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Research Article

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A Tunnel mixed solar dryer for the drying of fishery products: design and experimentation

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Abstract In order to reduce the losses during the drying and solve hygiene problems encountered in the drying of fishery products in Senegal, we designed and manufactured a mixed tunnel solar dryer with forced convection, consisting of an air collector with fans and a drying cabin. This dryer has been tested under different drying conditions and in different ways, under vacuum, then loaded. An efficiency study was carried out to determine thermal performance and drying efficiency. The results obtained during the no-load tests gave thermal efficiencies ranging from 17% in rainy weather, to 60% in sunny periods for the collector and from 0% in rainy weather to 5.7% in sunny periods for the drying cabin. Drying the fish under the conditions of an average irradiance 592.76 W/m² gave a Specific Moisture Extraction Rate (SMER) of 0.49 (kg water/kW.h) for a drying efficiency of 32% in an average temperature of 49.5 °C. The different probes placed on the products on the four trays showed a uniform distribution of the temperature in the dryer. Therefore, the fishes underwent a uniform drying from a moisture content of 65% to a moisture content of 32% in 16 hours of drying.

Keywords fish; solar dryer; thermal performance; drying efficiency; collector; drying cabin

Nomenclature

E_T	the total energy received on the dryer
c_p	heat capacity (J/kg. °C)
G	irradiance (W/m²)
L_v	Latent heat of vaporization (kJ/kg)
M_e	mass of water contained in the product (kg)
m_i	initial mass (kg)
m_f	final mass (kg)
m_t	mass of product at the moment t (kg)
m_s	dry weight of the product (kg)
P_n	fan power (W)
S_b	collector area (m²)
S_c	tray area (m²)
T m	mean temperature
T_f	temperature of the fluid at the dryer outlet (°C)
T_e	temperature of the fluid at dryer inlet (°C)
t_h	time of drying (hours)

$\dot{m}$ air mass flow rate (kg/s)

η_{th} thermal collector Efficiency

Abbreviation

I.G.D.C: Inside face cover Glass side Drying Chamber

O.F.G.C: Outside face cover Glass side Collector

I.F.G.C: Inside Face cover Glass side Collector

F.C: Front side of the Collector

R.C: Rear side of the Collector

O.G.D.C: Outside face cover Glass side Drying Chamber

B.D.C: Bottom Drying Chamber

P.C.A.F: Part of the Collector Away from the Fan

P.C.C.F: Part of the Collector Close to the Fan

A.I.D.C: Air Inlet Drying Chamber

A.O.D.C: Air Outlet Drying Chamber

1. Introduction

Traditional solar drying of fish products is one of the preservation techniques that has been used for many years. It often involves exposing the product to the open air, under the sun. This type of process, which is still widely practised in Senegal today, has considerable disadvantages. In fact, under the action of dust, bad weather, bacteria, high humidity, the drying process might not go well, which gives as result, the detoriation of the products [1-2]. This leads to storage difficulties, a decreasing in the nutritional value of the product, as well as a lack of supply to local markets, and regional and international export difficulties [2-3].

Nowadays, the drying of fish products is better organised and has become an increasingly lucrative activity. There are several processing units throughout the country. These units are made up of women who are often organized in associations called GIE (Economical interest group), and who receive support from public authorities or non-governmental organizations. For the women, the use of raised trays has become one of the alternatives to floor drying. These trays are hollow wooden tables on which a net is hung. However, drying on these trays is done in the open air and that has as consequences a slow drying, and hygiene problems related to the exposure to dust, animals and insects.

The use of solar dryers has become a necessity. These devices are capable of converting solar radiation into heat in order to carry out the drying process. Several works have been published to study the performance of some devices for drying fishery products, as well as the conditions in it. Among them we can list, Bala et al which designed a solar tunnel dryer for 150 kg of fishes, the air temperature varies between 35.1°C and 52.2 °C, and the drying of salted fish is done in 5 days from a humidity of 67% to a final humidity of 16.78% [4]. In Surajudeen et al 2018, the direct solar forced convection dryer was developed for tilapia and catfish, they obtained a thermal efficiency of 74.3% in the dry season. The final humidity obtained is 13.97% for catfish and 13.35% for tilapia [5]. When developing the solar forced convection fish dryer in kamolafe et al, it was provided a power of 900W and a ventilation speed of 180 rpm to obtain a maximum chamber temperature of 110°C [6]. Lamsyehe et al 2020, use an indirect dryer for the drying of anchovies and it found an optimal value of water activity for the conservation of anchovies of $a_w = 0.3$ [7]. Bahammou et al 2019 made the valorisation of sardine waste co-products by physical treatment under natural and forced convection solar drying [8]. They concluded that increasing the drying air temperature and flow rate, reduces the moisture content of the sardine heads in this dryer. Mehta et al 2018 studied the performance of a solar fish dryer, the average collector outlet temperature during the experimental period is 75°C and its efficiency is 25.42% [9].

Besides this work other authors have also developed tunnel dryers for other products. We can mention products such as: meat [10], mint leaves [11], ghost pepper and ginger [12]) and turmeric (Curcuma longa) [13].

However, these works did not study the behaviour of dryers according to climatic conditions, like in periods of clear sky, cloudy sky and rainy weather. But also, they did not evaluate the contribution of the drying cabin in the thermal performance of the dryer. Our model is a mixed tunnel dryer consisting of a collector and a trapezoidal shaped drying cabin.

The objective of this work is:

-To design and manufacture a solar dryer for fishery products.

- to study the performances of this dryer.

- to study the behaviour of fish during the process.

