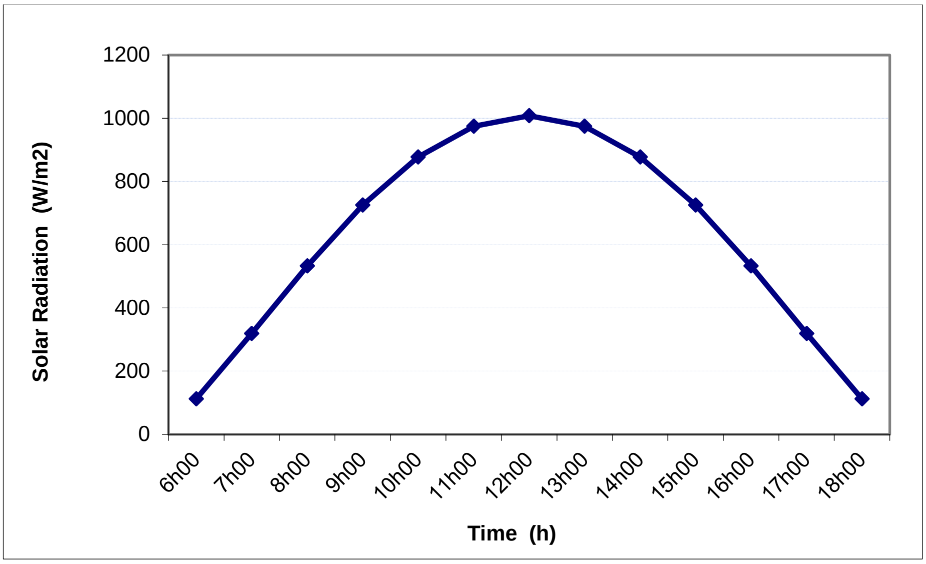

Figure III. 12. Evolution of solar radiation

III.3.2.2. Ambient temperature

Figure III.13 illustrates the variation of the ambient temperature in °C as a function of time. The temperature starts to vary between 23°C at launch and reaches a maximum of about 32°C between 12:00h and 18:00h. The day was hot.

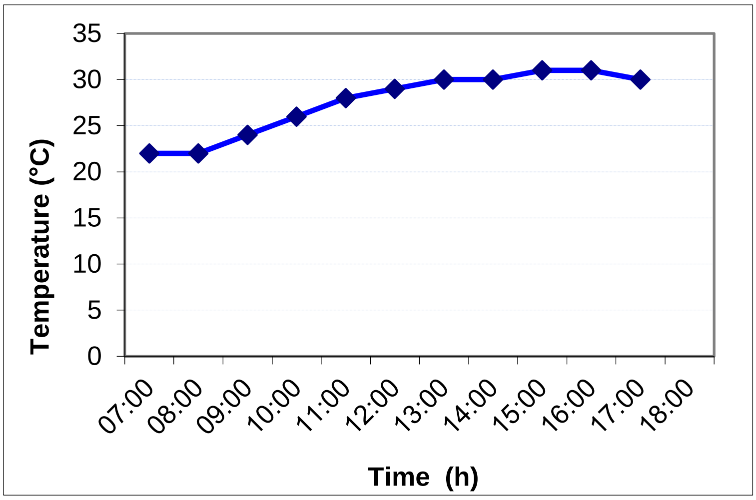

Figure III. 13. Evolution of ambient temperature

III.3.2.3. Temperatures between water- inner face glass

The heat transfer in the distiller D1 is done through a single wall (glass) so the glass cover receives heat by convection than by conduction then it releases heat to the outside by convection. Whereas in the case of D2 the heat transfer is done through inner glazing, as in D1, and stopped by a thin film of air between the two glazing which plays a role of the insulator to the heat. Figure III.14 shows the temperature evolution at inner face glass D2 and its change in the basin water. It is worth noting that there is almost no difference in the average temperature between the inner face glass D2 and the one of the water (ΔT= 0.5°C). The temperature of the water sometimes is higher than the glass one during the whole day. As it was known condensation needs a considerable difference of temperature to produce distilled water (*i.e* gradient of temperature). This feeble difference in temperature will be followed by feeble productivity during the day and leads to a weak efficiency of D2 distiller.

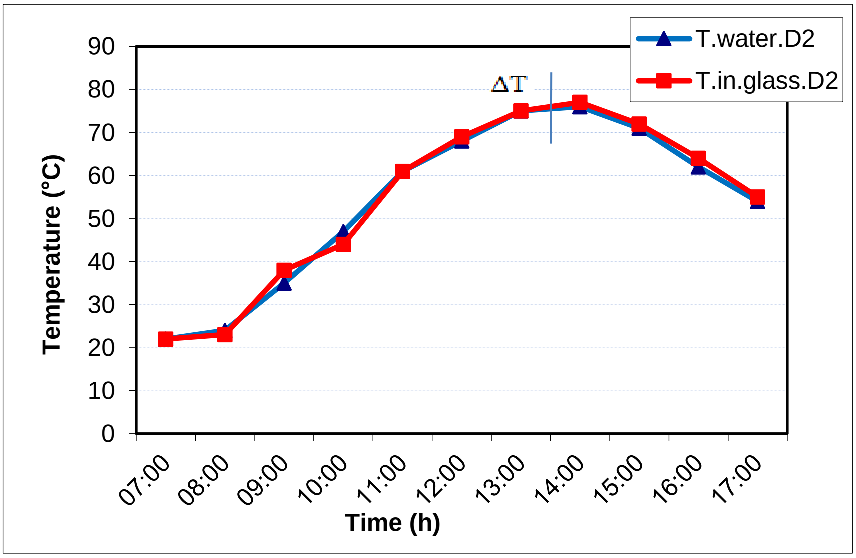

Figure III. 14. The glass inner and the basin water temperatures evolution of the distiller D1

Figure III.15 shows the temperature evolution at inner face glass D1 and its change in the basin water. It should be noted that there is considerable difference in the average temperature (ΔT= 4.2°C) between the inner face glass D1 and the one of the water. As can be seen the temperature of the water is higher than the glass one during the whole day and leads to a considerable gradient of temperature. This temperature gradient will be followed by great productivity during the day and leads to a strong efficiency of D1 distiller. So the productivity of the distilled water is directly related to the temperature gradient. Whenever this gradient is large, the productivity is interesting as it was meted in the case of the D1 distiller. Whereas, in the case of D2, this gradient is very low and the productivity of the D2 distiller of water is low also.

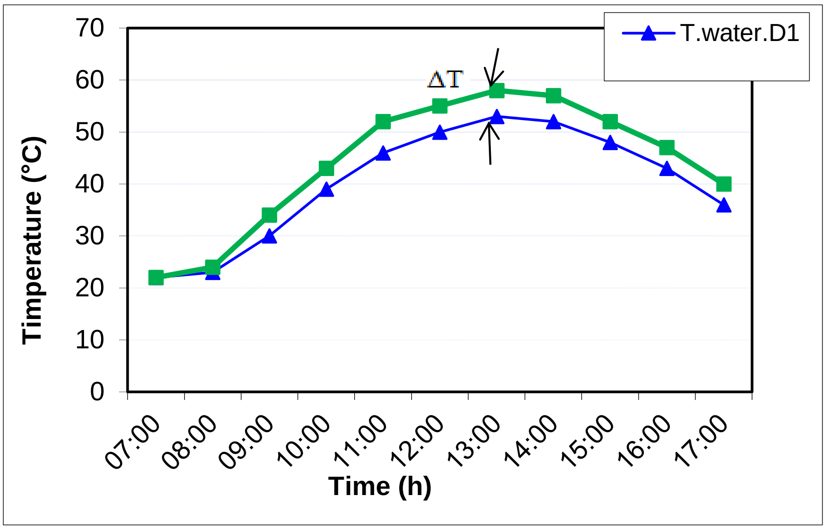

Figure III. 15. The glass inner and the basin water temperatures evolution of the distiller D1

III.3.2.4. Distilled water productivity

Figure III.16 shows the productivity evolution of the distilled water (in ml/hour) during the whole day. According to these results, it has been noted that the productivity of the distiller with the double glazing D2 is infinitely neglected compared to the productivity of the control distiller D1. The maximum value of D2 did not exceed 20 ml while the maximum value of D1 exceeded 100 ml. The average value of D1 productivity exceeded 60 ml/hour whereas for the distiller D2 did not exceed 07 ml/hour. The quantities of distilled water are related to the temperature gradient between the water basin and the inner face of the glass. Any increase in this temperature gradient will be followed by an increase in productivity of the distilled water. The maximum productivity was reached between 12:00h and 14:00h PM for D1. Whereas, this maximum was reached early for D2 and the quantities are 108.6 and 19 ml for D1 and D2, respectively.

The productivity of a solar distiller depends on the temperature of the pond water and the temperature of the inner face of the glass cover. The higher the temperature of the water in the pool, the lower the internal temperature of the glass cover, which means that the temperature difference between the water and the cover is higher. Therefore the evaporation will be higher. These results are also confirmed by research studies [15, 16].

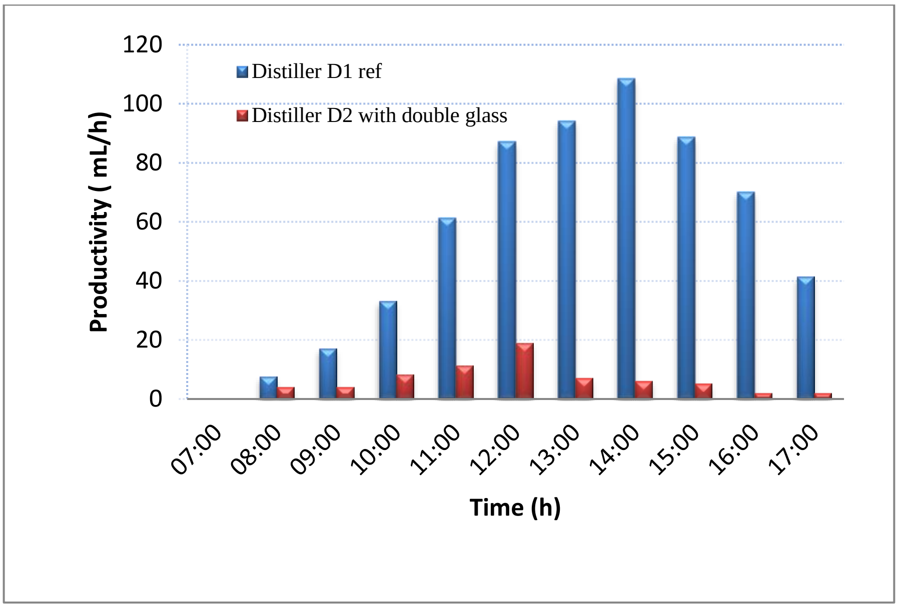

Figure III. 16.Productivity of distilled water

III.3.2.5. Accumulated of distilled water

Figure III.17 represents the accumulation evolution of distilled water in time during the whole day. Throughout the experiment from 7:00h to 17:00h, the accumulation of pure water of the distiller D2 did not exceed 70 ml but the distiller D1 exceeds this value until reaching 609.8 ml. The cause of this difference in accumulation is due to the difference in temperature between the water and the glazing. The latter is large in the distiller D1 and it is low in the distiller D2.

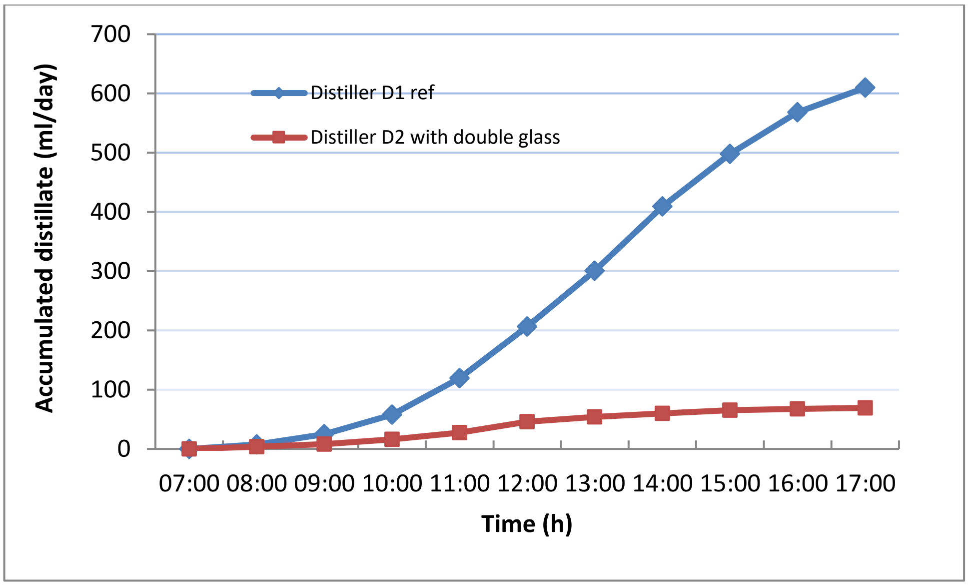

Figure III. 17.Accumulated of distilled water

III.4. Conclusion

According to the results obtained in the present work, solar distillation is more productive and more favourable in the summer period than in the winter period. This fact is due to the increase of the solar radiation. The maximum distilled water quantity for 6 hours and 40 minutes is recorded in May 2017 (in summer) for an amount of 1127 ml, whereas in January 2017 (in winter), the yielded quantity is about 119 ml. Those results demonstrate manifestly the difference in distilled water productivity between the two seasons. Therefore, any increase in solar radiation necessarily yields an increase in the distilled water productivity, without neglecting other key parameters such as ambient temperature.

The gradient of temperature between the basin water and the inner side of the glass has a primordial role in the productivity of distilled water. If this it is close to zero the production of distilled water becomes weak. It is the case of the distiller with double glazing D2; the productivity was about 69.3 mL/day. When the gradient of temperature is greater as in the case of D1; the productivity was about 609.6 mL/day. Double glazing increases the temperature of the glass and brings it closer to the temperature of the pond water, which reduces the temperature gradient by 9 times compared to the single-glazed still.

It can be concluded without any doubt that solar radiation and the difference in temperature between the water of the basin and the inner face of glazing are indeed vital factors in solar distillation. Any increase or any decreases in these two bills will be followed by an increase or decrease in the productivity of pure water. This has been proved experimentally under the climate of El Oued, South East Algeria.

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Chapter 4

Results and discussion of experiences

IV.1. Introduction

In this chapter, we will present the results of the experiments obtained during the tests carried out at the University of El Oued. Experiments on the effect of radiation and the effect of the temperature gradient have already been discussed in chapter III, and the experiments on sand effect experiments and the effect of an isolated chamber used as a cover will be discussed in Chapter V and VI. Therefore the remaining series of experiments will be dealt in this chapter. The results discussed mainly concern sunshine, ambient temperature, two faces temperature of the glazing, the temperature of the pond water, the productivity and the accumulation of pure water.

IV.1. Evaluation of experiences

IV.1.1. Similarity experience

In this experience, four distillers are exposed on the 12/05/2017 to the sun under the same conditions in order to see the resemblance between them and to see the difference in behaviour of distillers in order to choose two distillers almost perfectly similar with an error $\Delta e < 5\%$.

Figures IV.1 and Figure IV.2 interpret the evolution of solar radiation and the evolution of the ambient temperature.

