



Development and Preliminary Analysis of a Solar Dryer for Flour Dehydration

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Until now, drying flour in full sunlight has been the technique most widely used in Burkina Faso. This method exposes the flour to numerous risks of poisoning, pollution, soiling and destruction of nutritional qualities. Despite this, there are very few documented solutions to the problem. This has prompted this work on the design and preliminary study of a solar dryer for drying flour. To this end, the design approach based on unfavourable periods was used to dimension the solar collector elements. The initial studies were carried out experimentally, starting with a no-load study and then

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a load study. As a result of this work, a two-in-one solar dryer was designed and built. It was able to heat the drying air to 65°C in unfavourable weather conditions. During drying, the temperature reached 58°C in forced convection. However, the average drying temperature was below the predefined drying temperature range (45-55°C). The drying speed was less than half that predicted. As a result, the drying time was 10 hours 20 minutes instead of the planned 4 hours. The water content lost through the flour reached 31.14% on rack 1, whereas it was assumed to be 25%.

Keywords: Solar dryer; flour; preliminary; design; drying rate and moisture content.

1. INTRODUCTION

Drying is one of the oldest operations instinctively applied whenever humans need to preserve a body that is initially moist for a long time. It is the oldest method of food preservation, as noted by Ojediran & Raji [1], N. Ahmed et al. [2], Harrison & Andress [3], Jayas [4]. At a distant stage of technological development, sun drying, referred to as traditional drying, and smoking were the most commonly used methods to obtain dry products [5]. Although sun drying is less expensive, it is not well-suited to agri-food products. Several studies have easily demonstrated this [6]. Smoking, which adapts only to a limited number of food products, is also very energy-intensive, as it requires temperatures above 85 °C [7] and takes a long time. The advent of dryers has redistributed the roles in the drying of agricultural products. A significant number of drying technologies have been developed, as evidenced by their abundance in the scientific literature [8,9,10,11] etc. This is justified by the complexity of drying and the specific needs for energy, temperature, air renewal, relative humidity, and drying duration. For flour, Bassene et al., [12] and Aziz et al., [13] investigated the drying kinetics of flour pellets dried at 40°C, 50°C, 60°C by varying the drying air velocity from 1m/s to 2m/s through an air blower called a drying vein. They found that at 60°C and 2m/s the drying time was very short, equal to 30 minutes. They also noted the lack of thermal and constant speed phases. As their prototype is electric, there may be a problem of accessibility for rural areas that have no electricity.

In Burkina Faso, especially in rural areas, the staple food is Tô. A dish made from corn or millet flour (sorghum and small millet). However, for the vast majority of households, flour is still dried in the open air under the sun. This exposes it to dust, animals, insects, and potential contamination. Moreover, drying in the open air and under the sun may alter the nutritional quality of the products [14 and 15] including flour,

as the thermal conditions are uncontrolled and uncontrollable. Furthermore, Alam et al., [16] found that the loss due to sun drying paddy averages 3.1%, compared to only 0.39% for machine drying. Similarly, Roy et al., [17] reveal that the average loss from sun drying is $2.12\% \pm 1.24\%$ compared to the drying in the solar dryer S4S, which is only $0.41\% \pm 0.55\%$. Aware of these situations, some households attempt to dry their products indoors to avoid dust and protect against predators (poultry and animals). In this case, improper drying often occurs due to insufficient ventilation and/or excessive relative humidity of the drying air. Therefore, it is necessary to find an effective and accessible means for flour drying, as this concerns the health of the population. This has motivated the development and experimental analysis of a solar dryer specifically for flour.

To this end, a disadvantaged period approach has been adopted for the design calculations. That is to say, the period with low values of the central parameter, such as the thermal solar flux in the present study. After construction, the dryer was first tested empty to evaluate its capacity to heat the air, and then under load to study the drying process.

2. MATERIALS AND METHODS

The equipment used is a "midi LOGGER GL220" datalogger, thermocouples (as used by Boukaré et al., [18]), a UNI-T UT330B IP67 hygrometer Fig. 1 (a) and an SF-550 electronic balance Fig. 1 (b).

2.1 Design Methodology and Construction

2.1.1 Calculation assumptions and hypotheses

The aim is to build a mobile solar dryer that takes up less space and is able to operate both during periods of favourable solar thermal flux and during periods of unfavourable solar thermal flux.



Fig. 1. (a) hygrometer and (b) electronic scales

Table 1. Design data

Parameters	Conditions
Location and latitude	12,2
Product	Corn flour
Capacity	10 kg
Density	0,49-0,56 g/ml
Maximum drying temperature	45-55°C
Initial moisture content	25 %*
Final moisture content	13 %
Thickness of flour layer	4 cm
Drying time	4 hours
Period	Except August
Ambient temperature	32°C
Incident solar irradiation	600W/m ²
Type of collector	Flat plate solar thermal collector
Tilt angle of solar collector	42,2°
Author of the dynamic vienne	5 cm
Type of absorber	Aluminium painted black
Absorber thickness	0,30 mm
Type of glass	Clair
Thickness of glass	5 mm
Type of insulation	No isolant
Number of racks	2 racks
Distance between racks	20 cm

With the exception of August, when there is too much cloud cover, the period of low solar thermal flux lasts from the end of November to mid-February of the following year. We therefore adopt the idea of 'two in one' by combining the solar collector and the drying chamber. The disadvantaged period approach is also used for the solar thermal flux. The food to be dried is grain flour (millet, sorghum, maize, wheat, rice, etc.).

The drying temperature will be between 45 and 55°C because the water contained in the flour is that of wetting, i.e. unbound water. It will not be

insulated for the simple reason that the 45-55°C drying temperature range is not very far from the ambient temperature, which often reaches 45°C in the shade. The other assumptions and considerations are set out in Table 1. The assumption of 4 hours as the drying time is motivated by the fact that the water in the flour is not bound water. It is wetting water and therefore easy to release.