2. Dryer Design

Most of the dryers that are manufactured are often intended for agri-food products or medicinal herbs. On the other hand, for fish products, the dryers found are unsuitable or have been designed without taking into account the various drying parameters. To build our model we will assign it well defined objectives:

- The drying of the Products must be uniform.
- Quality and texture must be preserved.
- The Products must be protected from dust, from flies and insects …
- Drying must be fast enough to prevent germination or mold formation.
- The dryer must be robust, made of durable materials.

The design of a dryer is based on the knowledge, on the one hand, of the biological constraints of the product concerned. and, on the other hand, of the laws governing the drying process, namely thermodynamics and fluid mechanics [14].

2.1. Characteristics of the dryer

We have manufactured a mixed solar dryer; this dryer is of tunnel type made up of three parts:

- A 50Wc, 12-volt photovoltaic module will be use to operate two 12 volts 1.3 A fans.
- A collector with a surface area of 1.5m², which heats the air taken in as a drying gas.
- A drying cabin of 2m² with four trays at the same level of 0.5m² each.

2.2. Operation of the dryer

Our dryer will use only one source of energy, namely solar energy, and will operate as follows (Fig. 1): First, the photovoltaic module will rotate the fans that will send air to the collector. However, here switches are placed between the module and the fans to be able to control the ventilation. Then the air reaches the absorber where it will be heated before going to the drying cabin. Finally, the air is conveyed in the drying cabin and will be used to dry the product, before exiting through the openings of the dryer.

The cover of drying cabin being made of glass, will let the solar irradiance pass inside, causing a greenhouse effect inside, which will contribute to increase the temperature inside the dryer.

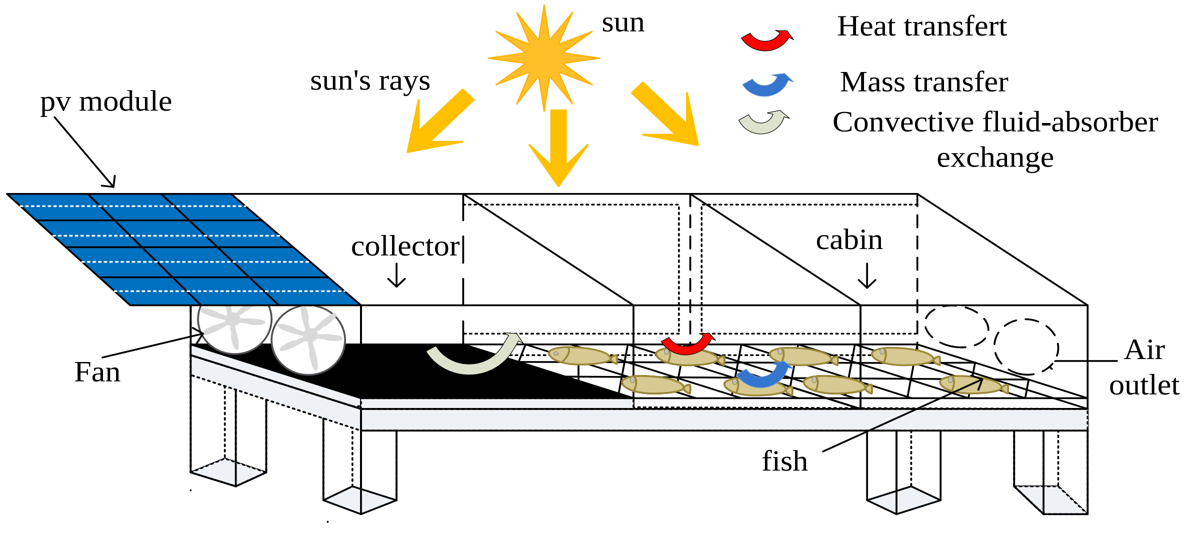


Figure 1: Diagram of dryer operation

2.3. Manufacturing Materials

We will use for the manufacture of our dryer the following elements:

Polyurethane plates: These are aluminum plates insulated with polyurethane. They are used as an absorber and as an insulator.

Glass: It represents the cover of the dryer and the collector.
Rectangular tube: They are used for the support of the dryer and the frame.
Black steel sheet 12/10: for the connections and assembly of the parts.
Fishing net: It is used as a drying support on the trays.
Aluminum profiler: For the frame of the trays.

Table 1: Materials Characteristics

Designation	Conductivity (W/mK)	Thickness
polyurethane	0.23	4cm
Glass	1	6mm
Black sheet steel 12/10	50.2	1.5 mm
aluminum	205	1mm

3. Experimental Study

3.1 Experimental device

- Solar dryer

We have a mixed tunnel dryer consisting of a photovoltaic module, a collector and the drying cabin (fig 2). The solar radiation arriving at the surface of the dryer is converted, at the module level into electricity to operate the fans, and heat in the collector and drying cabin.

Figure 2: Solar dryer

- Solarimeter**:** Measurement of irradiance

Characteristic: Model: PYR 1307 Range: 0 to 1999W/m² Accuracy: 5%

- Thermochons**:** these are button-sized stainless-steel devices that can be placed directly in your test environment without the need for external probes.

Characteristic: Model: DS1922T Range: 0 to 125°C Accuracy: 0.5°C to 0.0625°C

- Digital thermometer: for measuring room temperature

Characteristic: Model: checktemp Range: -30 to 120°C Accuracy: 0.3°C
Anemometer: For air velocity measurement
Characteristic: Model: XINTESTHT-9819 range: 0.40-30m/s Accuracy: 3%

- Precision balance : for sample weighing

Characteristic: Model: CX 265 range: 0 to 60g Accuracy: 0.01mg

3.2. Experimental Procedure

The tests were carried out at the CERER (Centre for Studies and Research on Renewable Energies) in Dakar latitude 14.72 - longitude -17°.44, between February 2019 and January 2020. The dryer was tested under three drying conditions: in periods of low sunshine when the sky is cloudy, in periods of high sunshine when the sky is clear and in rainy weather. Temperatures were measured using temperature sensors called thermochrons, which record at regular intervals the temperature of the objects they come into contact with. They were placed on the different walls of the dryer, on the absorber side and on the cabin side. The same applies to the air inlet and outlet of the drying cabin. Further sensors were placed on the products on the four drying trays of the dryer to determine their temperature during the drying process. Thermometers and a solarimeter were used to collect the climatic data of the place. Measurements were taken at 30-minute intervals between 9 am and 6 pm. Drying operations were carried out on fish and other products such as mango leaves and moringa leaves. Regular weighing of the mass losses was carried out using a precision digital balance. At the end of the drying process, the samples were placed in an oven at 105°C for 24 hours to determine the anhydrous mass.