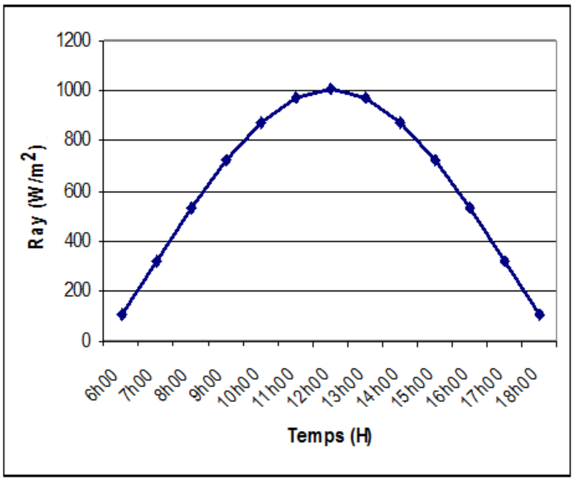

Figure IV. 1. Solar radiation evolution

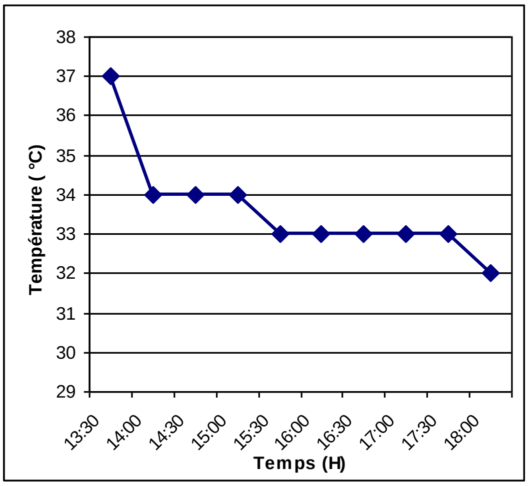

Figure IV. 2. Ambient temperature evolution

Figures IV.3 and IV.4 show the evolution of the glazing temperature (outer face and inner face), we note that the temperatures are almost the same.

Figures IV.5 and IV.6 show the evolution of the temperatures of the interior of the distiller and the temperature of the water in the basin and we notice that the evolution of the temperatures is very close.

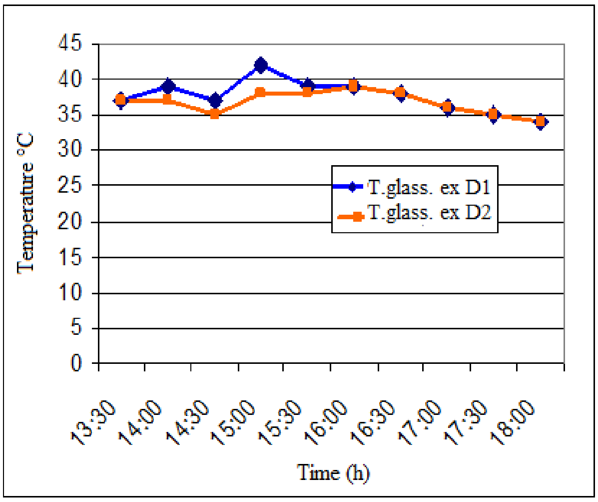

Figure IV. 3. Evolution of the glazing temperature, external face

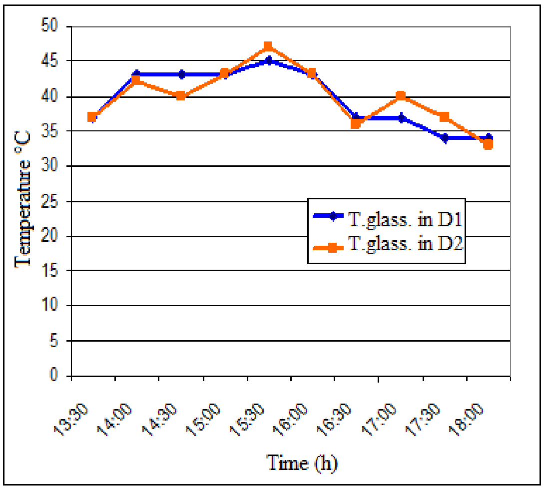

Figure IV. 4. Evolution of the glazing temperature inside face

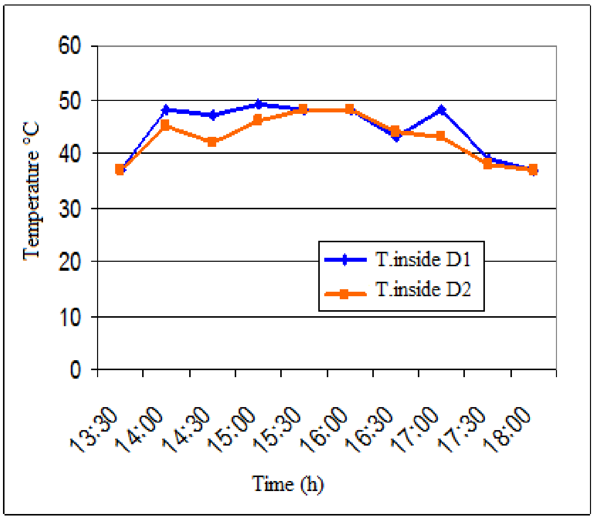

Figure IV. 5. Evolution of the internal temperature of the distiller

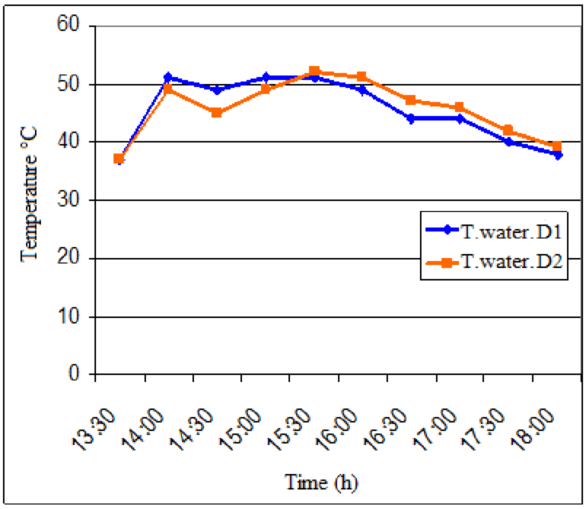

Figure IV. 6. Evolution of the water temperature of the pond

Figure IV.7 reflects the productivity of the two distillers which are very close with a Δe = 0.35%.

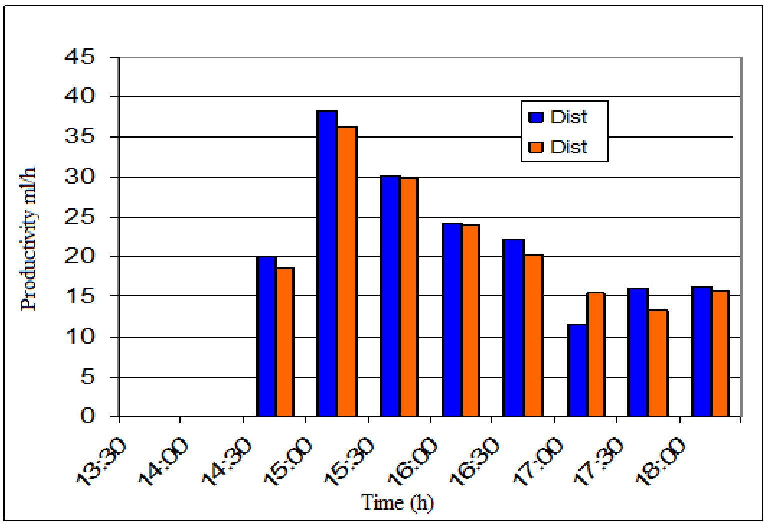

Figure IV. 7.The productivity of the two selected distillers

As a conclusion, the two distillers are similar with an error of 0.35% so they can be considered as two similar distillers. In the experiments that follow one will be used as a reference (witness) and the other will be to study an effect of improvement.

IV.1.2. Effect of a metallic absorber

In the present experience, emphasis has been placed on the study of a single slope solar distiller having as dimension 50 × 50 cm, in the thickness of the impure water is 1 cm. Solar distillation used thermal storage materials to improve the thermal performance of a solar distiller [1-4]. Copper, stainless steel, Mica and Aluminum are used in solar distillation as a heat storage material. Experience shows that the improvement in freshwater productivity is between 17.2 and 42.2% [5]. Previous study was done to determine that the sand is also a heat storage material [6]. The use of sand in solar distillation differs from one study to another. The way of using sand under many forms has a very important influence on the productivity of fresh water. Some experiments show it has an improvement in productivity using sand in tissue pouches placed on the bottom of the distiller [7, 8]. The objective of this experience is to increase the temperature of the water in the distiller's basin to widen the temperature difference between the water and the inner face of the glazing. For that a so simple technique was used, it is to put a metal plate of Zinc in the water basin of the distiller Ds and the other distiller Dc is used as a reference.

The metal plate of Zinc is stained black, dimension 48 x 48 cm, thickness 0.2 cm, thermal conductivity of K = 116 W / m K, melting energy of about 7.322 kJ / mol. Zinc has melting points about 419.5 °C and boiling point of 907 °C. Figure IV.8 shows a diagram of the solar distiller with the zinc metal plate, it also shows the positioning of the K type thermocouples.

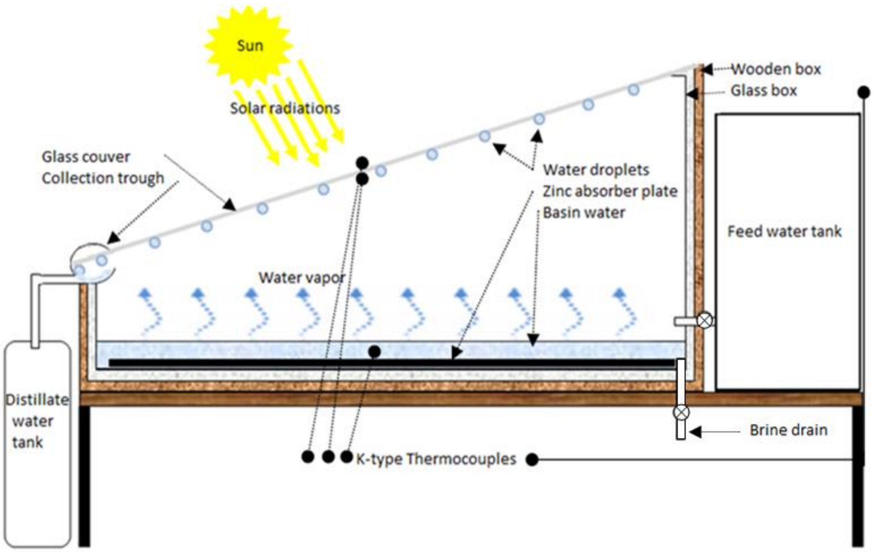

Figure IV. 8. **Schematic diagram of solar distiller with a black plate of Zinc**

Figure IV.9 shows the amounts of hourly water produced by both distillers (in ml/m^2.h) throughout the day. The productivity of the distiller Dc is remarkably lower than the productivity of the distiller Ds. The maximum value of the water collected from the Dc still did not exceed 440 ml /m^2.h while the maximum value of the Ds distiller exceeded 460 ml /m^2.h. This difference in production is clearly due to the fact that the distiller Ds has a metal plate of Zinc.

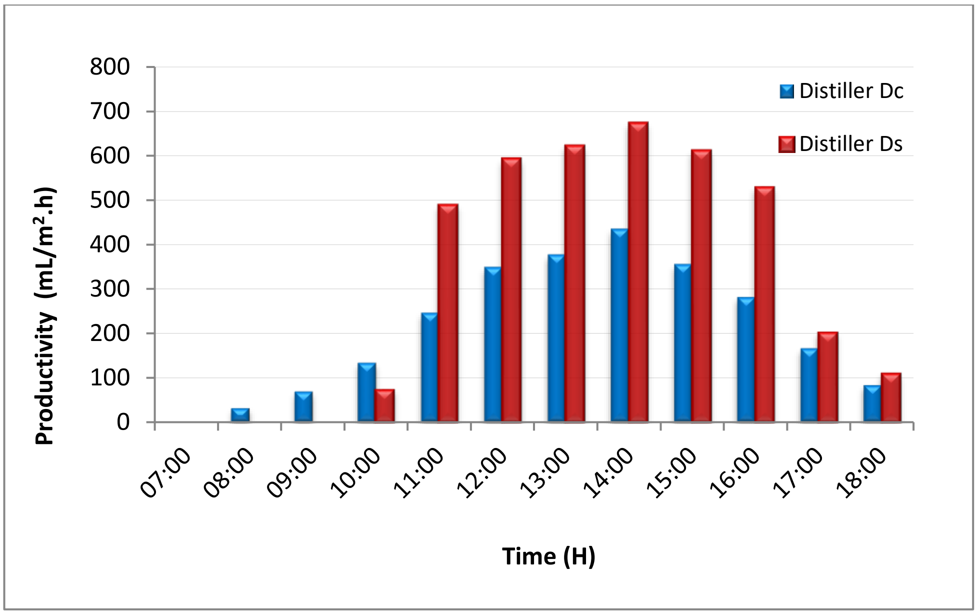

Figure IV. 9. The hourly productivity of two distillers Dc and Ds

Figure IV.10 shows the distillate measurements accumulated daily for the two distillers for 11 hours from 07:00 to 18:00. It is quite clear that the accumulated distillate of Ds has reached an approximate value of 3894.4 ml / m² / day which is much higher compared to the distiller Dc which is 2520.8 /m^2.day. The difference between the two distillers is 1.83 times larger.

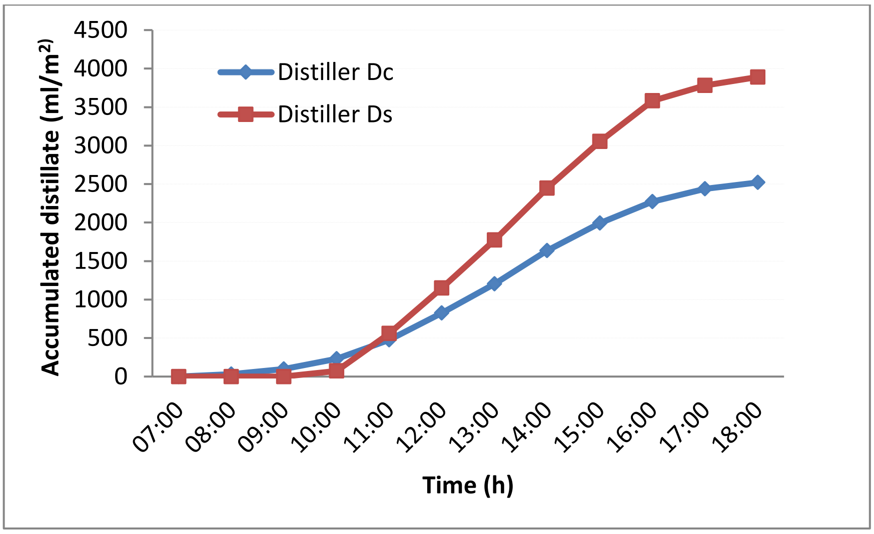

Figure IV. 10. Accumulated distillates for the two solar distillers (Dc and Ds)

As conclusion, The distiller Dc started to produce the first hour but the distiller had to start producing after 3 hours. At the end of the day, the control distiller Dc produced 2520.8 ml /m^2.day and the distiller Ds produced 3894.4 ml /m^2.day. This improvement of 1373.6 ml /m^2.day (1.83 times) is caused by a simple zinc plate available on the market.

