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DESIGNING AND TESTING A LOW-COST SOLAR WATER HEATER

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Dedication

To our parents

To our brothers and sisters

To our teachers and our friends

To our supervisor Mr. ZIANI Lotfi

To each other

we devote this humble work

Mohammed Anis Khemissat

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Nomenclature

Symbol	Designation	Unit
α	The thermal diffusivity of the air	m^2s^{-1}
a_a	Absorption factor of the air	**--**
A_c	collector area	m^2
A_i	The surface area of an index body	m^2
A_{Lat}	Surface of the side faces of the collector	m^2
a_p	Absorption factor of the absorber plate	--
e_{isLat}	Thickness of insulation on its side faces	m
G_t	Index systems i and j	$W\ /m^2$
$h_{c,c-am}$	Exchange coefficient by convection between the glass and the environment	$W/m^2.K$
$h_{c,p-c}$	Coefficient of heat transfer by convection between the glass and the absorber	$W/m^2.K$
$h_{r,c-ciel}$	Exchange coefficient by radiation between the glass and the sky given	$W/m^2.K$
h_{rp-c}	Heat transfer coefficient by radiation between the pane and the absorber given	$W/m^2.K$
Q_{sa}	The solar energy absorbed by the absorber	W
Q_u	Useful energy	W
Q_p	Thermal energy principally	W
$Q_{c,i-j}$	Radiation heat exchange coefficient	W
L_c	Characteristic length (space between the absorber and the glass)	W
N	Number of panes	--
η	Efficiency	--
m_i	Heat flux exchanged by radiation between two	Kg
P_i	Index systems i and j	W
Ra	The Ray light number	--
T_{am}	Ambient temperature	$°K$
T_{pm}	Average plate temperature	$°K$
T_i	Heat flux exchanged by conduction between two	$°K$
T_m	The average air temperature between the absorber and the glass, given	$°K$
ν_a	The kinematic viscosity of air	m^2s^{-1}
V_{vent}	Wind speed	Km/h
τ_c	Transparent cover transmittance	--
ε_c	Glass emissivity	--
ε_p	Absorber emissivity	--

Index	Designation
A	Air
Am	Ambient
c	Cover
f	Coolant
fe	Fluid at collector inlet
fs	Fluid at collector outlet
Is	Insulating
P	Absorbent plate
St	Storage

Greek letter	Designation Unity	Unity
α	Absorption factor	-
β	Collector Tilt	°
ε	The emissivity of a body	-
η	Instant efficiency	-
λ	Thermal conductivity	W/$m^2.K$
μ	Dynamic viscosity	Kg/m.s
ρ	Density	Kg/m^3
τ	Transmission Factor	-
σ	Stefan's constant	W/$m^2.K^{-4}$

Abbreviation

(DHW): Domestic Hot Water

(ISWH): Individual Solar Water Heater

(SWH): Solar Water Heater

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General Introduction

General Introduction

The use of fossil resources poses a significant risk to the environment. Their use is being held responsible for global warming. In addition, oil reserves are beginning to run out. In addition, the cost of a barrel of oil continues to rise. This is why there is a strong incentive to focus on renewable energy sources such as biomass, solar, wind, and water.

Solar energy is technically, ecologically, and financially advantageous. It ensures life on Earth. Man has learned to exploit it for a very long time, in various forms. These include solar lighting, solar cooking, solar drying, and the production of hot water.

Algeria has a large solar field with very advantageous durations and intensities of sunshine [1]. Among the easiest ways to harness solar energy is to use it for water heating.

In the present work, it is a question of realizing and testing two low-cost solar water heaters. The solar water heaters we build here will serve to heat an irrigation pond that will be used for fish farming.

To realize the two solar water heaters at a reduced price. We did this in artisanal ways using available and cheap materials. For reasons of economy and to be environmentally friendly we used palm fiber as thermal insulation in solar collectors. The use of palm fibers from date palm waste as thermal insulation has been reported and the thermal properties demonstrated by many authors [2.3]

Due to lack of time, we have not finished realizing the hot water storage tank for both collectors. The tests in this work will limit this, therefore, to the test of the collectors. We carried out tests in compliance with the European standard EN 12975-2-2006 [4].

To carry out the study presented here we have adopted the following work plan:

- Chapter 1: Solar water heater; in this chapter, we present the different elements of a solar water heater and the operating principle. We present bibliographical research on low-cost solar water heaters and the use of palm fiber as thermal insulation.

- Chapter 2: Modeling of a solar water heater; in this chapter, we present a mathematical model for the simulation of the thermal behavior of solar water heaters.

- Chapter 3: Realization and Instrumentation; in this chapter, we explain the instruments and the procedure for performing the tests. We also explain the procedure for the construction of solar water heaters.

- Chapter 4: Results and Discussions; where we present the results of simulations and experimental tests conducted on the two solar water heaters.

Chapter 1:

General information

1. Introduction

Turning solar energy into hot water is now the best way to reconcile high technology with clean use of natural resources. The principle of a solar water heater is based on capturing the energy produced by the sun's rays and using this energy to produce domestic hot water.

Thus, solar water heaters are considered a future solution.

This chapter contains a brief review of the thermal transfer modes, general information on solar water heaters, different types, and main components, and the last part is devoted to the flat glass collector, the subject of our study.

2. Solar Water Heater

A solar water heater is a device for capturing solar energy intended to provide part or all of domestic hot water (DHW).

This type of heating generally complements other types of water heating using other energy sources (electricity, fossil fuels, biomass, etc.). In favorable conditions, it allows to replace them completely.

An individual solar water heater (ISWH) can capture solar energy to provide hot water for various uses: sanitary, washing machines, swimming pools, etc.

It consists mainly of solar thermal collectors and a hot water storage tank.

2.1. Types of Solar Water Heaters

The energy intercepted by the solar collector and converted into heat is transmitted to the coolant and transferred to a storage tank. Thus, depending on the nature of the fluid circulation, two ISWH systems can be distinguished.

2.1.1. ISWH thermosiphon

Under the effect of solar radiation, the water contained in the collector heats up and its density decreases, according to the principle of gravitation it rises in the circuit and is replaced by colder (and therefore heavier) water coming from the balloon. This is the thermosiphon effect. So that the circulation of the fluid in the circuit is ensured, the balloon storage must be placed higher than the collectors at a predefined height.

The advantages of a thermosiphon SWH are:

- It does not have pumps or regulations, and does not require connection to an electrical grid;
- The risks of failure and malfunction are therefore very reduced.

Depending on the arrangement of the storage bag about the collector, the SWH thermosiphon Monobloc and ISWH thermosiphon with separate elements, Figure (1-1). [5]

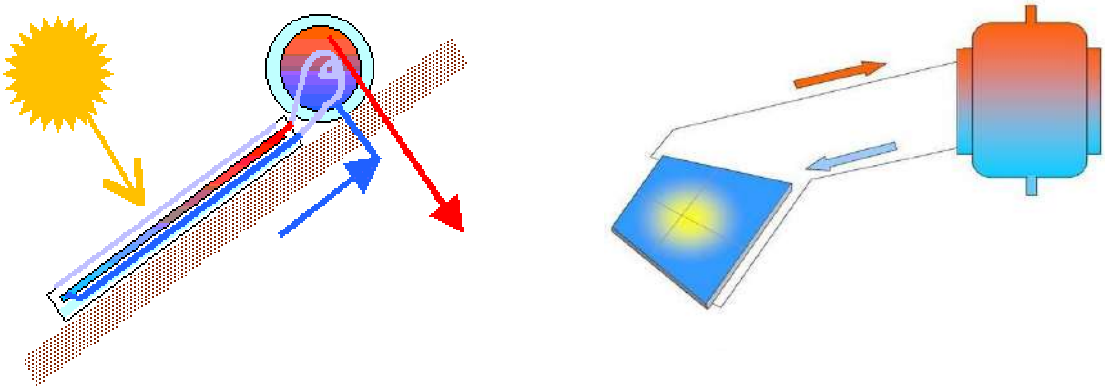


Figure (1- 1) (a): SWH One-piece thermosiphon (b): SWH Separate element

2.1.2. Forced Circulation ISWH

This category includes solar water heaters that use a circulator to transfer the heated water into the collector from the solar collector to the storage. Unlike thermosiphon water heaters, the relative of the ball and collector is completely free. This is one of the advantages of a forced-circulation solar water heater system

Several types of forced circulation ISWH are used: [5]

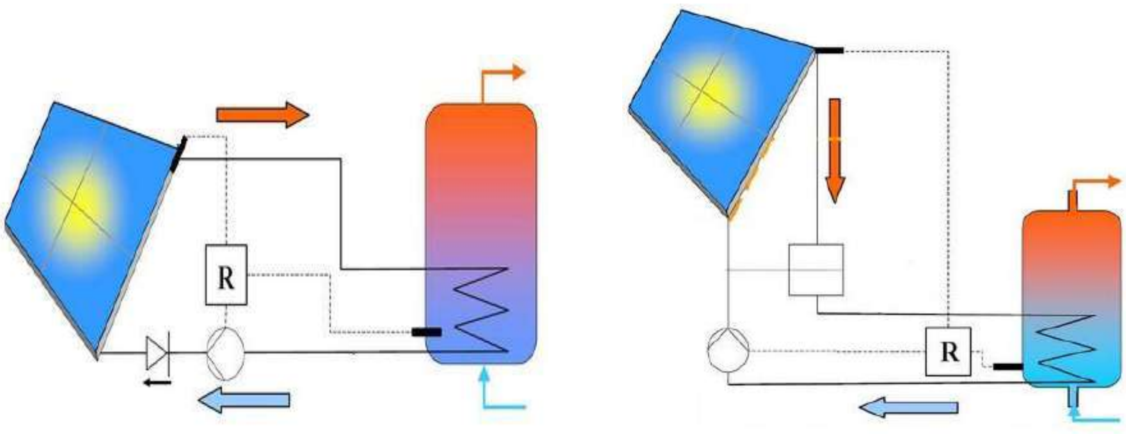


Figure (1- 2) (a): ISWH with forced circulation (b): ISWH with forced circulation under self-draining pressure

2.2. Comparison between the two types of SWH

- **Solar water heater price: advantage for thermosiphon**

The solar thermosiphon water heater running on its own without a pump or regulator is the cheapest of the two systems.

- **Installation of the solar water heater: advantage for the thermosiphon**

The installation of a thermosiphon solar water heater is simpler than a forced circulating solar water heater (no regulator, pump, and expansion tank to be installed) and therefore requires less labor.

- **A lifetime of a solar water heater: advantage for the thermosiphon**

The regulator and the pump of a forced circulation system are the first causes of failure. Without these fragile elements, the thermosiphon solar water heater greatly simplifies maintenance and significantly improves the service life of the solar system.

- **The flexibility of installation: advantage for forced circulation**

This is the big strength of the forced circulating solar water heater compared to the thermosiphon solar water heater, the solar balloon being able to position (almost) everywhere, especially below the thermosiphon sensor.

- **Use: advantage for a forced circulation SWH compared to**

A thermosiphon ISWH that can be used only as an individual. Forced-circulation SWHs are generally used for collective or industrial uses and may have several collectors.