2.1.2 The mass of water to be evaporated

It is the preferred generic model used by a large number of researchers [19,20,21,22,23].

$$M_w = W_p \times \frac{(M_i - M_f)}{(1 - M_f)} \quad (1)$$

W_p : product mass

M_w : mass of water to be evaporated

M_i : initial moisture content

M_f : final moisture content

$$M_w = 25 \times \frac{(0,25 - 0,13)}{(1 - 0,13)} \Rightarrow M_w = 3,45 \text{ kg}$$

2.1.3 Volume of drying air

The volume of drying air is calculated according to the model used by Forson et al., [24].

$$V_{air} = \frac{M_w \times L_t \times R_a \times T_a}{C_{p_{air}} \times P_{at} \times (T_c - T_f)} \text{ avec } T_f = T_a + 0,25\Delta T \quad (2)$$

with

$C_{p_{air}}$ the specific heat of the air (J/(kg K)).

R_a the perfect gas constant (J/(kg K)). Air is assumed here to be a perfect gas.

L_t is the latent heat of vaporisation.

T_a the ambient temperature

T_f air temperature at the outlet of the drying bed (°C)

T_c drying temperature (°C), P_{at} atmospheric pressure, (N/m²)

$$C_{p_{air}} = 1,005 \text{ kJ/kg}$$

$$L_t = 2257 \text{ kJ/kg}$$

$$V_{air} = \frac{M_w L_t R_a T_a}{C_{p_{air}} \times P_{at} \times (T_c - T_f)}$$

$$V_{air} = \frac{3,45 \times 2257 \times 0,287 \times 32}{1,0005 \times 101325 \times (55 - 36,39)}$$

$$V_{air} = \frac{71512,5936}{1895086,54125}$$

$$V_{air} = 0,0377357 \text{ m}^3 \cong 0,038 \text{ m}^3$$

2.1.4 Expression of air mass m_{air}

Knowing the volume of air V_{air} , we can deduce its mass by:

$$m_{air} = V_{air} \times \rho_{air} \quad (3)$$

ρ_{air} is the density of air. We use the one presented by Forson et al., [24] to find the air mass using the equation ...

$$m_{air} = \rho_{air} \times \frac{M_w \times L_t \times R_a \times T_a}{C_{p_{air}} \times P_{at} \times (T_c - T_f)} \quad (4)$$

2.1.5 Useful power transmitted by the solar collector to the heat transfer fluid

It is a function of the power of the solar radiation incident on the sensor and its optical properties.

$$P_u = S \times \varepsilon P_a \text{ avec } P_a = \alpha P_v \text{ et } P_v = \tau P_i \Rightarrow P_a = \alpha \tau P_i \Rightarrow P_u = S \times \varepsilon \alpha \tau P_i$$

P_u useful power (W)

P_a the power collected by the solar collector absorber (W/m²)

P_v the power transmitted by the glass (W/m²), P_i

the power or incident solar radiation (W/m²)

S the heat exchange surface or the surface of the solar collector (m²)

α the absorbtivity ε the emissivity and τ the transmittivity. The last three are adimensional numbers.

2.1.6 Incidence angle or tilt angle of the solar collector

The tilt angle (β) of the solar collector has been discussed by several authors, as pointed out by Stanciu & Stanciu [25]. Expressions of tilt angle as a function of latitude φ regularly encountered include: $10^\circ + \varphi$ [26], $\varphi \mp 15^\circ$ [27], $\varphi - 10^\circ$ [28], $0,917\varphi + 0,321$ [29], $\varphi + (10 \dots 30^\circ)$ [30].

To take account of the idea of "two in one", i.e. solar collector and drying chamber in one unit, and to optimise the drying surface area, we are forced to have a relatively high inclination. In this context, the model of Löff & Tybout, [30] will be chosen.

$$\beta = \varphi + 30^\circ = 12,2 + 30^\circ = 42,2^\circ$$

2.1.7 Heat of the drying air

The energy used to dry the flour is the energy received by raising the temperature of the drying air. It is therefore called useful energy and is expressed by the equation ...

$$E_u = m_{air} \times C_{p_{air}} (T_c - T_a) \quad (5)$$

With m_{air} en kg ; $C_{p_{air}}$ en J/kg °C ; $T_c = 55^\circ\text{C}$ et $T_a = 32^\circ\text{C}$

T_c is the collector or absorber temperature and T_a is the ambient temperature.

2.1.8 Solar radiation collection surface

By identifying the basic relationship of the unit of measurement of energy in the International System of Units (SI) ($E = P \times t$) with the useful energy received from the sun by the drying air, we deduce the surface area of capture (S) Eq (6).

$$P_u \times t = E_u \Leftrightarrow E_u = \varepsilon \alpha \tau P_i \times S \times t$$

$$\Rightarrow S = \frac{E_u}{\varepsilon \alpha \tau P_i \times t} = \frac{m_{air} \times C_{P_{air}} (T_c - T_a)}{\varepsilon \alpha \tau P_i \times t} \quad (6)$$

By replacing the mass of drying air m_{air} in (6):

$$S = \rho_{air} \times \frac{M_w \times L_t \times R_a \times T_a \times (T_c - T_a)}{\varepsilon \alpha \tau P_i \times P_a \times (T_c - T_f) \times t} \quad (7)$$

Like $T_f = T_a + 0,25\Delta T$ avec $\Delta T = 2\beta(T_b - T_s) \frac{P_i}{P_0}$

T_b =Boiling temperature and T_s = solidification temperature.

$$P_0 = 1367W/m^2 \quad \beta \in 0,14 - 0,25 \quad [24]$$

So S becomes:

$$S = \frac{\rho_{air} M_w L_t R_a (T_c - T_a)}{t \times \varepsilon \alpha \tau P_i (T_c - (T_a + 0,25 \times \Delta T))}$$

T_a = the ambient temperature of the drying room.

$$\Delta T = 2\beta(T_b - T_s) \frac{P_i}{P_0}$$

$$S = \frac{\rho_{air} M_w L_t R_a (T_c - T_a)}{t \times \varepsilon \alpha \tau P_i [T_c - T_a - 0,25 \times 2 \times 0,25 (T_b - T_s) \frac{P_i}{P_0}]}$$

P_i = overall power incident on a horizontal surface.