IV.1.3. Effect of an external refractor

Different experiments have been done on a conventional solar distiller attached to an external single refractor, the results show that the improvement varies between 9 and 21% [9, 10-12]. This experience is based on a purely experimental study in order to obtain drinking water that can alleviate the drinking water needs of a Saharan community. This experiment highlights the positive influence of the addition of a simple external flat refractor on the productivity of a traditional solar distiller.

Figure IV.11 shows the evolution of the accumulated distilled water of the two distillers D1 and D2 with time. Both graphs start from zero milliliters, as time passes, the amount of water produced by the two stills accumulates slowly. At 18: 00h the amount produced from the distiller with the refractor is 4840.4 ml/ m^2.day and the amount produced by the simple distiller without refractor is 3408.4 ml /m^2.day. The difference between the two productions is surely due to the refractor.

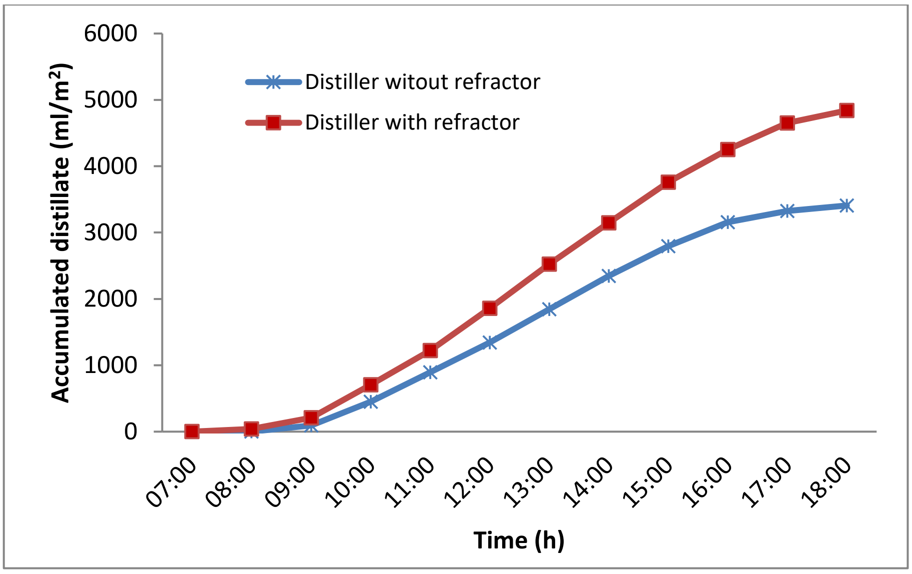

Figure IV. 11. The evolution of ΔT of the distillers

Figure IV.12 shows the variation in daily productivity for D1 and D2 distillers throughout the day. The productivity of the two distillations increased from zero to a peak of 405.8 ml / m^2.day for the D1 still and 664 ml / m^2.day for the D2 distiller. After 13:00 the productivity begins to decrease slowly to reach its minimum value at 18: 00. The total amount of water produced by the distiller D1 is 3408.4 ml / m^2.day and that produced by the distiller D2 is 4840.4 ml / m^2.day during the same period. This is a production improvement of 1432 ml /m^2.day due to the only difference between the two distillers; it's just the commercial refractor.

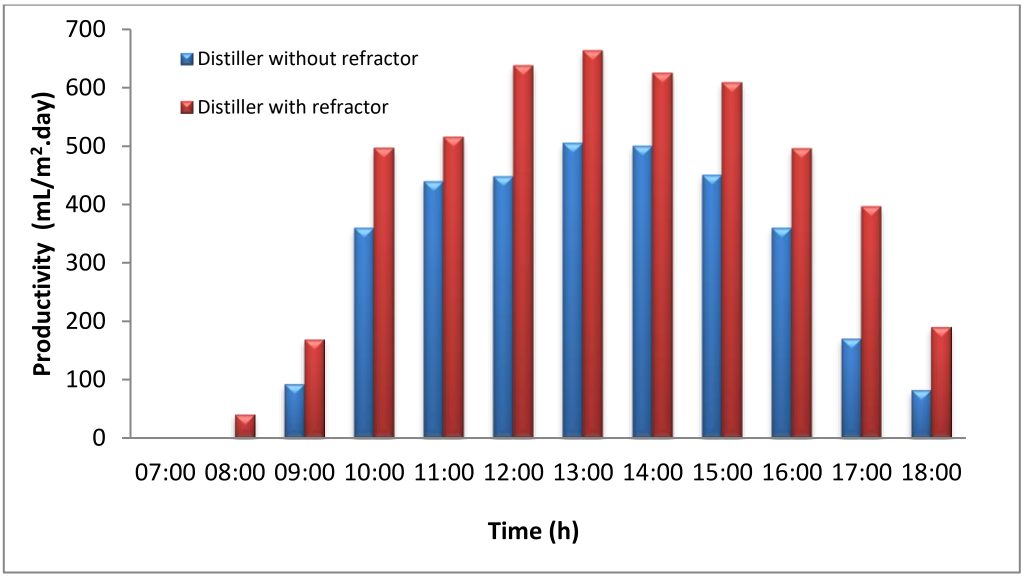

Figure IV. 12. The variation in productivity of the distillers

As results, the difference in average temperature between the inner glazing and the water of the distiller D2 basin is 63 ° C and that of the distiller D1 is 38 ° C. Therefore, the distiller which has the greatest difference in average temperature (in our case the distiller D2), will have a high productivity.

IV.1.4. Effect of glass cover thickness

The objective of our work is to see the influence of the thickness of the glass on the performance of a single-slope still with three different thicknesses of glass (3, 4 and 5 mm).The Figure IV.13 shows the productivity of the distilled water of the three distillers, it is very clear that the amount of water produced by the distiller at 3 mm (in black) is very large compared to that of the distiller at 5 mm (in red) and finally the distiller at 6 mm (in blue). The first droplets appeared in the distiller at 3 mm. In the first sample we collected a quantity of water from the distiller at (3 mm) but we received nothing from the other two. The largest amount was harvested between 12:00 and 15:00 or solar radiation is maximum.

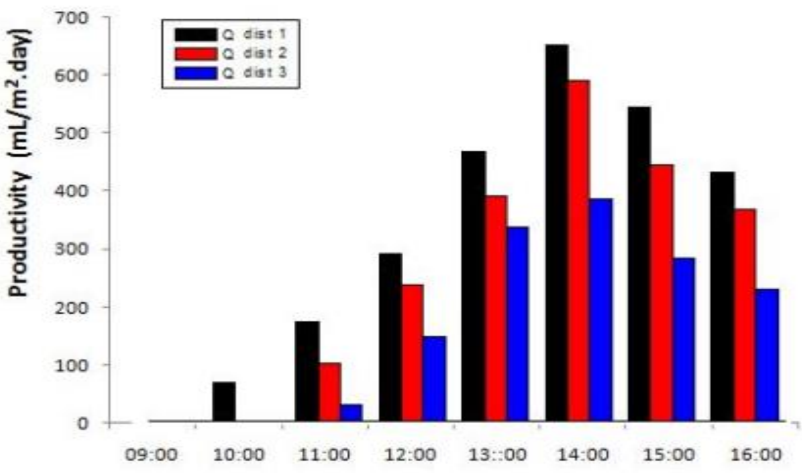

Figure IV. 13. **The variation in productivity of the distillers**

As conclusion, the experiments show that the production is better improved when the thickness of the glazing is low e = 3 mm with a total production of 2313.2 ml /m^2.d for the distiller D1; when e = 5 mm, the production is 1876 ml / m^2.d for the distiller D2 and at the end when e = 6 mm, the production of the distiller D3 is 1236 ml / m^2.d. It can be deduced that any increase in thickness will be followed by a decrease in productivity in pure water.

IV.1.5. Effect of cylindrical plastic fins

Two distillers were posing on the same table of experience in the same climatic conditions in the region of El Oued, southeast of Algeria. The distiller D1 is taken as reference and the distiller D2 are the object of our study. Plastic tubes with a diameter of 0.5 cm and a length of 5 cm were fixed in the bottom of the distiller, thus playing the role of the fins. The experience was between 10:00 and 16:00 and in good weather conditions. The results obtained are represented by Figure IV.14.

Figure IV.14 shows the evolution of the productivity of pure water of the two solar distillers D1 and D2 as a function of time. Note that the productivity proceeds normally but with a gap for the distiller D2 which contains the fins. This difference is very remarkable between 13:00 and 16:00 h. the amount of the total water produced by the two distillers is as follows, the distiller D1 produced 1092 ml /m^2.day and the distiller D2 produced 1564 ml /m^2.day. Since the two distillers are similar then this difference in productivity of pure water is due to small plastic tubes attached to the bottom of the distiller D2.

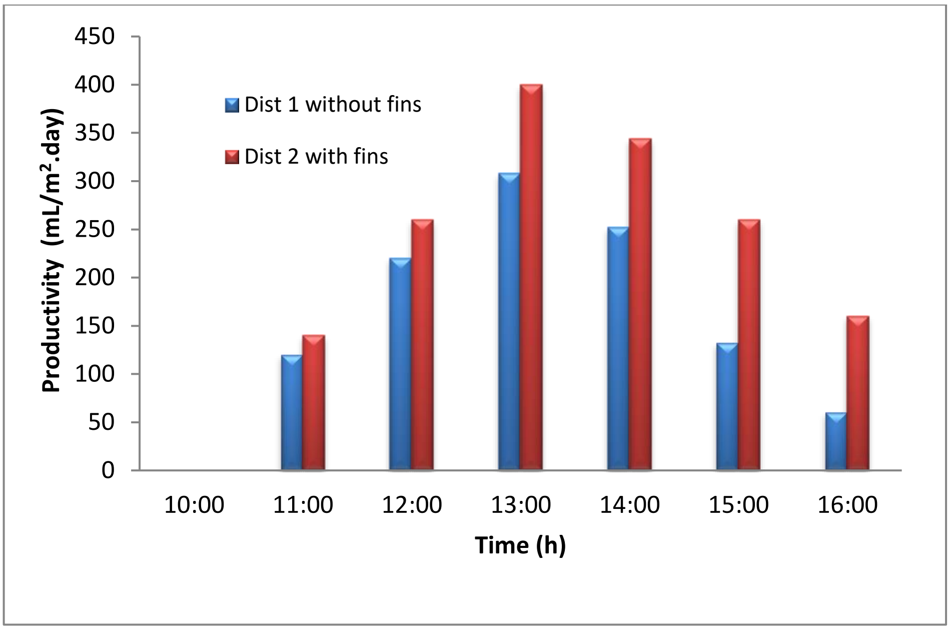

Figure IV. 14. Evolution of the distillers productivity

It can be concluded that cylindrical plastic tubes have a positive effect on the productivity of pure water with an improvement of 1.43 times.

IV.1.6. Effect of effect of aluminium balls

The idea behind this experiment is used aluminium balls made by commercial aluminium sheets. His balls are placed in the distiller D2 and as always another distiller D1 without balls is taken as reference. The experiment was carried out under favourable climatic conditions. Figure IV.15 shows the productivity of pure water of distillers D1 and D2 as a function of time. We notice from the first hours, the production of distiller D2 (with the balls of aluminium) is remarkably superior to that of distillers D1 preference. This difference is maintained throughout the period of the experiment from 9:00 to 16:00 h. This productivity gap between the two is certainly due to aluminium balls.

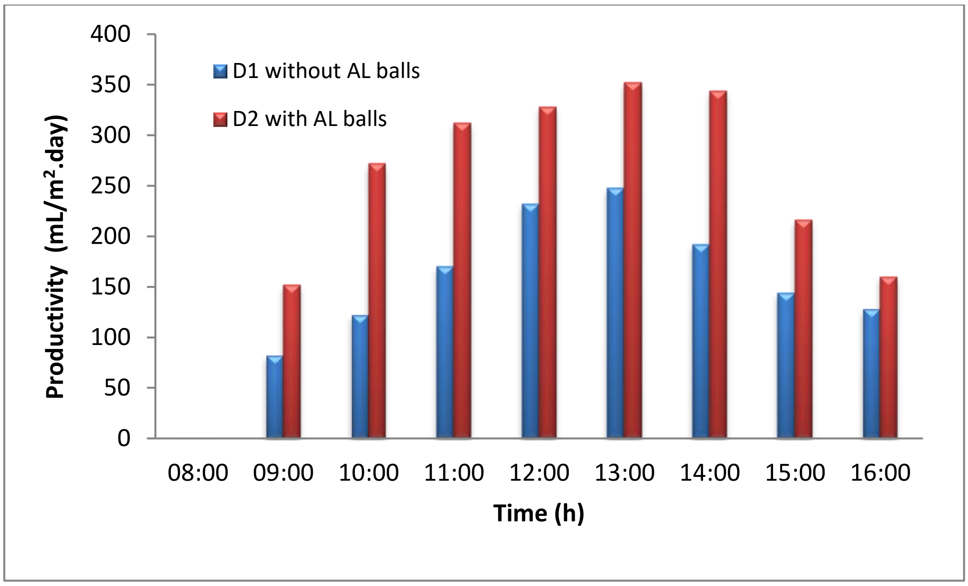

Figure IV. 15. Evolution of the pure water productivity

The values of the productivity of pure water obtained by this experiment give a clear idea of the efficiency of this simple technique. Reference D1 still produced 1318 ml /m^2.d and distiller D2 with alumina balls gave 2136 ml / m^2.d, in other words, there is an improvement of 1.62 times.

IV.1.7. Effect of a flat solar collector

In this experiment we go from passive mode to active mode of solar distillation. Two similar distillers are used at the same time, the distiller D1 is a reference still and the distiller D2 is connected to a flat solar collector as shown in Figure IV.16.

Figure IV. 16. Experience setup

The polluted water flows in a closed cycle between the tank of the distiller D2 and the solar collector. In the basin, there are 2 holes, the inlet hole of the hot water H_{inlet} and another outlet hole H_{outlet}. Figure IV.16 shows the box of the distiller D2 with the two diagonal holes, the water leaves the H_{outet} to flow into the solar collector via a pipe. The water warms it in the solar collector and then it will be poured into the basin by the H_{inlet}.

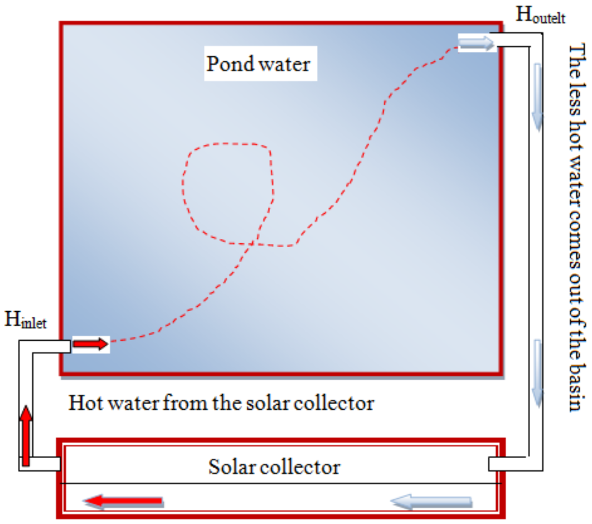

Figure IV. 17. The distiller D2 connected to the solar collector

The system works under the pressure of Archimedes, in other words without electric pump. As time passes, the temperature of the pond water increases remarkably with respect to distiller D1 as shown in Figure IV.17. We notice that there is a big temperature difference between the waters of the two distillers. This increase in temperature causes a great evaporation of water and therefore a high productivity of pure water. It is noted that there is a great temperature difference between the waters of the two distillers along the experiment. Between 12:50h and 13:20h this difference is at most with a value of 35 °C. This value is still very important and it is due to the solar collector connected to the distiller D2. This increase in temperature causes a great evaporation of water and therefore a high productivity of pure water.