- **Performance: advantage for forced circulation**

A slight advantage of the solar water heater with forced circulation, especially in areas with low sunlight or heat loss, is faster in the thermosiphon flask and where the regulator allows recovering the maximum of solar input.

2.3. Components of a solar water heater

A solar water heater consists mainly of two elements figure (1-3):

- The storage tank,
- The solar collector.

Other components are added: circuit lines, pump, check valve, expansion tank, safety valve, drain valves, bleeders, and regulator.

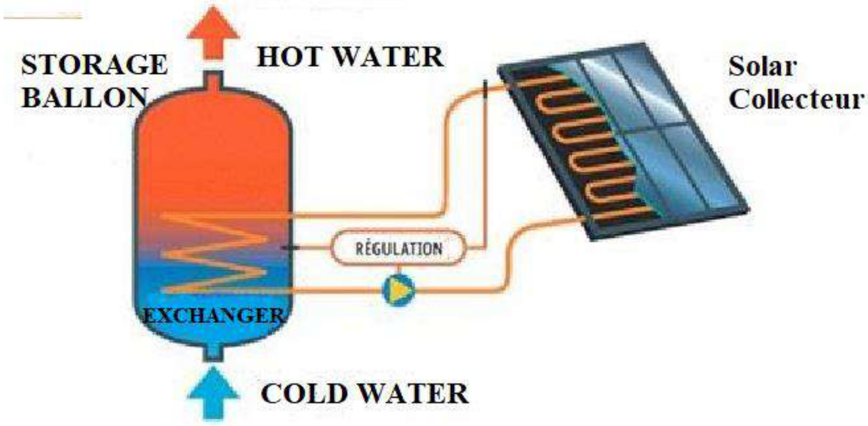


Figure (1-3) : Components of a solar water heater

2.3.1. The storage bag

Except in specific cases (sensor surface less than 20-30 m^2), storage balloons are "DHW buffer" type balloons without incorporated heat exchangers. Indeed, for reasons of cost and performance, plate heat exchangers are recommended to transfer energy to domestic hot water.

For some applications, or more particularly for some installations of storage balloons with low temperatures, balloons with an internal heat exchanger are used to avoid the risk of freezing in the pipes and the plate heat exchanger. In this case, the cold and hot water pipes must be insulated effectively. Special attention is paid to the temperature resistance of hot water balloons.

Some products are guaranteed only if the storage temperature is less than or equal to 60°C. A minimum temperature holding of 80°C is required for solar storage balloons.

Particular attention is paid to the temperature resistance of the domestic hot water tanks.

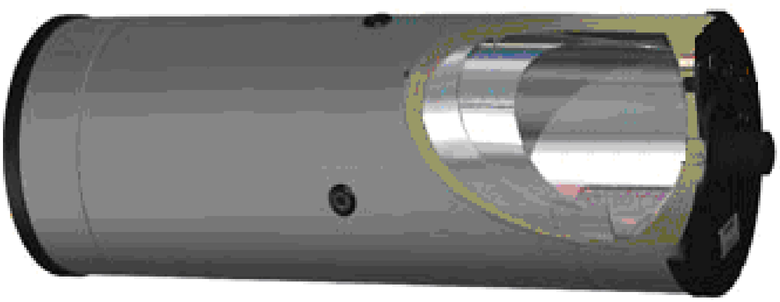


Figure (1-4): SWH storage tank

2.3.2. The solar collector

Solar thermal collectors are the essential element in solar energy thermal conversion plants.

The solar radiation is absorbed by a black surface, covered by a coolant that extracts the thermal energy and transfers it to its place of installation or stockpiling.

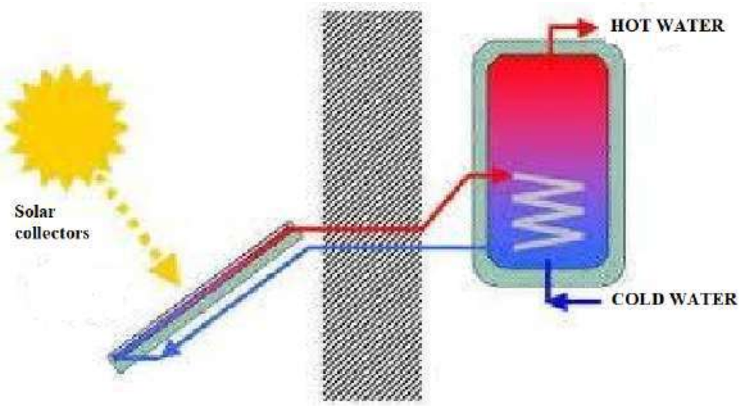


Figure (1-5): Solar thermal collector

2.3.3. Other components of a solar water heater

- The circuit lines:

Usually, the materials used for piping are copper tubes or simple steel tubes.

Complete systems including aisle and return piping as well as cable for the sensor temperature probe and insulation. This piping system saves installation time.

The pipes in the primary circuit should be insulators to limit heat loss between the collectors and the storage tank.

Under no circumstances can the insulation of these systems be made using insulation for the usual sanitary pipes, since it is essential to take into account the temperatures at which they will be explored, the insulation normally used can withstand a continuous temperature of 150 to 180°C

Figure (1-6): Insulated connecting lines

➢ A pump (circulator):

The role of the circulator is to ensure the circulation of the heat transfer fluid in the solar loop, the circulators used in central heating installations with radiators (resistant to temperatures of up to 120°C) are normally also suitable for installations with solar water heaters.

Figure (1-7): The circulator

➢ The non-return valve:

The function of the non-return valve is to prevent, in systems without draining, that a thermosiphon effect does not lead to a reversal of the primary circuit if the pump stops.

Figure (1-8): Check the Valve

➢ Drain valves:

Drain and fill valves must be placed at the lowest point of the solar circuit and on the cold water inlet to be able to completely drain the installation.

Figure (1-9): Drain valve

3. The different types of solar collectors

To intercept energy from solar radiation, there are several kinds of solar collectors. The following is a brief description of the three most common types of flat solar collectors.

3.1. Flat collectors without glazing

It is the simplest model, the most economical but the least efficient. It usually consists of a simple plate of metal or plastic (absorber) on which are glued several tubes carrying heat transfer fluid. The glass-free surface collector is not insulated on the front, which is why they respond better to low-temperature applications (below 30°C).

The main area of use of this type of collector is the heating of outdoor pools. Because they do not have glass, these collectors absorb a large part of the solar energy. However, because they are not insulated on their front face, much of the heat absorbed is lost when there is especially wind and the outside temperature is not high enough. Stirred by warm air, these collectors absorb the heat exchanged especially during the night when the temperature is high in the presence of the wind outside. The typical architectural integration allowed by this type of product allows the implementation of a larger surface area, to compensate for the difference in efficiency with flat glass collectors, especially during the winter**.**

Figure (1-10): Flat collectors without glazing [6]

3.2. Flat glass collectors

Flat glass solar collectors are very common. They exist in the form of water collectors and air collectors.

These collectors are best suited for moderate temperature applications where the desired temperatures are between 30°C and 70°C. Water flow sensors are more commonly used for the production of domestic hot water on an individual or collective scale. for industrial use, as well as for indoor pools.

Air collectors are used for drying, space heating also ventilation air.

Figure (1-11): Flat glass collectors

3.3. vacuum collectors

"Vacuum" solar collectors are made up of a series of transparent glass tubes.

Figure (1-12): Vacuum collectors

In each tube, there is an absorbent plate to capture the solar radiation and an exchanger to promote the transfer of thermal energy.

The tubes are vacuum-packed to avoid convective thermal losses of the absorbent plate and the Absorbing plate receives selective treatment to prevent radiation from dissipating in the form of long-wavelength. Thus, it is possible to realize efficient solar collectors without thermal insulation or a protective box. [7]

4. The main components of a glazed flat collector

A glazed flat collector consists mainly of a transparent cover, an absorber, and a thermal insulation figure (1-13).

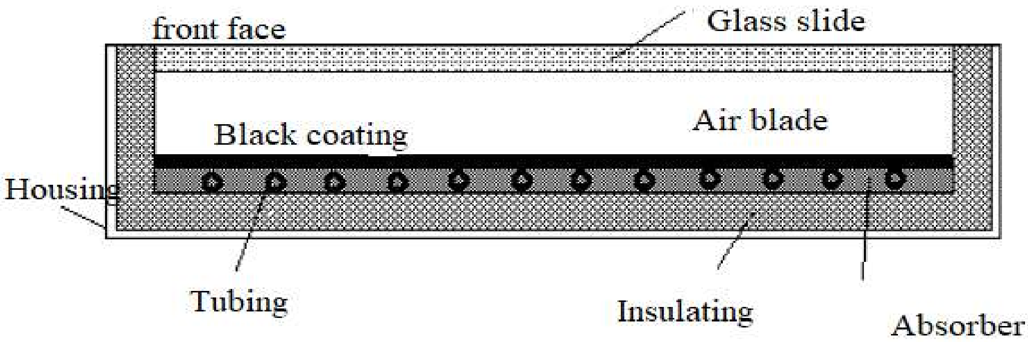


Figure (1-13): Schematic section of a glazed flat collector

4.1. The transparent cover

Due to its resistance to mechanical aggressions (shocks, hail, snow, etc.) and thermal aggressions (sudden cooling, etc.), the secured glass is specially used as a transparent cover. To be most possibly transparent and transmit solar radiation, it is preferable that the glazing is low in iron oxide.

For roof-integrated collectors, synthetic materials are sometimes used.

They are lighter, cheaper, and easier to set up, but their lifespan is less than that of ordinary glass.

More often, the glazing is slightly structured, so it spreads the reflected fraction of the incident solar radiation, to reduce any glare.

The main features of glazing are:

- It's coefficient of transmission (τ)
- Its emission coefficient (ε)

The coefficient of transmission (τ) is essentially determined by the structure of the glazing (double or triple, the thickness of the windows, the spaces, and the nature of the filling gas between the absorber and the glazing).

Table (1-1) summarizes the various types of glass used. [8]

Glass	Reflection	Absorption	Transmission
Clear glass	8%	9%	83%
Low-grade glass Fe_2O_3	8%	2%	90%

Table (1-1): Optical characteristics of some lenses

The special feature of good glazing is its low absorption of solar radiation and its maximum energy transmission to the absorber. Currently, the glass most often adopted for flat collectors is prismed glass. Its specificity is its low reflection of radiation (1.5%). It can transmit up to 96% of the radiation.

4.2. The collector

The main role of a collector is the capture of solar radiation and its conversion into calorific energy. It is usually painted black to absorb all radiation in the spectrum of the visible, ultraviolet, and a small amount of infrared.

The collector is chosen according to the following characteristics:

- ✓ A good absorption coefficient;
- ✓ Good thermal conductivity;
- ✓ Good corrosion resistance.

The choice of material and the construction process have a great influence on the quality of a collector. Because of their high conductivity, copper, steel, and aluminum are the most commonly used materials.

The characteristics of various materials used as absorbers are given in Table (2-2). [9]

Matter	Conductivity (w/m °C)	Coefficient of expansion
Aluminum	230	2,38
Copper	380	1,65
Zinc	112	2,9
Steel	52	1,15
Inox	52	1,15
Plastic	0,2-0,4	7-20

Table (1-2): Characteristics of the materials used as an absorber

To reduce radiation losses, absorbers are generally coated with a selective layer. Nickel and chromium are the primary metals used for selective coatings for most collectors.