$$\rho_{air} = 1,29/m^3 \quad [20]$$

Numerical application

$$\Delta T = 2 \times 0,20 \times 100 \times \frac{600}{1361} = 17,5$$

$$\Delta T = 17,56^\circ C$$

$$\tau = 0,78$$

$$T_f = T_a + 0,25\Delta T = 32 + 0,25 \times 17,56 = 36,39^\circ C$$

$\varepsilon \in [0,86 - 91]$ We take 0.86, the most unfavourable

$$\alpha = 0,97$$

$$L_l = 2257kj/kg$$

$$S = \frac{1,29 \times 3,45 \times 2257 \times 10^3 \times 0,287 \times (55 - 32)}{4 \times 3600 \times 0,78 \times 0,86 \times 0,97 \times 600 (55 - 36,39)}$$

$$S = \frac{66.305.582,8785}{104622434,3104}$$

$$S = 0,63376 \cong 0,64m^2$$

2.1.9 Determining the dimensions of the flat plate collector

The flat-plate solar collector is rectangular in shape. Then we have:

$$S = L \times l \quad (8)$$

According to FORSON [31] quoted by Forson et al., [24] the ratio between the length of the solar collector and its width of 1.5 is recommended for optimal performance.

This means that

$$\frac{L}{l} = 1,5$$

$$L = 1,5 \times \frac{S}{L}$$

$$L = 1,5 \times \frac{S}{L} \Rightarrow L = \sqrt{1,5 \times S} \quad (9)$$

$$L = \sqrt{1,5 \times 0,64} = 0,98 m$$

$$L = 1m$$

$$l = \frac{0,64}{0,98} = 0,65306122 \cong 0,65m$$

$$l = 0,65m$$

2.1.10 Air change rate

The drying air flow rate is the ratio of its volume to the expected drying time.

$$Q_V = \frac{V_{air}}{t} \quad (10)$$

The desired drying time is 4 hours. $V_{air} = 0,038 m^3$

$$Q_v = \frac{0,038m^3}{4h} = 0.0095m^3 \cdot h^{-1}$$

2.1.11 Ventilation power

It is calculated using the formula:

$$P_v = \frac{1}{\eta_v} \frac{Q_v}{3600} \Delta P_t \quad (11)$$

With:

Q_V : required flow in m³/h;

η_v : Fan efficiency in accordance with supplier's specifications;

3600 : hour/second conversions;

ΔP_t total pressure drop in Pascals.

2.2 Drying Maize Flour Proceeding

2.2.1 Preparing the flour

The quality of the flour depends directly on the quality of the cereals used. So, to guarantee the best quality, a protocol for processing the cereal until the flour is obtained has been clearly defined. The cereal must undergo the following operations:

- winnowing and sorting: the quantity of cereal to be processed must be winnowed and sorted to remove all kinds of impurities (foreign bodies and mouldy grains);
- moistening: after winnowing and sorting, the grains are slightly moistened by suction to allow hulling;
- winnowing and sifting: this stage first removes the bran from the hulled grains, and then separates the grits from the coarse fraction of the flour;
- soaking (Fig. 2 (a)): the resulting product is then soaked in water for around 24 hours to make it easier to grind;
- draining/washing (Fig. 2 (b)): the wet product is drained using a plastic sieve or clean basket, then washed again with clean water;

- Grinding: the wet product is ground to obtain flour.

2.2.2 Moisture content and moisture ratio

The flour was spread out on a mat on each of the two racks, as shown at Fig. 3.

The flour on each rack was weighed at one-hour intervals, as shown in the diagram. The moisture content on a wet basis at each point in time was calculated using the following formula: as employed by Adelaja & Babatope [32].

$$X_t = \frac{m_i - m_t}{m_i} \times 100 \quad (12)$$

Avec: m_t the mass of flour at each moment, m_i the mass of wet flour and X_t the moisture content of the flour at each moment.

The moisture ratio is assessed using the model used by Sehrawat & Nema, 2018)

$$MR = \frac{m_t}{M_i} \quad (13)$$

2.2.3 Drying rate

The flour drying rate is evaluated by the Eq. (14) used in numerous works such as [32].

Average drying speed

$$DR = \frac{m_e}{t_s} \quad (14)$$

DR: drying rate (en kg/h);

t_s : drying time for the product in question (in hour).

m_e : mass of water to be extracted from the product (en kg).

The different flour masses are obtained by weighing as shown in Fig. 4.



Fig. 2. (a) Soaking (b) Draining

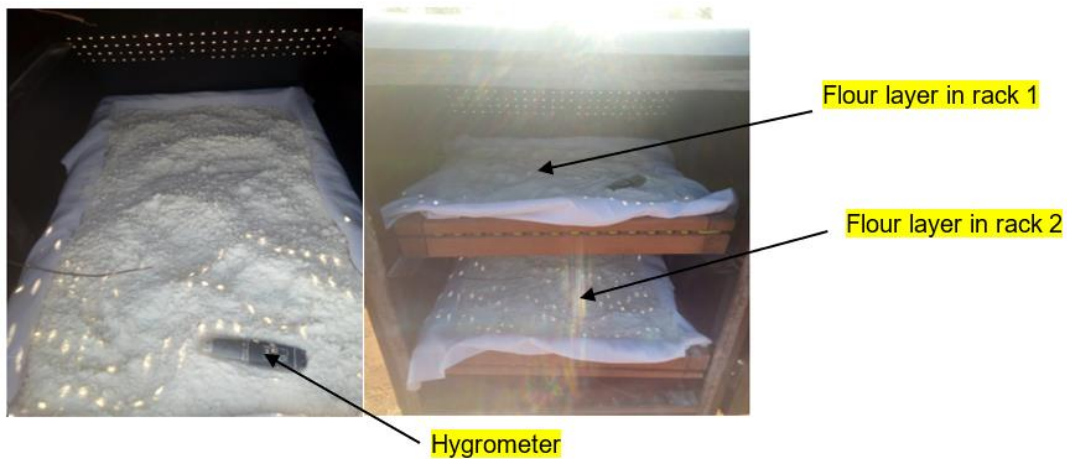


Fig. 3. Flour drying



Fig. 4. Weighing the flour

3. RESULTS AND DISCUSSION

3.1 Prototype Solar Dryer

The solar dryer designed (Fig. 5) and built (Fig. 6) consists of a flat solar collector, a drying chamber, a 24 cm chimney, supports and wheels. The solar collector consists of a surface that is transparent to the sun's rays: the pane, and an opaque surface: the absorber. In between is the dynamic pane. The absorber is pierced by two rows of holes (Fig. 6) corresponding to the entrance to each rack, to allow the drying air to pass over the layer of flour. The drying chamber is equipped with two shelves. They are 30 cm apart. The upper rack is 55 cm long and 50 cm wide and the lower rack is 87 cm long and 50 cm wide.