3.3. Drying Performance Study

Testing a dryer allows it to be evaluated and compared with other existing dryers, but also to predict the performance of the dryer under conditions different from that of the test [15]. Several criteria are studied to evaluate the dryers. Among them are: thermal performance, [16-18], evaporative capacity [19] and the specific rate of humidity extraction [20-21].

3.3.1. Useful thermal energy

The useful thermal energy is determined by measuring the inlet and outlet air temperature of the collector as well as the air flow rate through the collector. The useful thermal energy is defined by equation (1,2,3) [22-25].
The useful thermal energy of the collector is given by equation (1).

$$\phi_{cap} = \dot{m} c_p (T_f - T_e) \tag{1}$$

Where: $\dot{m}$ air mass flow rate, c_p heat capacity, T_f temperature of the fluid at the collector outlet T_e temperature of the fluid at collector inlet

The useful thermal energy of the drying cabin is given by equation (2).

$$\phi_{cab} = \dot{m} c_p (T_s - T_f) \tag{2}$$

T_s : temperature of the fluid at the dryer outlet

Thus, the total useful thermal energy of the dryer is the sum of that provided by the collector (eq 1) and the drying cabin (eq 2).

$$\phi_s = \phi_{cap} + \phi_{cab} \tag{3}$$

With ϕ_{cap} useful thermal energy of collector and ϕ_{cab} useful thermal energy of the drying cabin

3.3.2. Collector thermal efficiency

The efficiency of a collector depends on several factors such as the collector area, the climatic conditions at the site and the air speed inside the dryer[26].The thermal efficiency of this collector is given by equation (4)[27],[28].

$$\eta_{th} = \frac{\dot{m} c_p (T_f - T_e)}{G S_c} \tag{4}$$

With G the irradiance and Sc the collector area

3.3.3. Drying performance

The output of the dryer allows us to determine the quantity of water extracted from the product in the dryer for a period t [29-30], it is defined by equation (5).

$$\eta_s = \frac{M_e L_v}{G S_c + P_n} \qquad (5)$$

Where: M_e the mass of water to be evaporated, Lv the latent heat of vaporisations, Sc the collector area and Pn the power of the fans.

3.3.4. Specific Moisture Extraction Rate (SMER)

This is an index which evaluates the drying efficiency, and is described as the ratio between the moisture content of the product removed during the drying process and the total energy received on the dryer [31].

$$SMER = \frac{m_i - m_f}{E_T} \qquad (6)$$

with m_i the initial mass, m_f the final mass and E_T the total energy received on the dryer

3.4. Determination of moisture content

The mass losses on the product at a time t shall be determined by successive weighing of the mass of the product at time intervals of 1 hour, until reaching a steady mass. Thus, the product after drying is placed in an oven at a temperature of 105°C for 24 hours to determine the anhydrous mass [8].

The moisture in an instant t, in dry basis is given by equation(7) [31].

$$H(t) = \frac{m_t - m_s}{m_s} \qquad (7)$$

Where m_t is the mass of sample at any time t and m_s is the anhydrous mass.

3.4. Uncertainty analyzes

The uncertainties are calculated by considering the differential (variation) of the function (M) with respect to the different variables (x_i). The values of the different quantities x_i were obtained by statistical averaging over a number of repeated measurements. The general formula for the uncertainty is given by equation (8) [21, 28-30, 32, 34].

$$\delta M = \left[\sum_{i=1}^{N} \left(\frac{\partial M}{\partial x_i} . \delta x_i \right)^2 \right]^{1/2} \qquad (8)$$

With δ the uncertainty

Uncertainty of moisture content is given by equation (9).

$$\delta H = \sqrt{\left(\frac{\partial H}{\partial m_i} \delta m_i \right)^2 + 2 \left(\frac{\partial H}{\partial m_s} \delta m_s \right)^2} \qquad (9)$$

Uncertainty of Collector thermal efficiency is given by equation (10).

$$\delta \eta_{th} = \sqrt{\left(\frac{\partial \eta_{th}}{\partial \dot{m}} \delta \dot{m} \right)^2 + \left(\frac{\partial \eta_{th}}{\partial T} \delta T \right)^2 + \left(\frac{\partial \eta_{th}}{\partial G} \delta G \right)^2} \qquad (10)$$

Uncertainty of Specific Moisture Extraction Rateis given by equation (11).

$$\delta (SMER) = \sqrt{\left(\frac{\partial (SMER)}{\partial m_i} \delta m_i \right)^2 + \left(\frac{\partial (SMER)}{\partial m_f} \delta m_f \right)^2 + \left(\frac{\partial (SMER)}{\partial E_T} \delta E_T \right)^2} \qquad (11)$$

Uncertainty of drying performance is given by equation (12).

$$\delta\eta_s = \sqrt{\left(\frac{\partial\eta_s}{\partial M_e}\delta M_e\right)^2 + \left(\frac{\partial\eta_s}{\partial G}\delta G\right)^2} \tag{12}$$