Table (2-3) gives the coating methods most often used. [5]

Revetment	Absorption	Episode
Black paint	0,92-0,97	0,95
Black chrome on copper (selective)	0,95	0,14
Black chrome on steel (selective)	0,91	0,07
Tinox (selective)	0,95	0,05

Table (1-3): Coatings of absorber surfaces

4.3. The heat transfer fluid

To evacuate the heat stored by the absorbing plate it is generally used as heat transfer fluid either air or water. Compared to water, the air has the following advantages:

It does not have frost problems during the winter or boiling during the summer,

- Dry air does not present corrosion problems,
- An air leak is inconsequential,
- It is not necessary to use a heat exchanger for local,
- The system to be implemented is simpler and more reliable.

The use of air for water has the following disadvantages:

- The air can only be used for space heating,
- Pipes must have a large section to allow flow sufficiently,
- Heat transfers are less good than water.

In the case of welded piping on the back face of the absorbent plate, care must be taken with the welds to minimize the thermal resistance of contact [10].

4.4. Insulation

A collector must be well insulated with suitable materials.

The latter must have a low thermal conductivity, to minimize thermal losses by conduction through the faces of the collector. Generally, the thickness of insulation is in the range of 5 to 10 cm. Mineral wool and synthetic materials (glass wool, expanded polyurethane foams, or polystyrene) are generally the insulation materials used. They must withstand the high temperatures that can be reached inside a collector. For the optimal selection of an insulating material, the following parameters should be considered:

- Density

- Maximum operating temperature
- Fire, rodent, and rot resistance
- Moisture sensitivity
- Its cost

Table (1-4) groups the properties

The properties of the most commonly used insulation are listed in Table (1-4) [8].

Insulating	Thermal conductivity at 500w/m°C max	Temperature max
Glass wool	0,041	150
Rock wool	0,05	150
Polyurethane	0,027	110
Polystyrene	0,039	85
expanded cork	0,042	110

Table (1-4): Some properties of insulators

5. Principle of operation of a flat glass collector

Some of the solar radiation that comes into the glass goes through it to reach the absorbing plate. The latter heats up and transfers heat to the heat transfer fluid which circulates through the tubes. Like anybody that heats up, the absorber emits radiation (mainly in the infrared) which is reflected by the glass, it is the principle of the "greenhouse effect". Insulation has the function of minimizing losses

with the outside. Indeed, most of the energy absorbed must be transmitted to the fluid, it is, therefore, necessary to minimize the losses in the near environment.

6. The parameters characterizing the operation of a flat collector

The parameters characterizing the operation of a flat panel collector can be classified into two categories: external parameters and internal parameters.

6.1. External parameters

The main external parameters that can directly affect the performance of a flat panel collector are:

- ✓ Sun parameters: solar radiation, the position of the sun, duration of exposure, etc.

- ✓ Ambient temperature
- ✓ Wind speed

6.2. Internal parameters

- ✓ Geometric parameters:
- ✓ Position parameters: tilt angle, collector orientation.
- ✓ The surface of the collector
- ✓ Dimensions of different elements: thickness, length, and width
- ✓ Operating parameters:
- ✓ Coolant inlet temperature
- ✓ The mass flow of the coolant
- ✓ Temperatures of the different collector elements

These parameters are very important. They allow, taking into account the cost, to have a high fluid output temperature (high useful power). In other words, better collector performance.

7. Optimum collector tilt

To allow a collector to capture the maximum amount of solar radiation, it must be tilted at a particular angle called the optimum inclination. This amounts to a position perpendicular to the solar radiation.

Taking into account the permanent displacements of the earth and the sun, each moment corresponds to an optimal inclination, the best solution is to equip the collector with a tracking system. However, this solution can be costly [11].

8. Literature review on low cost water heaters

The reduction of the production costs of solar water heaters is a major concern to make these devices available to a wide public. This is to reduce energy costs or to allow access to comfort in isolated areas.

Several studies are concerned with the development and improvement of low-cost solar water heaters.

In 1997, Tisilinginis [12] built and tested a solar water heater at a lower cost. He designed it as a flat tank covered with a plastic film. During the tests, it reaches a temperature of 45°C with an efficiency of up to 60%.

In 2001, Hirunlabh [13] built a solar water heater with PVC tubes. This choice of materials limits the production temperature which cannot exceed 60°C.

Siqueira et al, in 2011 [14], tested a cheap water heater made with PVC pipes that has a honeycomb structure but is not covered. The maximum temperature reached by this solar water heater is 46°C.

Taheri et al, in 2013 [15], tested a passive low-cost solar water heater. The collector was made using black colored send immersed in a tank. The water heater achieved a daily efficiency of 70%.

Hossain et al. in 2015, [16] tested and evaluated the performance of a solar water heater using copper tubes with a polystone collector. They obtain an output temperature of 70°C in July. The cost of this solar water heater is estimated at 148 Dollars for a useful surface of 1 m^2.

Finally, in 2019, Barbosa et al. [17] investigated the effect of the manifold pipe arrangement on the efficiency of the solar water heater. The authors report a maximum efficiency of 40.9%.

The list of work presented here is not exhaustive. In our case, we are talking about making two solar heaters with an insulating material based on palm waste. The latter, in addition to being cheap, has the advantage of having a small footprint on the environment.

9. Use of date palm fibers as insulation

Date palm waste seems to be a potential insulating material. It is either used alone or serves as a matrix for composite material. In 2003 Alsulaimani [18] prepared a composite material based on synthetic resin and date palm fiber to serve as an insulating material.

Oushabi et al 2015 [2] carried out tests on a material prepared from date palm waste. The authors report a thermal conductivity of 0.041 W/mK equivalents to that of glass wool. In 2017, Ali et al [3] tested a material based on date palm fiber and starch. They obtain a thermal conductivity between 0.046 and 0.06 W/mK depending on the starch content.

Date palm fibers are also used in construction to improve the thermal and mechanical properties of building materials [19].

10. Integrated fish farming

Small-scale agriculture-aquaculture integration offers an opportunity for sustainable agricultural development. Agriculture-aquaculture integration offers particular benefits that go far beyond its role in waste recycling and its importance in promoting better water management in agriculture. Fish can efficiently convert low-grade feeds and waste products into high-value protein.

10.1. Definitions

Fish farming is one of the branches of aquaculture, which refers to the rearing of fish. This rearing is practiced in fully or partially enclosed spaces (ponds, concrete or plastic basins, traps or cages, etc.).

10.2. Integrated fish farming

Figure (1-14): integrated fish farming

This is the introduction of fish farming in an agricultural environment. The process consists in developing the two activities, in parallel or sequentially, benefiting from the advantages of one for the other. In general, integrated fish farming is more recommended in rural areas, especially at the level of medium and small farms, for its significant protein intake.

10.3. Advantage of integrated fish farming

The integration of fish farming into agriculture makes it possible to:

-Guarantee an additional protein intake.

-Decrease malnutrition through a supply of food with high nutritional value.

-Diversify farm income and improve the quality of life of farmers, especially on small farms.

-Enhance the use of water bodies, natural and artificial.

-Create a micro-ecosystem that makes it possible to recycle agricultural residues in fish farming, and vice versa, while reducing organic pollution.

-Reduce the use of chemical fertilizers.

-Reduce the cost price of fish for the farmer and his family.

11. Conclusion

Solar water heaters consist essentially of a solar collector and a storage tank. They are intended for the production of domestic hot water. Depending on the capacity of use, there are natural circulation solar water heaters (thermosiphons) for individual use and circulation solar water heaters forced for collective or industrial use. Their performance depends essentially on the ability of the collector to capture solar energy and transmit it to the coolant. For this, a study on the performance of solar collectors and the parameters influencing their efficiencies is essential for better use and a better design.

Chapter 2

Modeling of a solar water heater

1. Introduction

To simulate the behavior of a plane collector exposed to radiation solar to a given geographical position and period we must in the first place establish the mathematical equations and balances that govern the thermal phenomena in the flat solar collector.

- In the following, particular attention will be paid to:
- Establish the energy balance at the collector level;
- Formulate hypotheses to simplify our calculations;
- Determine the different heat transfer coefficients and the global exchange coefficient;
- Establish the electrical-thermal analogy;
- Determine the various factors related to the geometry of the absorber;

Establish a program using MATLAB simulation software that will simulate the water collector behavior in a specific environment and then predict its thermal performance based on equations established in the manuscript by Duffie and Beckmann [20].

2. Collector Energy Balance

Either $Q_{sa}$the solar energy absorbed by a collector, part of it is recovered by the coolant it is the useful energy Q_u . This energy can be used directly or transferred to a storage system (hot water tank for example).

A solar collector is also subject to thermal losses. Some of the energy absorbed is transferred to the environment in the form of thermal energy mainly by convection and radiation. These losses will be noted Q_p .

Finally, if we are interested in a period of temperature setting of the system (at start-up for example) we will have to take into account the energy absorbed by the collector necessary for this temperature rise. This energy, noted Q_{st} , depends on the thermal inertia of the installation. Thus the overall thermal balance is written [10]:

$$Q_{sa} = Q_u + Q_p + Q_{st} \qquad (2.1)$$

2.1. Hypotheses

To simplify our study, several assumptions were considered [20]:

1. The collector surface is uniformly illuminated;

2. The sky is considered a black body at T_{ciel} temperature;

3. Each element of the collector is at a homogeneous temperature;

4. Permanent regime;

5. Negligible thermal inertia collector (low component mass and heat specific);

6. The temperature of the surrounding air is homogeneous, therefore heat losses to the front and back are at the same ambient temperature,

7. The dust deposition effect and the masks on the sensor are negligible,

8. One-dimensional heat flow; Assumptions 4 and 5 make the flow stored in the collector negligible,

$Q_{st} = 0$, and so the balance equation becomes:

$$Q_{sa} = Q_u + Q_p \tag{2.2}$$

Knowing that the solar energy absorbed by the absorber Q_{st} is worth:

$$Q_{sa} = \tau_c a_p G_t \tag{2.3}$$

with,

τ_c : Transparent cover transmittance,

a_p : Absorption factor of the absorber plate,

G_t : The global illuminance incident on the collector

2.2. collector performance

According to [21], the C.E.C standard stipulates that the most significant study of the performance of a flat plate collector is to determine its instantaneous efficiency defined as being the ratio between the useful flux recovered, on the incident global solar irradiance on the sensor such as:

$$\eta = \frac{\int \dot{Q}_u dt}{\int Q_t dt} \tag{2.4}$$

If the conditions are constant over some time, the efficiency decreases to:

$$\eta = \frac{Q_u}{G_t} \tag{2.5}$$

Or,

G_t: the global solar irradiance incident on the collector

2.3. Evaluation of collector thermal losses

The electrical analogy linked to the different thermal resistances during the heat exchanges carried out on the different elements of the collector can thus be adapted to carry out the thermal analysis.

Thermal losses are due to the difference in temperature between the different components of the solar collector as well as with the ambient environment. They manifest in the three heat transfer modes described above. They are divided into three

categories:

- Forward losses,

- Losses to the rear,

- Lateral losses.