3.2 Temperature and Relative Humidity

3.2.1 No-load test

Before the drying operation, the dryer was tested empty and under natural convection to verify the temperature increase in the drying chamber. Three tests were conducted, and the results are presented in Figs. 7, 8, and 9. These tests took place on 25th and 29th November, as well as on 1st December 2023. It is observed that the temperature at the level of rack 1 is higher than that at the level of rack 2. This is due to the fact that the inlet of rack 2 is closer to the air inlet of the solar collector (Fig. 6). For test 1 (Fig. 7), the maximum temperature reached is 65.1 °C at 13:29. The minimum temperature recorded is 43.8 °C at 16:15, and the average temperature is

58.56 °C. On rack 2, the maximum, minimum, and average temperatures are 57.6 °C at 12:39, 40.8 °C, and 52.25 °C, respectively. During the second test (Fig. 8), rack 1 recorded a maximum temperature of 55.1 °C, a minimum temperature of 35.7 °C, and an average temperature of 48.67 °C. rack 2 recorded a maximum temperature of 51 °C, a minimum temperature of 32.7 °C, and an average temperature of 44.57 °C. For test 3 (Fig. 9), the recorded temperatures are 58.8 °C max, 35.1 °C min, and 51.01 °C on average for rack 1, and 55.2 °C max, 34 °C min, and an average of 48.46 °C for rack 2. The temperatures appear to

fall within the range of 45 to 55 °C recommended for flour drying. However, under forced convection, they might drop below this threshold, as they spend less time in the dynamic phase. It is also noted that the temperatures in the racks are significantly different from the ambient temperature, indicating that the heat transfer fluid is primarily heating up. Lingayat et al., [33] found similar temperature profiles and solar radiation, with peaks larger than ours. Similarly, Krabch et al., [34] observed the same pattern, but with maxima close to those in this study as they required low temperatures, as is the case in this work.