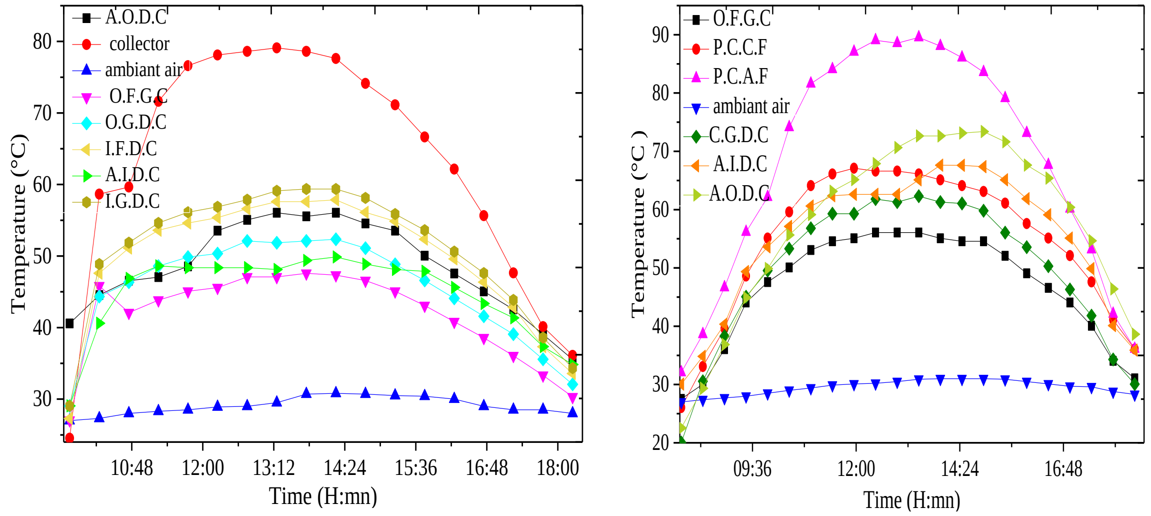
The maximum values of the uncertainties of the different parameters above are represented in the table 2.

Table 2: Uncertainty on the various performance criteria

Parameters	**Uncertainty**
moisture content %	±0.006
Specific Moisture Extraction Rate (SMER) kg water/kw h	±0.14
Collector thermal efficiency %	±2.6
Drying performance %	±1.8

4. Results and Discussions

We observed the behavior of the dryer over two days in sunny wheater (Fig. 3), for an irradiance varying between 150 W/m² at 8H-10min and 880 W/m² at 12H-45min, for a wind speed varying between 2.7 and 5.55 m/s. In the morning, the temperatures of the different elements of the dryer are low. They increase with the increase of the solar radiation. Until reaching a maximum around noon, before going down in the evening with the decrease of solar radiation. It can be seen that the fans have a great influence on the cooling of the collector. So, the higher the flow rate, the more the collector cools down. The temperature of the air inside the cabin during the day reaches 70°C when both fans are running (figure a), and 60°C when one is stopped (figure b). In natural convection when both fans are off, it reaches 50 °C. At the collector the cooling takes place in several stages. The part of the collector closest to the fans at lower temperatures than this is on the other side of the collector. This is because the heat transfer medium is charged with heat, as it flows through the collector. However, at the inlet side, the exchange is higher due to the considerable temperature difference between the air and the absorber. As the fluid progresses, this gap narrows and exchanges become less important. The temperature recorded at the cover reveals a small difference between the two parts of the dryer. The average daily temperature of the cover on the collector side is lower (Tm= 47.97 °C) than the average daily temperature on the cabin side (Tm = 50.5 °C). This difference is observed between the inner side of the glasscover, with the lowest temperature (Tm=41.07 °C) and the outer side of the glass cover with the highest temperature (Tm=44.5 °C).



(a) (sunny 1) (b)(sunny 2)

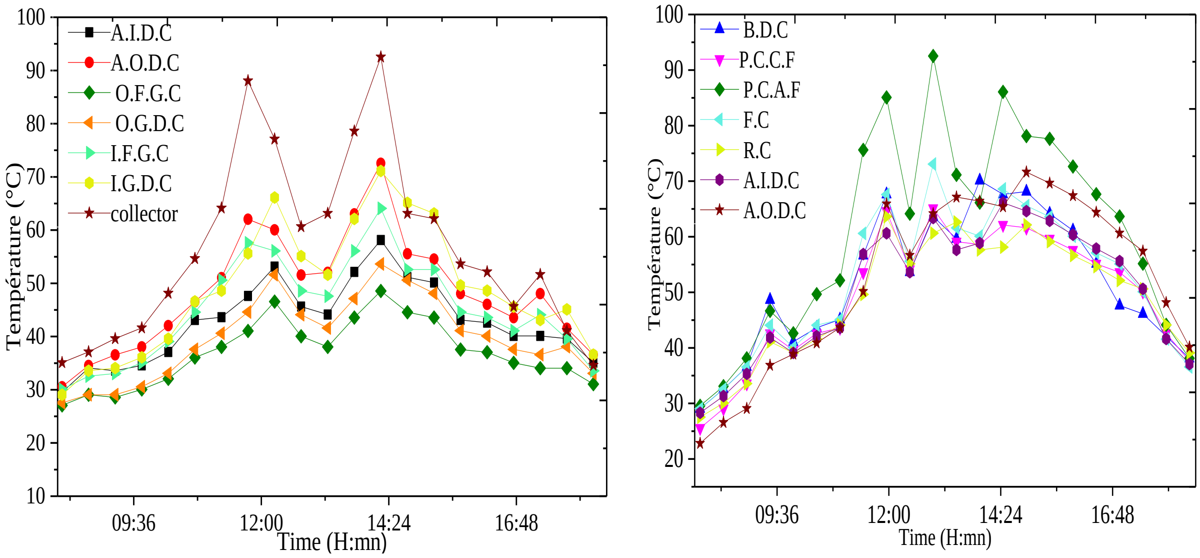
Figure 3: Temperature variation of the different elements of the vacuum dryer (sunny)