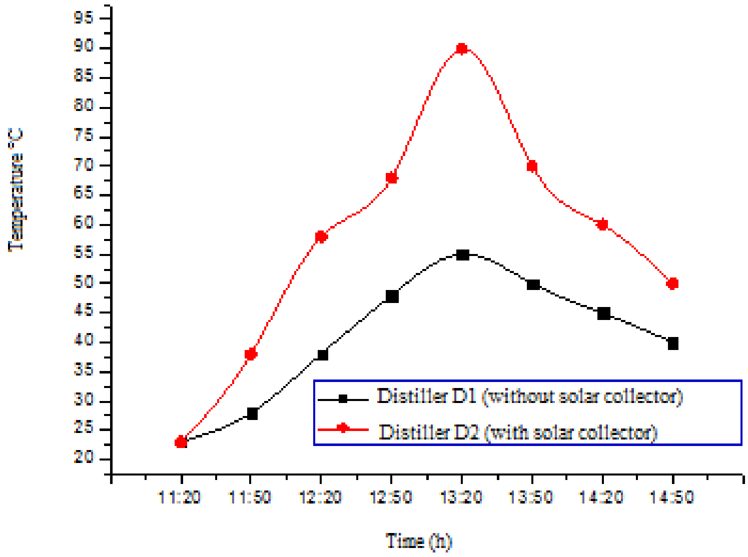

Figure IV. 18. Water temperature of distiller D1 and D2

Figure IV.18 shows the productivity of pure water as a function of time. It is noted that the productivity of the distiller D2 is greater than the distiller D1 from the first hour of the experiment. The difference in productivity is remarkable between 12:20h to 14:50h and it is maximum at 13:20h with a value of 220 ml/m^2.day for distiller D2 and 92 ml/m^2.day for distiller D1. The total productivity of the distiller D1 was 1144 ml /m^2.day and against the distiller D1 was about 416 ml /m^2.day. This difference between D1 and D1 is due to of course the flat solar collector.

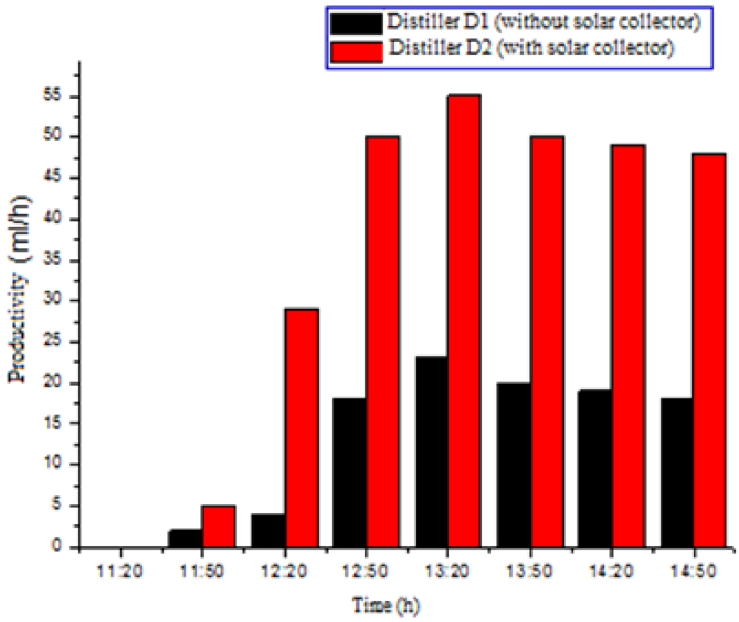

Figure IV. 19. Pure water productivity of distiller D1 and D2

As conclusion, the improvement of distiller D2 caused by solar collector is better than 2.75% compared to the reference distiller D1.

IV. Conclusion

All experiments are done with two similar distillers. Both solar distillers are tested under the same weather conditions. The results obtained by the series of experiments are as follows:

- The two stills selected from 4 solar distillers are very similar with a production error of less than 5%.
- The improvement caused by a black metal absorber is better than 2.83% compared to the reference distiller.
- The improvement caused by an external mirror is better than 2.38% compared to the reference distiller.
- the productivity of a solar distiller is a function of the thickness of the glazing, it is inversely proportional to the thickness.
- The improvement caused by cylindrical fins is better than 1.62% compared to the reference distiller.
- The improvement caused by solar collector is better than 2.75% compared to the reference distiller.
- According to the results of the simulation, the best position of the inlet hole and the outlet hole of the polluted water is on the same diagonal.

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Chapter 5

Sand dunes effect on the productivity of a single solar distiller

V.1. Introduction

The drought and observed climate changes which have prevailed for many years in North Africa have had a negative impact on drinking water resources [1]. Faced to with these challenges, Algeria has adopted the phase change process liquid to vapor as a solution [2]. The efficiency of this technique is relatively low compared to other modes but it remains the most economical way to desalt water. The low-cost solar distiller can be studied, designed, and improved with simple methods in order to provide water for communities living in remote or arid areas. It can also be used to remove fluoride [3]. The region of El Oued, like all regions of southeastern Algeria, is catastrophically affected by a high level of fluoride in deep waters, The Fluorine rate that varies between 0.8 and 4.3 mg / l depending on the different regions and this largely exceeds the standard adopted guideline values 0.8 mg/l published by the World Health Organization (WHO) [4,5]. This excess causes a huge health and economic problem, thousands of families buy daily filtered drinking water distributed by tank cars. This situation prompted researchers to conduct local studies [6-7] which aims to improve and perform a small solar distillation station under the actual insulation for underground water desalination of affected water in arid regions at southeast of Algeria. The small station has a daily capacity over more than 15 liters / m^2 of distilled water [8]. The solar distiller is one of the most economical and easiest solutions for drinking water supply in remote, arid and dry areas. To see some factors of increase or decrease in the productivity of conventional solar systems, studies have been carried out in several labs of research in the world [9-15]. The south-east of Algeria is arid area which is a very hot area in summer and very cold in winter. A study has been done to show the influence of the seasons on solar distillation[16]. Nanofluid technology is a technique that uses nanofluid as a potential source of heat to improve the thermal performance of a solar distiller [17-20]. Copper, stainless steel, Mica and Aluminum are used in solar distillation as a heat storage material. Experience shows that the improvement in freshwater productivity is between 17.2 and 42.2% [21]. Previous study was done to determine that the sand is also a heat storage material [22]. The use of sand in solar distillation differs from one study to another. The way of using sand under many forms has a very important influence on the productivity of fresh water. Some experiments show it has an improvement in productivity using sand in tissue pouches placed on the bottom of the distiller [23-24]. This experimental work is based on the use of natural sand dunes so as the distribution of this sand on the bottom of the basin of the conventional solar distiller in a homogeneous manner thus forming a layer on the absorber. In attempt to investigate the use of sand under a plate form in the basin to improve the productivity of the solar still.

V.2. Method and material

V.2.1 Groundwater in the El Oued region - Algeria

The region of El Oued is located in southeastern Algeria with a circumference area of 54573 m^2 and almost 700000 inhabitants. The geographical coordinates of El Oued in decimals are: 33.3683 ° of latitude and 6.8674 ° of longitude with an average altitude of 60 m. The region is very rich in groundwater but unfortunately this water is affected by a high content of fluoride. The problem of endemic fluorosis in Algeria was reported for the first time in 1936 by the Institut Pasteur in Algiers, which found this intoxication [25]. According to the work of the National Institute of Public Health (1977), fluoridated intoxication was coming from a prolonged exposure to excessive of drinking water in the Souf region with levels higher than 0.8 mg / l. It is wothe nothing that the fluorine rate exceeds 4.30 mg / l in several localities of El Oued. Figure V.1 shows the distribution of groundwater in the El Oued-Algeria region [26].

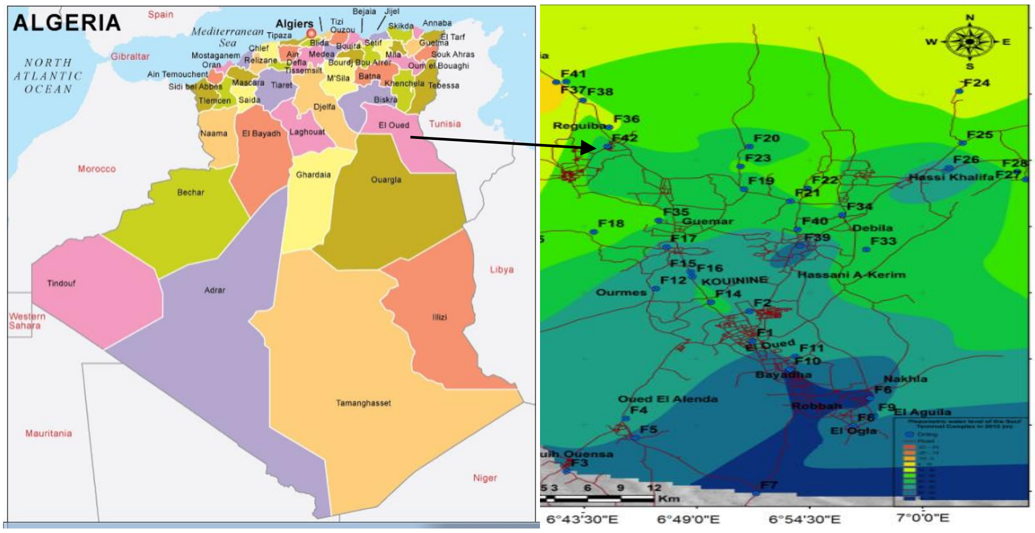


Figure V. 1. Water Disposal Map of groundwater in the El Oued-Algerie region

V.2.2. Description and principle of operation

The well-known single slope solar still has a simple design and low coats (homemade). It consists of a square wooden box (0.50 x 0.50 m), closed with a blanket of ordinary glass having as dimensions (0.55 x 0.55 m) and 0.004 m thick. The glass makes an angle of 20° with the horizontal as shown in Figure V.2. The water droplets are grouped in the PVC plastic tube of 0.60 m long and 0.025m diameter then the distilled water is collected into a tank for the accumulation.

The single-slope solar distiller is very economical device for producing fresh water. Its operating principle is based on the greenhouse effect. It has a transparent glass lid that lets in solar radiation. The get in radiations are absorbed by a black absorber at the bottom of the basin which , in our case, is a thick and waterproof layer of black silicone. This layer, acting as an absorber, prevents water-wood contact. The water evaporates because of the sun heat. The steam migrates towards the glazing and starts to condensate on it interior face. Droplets appear and slide under the gravity into the collection tube. The gathered droplets of distilled water are collected into a tank. The Figure 5.2 shows also the location of the thermal sensors that measure the water temperature and both sides of the glazing.

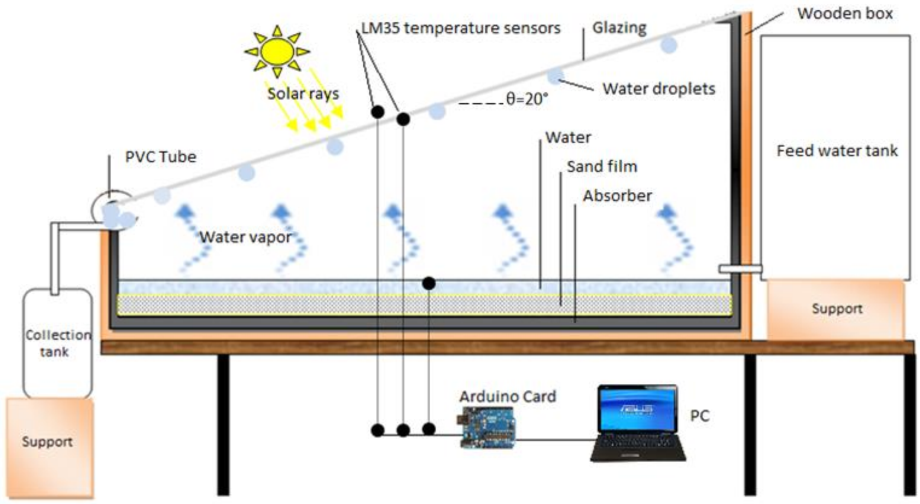


Figure V. 2. Schematic representation of the single slope solar distiller

V.2.3. Experience and measuring instruments

The experiments were made on May 17th, 2017 with two distillers D1 and D2. The day was very clear no clouds nor the wind. The distiller D1 is taken as a reference and the distiller D2 have been filled with a homogeneous layer of sand dunes to see the effect of this layer on productivity in fresh water productivity. D1 et D2 distillates have the same amount of water, they are exposed to the sun on the same horizontal platform and they are side by side in a way that does not shadow one to the other. The glass face of the two distillers is oriented towards the south for maximum exposure to solar radiation. The quantities of distilled water recover are manually measured each hour by a graduated cup.

Regarding temperature measurements, they are measured every hour with LM35 temperature sensors that are connected to an electronic card called Ardunio [27], it is an open-source electronic prototyping platform, based on hardware and easy-to-use software packages. This card is connected to a PC via USB cable as shown in Figure V.3.

Figure V. 3. Temperature measuring instruments

V.2.4. Sand dunes preparation

A dune is a relief or a model composed of sand. All dunes are composed of sand, we do not speak of "sand dune", except to specify the quality of the sand which composes it: "Dune of white sand". Figure V.4 shows the sand dunes of El Oued region where this sand is taken as a parameter to study in solar distillation.

Figure V. 4. Temperature measuring instruments

The natural sand was recovered at the top of a dune in the area and it repaired as follows:

• The sand is sifted to have grains of the same size.

• Firstly, the sand was washed with tap water several times to avoid consuming distilled water and then was washed twice with distilled water to remove impurities or other microorganisms that may influence distillation.

• A 0.5 kg of sand is poured into the D2 distiller bottom to obtain approximately a layer with homogeneous thickness and then 3 liters of polluted water are poured too into the same distiller as is illustrated in Figure V.5.

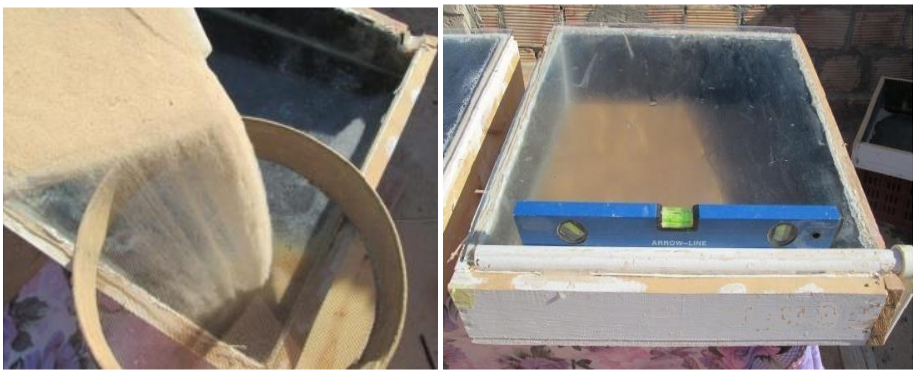


Figure V. 5. Photographic view of the experimental set-up

V.2.5. Physicochemical properties of the dune sand of El Oued- Algeria

The sands of the dunes are very abandoned in the region from where the idea of using it as a factor of improvement. The sand has a yellowish color, composed of Fe_2O_3, $CaCO_3$, Al_2O_3, SiO_2 and, of course, impurities. The heat capacity is 290 $J.Kg^{-1}\,°C^{-1}$ and the density is 2700 $Kg.m^{-3}$. Figure V.6 represents the dimensions of the sand grains of our region [28].