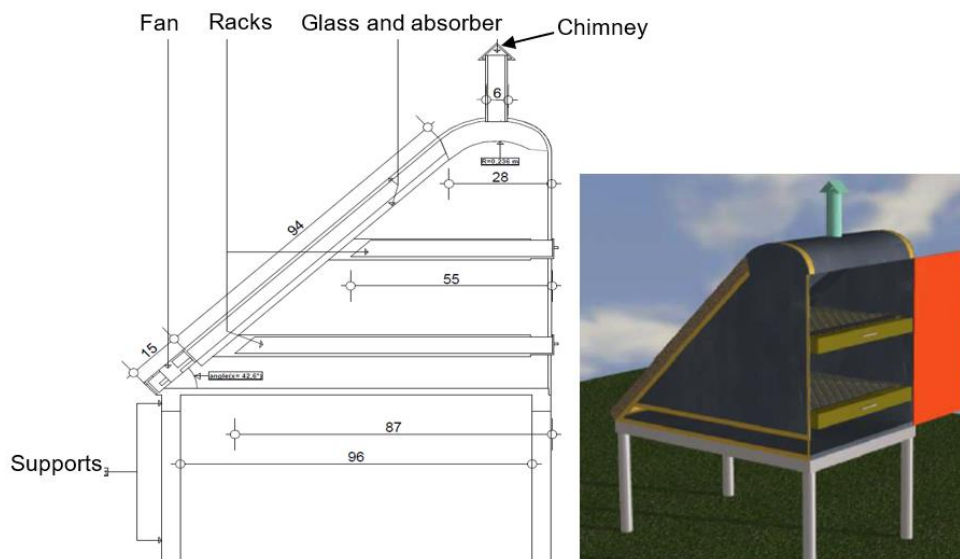


Fig. 5. Model of dryer designed



Fig. 6. Dryer built in instrumentation

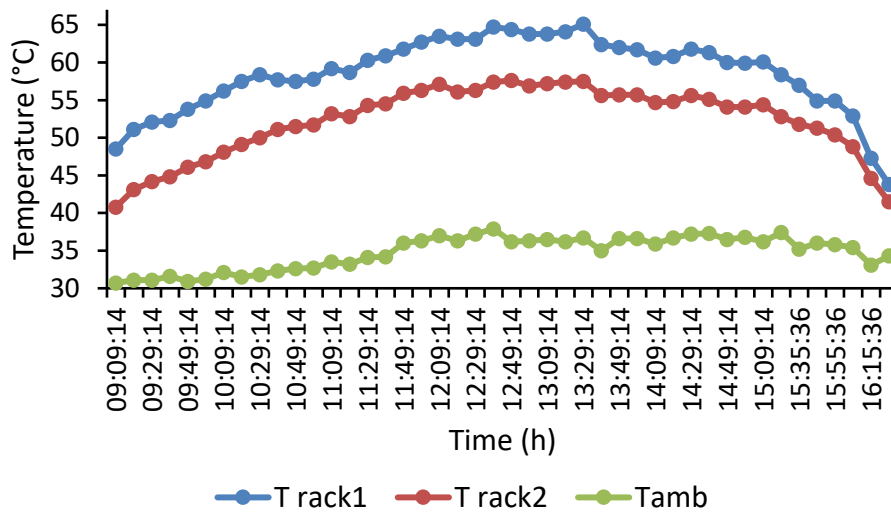


Fig. 7. Temperature changes in the drying chamber during the test1

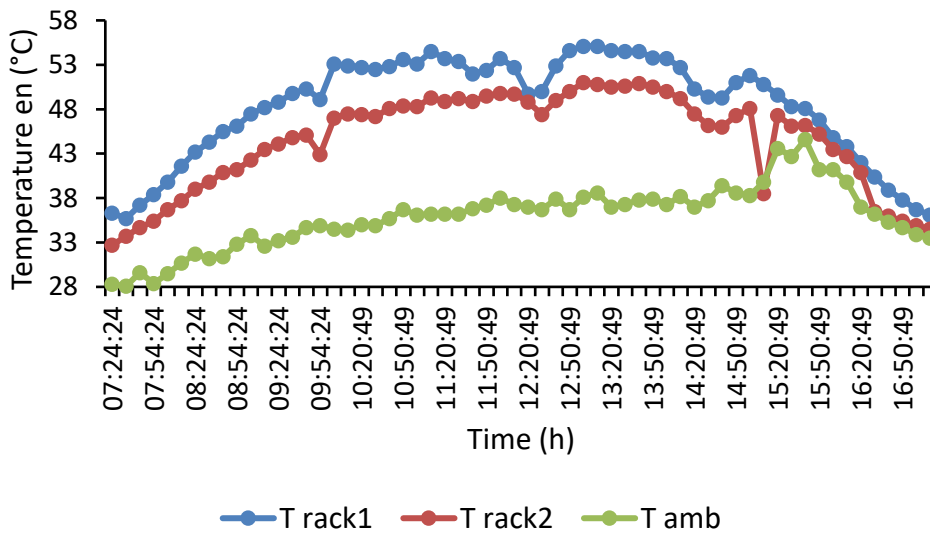


Fig. 8. Temperature variations in the drying chamber, test2

3.2.2 Laod test

The temperatures of the drying air in the racks during the drying operation are shown in Figs. 10 and 11 for the two tests respectively. Test 1 was carried out over two days: 27 and 28 November 2023. On the first day, it can be seen that the air was unable to heat up properly, as the average temperature was below 40°C. As a result, the test started late.

On the second day, the drying air in rack 1 heated up well, while that in rack 2 remained superimposed on the ambient temperature for most of the time (see Fig. 10). This indicates that

it did not heat up sufficiently. This could explain the long drying time (around 16 hours of discontinuous drying).

In test 2 (see Fig. 11), the temperature in rack 1 increased more effectively than in rack 2, with an average of 46.42°C and a peak of 53.2°C. However, it remains limited, as the required drying temperature range is between 45 and 55°C. It can still be seen that rack 2 has a temperature that is almost the same as, and at times even lower than, the ambient temperature. This could justify reducing the ventilation speed, as rack 2, located further away from the sensor air intake, has an average temperature close to

the lower limit of the drying temperature range. In addition, there is a volume of air below this rack (see Fig. 6), which could contribute to its cooling.

Drying depends not only on thermal conditions, but also on humidity and pressure parameters, which are measured to analyse hygrometric and barometric conditions. The results are shown in Fig. 12 and 13. Test 1 (Fig. 12) shows that on the first day of drying, the relative humidity, which was 79.5 %, fell to 49.4 % around 4 p.m. and rose again to 84.9 % at 7 p.m. during the night. This shows that the flour had become moist. This

could be due to the thermal inertia of the flour, which has stored the heat received, giving it a higher temperature than the air between 5 pm and 7 pm. This allows moisture to be transferred from the fresh air to the flour. It drops later in the night, perhaps as a result of uninterrupted forced convection. In the second test (Fig. 13), relative humidity and pressure decreased with drying time, indicating that water evaporation was decreasing. It should also be noted that Fig. 12 and 13 show that relative humidity falls at the time of maximum temperature, as found by Krabch et al., [34].