The behavior of the dryer during two different climatic conditions, namely during rainy periods and when the sky is cloudy, is shown in Fig. 4. The same temperature variations are observed on the different walls of the dryer as in Fig. 3. By differentiating the average daily air temperature inside the dryer, in clear sky (Fig. 3) and in cloudy sky (Fig. 4a; Fig. 4b), we obtain a maximum deviation of 10 °C. The average air temperature obtained is about 47 °C, for the days in Fig. 4.a and Fig. 4.b. This is well within the acceptable temperature ranges for drying fish [2], so drying in cloudy weather does not necessarily require auxiliary energy.

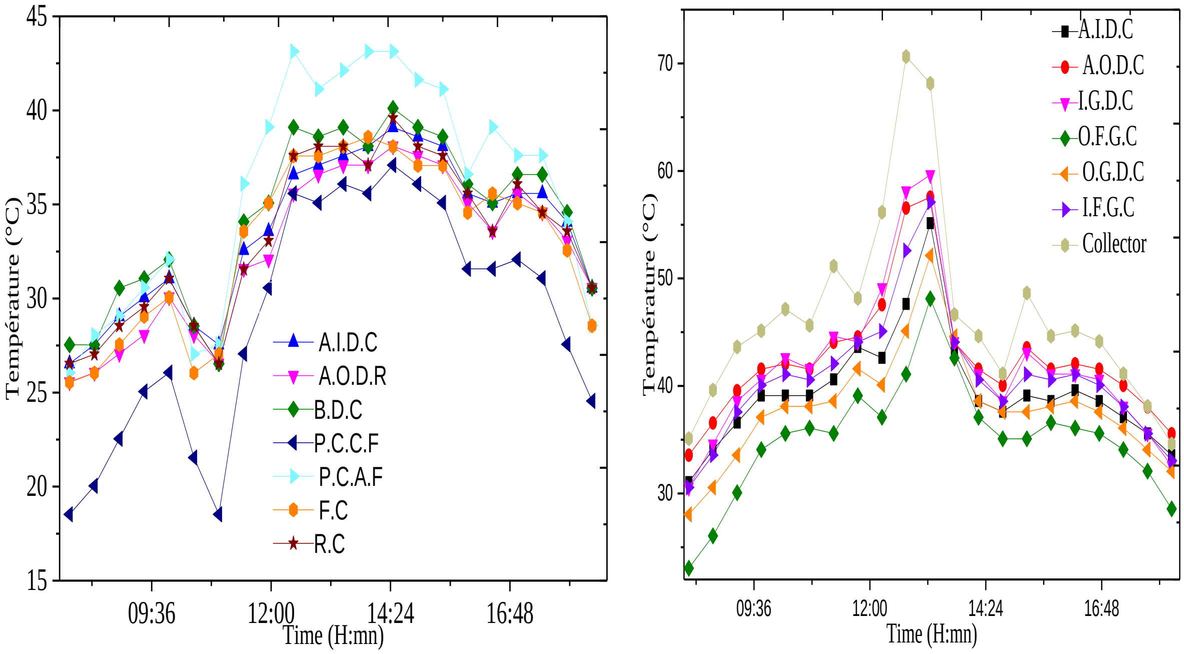
On the other hand, in rainy weather (Fig.4c; Fig.4d), the maximum temperature reached is 37 °C (Fig.4d), with a daily average of 29 °C. This temperature is low to dry the products, so auxiliary energy will have to be used.

The collector has a trapezoidal shape, which in addition to the bottom, has identical side walls to thisone. These walls have high temperatures that contribute to the heating of the drying air (Fig.4b, Fig.4c). For more efficiency on the collector, it would be more judicious to put stops at the outlet of the collector. This will allow the fluid to spend more time in, and benefit from the energy supplied by the bottom and side walls of the collector.

In Figures 4a, 4b and 4d, we see a temperature difference between the inside and outside, and between the absorber side and the side of the drying cabin. These results illustrate perfectly the exchanges of the cover with the inside of the dryer and with the outside environment. This results in a higher temperature on the inner side than on the outer side. But also, the difference in colour between the absorber in black and the cabin in white, favoured the reflections of the solar flux towards the cover on the cabin side, which results in a higher temperature of the latter.



(a) (cloudy 1) (b) (cloudy 2)



(c) (rainy 1) (d) (rainy 2)

Figure 4: Behavior under different weather conditions (cloudy and rainy skies)

The behavior of the air during the drying process between the ambient and the inside of the dryer is shown in Table 3. We observe an increase in the temperature of the ambient air at the crossing of the collector and the cabin, for the different climatic conditions. This temperature is maximum for clear sky periods, when the solar radiation is optimal and minimal for rainy periods when solar radiation is low. The Average temperatures during clear and cloudy skies in the drying cabin range from 48°C to 57°C. During the rainy period, the temperature of the air in the dryer is higher than the ambient temperature, which allows the temperature of the product to be maintained during the rainy period.