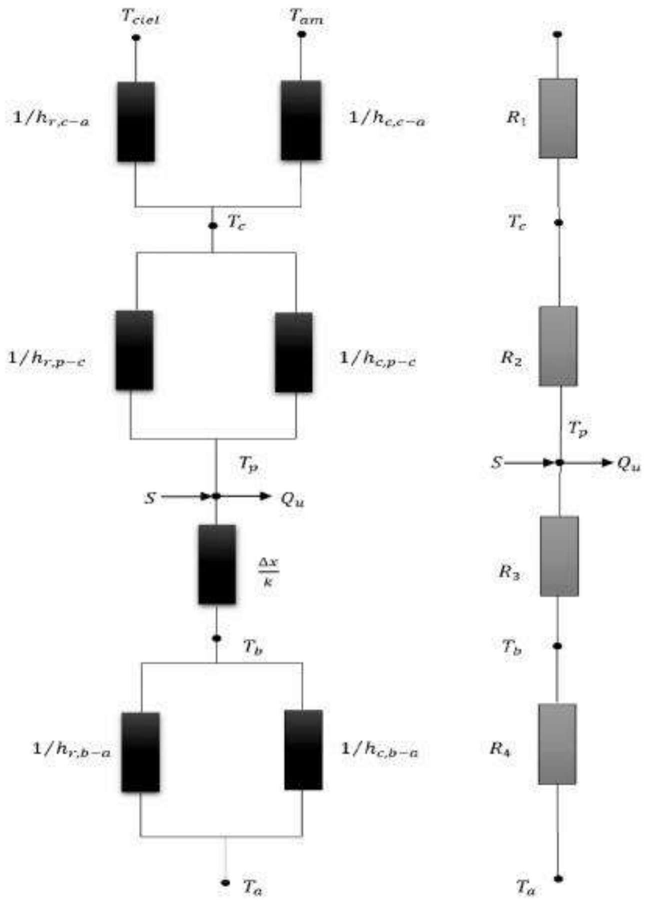


Figure (2- 1): Equivalent electrical circuit relating to a flat solar collector

From the equivalent electrical diagram, we define:

$R1$: Thermal resistance between the ambient medium and the glass,

$R2$: Thermal resistance between the glass and the absorber,

$R3$: Thermal resistance between absorber and insulation,

$R4$: Thermal resistance between the insulation and the surrounding environment.

2.3.1. Losses in front of the collector

- Heat exchange between the glass and the external environment

As shown in figure (2.1), the losses between the glass and the external environment are mainly due to heat transfer by convection and radiation.

$$Q_{p,av1} = \left(h_{c,c-am} + h_{r,c-ciel}\right)(T_c - T_{am}) \qquad (2.6)$$

$h_{r,c-ciel}$: exchange coefficient by radiation between the glass and the sky given by:

$$h_{r,c-ciel} = \frac{\sigma\varepsilon_c(T_c^4 - T_{ciel}^4)}{T_c - T_{am}} \qquad (2.7)$$

With:

$$T_{ciel} = 0.0552 T_{am}^{1.5}$$

$h_{c,c-am}$: exchange coefficient by convection between the glass and the environment;

$$h_{c,c-a} = 5.67 + 3.86 V_{vent} \qquad (2.8)$$

V_{vent}: wind speed

This allows us to write equation (4.6) in the form:

$$Q_{p,av1} = h_{c,c-a}(T_c - T_{am}) + \sigma\varepsilon_c(T_c^4 - T_{ciel}^4) \qquad (2.9)$$

Thus we define the equivalent resistance between the glazing and the ambient medium R_1 which is then given by:

$$R_1 \frac{1}{h_{c,c-a} + h_{r,c-ciel}} \qquad (2.10)$$

2.3.2. Heat exchange between the glass and the absorber

As before, the heat exchange between the two elements takes place by convection and radiation.

$$Q_{p,av2} = \left(h_{c,c-a} + h_{rp-c}\right)\left(T_p - T_c\right) \qquad (2.11)$$

Or,

h_{rp-c} : heat transfer coefficient by radiation between the pane and the absorber given by:

$$h_{rp-c} = \frac{\sigma(T_p+T_c)(T_p^2+T_C^2)}{\frac{1}{\varepsilon_p}+\frac{1}{\varepsilon_c}-1} \qquad (2.12)$$

ε_c : Glass emissivity;

ε_p : Absorber emissivity;

$h_{c,p-c}$: Coefficient of heat transfer by convection between the glass and the absorber.

To determine the convection coefficient $h_{c,p-c}$, the following correlations will be used [9]:

$$Nu = 1 + 1.44\left[1 - \frac{1708(\sin 1.8\beta)^{1.6}}{Ra}\right]\left[1 - \frac{1708}{Ra\cos\beta}\right] + \left[\left(\frac{Ra\cos\beta}{5830}\right)^{\frac{1}{3}} - 1\right] \qquad (2.13)$$

With,

β: being the angle of incidence of the collector,

Ra: The Ray light number

$$Ra = \frac{g(T_p-T_c)L_C^3}{T_{ma}\,.a_a} \qquad (2.14)$$

Or,

L_c: characteristic length (space between the absorber and the glass);

a_a : Absorption factor of the air,

T_m: the average air temperature between the absorber and the glass, given by:

$$T_{ma} = \frac{T_p+T_c}{2} \qquad (2.15)$$

It allows evaluating the characteristics of the air $(\rho_a\ , \mu_a, \lambda_a, CP_a)$

ν_a: The kinematic viscosity of air,

$$\nu_a = \frac{\mu_a}{\rho_a} \qquad (2.16)$$

α: The thermal diffusivity of the air,

$$\alpha = \frac{\lambda_\alpha}{\rho_\alpha\,.CP_\alpha} \qquad (2.17)$$

$$\mathrm{N}u = \frac{h_{c.p-c}\,.L_c}{\lambda_\alpha} \qquad (2.18)$$

From where we derive the convection coefficient:

$$h_{c,p-c} = \mathrm{Nu}\frac{\lambda_a}{L_c} \tag{2.19}$$

The resistance R_2can be written:

$$\mathrm{R}_2 = \frac{1}{\mathrm{h_{c,p-c}+h_{r,p-c}}} \tag{2.20}$$

Thus, the loss coefficient in front of the sensor at ambient temperature is:

$$U_{av} = \frac{1}{R_1+R_2} \tag{2.21}$$

Duffy and Beckman (1980) gave an empirical relation due to Kelvin for the calculation of the global exchange coefficient at the front U_{av} with an error less than ±0.3 $W/m2$ [9] :

$$U_{av} = \left(\frac{N}{\frac{C}{T_{pm}}\left[\frac{T_{pm}-T_{am}}{(N+f)}\right]^{e}} + \frac{1}{h_{c,c-a}} \right)^{-1} + \frac{\sigma(T_{pm}+T_{am})(T_{pm}^2+T_{am}^2)}{\frac{1}{\varepsilon_p+0.0059NN_{c,c-a}} + \frac{2N+f-1+0.133\varepsilon_p}{\varepsilon_c} - N} \tag{2.22}$$

With:

U_{av}: Forward loss coefficient (W/m². K)

$f = (1 + 0.089h_{c,c-a} - 0.116 \times h_{c,c-a} \times \varepsilon_p)(1 + 0.07866N)$

$h_{c,c-a} = 5.67 + 3.86 \times V_{vent}$

$C = 520(1 - 0.000051\beta^2)$ $For\ 0° < \beta < 70°\ and\ For\ 70° < \beta < 90°\ We\ take\ \beta = 70°$

$e = 0.43(1 - 100/T_{pm})$

N: Number of panes,

β: Collector tilt angle,

T_{am} : Ambient temperature (K),

T_{pm} : Average plate temperature (K).

2.3.3. Losses behind the collector

It is often possible to neglect the resistance by convection in front of that due to the conduction within the insulation [9], so the losses behind the collector are given by the following formula:

$$Q_{p,ar} = \frac{(T_p - T_{is})}{\frac{e_{is}}{\lambda_{is}}} \quad (2.23)$$

Thus, from equation (4.23), we can thus define the coefficient of back losses U_{ar} such that:

$$U_{ar} = \frac{1}{R_4} = \frac{\lambda_{is}}{e_{is}} \quad (2.24)$$

Where λ_{is} and eis are the thermal conductivity and the back insulation thickness respectively.

2.3.4. Losses through the side faces of the collector

As previously the resistance by convection is neglected in front of that due to the conduction within the insulation, so the losses through the side faces of the collector are given by the formula:

$$Q_{p,Lat} = \frac{(T_p - T_{is})}{\frac{e_{isLat}}{\lambda_{is}} \frac{A_C}{A_{Lat}}} \quad (2.25)$$

Or,

A_c: collector area;

A_{Lat}: Surface of the side faces of the collector;

e_{isLat}: Thickness of insulation on its side faces;

We can thus define the coefficient of losses by the side faces U_{Lat} such that:

$$U_{Lat} = \frac{\lambda_{is}}{e_{isLat}} \frac{A_{Lat}}{A_c} \quad (2.26)$$

If we assume that all the losses are towards a temperature T_{am} (see hypothesis simplify number 6), then by summing the front, side and back we get the overall loss coefficient U_L

$$U_L = U_{av} + U_{ar} + U_{Lat} \qquad (2.27)$$

We can then write the density of the total heat flux lost as follows:

$$Q_p = U_L(T_{pm} - T_{am}) \qquad (2.28)$$

3. Calculation procedure

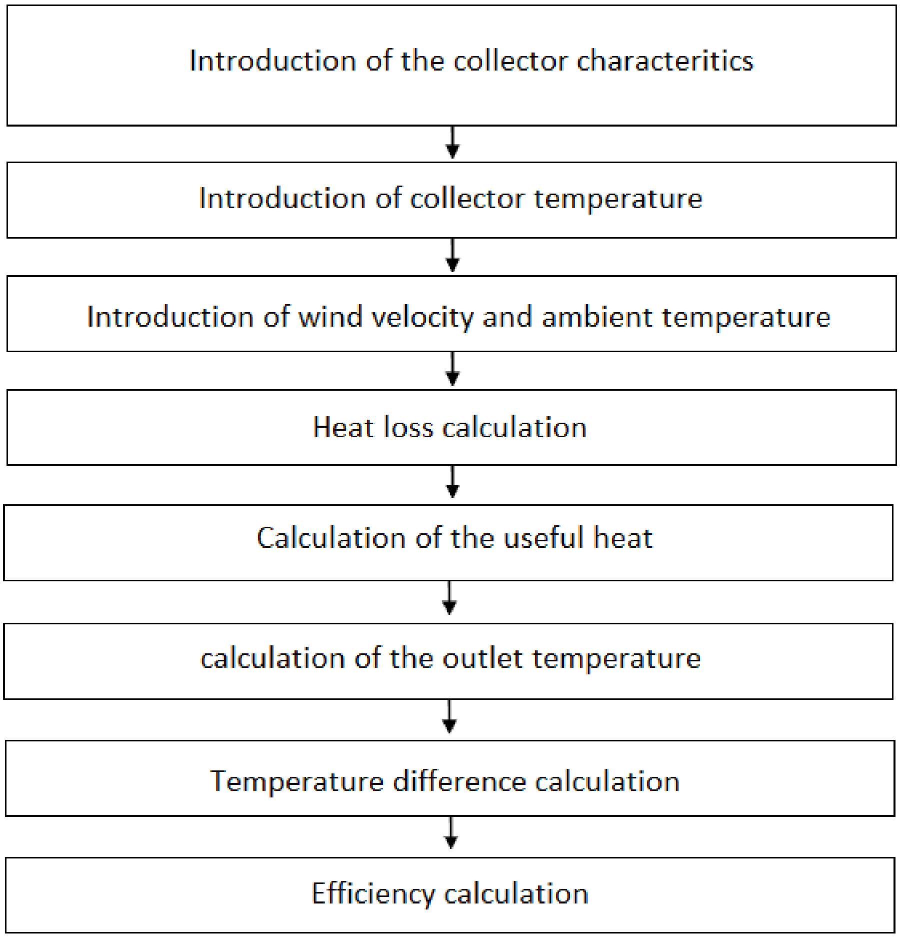


Figure (2- 2): Calculation procedure

4. Conclusion

We have presented in this chapter, mathematical modeling that allows the prediction of thermal losses and therefore the instantaneous efficiencies according to the operating parameters (internal and external parameters). We have presented in this chapter, mathematical modeling that allows the prediction of thermal losses and therefore the instantaneous efficiencies according to the operating parameters (internal and external parameters).