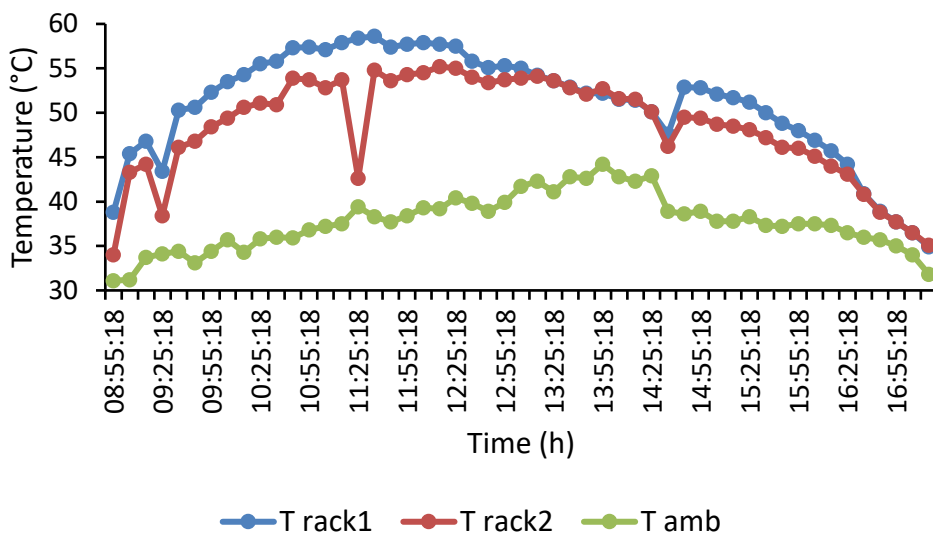


Fig. 9. Temperature trends in the drying chamber, test3

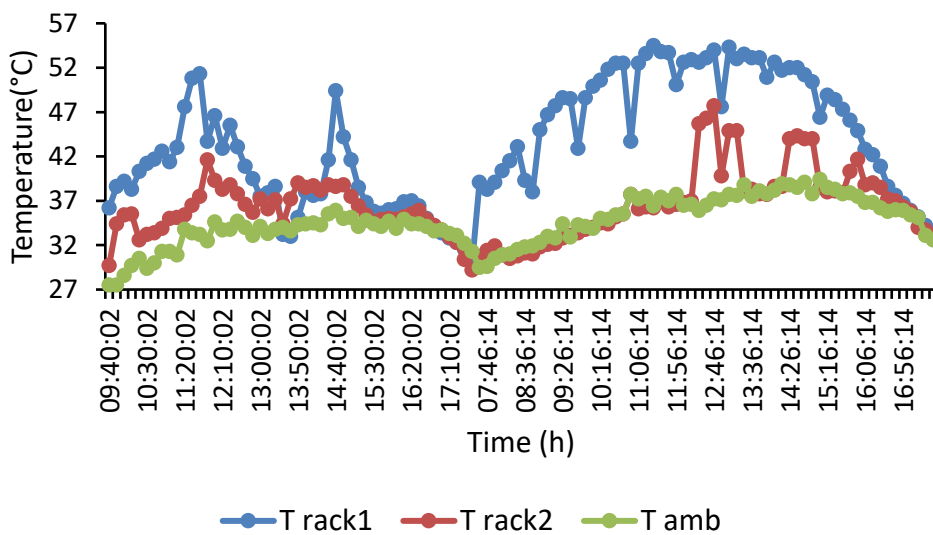


Fig. 10. Drying air temperatures in drying test1

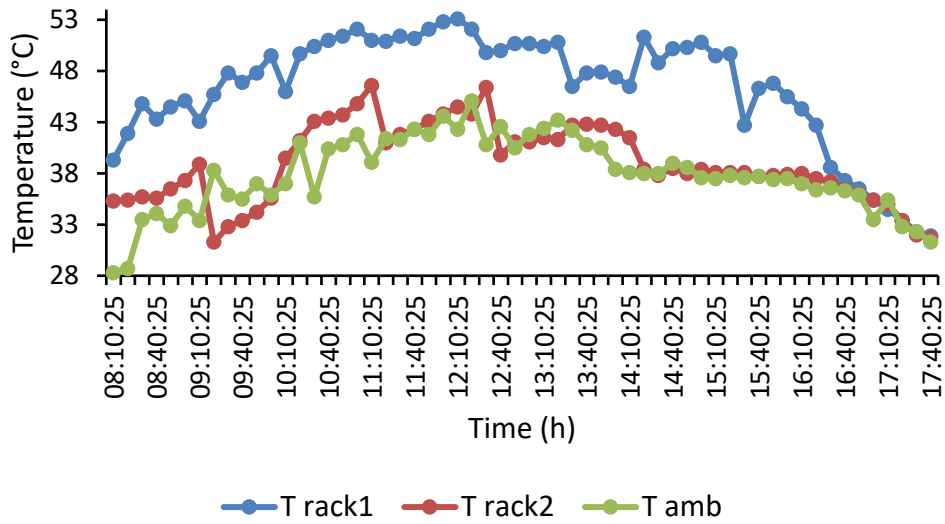


Fig. 11 Variation in drying air temperature at the Drying Test2

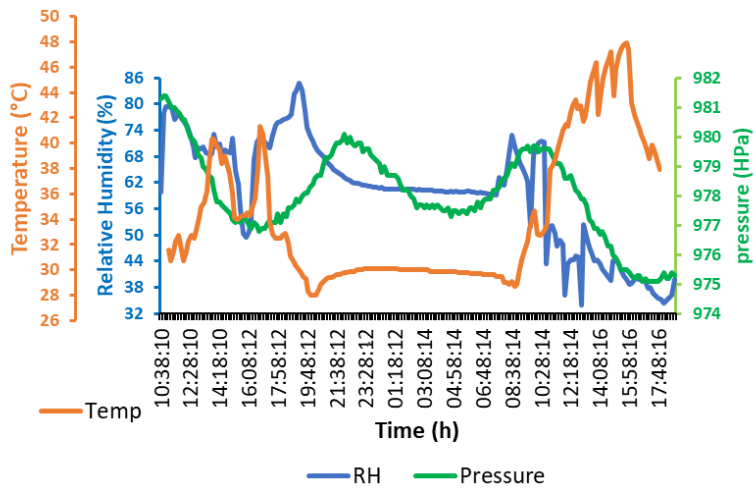


Fig. 12. Pressure, Humidity of air drying in Test1 of drying

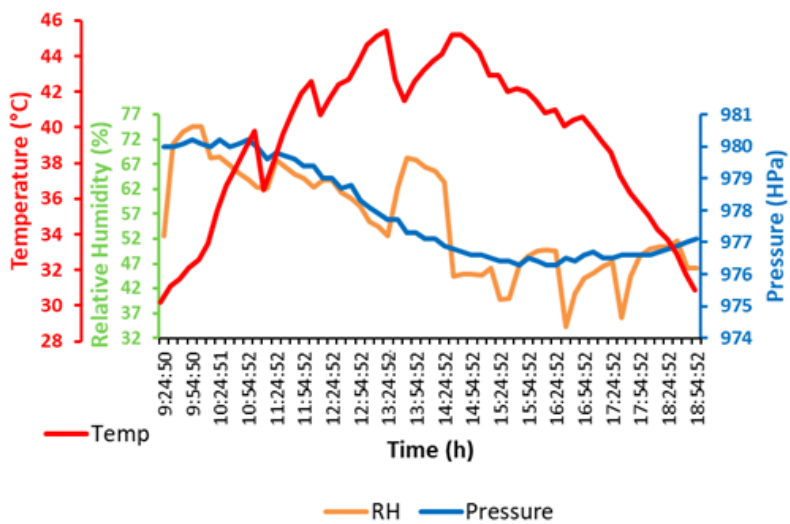


Fig. 13. Pressure, relative humidity of the drying air at the drying Test2

3.3 Moisture Loss and Moisture Ratio

The mass of water lost or the moisture lost by the flour during drying is presented in Figs. 14 and 15. It is observed that the amount of water released increases with drying time and stabilises to mark the end of the operation. This is somewhat the opposite of what was found by Khan et al., [22], who observed a linearly increasing trend. The flour in rack 1 releases more water than that in rack 2, despite its lower quantity. This could be explained by the amount of energy received at the two racks. Indeed, rack 1 receives more heat than rack 2, as the air entering rack 2 is cooler than that in rack 1, which is closer to the air inlet in the solar collector. Fig. 14 shows two phases, separated by a transitional phase. The first phase corresponds to the first two days of drying, while the second is related to the effect of forced

ventilation during the night. Differentiation indicates that 7.43% and 8.09% of water were released at night from rack 1 and rack 2, respectively. These significant amounts of water are released solely due to the effect of forced convection. The maximum amount of water lost from rack 1 is 31.14% and 25.22% from rack 2 (Fig. 14). During the second test (Fig. 15), the maximum water content lost from rack 1 and rack 2 is 23.21% and 21.14%, respectively.