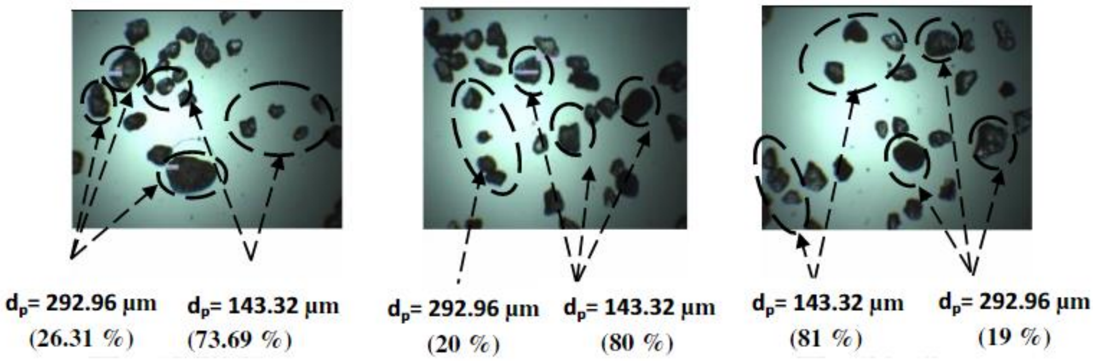


Figure V. 6. Microscopic picture of the size of the sand grains

V.2.6. Error Analysis

The measuring instruments have certain errors. These errors are the percentage of the uncertainties which affect the precision of the values given by its appariels. The LM 35 temperature sensors for measuring glass and water temperatures, the pyranometer (Kipp & Zonen CMP-11) for measuring solar radiation [29] and the calibrated cups for measuring the amount of water produced by distillers. Table V.1 recaptulates the uncertainties of the instruments.

Table V. 1. Uncertainty errors for various measuring

Device	Accuracy	Range	Error
Pyranometer (Kipp & Zonen CMP-11)	± 1 W/m^2	0 – 5000 W/m^2	0.153 %
The temperature sensors LM 35	±1 °C	-40 –110°C	3.846 %
Calibrated cup	± 5 ml	0 – 2000 ml	2.695 %
Errors in daily productivity	± 5 ml	0 – 2000 ml	0.12 %

V.3. Results and Discussion

V.3.1. Variation of solar irradiance and ambient temperature

Solar irradiance and ambient temperature variations during the distillers testing are shown in Figure V.7. It was recorded that the maximum solar irradiance of 1009 W/m^2 reaches at 12:00h and then decreased slowly at sunset. Moreover, a similarity in the temperature feature was remarked, but the maximum ambient temperature of 30°C was recorded at 13:00h then decreases during sunset hours. The daily average solar irradiance and ambient temperature during the testing was 698.09 W/m^2 and 26.73 ° C, respectively.

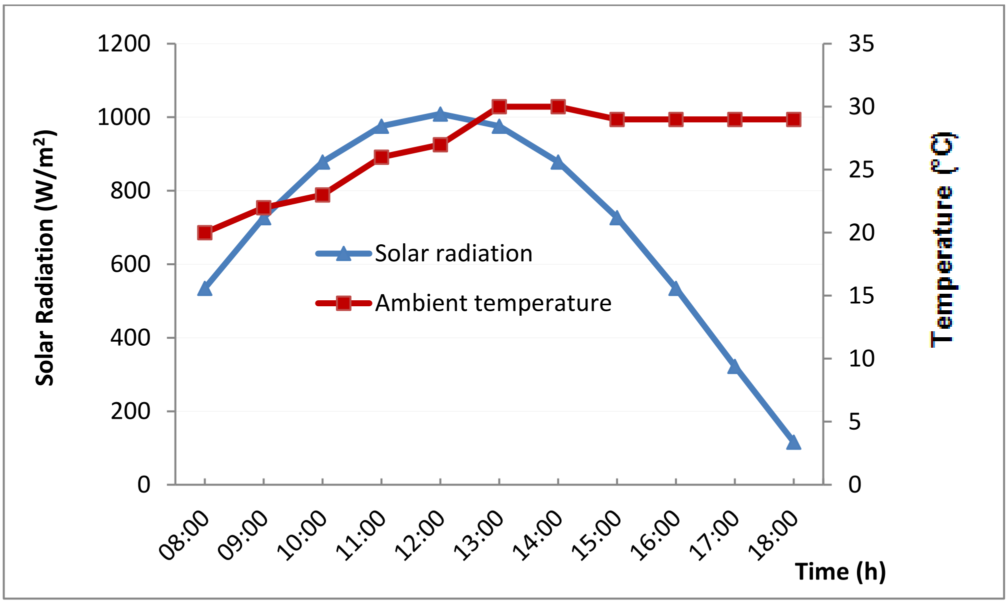


Figure V. 7. Time-wise variations of solar irradiance and ambient temperature

V.3.2. Time-wise variation of water, interior and exterior glass temperature

The time-wise variation of water, interior and exterior glass temperature for distiller D1 and D2 were plotted in Figure V.8. The variation of water and glass temperatures for both D1 and D2 has the similar curves. Water temperature increases during the sunrise hours and reached its maximum value of 59°C for distiller D1 and 63°C for distiller D2 at 1 P.M and then decrease during sunset hours. The daily average water temperature for distiller D1 and distiller D2 is 44.73 and 46.64°C, respectively. Revealing slight difference.

Shown in the Figure V.8 are the whole mesured temperatures of D1 and D2 distillers. The D1 and D2 maximum exterior glass temperatures were of 44°C and 46°C, respectively. The daily average exterior glass temperature was of 35.64 and 36.55°C for D1 and D2, respectively. Similarly the maximum interior glass temperatures of D1 and D2 were about 55 and 56°C and the daily average interior glass temperatures were of 41.36 and 42.36°C, respctively revealing 2°C as difference between them, which is concidered as neglected amount. It was observed that D1 and D2 daily average exterior and interior glass temperatures were about 2.49 and 2.36%, respecttively, which may be concidered as neglected amount too.

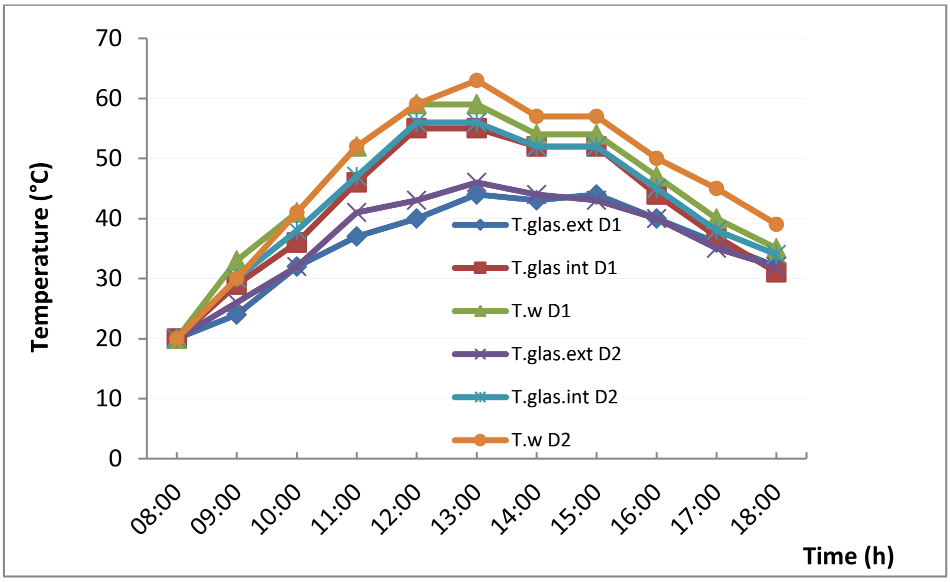


Figure V. 8. Time-wise variations of temperatures for both distillers

V.3.3. Time-wise variation of distilled water production

The temporal variation in D1 and D2 distilled water production is shown in Figure V.9. From this figure, it is identified that distilled yield is maximum at afternoon time and decreases during sunset hours. The productivity was maximum at 14:00h for the reference distiller D1 and was about 708 mL against the maximum value for the distiller D2 which was of 511 ml at 15:00h. In general, the yield of distiller D1 is higher than that of distiller D2 throughout the day from 8:00h to 18:00h As a result the difference in the amount of produced distilled water using the two distillers D1 and D2 is large. Although the previous results show a similarities in temperatures featurs, but the results show that the distiller D1 produces much more than the distiller D2 which contains the sand.

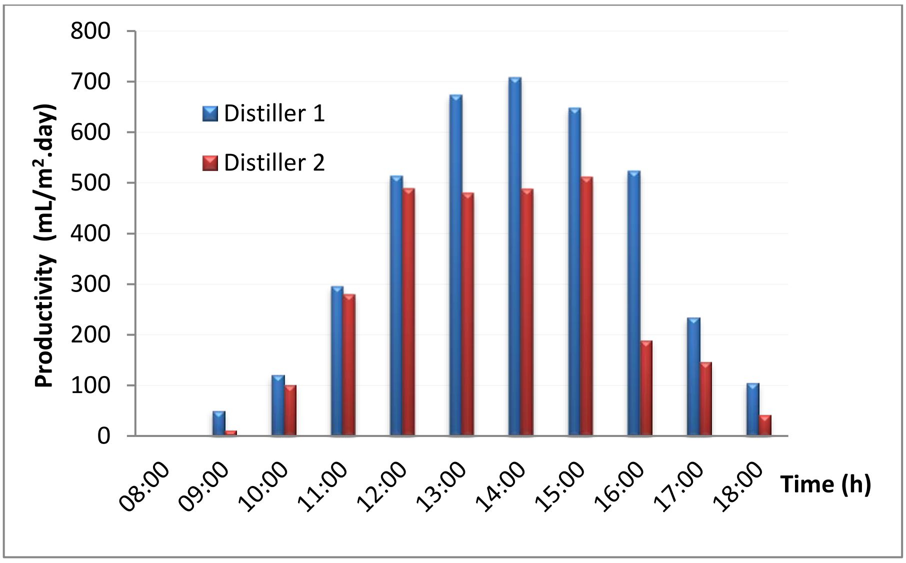


Figure V. 9. **Time-wise variations of distilled water production**

V.3.4. Time-wise variation of cumulative distilled

The cumulative distilled yield production from the distillers is plotted in Figure V.10. The daily yield produced from the distiller D1 and distiller D2 is 3870.8 and 2735.2 ml/m^2, respectively. It was found that distiller D1 produced 29.33% higher yield than the distiller D2. The accumulation curves clearly show the difference in productivity between the two distillers D1 et D2.

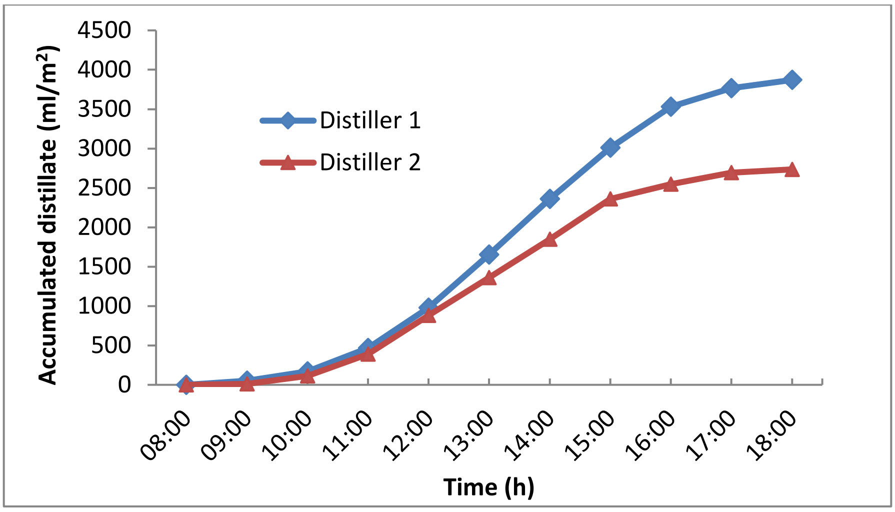


Figure V. 10.Time-wise variations of cumulative distilled water

V.3.5. Time-wise variation of Thermal efficiency

The time-wise variation of thermal efficiency of the distiller D1 and D2 is plotted in Figure V.11. The maximum hourly thermal efficiency of the distiller D1 is 61.28% at 16:00h and distiller D2 is 44.06% at 15:00h P.M. The daily average thermal efficiency of the distiller D1 and distiller D2 is 34.26 and 21.73%, respectively. It is found that distiller D1 produced 36.75% higher daily average thermal efficiency as compared to the distiller D2. The thermal efficiency of the distiller D1 is higher as compared to the distiller D2 because distiller D1 produced higher yield than the distiller D2. The thermal efficiency of the solar stills is given by [30].

$$\eta_{th} = \frac{m_{ev} h_{fg}}{I(t).(A).3600} \times 100 \qquad (1)$$

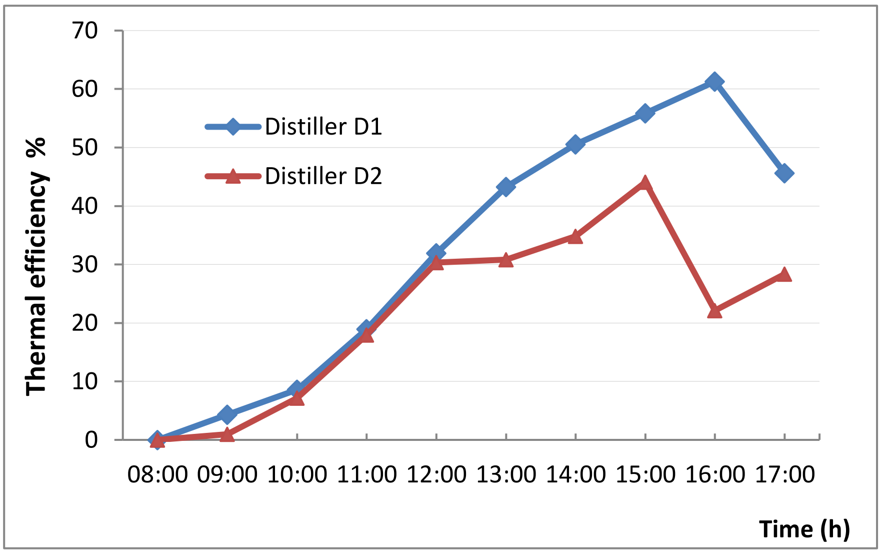


Figure V. 11. Time-wise variations of thermal efficiency

V.3.6. Exergy efficiency

The time-wise variation of exergy efficiency of distiller D1 and distiller D2 is plotted in Figure V.12. The exergy efficiency of the distillers increases linearly and reached its maximum value at 15:00h and further it decreases. The maximum hourly exergy efficiency of 4.58 and 4.01% is obtained for the distiller D1 and distiller D2, respectively. The daily average exergy efficiency of 4.58 and 4.01% is obtained from the distiller D1 and distiller D2, respectively. The distiller D1 produced 24.51% higher exergy efficiency than the distiller D2. The exergy efficiency of the distiller is mainly depends on the hourly yield so distiller D1 has the higher exergy efficiency as compared to the distiller D2. The exergy efficiency of the solar stills is evaluated using Eq. (2) for the test day and it is presented in Figure V.12.