Chapter 3

Realization and Instrumentation

1. Introduction

This chapter is dedicated to performing tests on our collector using the various measuring devices. To achieve a characterization of our solar collector, the following parameters were measured:

- The temperatures of the different sensor elements, namely: the input and output of the working fluid, cover, absorber, insulation, ambient as well as a tank of stockpiling.

- Mass flow of heat transfer fluid (water)

- Solar radiation

2. Construction of the Solar Water Heater

2.1. Construction of the box

In order to manufacture our solar collectors, we have made a metal structure to support the weight of the copper tubes and that of the glass which covers the collector.

On this structure, we glued wooden sheets of 4 mm thick.

Figure (3- 1): Construction of the box

2.2. Thermal isolation

One of the most important parts in a solar water heater is thermal insulation. Without it, a large part of the collected energy would be lost.
The originality of our work is the use of date palm waste as thermal insulation. The waste we are talking about here is dried palm leaves that we have crushed to obtain fibers.
We used these fibers in kind without adding nothing in the first collector.
In the second collector we mixed the palm fibers with precooked starch to obtain a relatively solid and mechanically stable material (which does not move)

Figure (3-2): (a): Date Palme fiber with starch (b): Date Palme fiber-free

2.3. The collector:

We made the water circulation circuit in copper. As can be seen in the following Figure (3-2), these are 11 parallel copper tubes with a diameter of 12 mmm connected to each other by a tube with a diameter of 22 mm.

On this copper grid, we placed aluminum sheets of 0.4 mm thick which we painted black. These sheets act as thermal collectors.

Figure (3-3): Dyeing aluminum sheets

2.4. Glass

In order to create a greenhouse effect in our collectors and limit heat transfer by convection on the face of the collectors, we have installed two 4 mm thick panes. The panes have a dimension of 2m x 1m. They are made of tempered glass so that it can withstand high temperatures above 100°C.

Figure (3-4) : Glass Installation Process

3. Production cost estimate

The goal of our work is to produce a low-cost water heater. The following is an estimation of the cost of the two solar collectors.

We have seen in this chapter the procedure adopted for the manufacture of the two collectors. In the following table, we present the prices of the different parts used.

The Product	Price (DA)
Iron	10000 DA
Wooden sheet	2700 DA
Stacking material	5000 DA
Palm fibers	3000 DA
Copper	23000 DA
Silicone	10000 DA
Glass	20000 DA
Starch	1000 DA
TOTAL :	74700 DA

Table (3-1): Production cost estimate

The estimate given in the preceding table includes the elements for the two collectors. Thus, the cost of collectors is given as follows

- Collector cost whose insulation is made with starch is estimated at 37,850 DA

- Cost of the collector whose insulation does not contain starch is estimated at 36,850 DA

This estimation takes into account only the price of the different elements without taking into account the cost of labor. In our case, it took us 40 hours of labor. Assuming that we need two workers paid at 50,000 DA/month, the cost of the two collectors amounts to:

- 38,950 DA for the collector whose insulation is made with starch

- 37,950 DA for the collector whose insulation does not contain starch.

Moreover, if we look at the market, a collector costs between 100,000 and 140,000 DA with an estimate of the manufacturing cost between 60,000 and 75,000 DA [22], [23].

4. Experimental apparatus

4.1. Description of the test bench

The characterization of solar systems must be carried out according to well-defined methods. By the methods of testing solar devices implemented by an accredited agency, will lead to better performance in the context of standardization.

For this purpose, a test bench according to the European standard EN 12975-2-2006 [4] has been prepared whose test conditions are mentioned in table (3-2)

Settings	Meaning	EN-12975
$\theta(°)$	Angle of incidence	0° to +40°
$(T_s - T_e)(°C)$	Input-output temperatures difference	of 1.5 to 15°
$T_a(°C)$	Ambient temperature	of 5 to 30°C
$I_g(W/m^2)$	Global solar irradiance	750W/m^2
m$(Kg/S.m^2)$	Mass flow per unit of surface	0.02Kg/S.m^2

Table (3-2): Test conditions according to standard EN-12975-2-2006

In this study, the working method is based on determining the thermal performance of solar collectors whose liquid circulation is quasi-stationary. It also defines test configurations for the exterior in real operating conditions of a solar water heater in terms of ambient temperature, sunshine, and wind.

Figure (3-5) below show the test bench carried out in this direction.

Figure (3-5) : Bench test

4.2. Collector’s Characteristics

The fluid used for our experiments is the alert water of the distribution network.

The support is fixed on an angle of inclination that corresponds to the latitude of the place (Hassi Ben Abdellah: 31.75°) and on a south orientation for better efficiency. The characteristics of the various constituents of our sensors are shown in table (5-2):

Figure (3-6): The flat solar collector studied

Characteristics	Solar heater 1	Solar heater 2
Dimensions (m)	2m*1m	2m*1m
Envelope	Wooden sheet Thickness=0.35mm	Wooden sheet Thickness=0.35mm
Radiator	Copper Number of tubes=11 Length=1.70m	Copper Number of tubes=11 Length=1.70m
Absorber	Aluminum Area=1.71m^2 With a selective black surface	Aluminum Area=1.71 m^2 With a selective black surface
Insulating	Palm fibers Bottom=150mm Sides=50mm	Palm fibers + Starch Bottom=150mm Sides=50mm
Window	Ordinary glass Thickness=4mm	Ordinary glass Thickness=4mm

Table (3-3): Characteristics of the elements of the collectors studied

The dimensions of two solar collectors have been chosen to correspond to the dimensions of the solar heaters produced by the company Thermo cad

We took this solar heater for the model because it was the subject of an express study at the level of the CDER [24]

Figure (3-7): Solar heater of the company Therms Cad

5. The Measurement instruments used

5.1. Measurement of different temperatures

Measurement of different collector temperatures (fluid inlet and outlet, the absorbing plate, the fast, insulating).

Figure (3-8) shows the ambient temperature provided by Type PT 100 thermocouples (Cromel-Alumel).

Figure (3-8): Type PT100 temperature sensor

Thus, 06 temperature probes of the PT100 type were used for each collector whose locations on the collector are illustrated in figure (3-9).

- 02 temperature sensors at collector inlet and outlet
- 01 temperature sensors are installed on the collector plate
- 01 temperature sensors shaded for ambient temperature
- 01 temperature sensors for glazing temperature
- 01 temperature sensors for insulation temperature

Figure (3-9): Arrangement of Thermocouples in The System

5.2. Measurement of working fluid flow

The flow measurement of the heat transfer fluid is ensured by a FIP float flow meter, picture (3-10).

Figure (3-10): Float FIP flowmeter.

5.3. Measurement of solar radiation

The measurement of the incident global illumination on the surface of our collector is carried out using a Pyranometer figure (3-11). The collector is mounted on a metal bracket installed parallel to the surface of the collector, and therefore has the same inclination as our collector.

Figure (3-11) : Pyranometer

5.4. Data Acquisitions

A GRAPHTEC midi logger GL840 is used for data acquisition. It allows the reading of the various temperatures, namely: the inlet and outlet temperatures of the fluid, the temperature of the absorbing plate, the temperature of the glazing, the temperature of the insulation, and the ambient temperature, also the solar illumination figure (3-12)

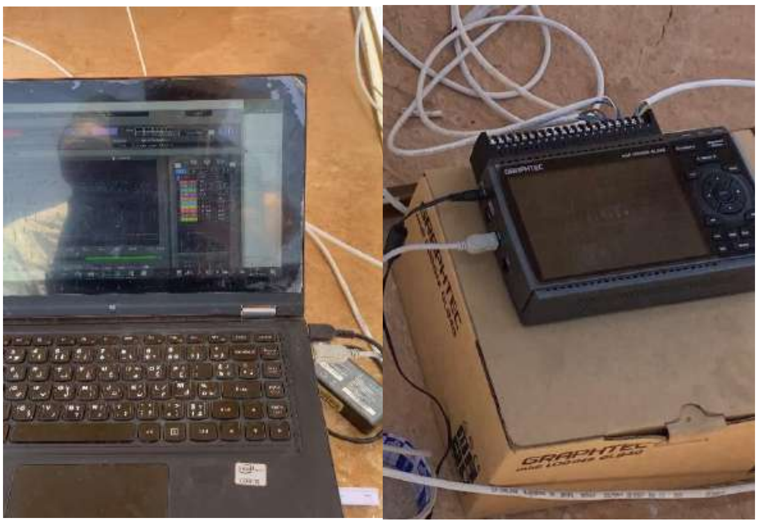


Figure (3-12): Data logger type GRAPHTEC midi logger GL840

6. Conduct Experimental Tests

6.1. Determination of fluid capacity

The water capacity of our collector is determined by calculating the internal volume of the entire hydraulic system. It is calculated from the point of entry to the point of exit.

Thus, the water content of the studied collector is equal to 2.272 L.

6.2. Flow Control

Standards for performance testing of solar systems generally require a mass flow rate. In this case, the European standard EN 12975-2-2006 requires a mass flow rate per unit area of 0.02 kg/s. m^2. The overall surface area of our collector is 1.71 m^2 and therefore the mass flow rate for the tests is:

$$\dot{m} = 1.71 * 0.02 = 0.0342 kg/s$$

A pump with a bypass-mounted valve controls this flow rate.

This makes it easy to adjust the coolant flow Figure (3-13)

Figure (3-13): Flow regulator (pump)

6.3. Variation of the inlet temperature of the heat transfer fluid

For characterization tests of solar collectors, according to standard EN-12975-2-

2006, the inlet temperatures of the fluid T_e are to be chosen according to the temperature ambient T_{am} like this:

T_e = T_{am}

T_e = T_{am}+10°C

T_e = T_{am}+20°C

T_e = T_{am}+30°C

T_e = T_{am}+40°C

They are regulated using electrical resistance.