Furthermore, Figs. 16 and 17 show the evolution of the ratio of the water content of the flour during drying. It is noted that this ratio decreases over the drying time and is dependent on the rack, thus on the amount of heat and the humidity of the drying air, as it does not have uniform thermal or hygrometric characteristics between the racks.

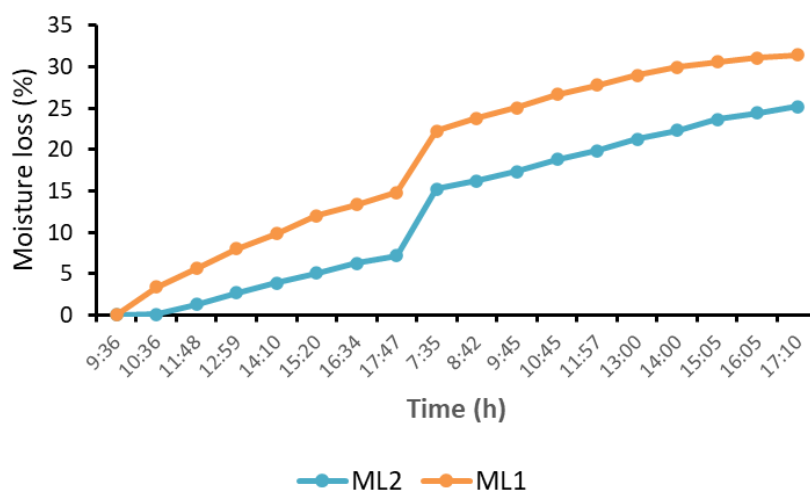


Fig. 14. Evolution of the moisture content lost by flour during drying, Test1

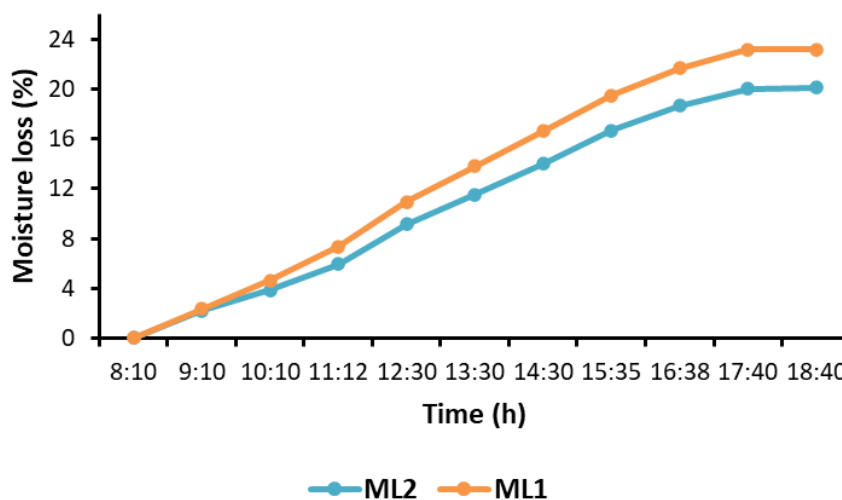


Fig. 15. Variation in moisture content lost from flour during drying, Test2

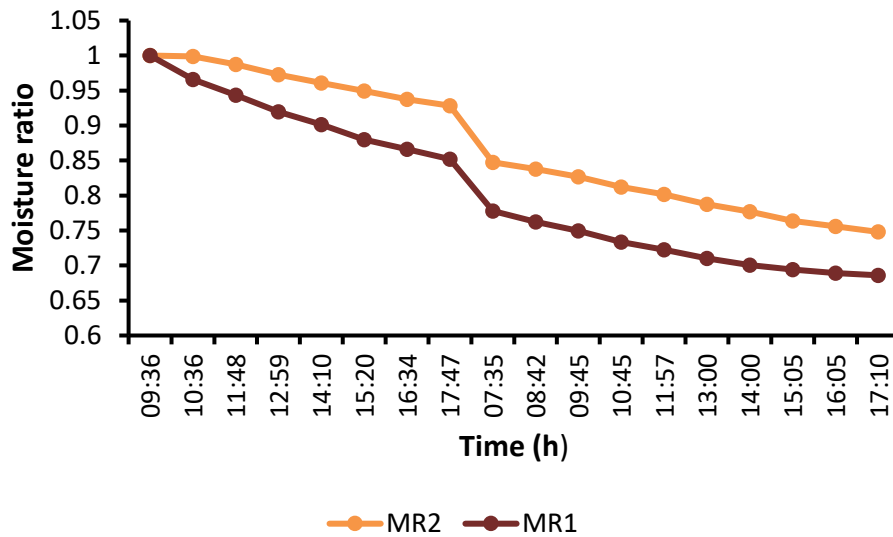


Fig. 16. Moisture ratio evolution during drying time, Test1

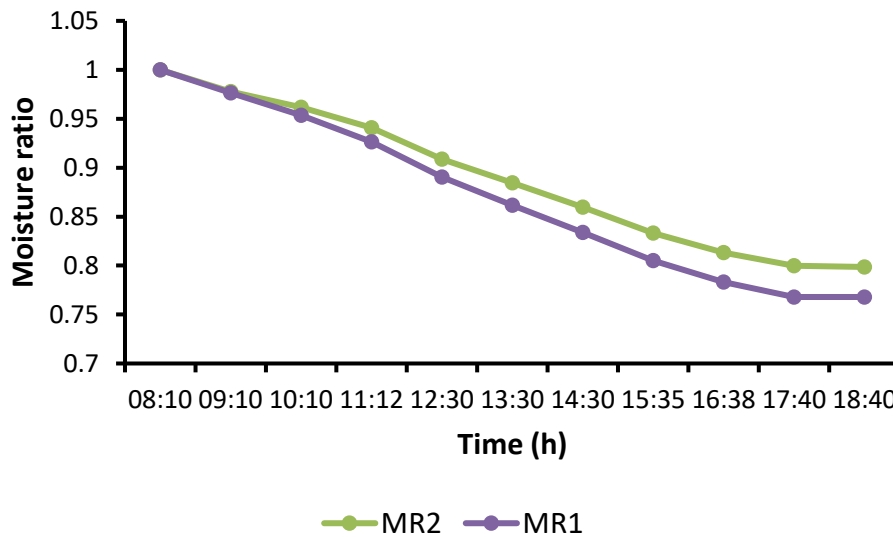


Fig. 17. Moisture ratio variation during drying time, Test2

3.4 Drying Rate

The drying rate or speed is shown in Figs. 18 and 19 for tests 1 and 2 respectively. Fig. 18 shows that there are two phases, each corresponding to two days of drying. The drying rate decreases dramatically with drying time on rack 1. For rack 2 the trend is less clear on the second day of drying. The drying rate for Test 2, shown in Fig. 19, shows a completely different trend to that of Test 1. It decreases and then

continues to decrease, reflecting a bell-shaped trend with a peak of 0.101 kg of water per kg of dry matter per hour at about 12 h 30 min and 0.093 101 kg of water per kg of dry matter per hour for Rack 1 and Rack 2 respectively. When the rate cancels out or tends to zero, this indicates the end of drying. Fig. 19 shows that the drying time was 10h20 min, more than double the expected time (4 hours). This could be due to the low heating of the drying air.