$$\eta_{p.e} = \frac{Ex_{output}}{Ex_{input}} \tag{2}$$

where Ex_{output} is the hourly exergy efficiency which is estimated by [30]:

$$Ex_{output} = m_{ew} L_{fg} \left(1 - \left[\frac{T_a + 273}{T_w + 273}\right]\right) \tag{3}$$

and Ex_{intput} is the hourly exergy input given by [30]:

$$Ex_{input} = A\, I(\mathrm{t}) \left[1 + \left(\frac{1}{3}\left[\frac{T_a + 273}{6000}\right]^4 - \frac{4}{3}\left[\frac{T_a + 273}{6000}\right]\right)\right] \tag{4}$$

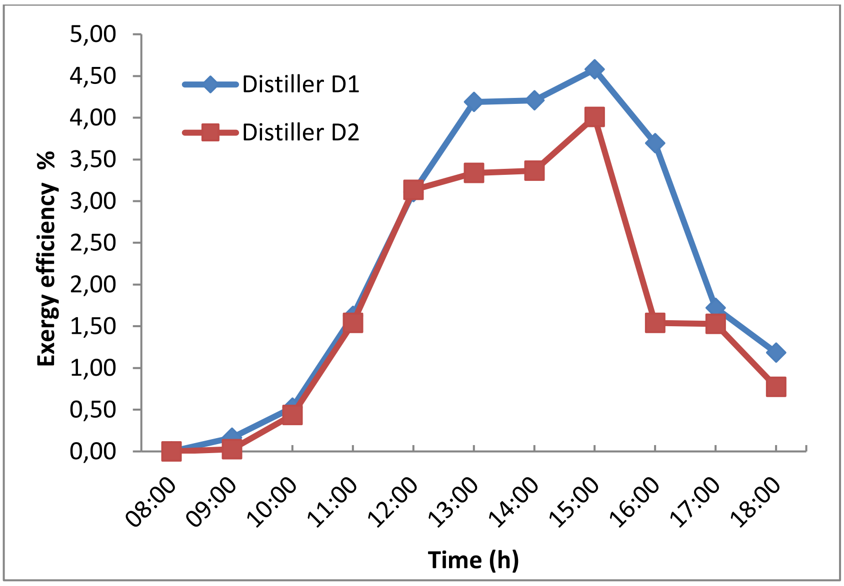


Figure V. 12.Time-wise variations of exergy efficiency

V.3.7. Discussion

The two distillers D1 and D2 have the same geometrical shape and they are in the same meteorological conditions. The results show that the variation of the water temperature, the two inner and outer faces of the glazing are similar that is to say that the temperature gradient between water and glass is almost the same. Normally the productivity of the distillers is the same as well as the energy and exergetic efficiency but we note that the productivity of the distiller D1 (without sand) is greater than that of the distiller D2 (with sand). It can be deduced that sand slowed down the phenomenon of evaporation.

The attraction between grains-water makes the sand lose its properties of granular; it then behaves like modeling clay. This is the effect of capillary adhesion, a physical mechanism for keeping two bodies in contact through a thin film of liquid as shown in Figure V.13. The solid structure formed of grains connected by water is actually made possible by a capillary force greater than the weight of the grains. This capillary force makes the water prevent sand grains from peeling off and traps water between the grains. This force can be calculated in many ways [28].

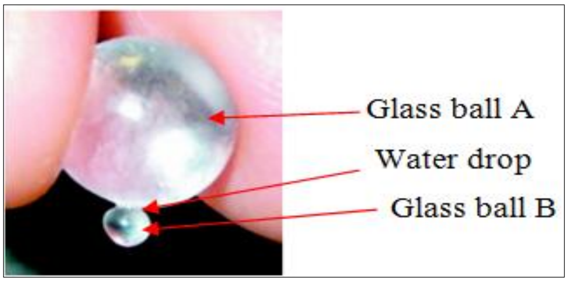


Figure V. 13. Capillary force [28]

Microscopic forces of attraction, called Van Der Waals forces, will be exerted between the molecules of water and between the molecules of water and the grains of sand. The water will seek the greatest possible contact with the grains and the smallest possible with the air, hence the hourglass shape of the capillary bridge. Figure V.14 explains the hydrogen bonding occurs when in a molecule of hydrogen atom is united to a highly electronegative A atom O, N, F, Cl.

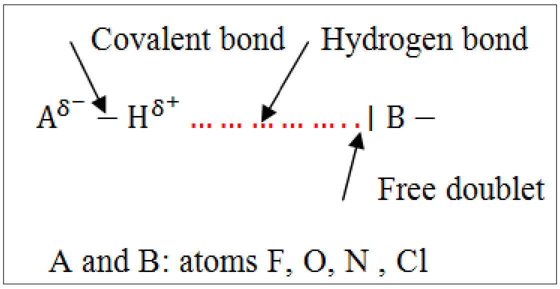
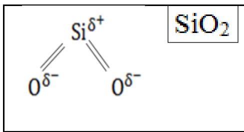
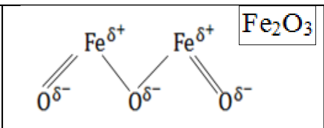
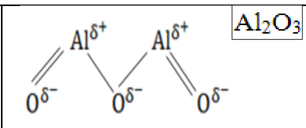
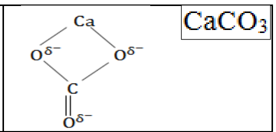


Figure V. 14. Hydrogen bonding

As a result, the unique electron of hydrogen moves to the atom A, which makes hydrogen a positive pole capable of attracting the free doublet of another electronegative atom B of a neighbour molecule. This attraction is purely electrostatic in nature. The atom H thus ensures, as a bridge, the bond between the atom A and the atom B of another molecule. Indeed, silica or silicon dioxide SiO2 is one of the main constituents of sand plus other like Fe_2O_3, Al_2O_3 and $CaCO_3$. Table V.2 shows the structures of the 4 components and it is noted that all components have free doublet atoms | B which is (O) oxygen.

Table V. 2. Structures of sand dunes corposants

			
02 free doublet atoms ready for hydrogen bonding	03 free doublet atoms ready for hydrogen bonding	03 free doublet atoms ready for hydrogen bonding	03 free doublet atoms ready for hydrogen bonding

Due to its three strengths, the evaporation in the distiller D2 is less important than in the distiller D1. This phenomenon participates in retarding water evaporation. In addition to this, the amount of free water to be distilled in D2 (i. e non linked to sand) is less than one in D1 hence there is no sand in D1 which decreases the amount of productivity as shown in Figure V.8 and Figure V.9.

V.4. Economic evaluation

The recovery period of the sum of money invested in the two distillers is determined by the cost of fabrication, the improved solar still, the maintenance costs, the operating costs and the cost of the feed water. To find the recovery period, just compose the rapport between total cost of manufacture to consider and net profit. Table V.3 shows this evaluation.

Table V. 3. Manufacturing cost of improved solar still

	Algerian Dinar DA	**Euro 1€= 136.03DA**	
Total cost of manufacture to consider	10000	73.51	
Cost per liter of distilled waterin Algeria	100	0.73	
Solar productivity (L/m^2 /day)			D1: 3.8708 L/m^2 /day D2: 2.7352 L/m^2 /day
Cost of water produced per day: (Solar productivity x Cost of water produced per day)	D1: 387 D2: 273.5	D1: 2.84 D2: 2.01	
Maintenance cost	50	0.37	
Net Profit: (Cost of water produced per day- Maintenance cost)	D1: 337 D2: 223.5	Dc: 2.47 Ds: 1.64	
Recovery period (day): (Total cost of manufacture to consider/ Net Profit)		D1: 30 day D2: 45 day	

V.5. Conclusion

The two solar stills are geometrically similar and they worked under the same weather conditions. the cover, water and temperature gradient are the same but we note that the production and efficiency are different. The distiller without sand produced 3.8708 L / m^2 / day and distiller with sand produced 2.7352 L / m^2 / day. The productivity ratio between the two distillers is 1.46 times. The energy and exergy efficiency of the distiller D1 is 38.27 and 24.51% higher than the distiller D2. The sand in the bottom of D2 is not suitable to improve the yield due to the hydrogen bonds between the components of the sand and the water. The D1 distiller has refunded the amount of money invested for its construction in 30 days whereas D2 distiller has refunded the amount in 45 days.

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Chapter 6

Black metal plate effect as a storage material on solar distillation

VI.1. Introduction

Solar distillation is one of the simplest, economical and environmental solutions for freshwater production, especially in remote and arid areas. This inexpensive technique is based on a completely free energy suffers from the low fresh water production of these devices. Experimental and theoretical studies are focused on improving productivity in the geometric side of distillers than on the metrological side [1-6]. In fact, these improvements affect evaporation or condensation or both at the same time. Since the evaporation rate depends mainly on the difference in temperature between the temperature of the pond water and the temperature of the glass cover [7, 8], several methods have been proposed by the researchers, such as reducing the depth of the pond water in the distiller [9] and use external or internal reflectors [10]. Incorporation of phase change thermal storage materials and nanofuides are advanced methods to improve the freshwater yield of a solar still. The Phase change material, or PCM, any material capable of changing physical state in a temperature range roughly between 10 °C and 80 °C. The researchers used the phase change property to improve productivity either in the day or after sunset [11-17]. Later, another technique appeared, it is the use of nanofluid in energy systems. The incorporation of nanofluids into solar distillers has given good results. A lot of studies are done to see the influence of these nano on productivity [18-20]. The combination between the two PCM techniques and the nano-fluids will give more good results. Studies on the solar distillation improve by both techniques at the same time make their test [21-25]. Incorporation of sensible heat energy storage materials is an effective method to improve the freshwater yield of the solar still. Incorporation of sensitive thermal energy storage materials is a simple method that does not require a large investment. It consists in depositing solid materials in the water basin to improve the fresh water yield of a solar still.This method is used in the present workto achieve our goal. Experiments were conducted on solar distillers to test the impact of different thermal storage hammers on the productivity of pure water. The results showed that daily productivity was improved by 42.2%, 15.2%, 20.1% and 17.2% when mica, stainless steel, aluminum and copper were used as floating sorbents [26]. Another study was done to compare the use of wicks in a solar still. The result shows that the maximum yield is obtained at 4.50 l / m² per day for a black cotton wick distiller and 3.52 l / m² per day for a jute wick at a depth of 2 cm and in same conditions [27]. A group of researchers experimentally investigated the location of sponges of different sizes placed in the pond water of a solar distiller and a 273% improvement was recorded [28]. The objective of this work is to increase the temperature of the water in the distiller basin to widen the temperature difference between the water and the inner face of the glazing. A very simple technique is used which consists of putting a free zinc plate in the distiller's basin. This application, the bottom of the basin is the eternal absorber of the distiller. So to change the absorber it is necessary to change the distiller or the complete basin. However in our case, the absorber is free and can be changed at any time.This technique gives a little novelty to our work.

VI.2. Experiment data

VI.2.1. Description of the solar distiller

The solar still is a conventionaldistiller known as the unique single-slope solar greenhouse still, with a simple design. The components are easily available and they are cheap. The tests were done in 15 May 2017, at the University of El Oued, south east of Algeria with the geographical coordinate of 33.3676° N latitude and 6.8516° E longitude. Two proposed solar distillers are composed essentially as shown in Figure VI.2.

Two distillers of the same geometric form were tested before the experiment to highlight their similarity. They are given almost the same amount of distilled water with a minimal difference.The two distillers are tinted from the inside by a black paint and each distiller has a second glass box with 0.5 cm thick, glued to the wooden boxes. Figure VI.1 shows the schematic diagram of solar distillers with a black plate of Zinc plate. The total thickness of the distiller box is 3 cm and this ensures good insulation as shown in Figure VI.2. The first device is the distiller of control (Dc), it is used as a reference or as a control and the second device is the distiller of our study (Ds). The distiller Ds is the object of our study. It has a black plate of Zinc placed at the bottom of the distiller.Thisis the only difference between the two distillers. In the present application, we are interested on the study of the influence of this plate on the distillation phenomenon.

the distiller is composed of:

- the metal plate of Zinc is stained black with dimension of 48 x 48 cm, thickness of 0.2 cm.The thermal conductivity is equal to K = 116 W / m K and the melting energy is about 7.322 kJ / mol. The Zinc has relatively low (419.5 ° C) and boiling (907 ° C) melting points;
- the commercial used glass cover presents 55 x 55 cm and 0.4 cm of the thick. It is inclined of α = 20 ° with the horizontal. This glass cover is used as a condenser;
- the PCV tube presents 60 cm of long and act as a water distilled collector;

- a collection tank of distilled water is produced by the distiller;
- the wooden box presents 50 x 50 cm and 2.5 cm of the thickness;
- A glass box measuring 49 x 49 cm and a thickness of 0.5 cm.

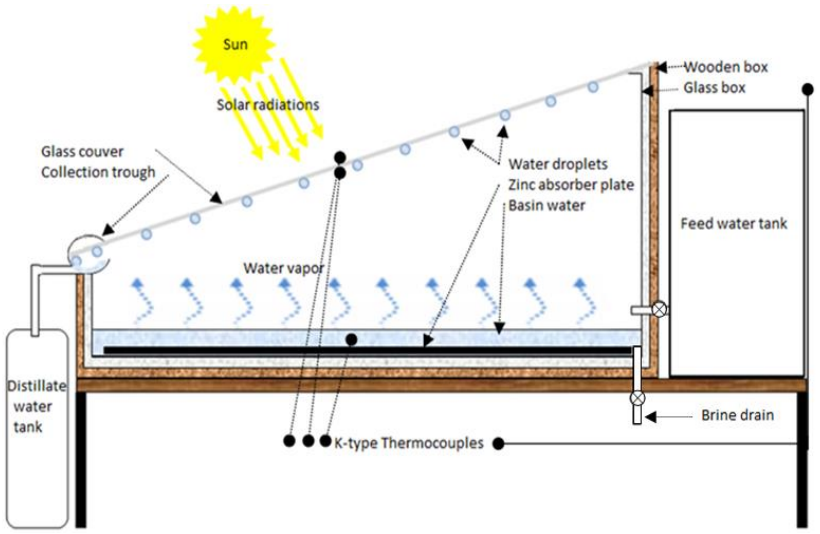

Figure VI. 1. Schematic presentation of the solar distiller with a black plate of Zinc

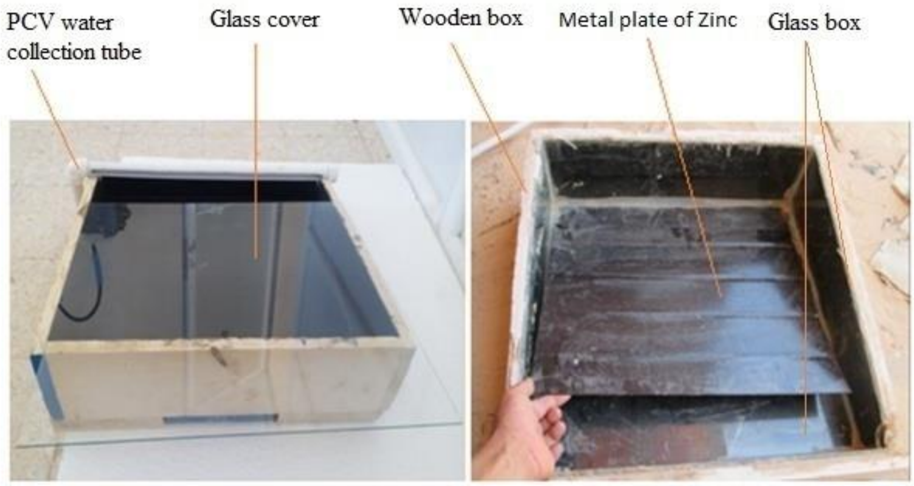

Figure VI. 2. Photo of the two solar distillers

VI.2.2. Principle of operations

The operating principle is based on the greenhouse effect.Via the glass cover, the sun's rays enter the solar distiller. The inside water begins to warm up and evaporate; the hot water vapour comes back to the glass. The hot water vapour condenses and formation of droplets on the inner side of the glass has been observed. The droplets slip into the collector and finally driven in the tank as shown in Figure VI.2.