7. The conditions to be met before performing the tests

Before starting the tests on the collector, the following conditions must be respected for proper operation:

- Ensure that there is no leakage or deterioration of the collector,
- Make sure the collector glass is properly cleaned,
- Ensure that there is no external disturbance (external heat source, shadow effect, etc.),
- It is preferable to orient the collector in the South for maximum capture

solar energy,

- The coolant flow rate must be adjusted according to the standard used $\dot{m} = 0.02\text{kg}/m^2$ for the European standard EN 12975-2-2006,
- The collector must be exposed to the natural conditions of clear sky and temperature within the range specified by the standard used for the actual determination of the collector performance.

8. Conclusion

In this chapter, we presented the experimental device used. We have also cited the essential parameters to be measured and their measuring instruments used.

Also the preliminary test steps according to EN 12975-2-2006. The tests of our collectors are carried out in a closed circuit.

Chapter 4

Results and Discussions

1. Introduction

In this chapter, we present the results obtained during the tests conducted on the two collectors. During the tests, we made sure to respect the conditions of the European standard.

Concerning our collectors (the collectors that we have built), we present here the results obtained by the experiments carried out on them as well as the results obtained by the mathematical models based on the thermal losses presented in the chapter: medialization of the thermal water heater.

The experiments carried out on the two solar water heaters took place during April. This delay is due to certain constraints regarding the availability of the material necessary for the realization of the solar water heaters.

We compared the result obtained by our experimental tests to the results of the experimental study of flat fluid-circulation solar collectors in a copper pipe manufactured by the company (Thermo Cad) [24]. The fluid used for our experiments is the water coming from the distribution network.

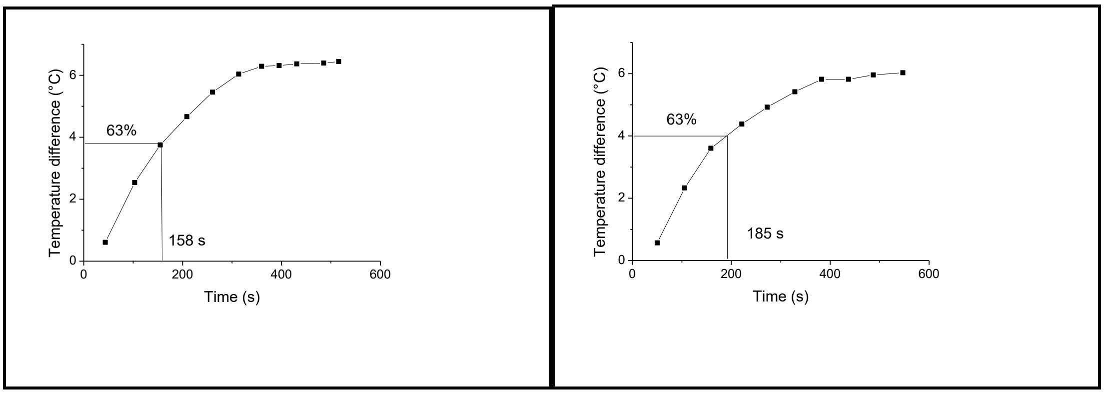
2. Time constant calculation

The time constant characterizes the thermal inertia of the system. The test for the determination of the time constant was carried out according to the European standard during the collector-heating phase, as follows:

The collector was completely insulated until the solar radiation exceeded 750W/m^2,

The water is put into circulation in the collector so that the temperature of the water at the inlet of the collector is equal to the ambient temperature. Then the cover is removed. Water temperatures at the inlet and outlet of the collector, ambient temperature, and global inclined solar radiation were recorded.

The tests were carried out under average irradiation of G_t=800 W/m^2.



(a) (b)

Figure (4- 1): Time constant (a): for the collector with insulant with starch, (b): for the collector with insulant without starch

The time constant corresponds to the time required for the collector to reach 63% of the maximum temperature rise of the collector.

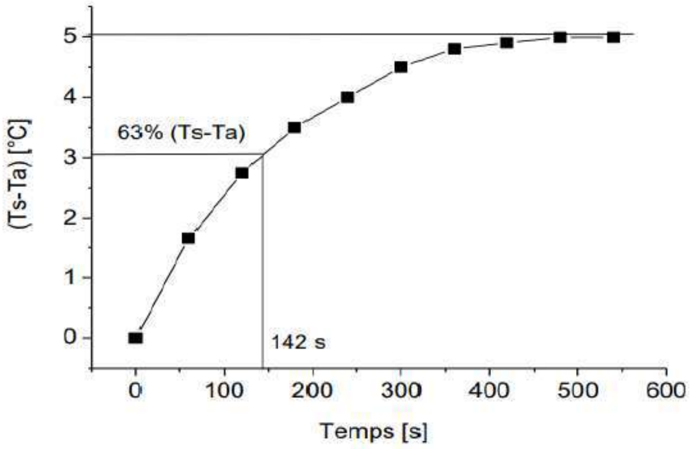


Figure (4- 2): Time constant of the thermo cad water heater [24]

Thus, as shown in Figure (4-1) and Figure (4-2): The time constants of the collectors are given as follows:

- The collector with insulant without starch: τ = 185 s = 3 mn and 5 s
- The collector with insulant with starch: τ = 158 s =2 mn and38 s
- The Thermo cad collector: τ = 142 s =2 mn et 22 s

3. Effect of solar irradiance intensity

Solar irradiation is a very important factor because it is the driving force of the solar water heater. It represents the primary energy from which our water heater draws to heat the water. Therefore, it is very important to see the effect of this parameter on the operation of the solar water heaters that are the subject of our study.

3.1.Effect on the efficiency

The solar water heater has several heat losses as presented in the chapter simulation of a solar water heater. This loss impacts the thermal power provided by the solar water heater, but what about the impact on the efficiency. This is shown by the figures presented in this section.

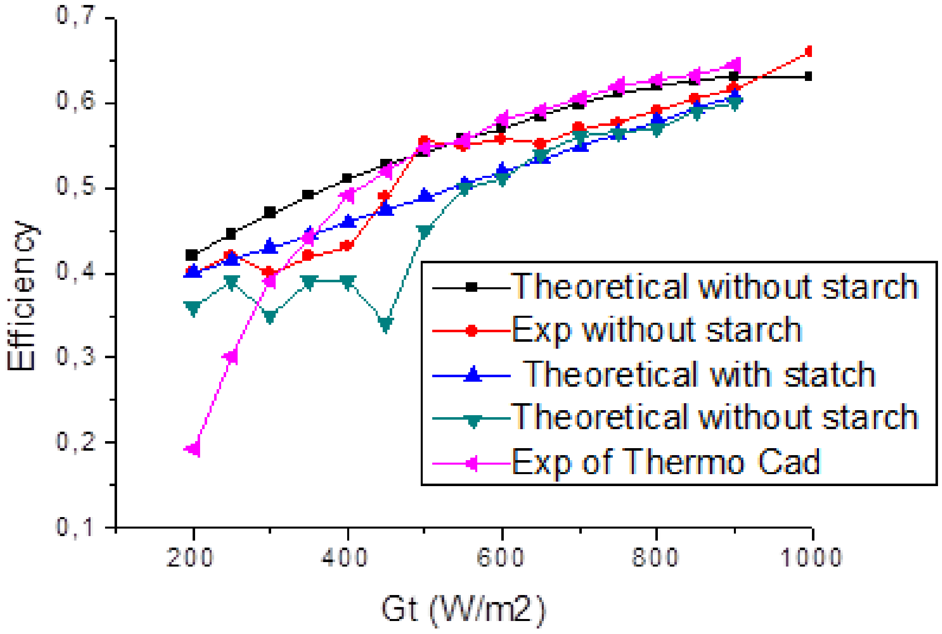


Figure (4- 3): Effect of irradiance intensity on the efficiency

Figure (4-3): gives the variation of the efficiency according to the intensity of the solar irradiation for the two solar collectors object of our study as well as for the collector manufactured by Thermo cad in the case of our collector Figure (4-3) gives the experimental results as well as the results obtained by the theoretical model. It is noted in all cases that the increase in the intensity of solar irradiation causes an increasing inefficiency.

With the increase in solar irradiation, the heat collected by the water in the tubes of the collector is greater than that which is dissipated through the various walls of the collector.

Moreover, we note that the predictions of the theoretical model are relatively close to the experimental results.

Finally, it should be noted that the performance of the collector with the starch-free insulation is close to that of the Thermo cad collector, except for the low level of radiation where our collector has better performance.

3.2. Effect on the temperature difference between inlet and outlet

The temperature difference between the inlet and the solar collector outlet tells us directly about the thermal power supplied to the water by the latter.

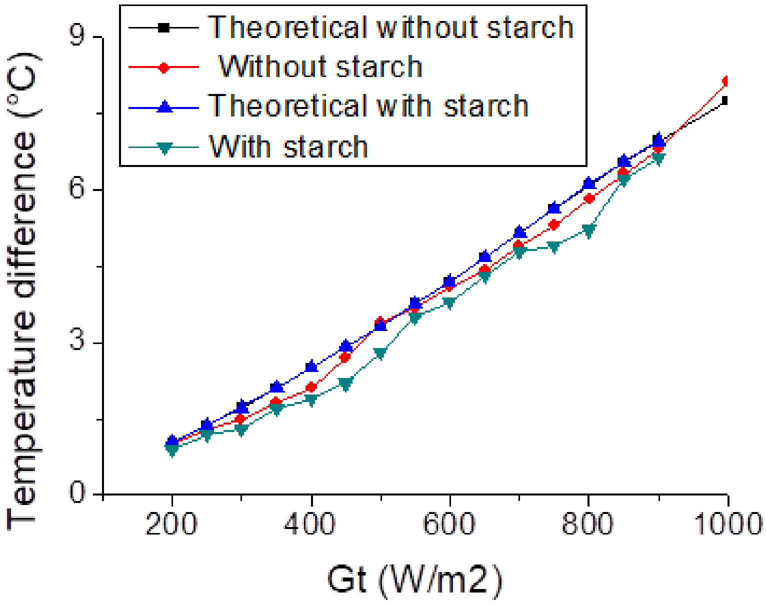


Figure (4- 4): Effect of irradiance intensity on the inlet-outlet temperature difference

Figure (4-4): gives the effect of the intensity of solar irradiation on the temperature difference between the input and the output of our collectors. We note of course that the increase in the intensity of solar irradiation leads to an increase in the temperature difference. The greater the irradiation, the more the water heats up in the collector (irradiation represents the input of thermal energy). We also note that the theoretical model well approaches the behavior of the collectors.

Finally, it should be noted that the collector whose insulation does not contain starch gives better results.

3.3. Effect on the temperature of the elements of the collector

In what follows, we will see the effect of the intensity of the irradiation on the temperatures of the various elements of our collectors. This aims to understand the thermal behavior of our collectors.