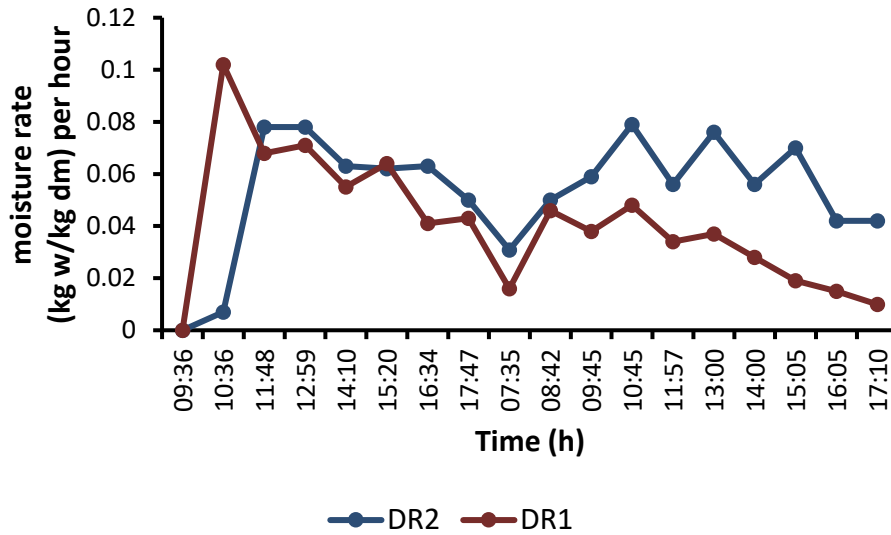


Fig. 18. Drying rate evolution with the time Test1

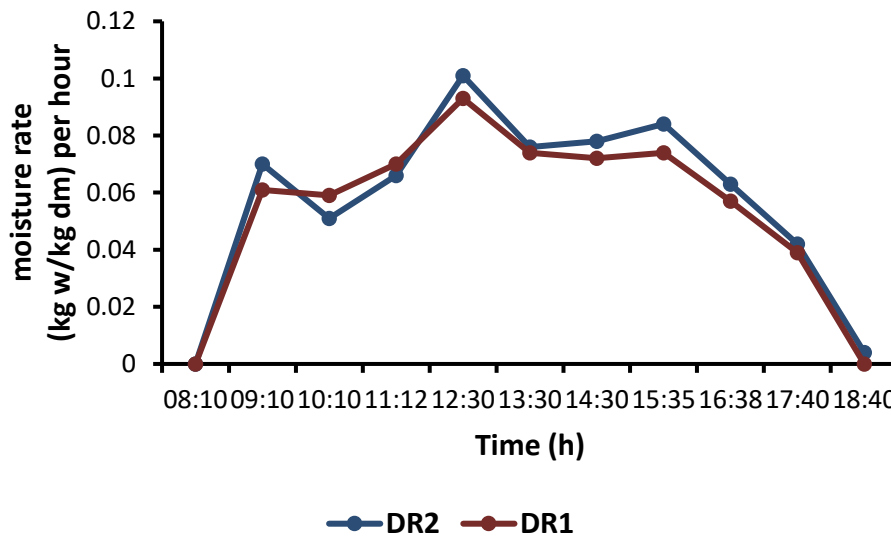


Fig. 19. Drying rate variation with the time Test2

4. CONCLUSION

At the end of this work, which involved the design and preliminary study of a solar flour dryer, some important conclusions, lessons and perspectives can be drawn. These include the following

- the solar dryer has been designed, built and studied in a summary manner,
- the drying air in the dryer can heat up to 65°C with natural convection and no load during the unfavourable period chosen for the study,
- with load and forced convection, the average temperature is less than or equal

to the lower limit of the predefined drying range,

- the hygrometric and barometric conditions are directly influenced by the thermal conditions and have an impact on the drying process,
- the planned drying time was more than doubled.

Among the lessons to be learnt are the following:

- the approach of designing the solar dryer during unfavourable periods increases the drying time and requires a precise estimation of the solar radiation flux according to the climatic conditions;

- the volume of air under the lowest shelf has a negative effect on drying.

A thorough and complete study of the dryer and the drying process would now be necessary. It would be preferable to eliminate the space under the bottom rack.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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