The temperature measurements are made by K-type thermocouples placed in these locations:

• Temperature of the inner and outside face of the glass.

• Temperature inside the distiller.

• Temperature of the basin water.

• Ambient temperature.

VI.2.3. Meteorological conditions of the experiments

Temperatures are taken every hour from 7:00 am to 6:00 pm that is 11 hours of sunshine. The meteorological conditions of the experiment are shown in Table VI.1.

Table VI. 1. Experimental conditions

Meteorological conditions on May 2017	
Sunrise	05:41 am
Sunset	07:19 pm
Ambient temperature	26-35°C
Atmospheric pressure	101325 Pa

VI.2.4. Experimental error analysis

The performance of solar distillers is related to several measurement parameters used in the experiment. These parameters are not perfect so they certainly include errors due to the measuring instruments and the measurement method. These errors are in fact the total percentage of uncertainties that directly affect the accuracy of the results given by the instruments [28]. The instruments used in our case are:

- Thermocouples for measuring pond water temperatures, glazing temperature and ambient temperature;
- a pyranometer to measure global solar radiation;
- A graduated cup to measure the amount of water produced by the solar distiller.

The error percentages of these instruments are based on the Holman calculation procedure [29]. The daily productivity error, the daily efficiency error and the uncertainty errors for various measuring are shown in Table VI.2.

Table VI. 2. Uncertainty errors for various measuring

Device	Accuracy	Range	Error
Solarimeter	$\pm$ 1 W/m^2	0 – 5000 W/m^2	0.153 %
Thermocouples	$\pm$ 1.1 ^{o}C	-200: 1250 ^{o}C	2.619 %
Calibrated flask	$\pm$ 5 ml	0 – 2000 ml	2.695 %
Errors in daily productivity	$\pm$ 5 ml	0 – 2000 ml	0.34 %

VI.3. Results and discussion

The test was made in south-east of Algeria in May 2017 dealing with two distillers. The distiller Ds is the object of our study and it has a black metallic absorber and the distiller Dc is used as a reference. The temperature samples are taken every hour. The results obtained are illustrated in the following figures.

VI.3.1 Ambient temperature and solar radiation

Figure VI.3 shows the solar radiation evolution during the day. The curve obtained has a normal form as it was found in literature and having its maximum radiation between 11:30 and 14. The sky was clear during the course of the experiment. Solar radiation is one of the major factors in solar distillation. The other curve shows the ambient temperature variation in °C over the time (in hour) varying between 22°C at launch and the maximum valuewhich is 34°C between 14:30 and 16:00. The day of the experiment it had no wind. So, all the process of the distillation is unrolled normally and without convection.

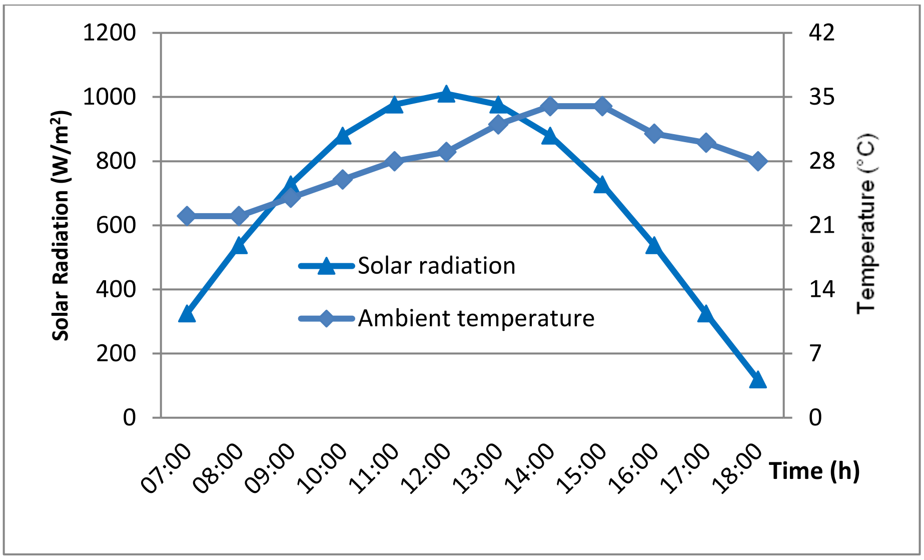

Figure VI. 3. Evolutions of the solar radiation and the ambient temperature

VI.3.2. Variation of the temperatures of the two distillers

Figure VI.4 shows the variation of the temperatures of the two distillers Dc and Ds over time. The duration of the experiment is from 07:00 to 18:00 and the measurements are taken every hour. The temperature of the glass and pond water of the two distillers evolves at the same time and in the same way except the temperature of the basin of the distiller Ds. Between 07:00h and 08:00h, all temperatures are progressing normally. But, the temperature of the distiller basin Ds has not increased as the temperature of the distiller basin Dc. This is due to the only difference between the two distillers is the zinc metal plate. This plate has absorbed the heat of the water received by the solar rays. At 09:00h, a stability between water and plate was restored and the temperature increased rapidly and it was the only one to exceed 60 °C between 13:00h and 14:00h. The influence of the Zinc plate was clearly remarkable in the distiller Ds. In our case the maximum of the radiation is at 12: 00 clock time. However, the maximum values of the temperatures are between 13:00h and 14:00h. This fact can be explained since it takes a little time for water and glass to reach their maximum.

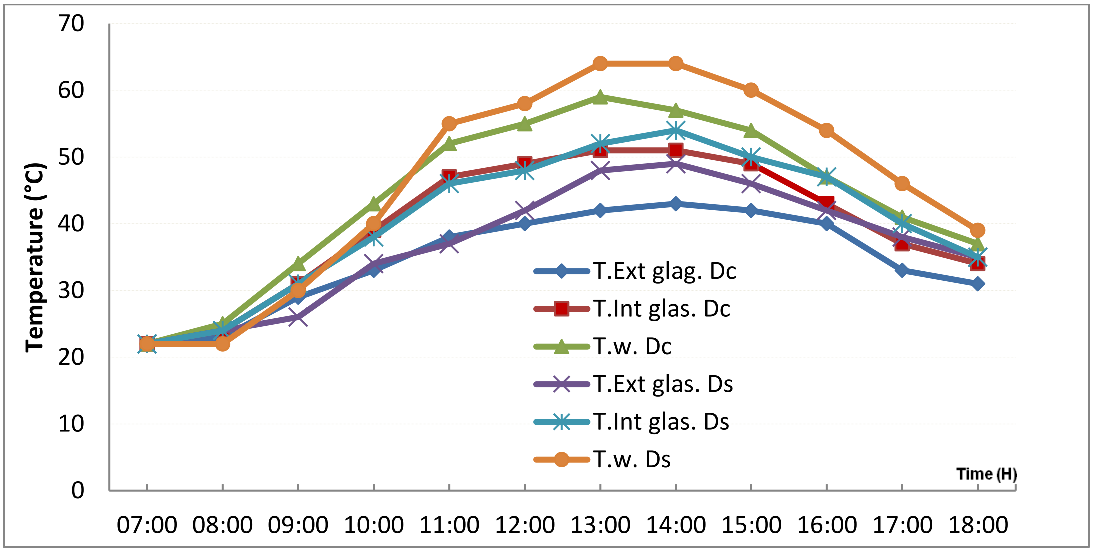

Figure VI. 4. Variation of the temperatures of the two distillers

VI.3.3. Effect of water-glass temperature on productivity

The Figure VI.5 shows the difference in temperature ΔT between the inner face of the glass and the water temperature of the basin compared to the productivity in ml/m^2. Between 07:00h and 09:00h,it has been notied that ΔT for the distiller Ds is negative and this is a non-logical thing but ΔT and the productivity for the distiller Dc are quite normal to what it finds in the literature. This negative value is due to the fact that the temperature of the pond water has not increased because the Zinc plate in the basin has absorbed the heat in the water. For this reason, the temperature of the glazing is bigger than that of water. This negative ΔT did not give a single drop of distillate and we see this clearly in Figure IV.5.

After 9:00h, the ΔT of the distiller Ds has risen rapidly to wait for a maximum of 12 ° C and the productivity has been launched to reach 672 ml / m^2 at 14:00. Similarly for the Dc distiller, where the ΔT maximum is 8 °C and the corresponding productivity is 434.4 ml / m^2 at 14:00. So any increase in ΔT of the two distillers will be followed by an increase in the productivity of both distillers and the opposite is true. This strong relationship between ΔT and productivity is clearly reflected in evaporative heat transfer between water and glass.

VI.3.4. Productivity of the distilled water

Figure VI.5 shows also the amounts of hourly water produced by both distillers (in ml /m^2.h) throughout the day. The productivity of the distiller Dc is remarkably lower than the productivity of the distiller Ds. The maximum value of the water collected from the Dc still did not exceed 440 ml /m^2.h while the maximum value of the Ds distiller exceeded 640 ml /m^2.h. This difference in production is clearly due to the fact that the distiller Ds has a metal plate of Zinc.

The productivity between 7:00h and 9:00h of the distiller Dc was started slowly because the temperature difference between water and the inside of the glass is acceptable to trigger the evaporation of the water of the basin. But the distiller Ds remained inactive because the heat from the water was transferred to the zinc plate which caused the cooling of the pond water. This fact means that the water temperature became lower compared to the glass cover (condenser). After 9 hours, the amount of heat stored by the plate became important and the distiller Ds began to produce fresh water to exceed the distiller Dc. The zinc plate has shown that it is a good sensitive thermal storage material between 9:00 am until the end of the day.

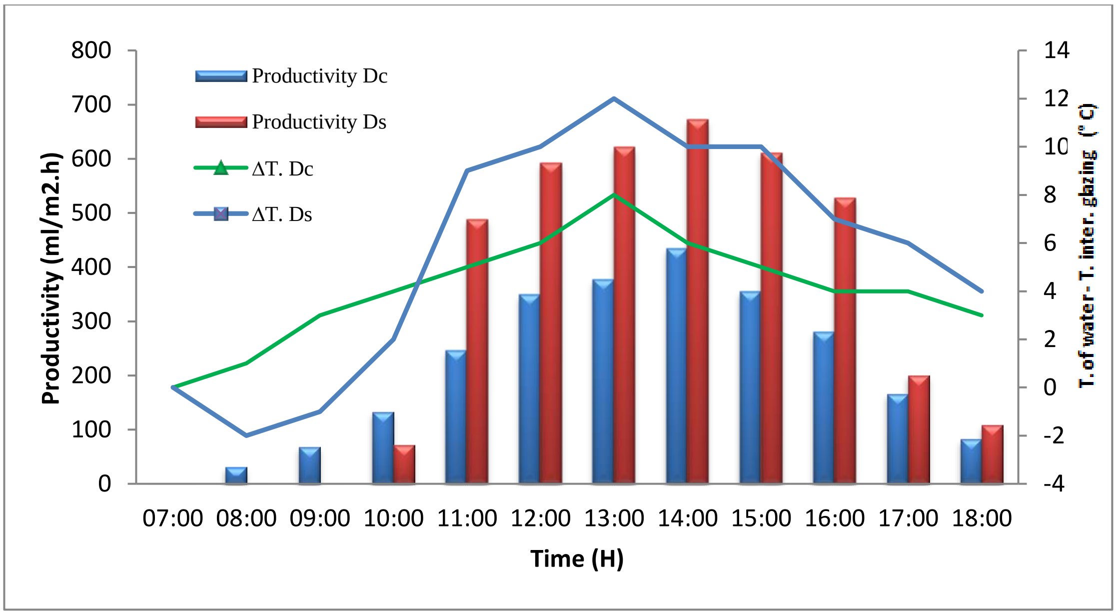

Figure VI. 5. Evolution of ΔT (T. water - T. interior glazing) and distillers productivity

VI.3.5. Accumulated distillate

Figure VI.6 shows the distillate measurements accumulated daily for the two distillers for 11 hours from 07:00 to 18:00. It is quite clear that the accumulated distillate of Ds has reached an approximate value of 3894.4 ml / m² / day which is much higher compared to the distiller Dc which is equal to 2520.8 ml /m^2.day. The difference between the two distillers is 2.83 times larger.

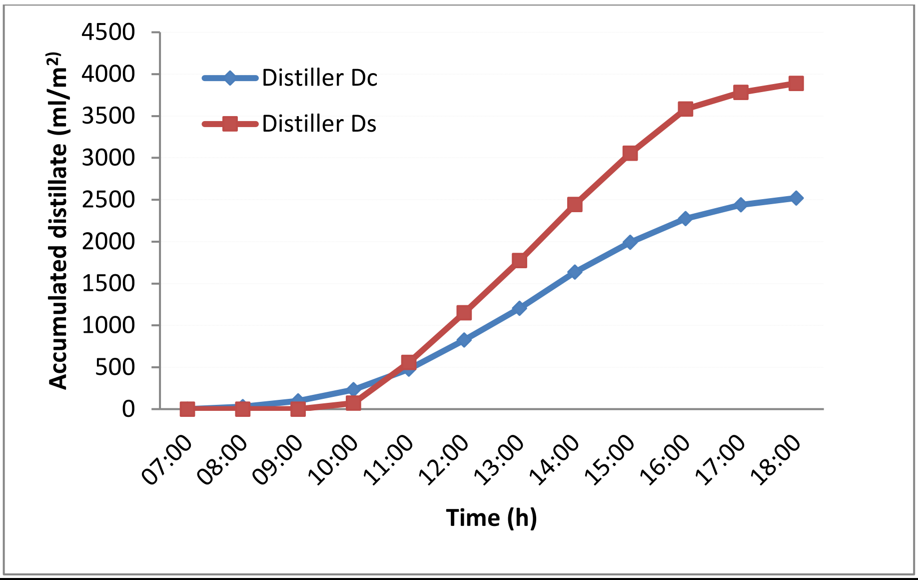

Figure VI. 6. Accumulated distillates for the two solar distillers (Dc and Ds)

VI.6. Hourly efficiency of the solar distillers

The hourly efficiency of two solar distillers Dc and Ds are shown in Figure VI.7. The efficiency of the distiller Ds began markedly to vary only after 10:00. It reached a maximum value of 68.84% around 13.00h against the maximum value of the distiller Dc which is equal to35.06%. In the period between 7:00h to 10:00h the hourly efficiency for distillate Dc is higher than that of distillate DS due to the low productivity of distillate Ds in this period. Howere, in the period from 10:00h until the end of the experiment, it is clear that the hourly efficiency of the distiller Ds is greater than the distiller Dc.