Table 3: Change in air temperature in the dryer

Days	**Ambient average temperature (°C)**	**Collector output average temperature (°C)**	**Drying cabin output average temperature (°C)**	**Average irradiance (W/m²)**
(sunny 2)	33.2	55.043	57.35	674.18
(sunny 1)	29.3	44.01	47.42	628.79
(cloudy 2)	32.8	50.42	52.45	642.37
(cloudy 1)	30.23	46.50	48.31	620.02
(rainy 2)	28	33.14	29.66	198.43
(rainy 1)	29.6	39.82	42.528	330.02

4.1. Thermal performance of the dryer

The temperature sensors placed at the inlet and outlet of the collector, at the inlet above and below the trays, at the outlet of the drying cabinet above and below the trays, gave the results following (Fig. 5). The average of the input and output temperatures is used to calculate the thermal useful energy given by equation (3). The output useful energy of the collector increases with solar radiation, but decreases at a slower rate than this. In fact, the thermal insulation of the dryer keeps this high useful energy for a few hours [17]. The contribution of the drying cabin is non-existent at the beginning, and becomes significant when the radiation reaches 300 W/m². It increases to a maximum at around 13:30 p.m, when the radiation is maximal. Before disappearing in the evening, when the solar flux is less than 300 W/m².

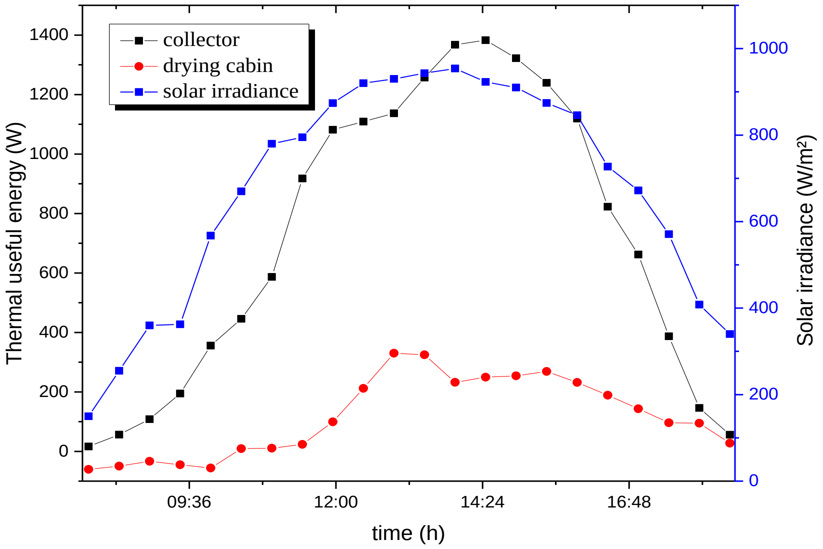


Figure 5: Variation of useful thermal energy and irradiance

The thermal efficiency of the dryer, more precisely that of the collector and the drying cabin, was studied for several months (figure 6). First of all, we have high efficiency days such as the days of(sunny1) and (sunny2). These are days with clear skies, for 10 hours of sunshine received on the dryer. Followed by the days of (claudy1) and (claudy2), with high average conversion yields. These are cloudy days with 8 to 9 hours of sunshine per day. Finally, the days of (rainy 1) and (rainy 2) which are days with low yields. These are rainy days with respectively 4 hours and 2 hours of sunshine per day. The thermal conversion efficiency at the collector is higher. It varies between a minimum of 17% (rainy 1) in rainy weather and a maximum of 60% (sunny 2) in sunny periods. The heat conversion efficiency in the drying cabin is lower. It varies between 0% in rainy weather and 5.7% in sunny periods.

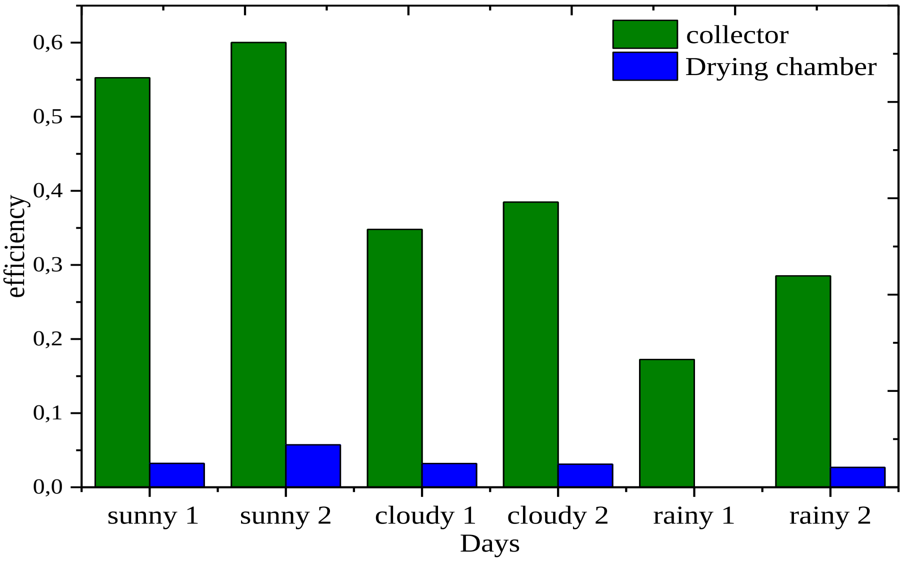


Figure 6: Variation in dryer performance for climatic conditions

4.2. Drying performance

Temperature probes ’’thermochrons’’ are placed on the fish samples on the four drying trays of the dryer. These sensors record the temperature changes of the fish inside the dryer at 30-minute intervals, as shown in Figure 7. The temperature is uniformly distributed over all the trays. This is facilitated by the ease of air circulation on the dryers. Nevertheless, there is a small difference in the temperatures of the products during the hot periods of the day between 12 and 15p.m.This is due to the fact, that the products receive input from the drying cabin, which is subject to the fluctuation of solar radiation. The samples on trays 3 and 4 at the end of the drying cabin, have a higher temperature than those on trays 1 and 2 at the outlet of the collector. This is due to the fact that the drying cabin converts solar radiation into heat, which allows to have a high temperature at the exit of the drying cabin. Tray 1 and 3 are closer to the glass. This therefore causes these temperature peaks but does not affect the uniformity of drying of all products in the dryer.