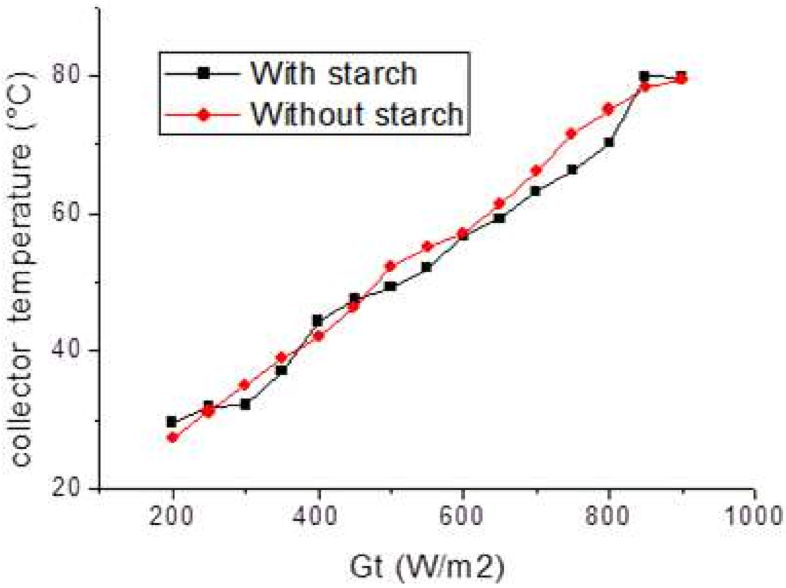


Figure (4- 5): Effect of irradiance intensity on the collector temperature

Figure (4-5): shows the effect of the intensity of the irradiation on the temperature of the collector. We notice, as is the case for the temperature difference between the inlet and the outlet, an increase in the temperature of the collector for both collectors at the same intensity.

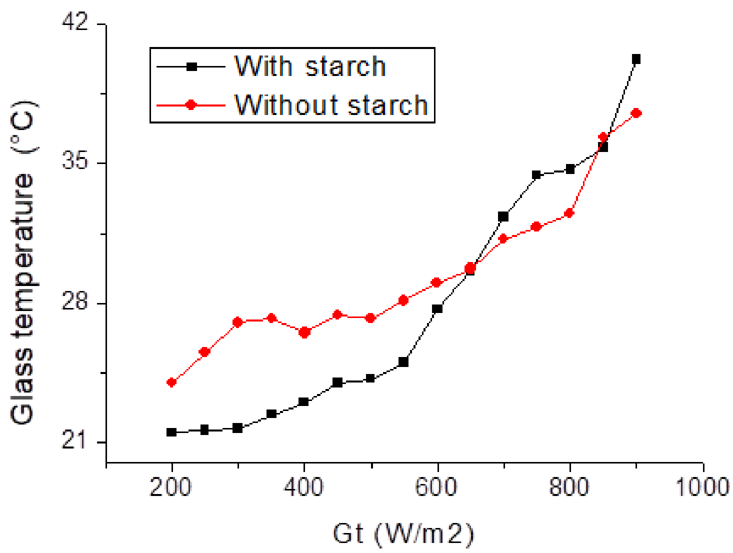


Figure (4- 6): Effect of irradiance intensity on the glass temperature

We can see in Figures (4-6): the effect of the intensity of solar irradiation on the temperature of the glass. We notice an increase in the temperature with the increase in the intensity of the irradiation so for the two collectors. This increase in temperature promotes losses through the glass.

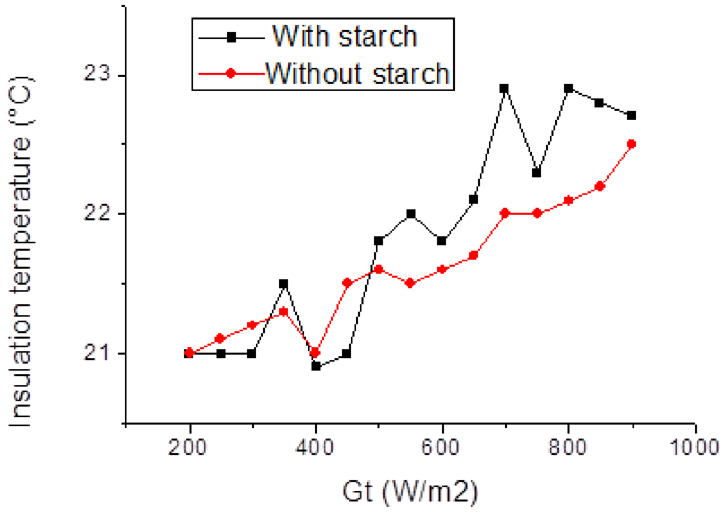


Figure (4- 7): Effect of irradiance intensity on the insulator temperature

In the previous Figure (4-7): we can see the effect of irradiation on the temperature of the insulation. We notice a small increase in temperature with the increase in the intensity of the irradiation in both cases. This increase accompanies the increase in the ambient temperature, which is between 21 and 22.5 °C during the tests.

4. Inlet temperature effect

In this part, we present the tests relating to the effect of the water inlet temperature on the performance of the two collectors studied.

During our tests, we varied the input temperature between 25 and 65°C and carried out the tests under irradiation of 900 W/m2, to meet the requirements of the European standard.

4.1. Effect on the efficiency

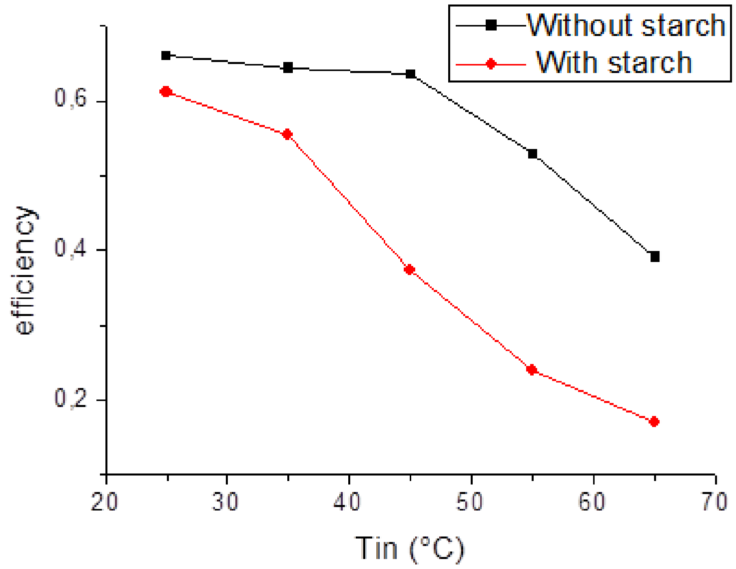


Figure (4- 8): Effect of inlet temperature on the efficiency

Figure (4-8): shows the evolution of efficiency as a function of water inlet temperature. It is observed that the efficiency decreases with the increase of the inlet temperature. Similar behavior is reported by Hakem et al. in 2008. [25]

4.2. Effect on the temperature difference between inlet and outlet

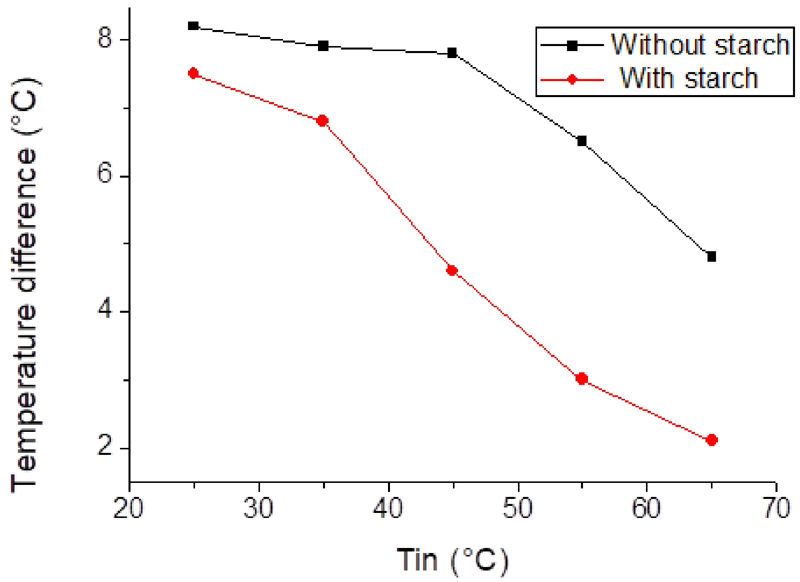


Figure (4- 9): Effect of inlet temperature on the temperature difference

Figure (4-9): gives the effect of the temperature inlet on the temperature difference between the input and the output of our collectors.

It can be seen that the temperature difference decreases with increasing the inlet temperature. This result agrees with the previous result (decrease in efficiency). In other words, less energy is recovered from the water.

4.3. Effect on the temperature of the elements of the collector

In the following, we will see the effect of the inlet temperature on the temperature of the various elements of the collectors to explain the behavior of the two collectors.

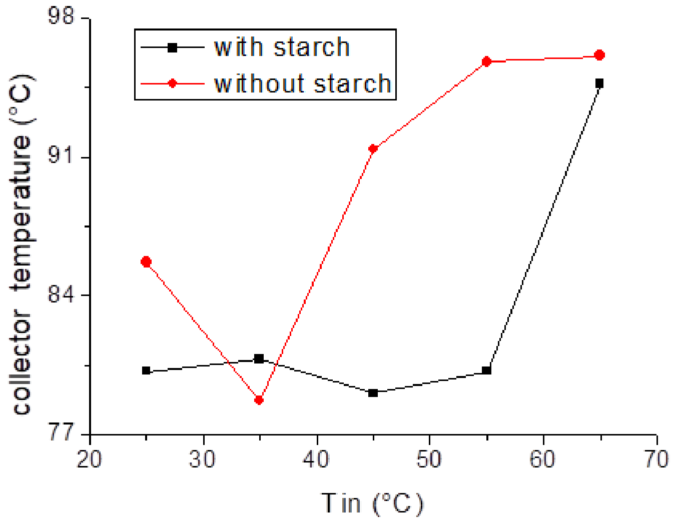


Figure (4- 10): Effect of inlet temperature on the collector temperature

In Figures (4-10) we can see the variation in the temperature of the collectors according to the inlet temperature of the water. we notice the increase in the temperature of the collector with that of the water at the inlet.

This trend is the same in Figure (4- 11) which gives the temperature of the window according to the water inlet temperature and to a lesser extent in Figure (4-22) which gives the temperature variation of the insulation.

This increase in the temperature of the elements of the two solar collectors that we are studying explains the drop in efficiency in both cases.

Indeed, the increase in the temperature of the glass increases the transfer of heat to the outside. The same goes for the insulation, even if it is less noticeable. This increase in heat loss results in a drop in inefficiency.