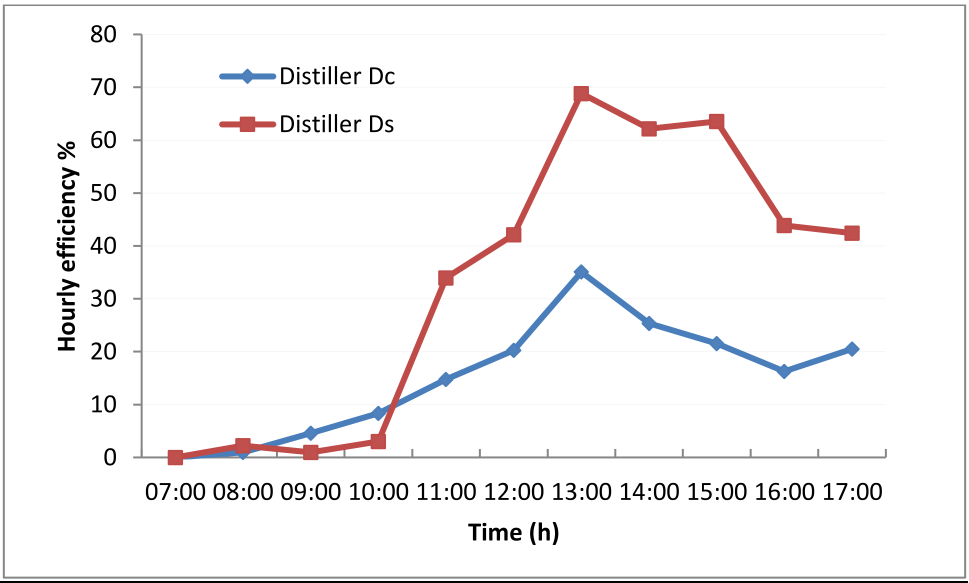

Figure VI. 7. Hourly efficaiency of two solar distillates

VI.7. Cost analysis

There are many ways to do an economic study to determine the period of recovery of the amount of money invested in a project as shown in Table VI.3. This period depends on the manufacturing cost of the improved solar distiller, the maintenance cost, the operating cost and the cost of the feed water. To find the time it takes for the solar distiller Ds to reimburse the amount invested in its construction and maintenance, just make the ratio between Total cost of manufacture to consider/ Net Profit. You see that the result is 30 days, in other words that the distiller Ds is a very profitable system. Since the life of Ds and long, then beyond this period it is a pure gain.

Table VI. 3. Manufacturing cost of improved solar distillates

	Algerian Dinar DA	**Euro** **1 € = 136.03DA**	
Total cost of manufacture to consider	10000	73.51	
Cost per liter of distilled waterin Algeria	100	0.73	
Solar productivity (L/m^2 /day)			Dc: 2.520 Ds: 3.894
Cost of water produced per day: (Solar productivity x Cost of water produced per day)	Dc: 252 Ds: 389.4	Dc: 1.84 Ds: 2.84	
Maintenance cost	50	0.36	
Net Profit: (Cost of water produced per day-Maintenance cost)	Dc: 202 Ds: 339.4	Dc: 1.47 Ds: 2.47	
Recovery period (day): (Total cost of manufacture to consider/ Net Profit)			Dc: 50 days Ds: 30 days

VI.8. Conclusion

Two similar conventional solar distillers Dc and Ds are exposed to the sun under the same weather conditions with only one difference that Ds contains a Zinc plate in his basin.

- The distiller Dc started to produce the first hour but the distiller had to start producing after 3 hours. At the end of the day, the fresh water productivity of the distiller Ds is 2.83 times better than the distiller reference Dc. This improvement is caused by a simple zinc plate available on the market.

- The average efficiency and cost of the estimated net profit for the two Dc and Ds solar distillers are respectively about 16.76% - and 36.30%.
- The recovery period of the sum invested is 50 days for the distiller Dc and 30 days for the distiller Ds.
- It is recommended to use this simple technique to improve the production of a conventional solar distiller.

The Ds solar distiller is improved in its daily productivity of 2.83 times compared to the Dc reference distiller and the Ds still is very profitable because it has paid back the amount invested in a month. In note that a liter of distilled water costs 100 DA (0.73 Euro) in Algeria.

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General conclusion

General conclusion

The main objective of this work was based on a purely experimental study of solar greenhouse distillation to obtain drinking water that can meet the needs of a Saharan community living in south-eastern Algeria. The water in the El Oued region is polluted with a very high concentration of fluorine that is well above international standards and this causes a major health problem in the teeth, bones and kidneys. This study helps to solve this problem by finding a simple ways and low-cost to improve and classify the productivity of pure water of conventional solar distillers. To do this study properly, several solar distillers have to be built to cover several series of experiments.

From the results obtained we can say that:

- A solar still was placed in the same place, same position and same amount of water but once in the summer season and once in the winter season. Solar distillation is better in the summer season of 9.47 times than in the winter season. The result shows that there is an improvement of 89.44%.
- This is due to solar radiation. The difference in temperature between the pond water is the inner face of the real glass and a factor not to be overlooked. Experience shows that productivity is a function of this factor.
- The use of a very simple method that involves placing a refractor behind the distiller. This technique improved the productivity of the distiller by 29.58%, ie 1.42 times better than the reference distiller.
- The use of a black metal absorber is also a very simple technique to improve the productivity of the pure water of a solar distiller by 45.50%, ie 1.83 times better than the reference solar distiller.
- Variation in the glazing thickness of a solar distiller influences productivity. A distiller with a glass thickness e = 3 mm produces 1.23 times better of a distiller with a glass thickness e = 5 mm and 1.87 times better than of the distiller with e = 6 mm.
- The use of the cylindrical plastic fins has improved the productivity of the distiller by 30.17%, ie 1.43 times better than the reference distiller,
- The use of Aluminium balls made from Aluminium commercial leaves also improved the productivity of the distiller by 38.01%, ie 1.62 times better than the reference distiller.

- The use of the active mode in the distillation can also have a remarkable influence. A distiller connected with a flat solar collector gave a good result of 63.64% improvement, ie 2.75 times better than the passive distiller reference.
- The use of sand dunes that are very abundant and free in the improve the productivity of the distiller. The result shows that the sand has slowed productivity by 29.43%, ie the reference distiller produces is 1.41 times better than the sand distiller. This is due to attractions between the seeds of the sand and the water molecules.
- The use of double glazing separated by 1 cm of air and close well on four sides prevented the capacitor from cooling because the air layer insulates heat from the first glass. This technique confirms that the distilled water production from the double-glazed distiller is 55.7% lower as compared to the reference distiller.
- The water in the El Oued region is affected by fluorine with a percentage that can reach 3.7 mg / l and exceeding the international standard of 0.7 mg / l. After the distillation of this water by solar energy, the results show that pH varies between 6.98 and 7.12 and that the electrical conductivity ranges between 200 and 230 10^{-2} s /m^2.

From the results cited above, there are factors that have improved productivity and others that have slowed productivity. To classify the improvement factors, we can say that:

- The use of an insulated chamber of the four corners as a cover of a solar distiller slows the production of pure water by 55.7%.
- the use of dune sand in a solar still slows productivity by 29.43% ;
- the use of an external refractor on a solar distiller improves productivity of pure water by 29.58%;
- the use of cylindrical fins in the pond of a solar distiller improves productivity of pure water by 30.17%;
- the use of aluminium balls in the pond of a solar distiller improves productivity of pure water by 38.01%
- The use of a black zinc plate in the water basin improves productivity of pure water by 45.5%,
- Using a flat solar collector connected to a solar distiller improves productivity of pure water by 63.44%

In the future, we recommand to collect all the bills of improvement in a single solar still, ie it is distilled polluted water in the summer season with the minimum thickness of the glass cover, with a black metal plate as an absorber,absorber with fixed aluminium balls. Finally, the distiller will be connected with a solar collector. This combination of several improvement factors in a single solar distiller will increase the productivity of pure water.

Publications

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Improvement of Solar Distiller Productivity by a Black Metallic Plate of Zinc as a Thermal Storage Material

Reference

A. Khechekhouche, B. B. Haoua, A. E. Kabeel, M. El Hadi Attia, and W. M. El-Maghlany, "Improvement of Solar Distiller Productivity by a Black Metallic Plate of Zinc as a Thermal Storage Material," *Journal of Testing and Evaluation* https://doi.org/10.1520/JTE20190119

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ABSTRACT

The lack of drinking water is a real global problem. Transforming polluted water into freshwater is another problem. Solar distillation seems a simple and economical solution to this problem, but the yield of a solar still is low, and this poses another problem. One of the best ways to improve the productivity of freshwater from solar energy is to incorporate sensible heat energy storage materials; i.e., the temperature elevation of a material allows for the storage of energy, and that is exactly the purpose of our work. Two similar solar distillers were exposed to the sun in May 2017 under the same weather conditions. Distiller Dc is retained as a reference and distiller Ds contains in its basin a black plate of zinc 48 by 48 cm with a thickness of 0.2 cm. This plate is used as a sensitive thermal storage material to improve the productivity of our device. The results of this simple and inexpensive technique have improved the productivity of distiller Ds by 1.54 times compared with the conventional Dc still. Thus, this technique AQ2 increases the productivity of the distiller and participates in solving a technical problem affecting the solar still.

Keywords

AQ4 solar energy, solar distillation, storage energy, evaporation, freshwater

Introduction

Solar distillation is one of the simplest, most economical and environmental solutions for freshwater production, especially in remote and arid areas. This inexpensive technique, based on a completely free energy, suffers from the low freshwater production of these

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ORIGINAL ARTICLE

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Exploitation of an insulated air chamber as a glazed cover of a conventional solar still

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Abstract

The countries of North Africa suffer from a serious problem that affects a large number of people. The trouble is the provisioning of drinking water. Several techniques are used but solar distillation; which seems to be an appropriate, economical, and easy solution. Conventional solar distiller is used in the Saharan areas but the yield of this device is low, that's why there are several studies that are focused on improving this distiller. The technique of double glazing gives an increase in the efficiency of a solar collector; hence, the idea of using the same technique in a conventional solar distiller. Two covers of glasses separated by 1 cm, isolated from the four sides was put on a distiller of dimensions 0.5×0.5 m. The results show that this technique minimizes the distiller's yield by 56.52% when compared with the conventional solar distiller.

KEYWORDS

drinking water, efficiency, glazing, solar distillation, zone isolated

1 | INTRODUCTION

One of the huge problems in this world is the lack of drinking water. The Greater Maghreb is not immune to this problem. Several distillation methods have been adopted, but solar distillation remains the simplest and most economical of all methods. Despite its low efficiency compared with other technologies, it has a great advantage as it uses solar radiation.

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Sand dunes effect on the productivity of a single slope solar distiller

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Original

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Abstract

Access to drinking water in many parts of the globe is shrinking over the years and much of the water resources are polluted or unpurified. North Africa is facing a huge water shortage due to drought and climate change. Water desalination has become very popular and serves as solar distillation which is proving to be an economical, simple and ecological technique, especially in rural and remote areas. Significant efforts have been made by many researchers in various laboratories to increase and improve the productivity of solar greenhouse distillation. In the present work, emphasis has been placed on the study of a single slope solar distiller having as dimension 50 × 50 cm, in the thickness of the impure water is 1 cm. Natural sand dunes from the El Oued South region of Algeria have been tested as a factor of efficiency improvement. A layer of this sand was deposited on the bottom of the distiller covering the whole surface on which the submit water is emerged. The results show that the productivity of distilled water has unfortunately decreased by 1.46 times.

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Traditional solar distiller improvement by a single external refractor under the climatic conditions of the El-Oued region, Algeria

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ABSTRACT

Desalination is now successfully practiced in many countries as drinking water supply has become a growing problem in most parts of the world. Algeria, like the Maghreb countries, has generally adopted two desalination processes (membrane processes and distillation processes which require a phase change, evaporation/condensation), the latter method is subject of our study. An experimental study was made on two similar stills with a single slope, size 1 m × 1 m, the first distiller D1 is used as a control and the second distiller D2 has a simple external mirror glued to its backlog. The same experience has been done in different climates with improvement results ranging from 9% to 21%. In our case, a complete study was concerning the improvement, the efficiency, the investment and finally the error analysis of the instrumentations that have not been done before. We obtained a very interesting improvement which varied between 42% and 45%, the efficiency is 35% and the recovery period of the sum invested is recovered in 23 d, which shows that this technique is more favorable under the climatic conditions of the West Southeast region of Algeria than elsewhere.

Keywords: Desalination; Distilled water; Evaporation; Condensation; Solar radiation

1. Introduction

Algeria has the largest solar field in the Mediterranean basin and it has a large underground water reservoir in the southeastern region of Algeria (region of El-Oued). This water is infected by the fluoride so what makes this water invaluable. Earth-water treatment plants have been designed for the reuse of wastewater. A procedure followed by several countries in the world [1].

Because the water problems are inextricably linked to food production; about 70% of all freshwater used in agriculture [2], Algeria faced this problem by adopting the membrane desalination process and the phase change method which can be coupled to low-grade and renewable energy source such as wind and solar energy [3]. In the southeast region, researchers have designed a small pilot distillation station. The studies aim at improving the performance of a small solar distillation station under real isolation for underground geothermal desalination of water in arid regions in southern Algeria [4], and they are also aimed at producing drinking water in arid regions [5]. The small station had a daily capacity of more than 15 L/m² [6]. A study

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Résumé

La région de L'Oued (Sud-Est d'Algérie) a un grand potentiel en eau souterraine mais malheureusement elle est souvent polluée. Cette eau cause des problèmes de santé au niveau: des os, les dents et les reins. La distillation solaire semble une solution environnementale, écologique et à bas prix pour transformer cette eau en eau potable. Notre étude expérimentale a cherché à utiliser des techniques simples qui peuvent améliorer la productivité des distillateurs solaires conventionnels. D'après les résultats obtenus, la productivité est améliorée entre 1.42 à 2.75 fois. Une étude économique montre que ce type de station solaire peut rembourser la somme d'investissement entre 30 et 60 jours.

Abstract

The Oued region (southeast of Algeria) has great groundwater potential, but unfortunately it is often polluted. This water causes health problems in the bones, teeth and kidneys. Solar distillation seems an environmental, ecological and low-cost solution to transform this water into drinking water. Our experimental study sought to use simple techniques that can improve the productivity of conventional solar stills. According to the results, productivity is improved between 1.42 to 2.75 times. An economic study shows that this type of solar station reimburses the investment amount between 30 and 60 days.

ملخض

تتمتع منطقة الوادي (جنوب شرق الجزائر) بإمكانيات هائلة للمياه الجوفية ، الا أنها غالباً ما تكون ملوثة وهذا ما يسبب مشاكل صحية في العظام والأسنان والكلى لسكان المنطقة. ويبدو ان التقطير الشمسي حلاً بيئيًا إيكولوجيًا ومنخفض التكلفة لتحويل هذا الماء إلى ماء شروب.

سعت دراستنا التجريبية إلى استخدام تقنيات بسيطة يمكنها تحسين إنتاجية المقطرات الشمسية التقليدية. وفقًا للنتائج التي تم الحصول عليها، فلقد تم تحسين الإنتاجية بين 1.42 إلى 2.75 مرة. وأظهرت دراسة اقتصادية أن هذا النوع من محطات الطاقة الشمسية يسدد مبلغ الاستثمار بين 30 و 60 يومًا.