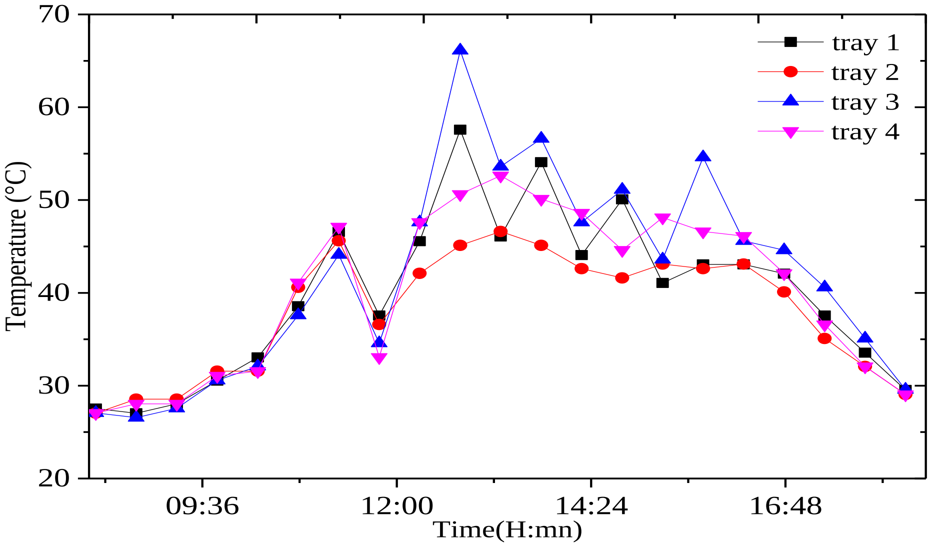


Figure 7: Change in fish temperature according to the position on the drying tray

4.3. Change in moisture content of products according to position and time

The drying of the fish in the dryer is studied for an average irradiance IR=592.76 W/m², and an average drying temperature Ts=49.5°C. The drying took place in 16 hours, from an initial moisture content of 66% to a final moisture content of 32% wet basis. The variation in fish moisture on each tray is shown in Fig.8.We find uniform mass loss on all samples, on all four trays in the drying cabin. This has led to almost the same final content, and therefore uniform drying of all products in the dryer. By comparing the samples by tray, we can see that the samples of tray 3 and 4 have greater mass losses than those of trays 1 and 2. This is explained by the high temperatures recorded on these trays. For even drying, it is better to place the thick products on trays 3 and 4 and the less thick products on trays 1 and 2.

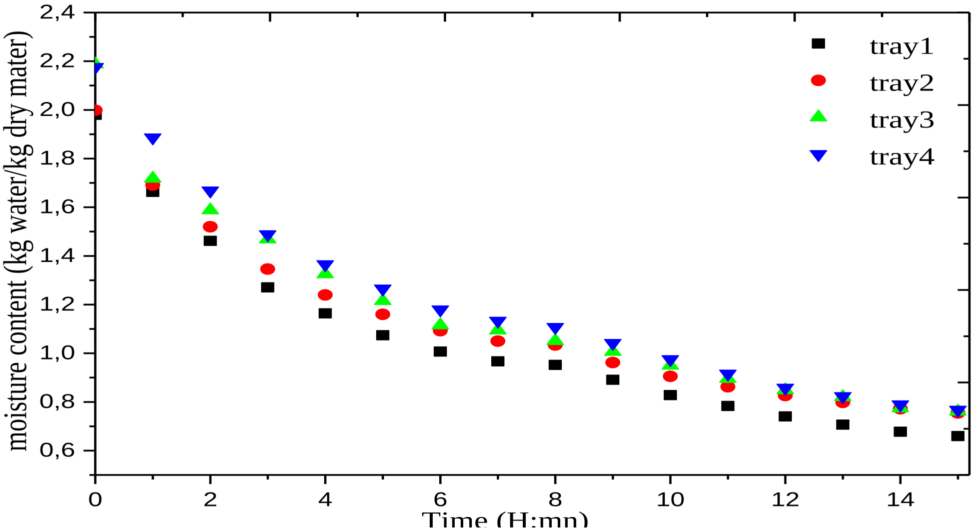


Figure 8: Variation in moisture content of the product

4.4. Comparison between the two drying methods

The difference between drying in the dryer and drying in the open air is shown in Figure 9. It Marks, a notorious difference between these two modes of drying. Drying in the dryer is changing faster than drying in the open air. this has an impact on the drying time, which is 16 hours for the dryer and 24 hours for drying in the open air [33]. Drying takes two and three days respectively, with stops at night.

After eight hours of drying, the drying process is stopped and resumed the next day. It can be seen that in the evening before drying stops, the moisture content of the product in the dryer does not change. While that of the product dried in the open air increased slightly. Because of the increase in the relative humidity of the air in evening. Same as the next morning even if the products are protected with the covering techniques used by the local transformers to prevent rewetting.