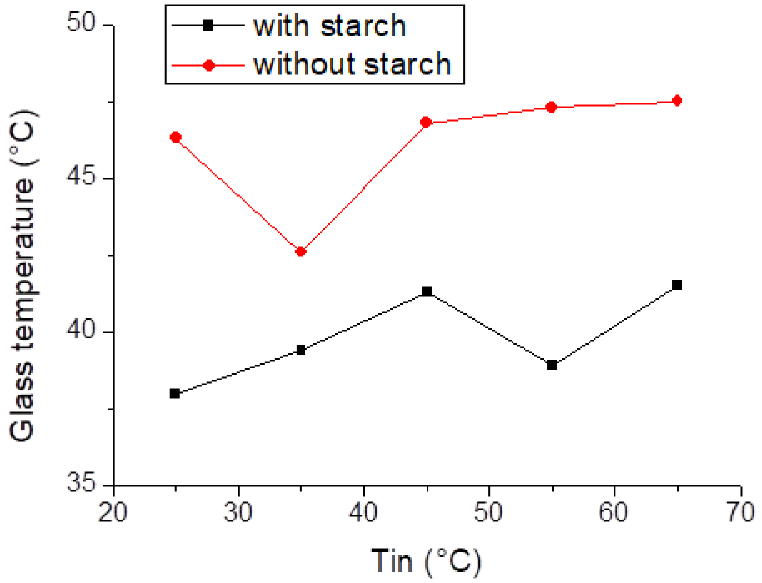


Figure (4- 11): Effect of inlet temperature on the glass temperature

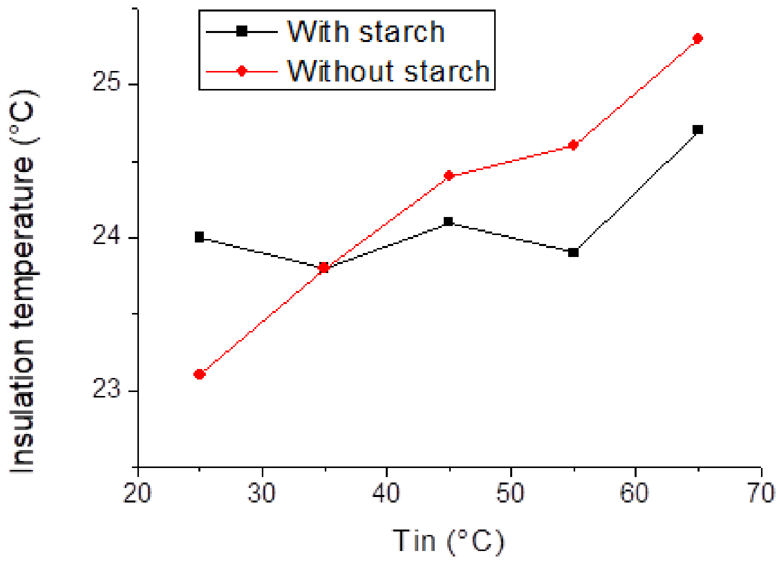


Figure (4- 12): Effect of inlet temperature on the glass temperature

5. Effect of the wind speed on the performances of the collectors

One of the factors that can affect the amount of heat lost by collectors is wind speed. In this part, we will see the effect of wind speed on collector performance.

For this, we have made measurements for the same ambient temperature (about 22°C) and the same intensity of solar irradiation (900 W/m2), for different wind speeds.

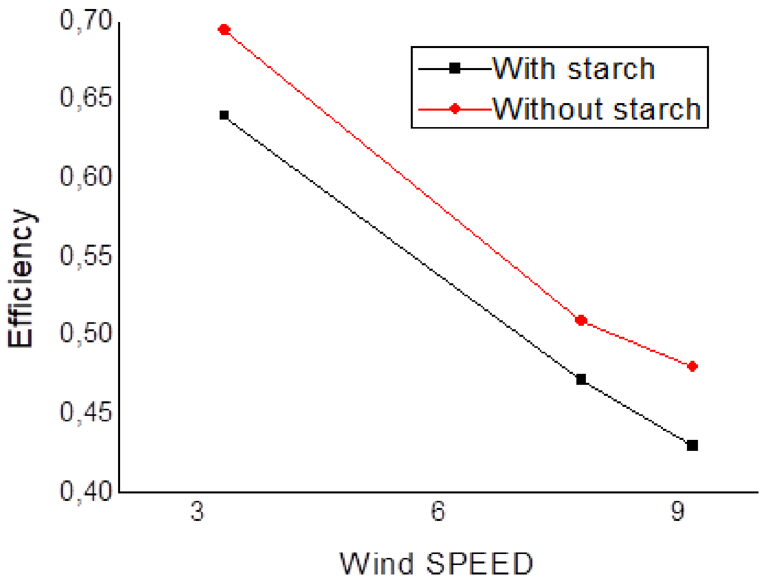


Figure (4- 13): Effect of wind speed on the efficiency

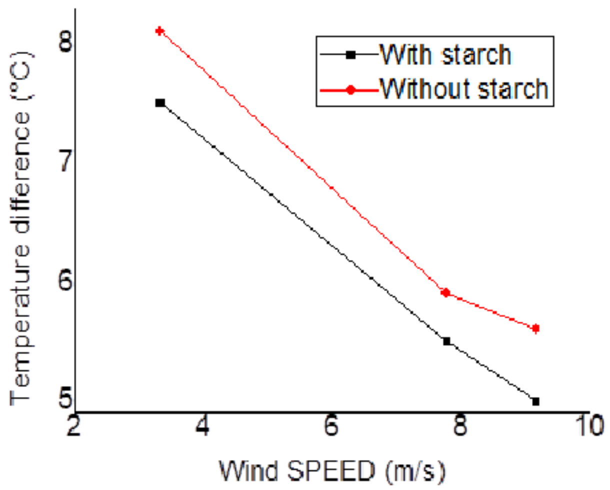


Figure (4- 14): Effect of wind speed on the temperature difference

Figures (4-13) and Figure (4-14) show the effect of wind speed on the efficiency and the temperature difference between the inlet and the outlet of the two collectors. The figures show that both temperature differences and efficiency decrease with the increase in wind speed.

This drop in the performance of the collectors is explained by the increase in heat losses due to the increase in heat transfer by convection due to the increase in wind speed.

6. Conclusion

At the end of this chapter where we presented the results of our experiments on the two collectors that we built, the following remarks are to be noted.

1- The time constant of the two collectors is greater than that of a commercial solar water heater.
2- Increase in efficiency with solar irradiation
3- Significant increase in the temperature of the collectors with the solar irradiation.
4- The increase in the inlet temperature reduces the performance of the collectors.
5- The increase in wind speed negatively affects the performance of both collectors.
6- The temperature of the two insulators is not very affected by the test conditions. This demonstrates that the two insulators used (with and without starch) fulfill their role well.

In addition, the significant increase in the temperature of the collectors and the relatively low efficiency compared to commercial water heaters as well as the relatively high time constant reveals a defect in the production of the two collectors. This defect is related to the contact between the collector, which is an aluminum plate, and the copper tubes to ensure the heat transfer from the collector to the tubes and then to the water circulating in the tubes.

This resistance causes an increase in the temperature of the collector and consequently that of the thermal losses.

General conclusion

General conclusion

As a part of our work, we undertook the construction and testing of two low-cost solar water heaters. We carried out the tests in compliance with the European standard EN 12975-2-2006 and compared the results with those obtained by mathematical simulation and with the results of tests on a solar heater marketed by Thermo cad.

At the end of this study the following conclusions should be noted:

- The inertia of the realized solar collectors is greater than that of the collector manufactured by Thermo cad. Indeed, the time constants of our collectors are more important.

- Our solar collectors have a thermal behavior similar to that of thermo cad and to that of the mathematical model. The results show that the efficiency of the collectors

  - Increases with increased intensity of irradiation
  - Decreases with increase in water inlet temperature
  - And decreases with increasing wind speed.

- The insulation used with date palm waste behaves well. We didn't notice any big temperature variation. thereby limiting heat losses.

- We can say that the solar collector whose insulation does not contain starch has better thermal behavior. This was predictable because according to the study by Ali et al [3] the conduction coefficient of mixtures containing starch is greater.

One of the goals of our work is to demonstrate the proper functioning of cheap solar water heaters. In addition to the good operation and performance close to those of the collector produced by Thermo cad, our collectors have a very low production cost. Indeed, our collectors cost about three times less.

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Abstract

A solar water heating system is a device that captures solar energy and transfers it in the form of heat to water. Solar water heaters are very easy to install and use. They can be adapted to any type of installation.

We undertook, in our work, to realize two solar collectors at a reduced cost. We have chosen to use date palm waste as thermal insulation for our solar collectors.

In the first solar collector, we used the waste from the date palm that we crushed without adding anything. In the second solar collector, we used a mixture of crushed waste and starch.

We have carried out tests in accordance with the European standard EN 12975-2-2006. In addition, we carried out modeling of the thermal behavior of the collectors.

The results showed that our solar collectors provided good behavior and good performances, close to the performance of a commercial solar collector, with a production cost up to three times cheaper.

Keywords: Solar energy, solar panel plane, heat-water-solar, heat exchange, digital, modeling, instantaneous output, palm fiber, date palm waste.

Résumé

Un chauffe-eau solaire est un dispositif qui permet de capter l'énergie solaire et la transférer sous forme de chaleur à l'eau. Les chauffe-eaux solaires sont très faciles à installer et utiliser. On peut les adapter à tout type d'installation.

Nous avons entrepris dans notre travail de réaliser deux collecteurs solaires à cout réduit. Nous avons choisi d'utiliser les déchets du palmier dattier comme isolant thermique de nos collecteurs solaires.

Dans le premier collecteur solaire nous avons utilisé les déchets du palmier dattier broyé sans rien ajouter. Dans le deuxième collecteur solaire nous avons utilisé un mélange de déchets broyé et d'amidon.

Nous avons effectué des tests en accord avec la norme européenne EN 12975-2-2006. Par ailleurs, nous avons effectué une modélisation du comportement thermique des collecteurs.

Les résultats obtenus montrent que nos collecteurs solaires démontrent un bon comportement et de bonnes performances, proches des performances d'un collecteur solaire commercial, avec un cout de production jusqu'à trois fois moins cher.

Mots-clés : Énergie solaire, plan de panneaux solaires, chaleur-eau-solaire, échange thermique, numérique, modélisation, rendement instantané, fibre de palmier, déchets de palmier dattier.

ملخص

سخان المياه الشمسي هو جهاز يلتقط الطاقة الشمسية وينقلها على شكل حرارة الى الماء، سخانات المياه بالطاقة هي سهلة التركيب والاستخدام، ويمكن تكييفها مع أي نوع من التثبيت الشمسي.

لقد تعهدنا في عملنا بإنجاز اثنين من مجمعات الطاقة الشمسية بتكلفة منخفضة. لقد اخترنا استخدام مخلفات النخيل كعزل حراري لمجمعات الطاقة الشمسية لدينا.

في اول مجمع للطاقة الشمسية، استخدمنا نفايات نخيل التمر المسحوق دون إضافة أي شيء، وفي المجمع الثاني استخدمنا خليط من النفايات المطحونة ممزوجة مع النشاء.

لقد أجرينا الاختبارات وفقًا للمعيار الأوروبي EN 12975-2-2006

.بالإضافة إلى ذلك، قمنا بتنفيذ نمذجة للسلوك الحراري للمجمعات.

تظهر النتائج التي تم الحصول عليها أن مجمعات الطاقة الشمسية لدينا تظهر سلوكًا جيدًا وأداءًا جيدًا، بالقرب من أداء المجمعات الشمسية التجارية، مع تكلفة إنتاج تصل إلى ثلاث مرات أرخص.

الكلمات المفتاحية: الطاقة الشمسية، الألواح الشمسية، الحرارة، المياه، الطاقة الشمسية، التبادل الحراري، النمذجة الرقمية، الإخراج اللحظي، ألياف النخيل، نفايات النخيل.