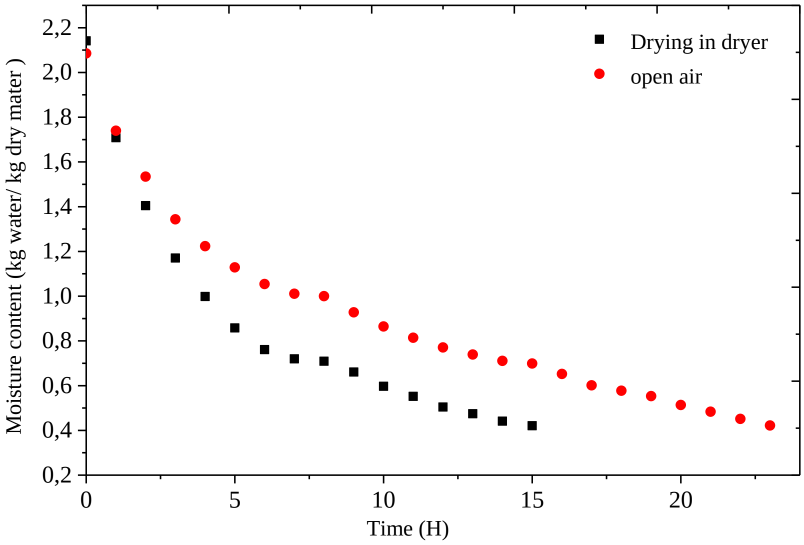


Figure 9: Comparative curve between drying in open air and in dryer

4.5. Evaluation of the specific moisture extraction rate (SMER)

We tried to test the dryer using three different products in order to find out its drying performance. The three products used were moringa leaves, mango leaves and lean fish.

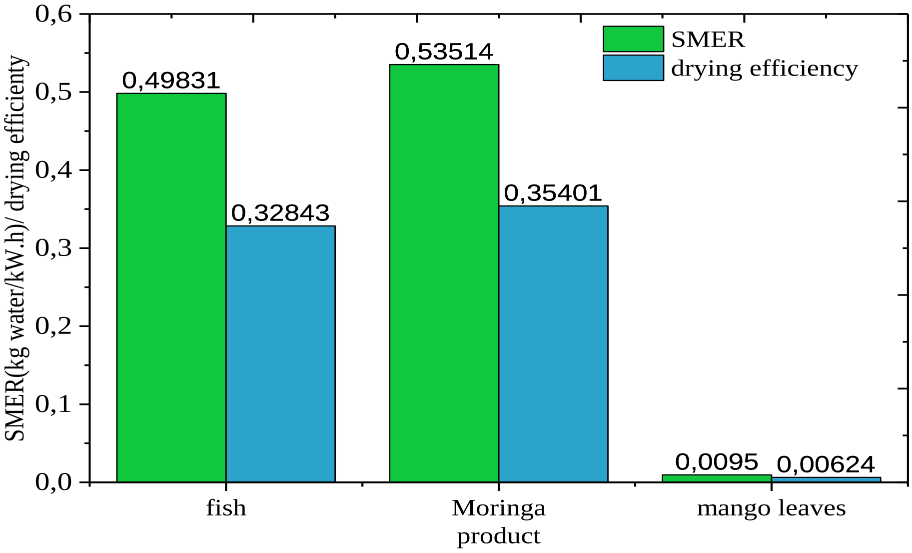


Figure 10: Change in drying performance

The results obtained showed that the performance of the dryer is higher when drying moringa leaves and fish. This translates into a SMER of 0.53 and 0.49 kg water/kW.h respectively and yields of 35% and 32% respectively. On the other hand, for mango leaf drying, performance is low, with a SMER of 0.0095 kg of water/kW.h and a yield of 0.6%. This is due to the fact that for the first two products the content is high and drying is easy. The third product has a low content because it is a pre-dried product. It can be said that the efficiency of the dryer depends on the nature of the product to be dried.

This also shows that the dryer is suitable for several types of products. It has the capacity to use the energy supplied by the collector, and at the same time, the energy supplied by the drying cabin. This gives it a considerable advantage for drying products where direct radiation does not affect the quality.

A comparative study of this work with previous work on solar dryers is carried out. This study is based on the main criteria for evaluating the performance of solar dryers. These criteria are: SMER, collector thermal conversion efficiency and drying efficiency, shown in Table 4. We find that despite the average climatic conditions recorded during the drying process, the dryer has performances that are close to the other systems [17] and even superior to its systems [12, 26].

Table 4: Comparison of this study with other studies

Author	**Type**	**Characteristics**	**Thermal Efficiency of the collector**	**Drying performance**	**SMER**
Present Study	Tunnel mixed solar dryer	Product:fish Mass= 20kg Time=16 h T drying :49,5°C	44.8%	32.84%	0.49
[17]	IFCSD	Product: Mango Mass: 24 kg Time: 13 h T drying : 52°C	53.5%	33.8%	1.67
[12]	Forced convection solartunnel dryer	Product: Ginger Mass: 13 kg Time: 33 h *T* drying : 37-57°C	23.30%	8.50%	0.113
[26]	Indirect Solar dryer	Product: banana Mass: 2kg Time: 10 h T drying : 44-55°C	31.50%	22.38%	

5. Conclusion

In this work, a solar dryer was developed to provide a solution to the issues related to the raised trays used by women in the fish processing areas. This dryer is a mixed solar tunnel with forced convection consisting of a photovoltaic module, a collector and a drying cabin.

It has been tested under different climatic conditions; clear sky, cloudy sky and rainy weather. The results obtained during the tests showed that the sunny and cloudy days are the most favourable for drying. The heat yields recorded at the collector are 60% on sunny days, 55% on cloudy days and 28% in rainy weather. At the drying cabin, the thermal conversion is 5% on sunny and cloudy days, and none on rainy days.

The capacity of the dryer is 20 kg of fish. With an average sunshine duration of 8 hours per day, drying takes place in 16 hours, i.e. two days. The fish is dried from an initial moisture content of 66% to a final moisture content of 30%. The SMER obtained under average sunlight conditions of 592.76 W/m² is 0.49kg water/kW.h and the drying yield is 32.84%. The temperature distribution within the products as well as the variation in moisture content evolved uniformly on all drying trays. The results showed that our system has much better performance than the other studied systems. In order to increase the performance of the dryer, other modifications could be made, either by reducing the air outlet at thecollector, or by intégration a make-up energy system into the dryer. We will also be able to study the exergy of the system and make an economic analysis of the dryer.

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