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Reviewing the experience of solar drying in Algeria with presentation of the different design aspects of solar dryers

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ABSTRACT

Solar drying is one of the processes that have found application in Algeria, because of the important quantities of solar irradiations that can be exploited in this country. Nevertheless, the experience of Algeria in solar drying is recent and limited to drying of fruits, vegetables, medicinal and aromatic herbs. The effectuated review has given an idea about the existing functional dryers in this country with presentation of their different design aspects and in some cases the mathematical modeling for well describing and predicting their behaviours. The solar dryers were classified into two classes according to their operation mode and without taking into account if the dryers are using auxiliary sources of energy. The two classes are: passive dryers and active dryers. On the other hand, each class was divided into subclasses representing the type. We have found the direct and indirect types for the passive dryers, but only indirect types for the active dryers. Mixed types were not developed. The solar dryers were developed and tested in two different climatic regions which are the north of the country and the Sahara. In the most studied cases, one or multiple auxiliary sources of energy were used in order to increase the performances of the dryer or to decrease drying time. Consequently, we register the utilization of pebbles as a heat storage system, resistances as electrical heater, gas-ring and photovoltaic cells in order to give independency against the use of the traditional electrical energy. In the case of the active dryers, adding fans and temperature and flow controllers has permitted the control of the drying conditions. Depending on the dryers, the dried quantities vary from 200 g to 36 kg. Comparison between many studied cases for different modes and types and with open sun drying method was furthermore done. With a few exceptions to some solar dryers which present problems of complexity and was not practical and easy for manipulation to the agricultural producer, the majority of the developed solar dryers have presented satisfactory results.

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Nomenclature

Cp	specific heat (J kg^{-1} °C^{-1})
D	air flow (kg s^{-1})
h	coefficient of heat transfer by convection (W m^{-2} °C^{-1})
hr	adapted radiative exchange coefficient (W m^{-2} °C^{-1})
$HS(i)$	global solar radiations flux incident in surface I (W m^{-2})
Lv	latent heat of vaporization (J kg^{-1})
$\underline{m}$	mass (kg)
$\overline{\overline{m}}$	mass of the evaporated water per second (kg s^{-1})
Q_{ij}	heat flux per second between two mediums i and j (W)
Qr_{ij}	radiative heat flux per second between two mediums i and j (W)
S	surface (m^2)
T	temperature (°C)
t	time (s)
V	volume (m^3)
Xr	dimensionless product moisture $\left(\frac{X-X_{eq}}{X_0-X_{eq}}\right)$
X_{eq}	equilibrium product moisture (kg kg^{-1})

Greek symbols

α	coefficient of absorption
τ	coefficient of transmission

Subscripts

a	air
$Cond$	conduction
ci	air-wall
cp	air-product
n	north wall
pi	internal wall
pr	product
s	ground
v	glass

1. Introduction

Due to the geographical situation, Algeria disposes of an important potential of renewable energies, such as geothermal, biomass, solar and wind energy. However, referring to the guide published by the Algerian Ministry of Energy and Mining, in 2007 [1], solar energy plays the most important role. Effectively, and following the same source and the World Energy Council report [2], the insolation duration in Algeria is around 2650 h per year for the coastal regions, 3000 h per year for the high plateaux regions and it increases to 3500 h per year for the Sahara. In terms of received energy, the coastal regions dispose of 1700 kW h m^{-2} year^{-1}; it increases to 1900 kW h m^{-2} year^{-1} for high plateaux and attains 2650 kW h m^{-2} year^{-1} for the Sahara. In fact, the total solar potential of Algeria is estimated to 169,440 TW h per year [2,3], which represents 5000 times the national annual power consumption in electricity and around 60 times the energy consumed by the European community.

Drying is known as an intensive process with high energy consumption, as well as, it represents 10–15% of the total world industrial energy consumption [4]. Subsequently, using free solar energy is expected to be useful and should decrease the cost of the process. In this way, the scientific research and the technological development have permitted the development of several and different functional solar dryers.

In general manner, solar dryers are classified, following their working mode, into two major classes: natural convection solar dryers, also called passive dryers and forced convection solar dryers, called active dryers [5–7]. Passive dryer is constituted of a chamber of which the roof and/or the wall sides are made with transparent materials such as glass. These walls allow penetration of the sunlights and the product absorbs directly the solar radiations, describing direct type as well known by integral type. Sometimes, and in order to avoid the deterioration of the product, other surface is added between the wall and/or the roof of the dryer and the product. The added surface is playing the role of an absorber; an indirect type is obtained, also called distributed type. Mixed type can moreover be obtained using the two modes in two different parts of the same dryer at the same time. Active or semi-artificial solar dryer uses solar collector to heat the ambient air before sending it to the drying chamber with the help of a fan driven by an electrical motor for keeping a continuous flow of the air through the drying chamber. The collector can be disposed in different manners. The combination of the types and the modes is eventually possible leading to six possible cases resumed in Fig. 1.

Ramana Murthy [8] added to the two major modes the green house mode. Fudholi et al. [9] and Imre [10] use also the two main operation modes and added the hybrid solar dryers. This mode of solar dryers is dotted with one or multiple following systems: thermal storage system [11], geothermal or waste waters [12], photovoltaic system [13–18], heat [19–22] or chemical heat pump [23], dehumidification system or auxiliary unit which comforts the use of electrical heating [24–28], biomass burner [29,30], gas burner [31] or diesel engine [32].

The Algerian experience in solar drying is a recent one, as we cannot find scientific publications dealing with this theme before 1999. The local developed solar dryers are applied essentially to dry different sorts of locally produced foods and medicinal herbs such as dates, tomatoes, figs, apples, grapes, apricots, mint and vervain. In this work, we are presenting these different solar dryers and their experimental performances with a special care to the design aspect and the used materials. As, the majority of the developed solar dryers are using auxiliary energy systems, we are not considering the hybrid mode. Along these lines, only passive and active solar dryers with specification of the type are presented.

2. Presentation of the solar dryers

We are presenting the solar dryers absolutely realised and experimented in Algeria. They were developed essentially in the Development Center of the Renewable Energies (D.C.R.E.) and the National Institute of Agronomy (N.I.A), both situated in the north of Algiers region. According to the information given by the National office of Metrology [33], the north region is characterized by a smooth and humid winter with temperatures varying from 8 °C to 15 °C and dry summer with hot temperatures attaining 47 °C, the velocity of the wind varies from 2.3 m s^{-1} to 4.5 m s^{-1} [34]. The annual precipitations of this region vary from 300 mm to 600 mm [35]. Other solar dryers were designed and assembled by the Energy Conversion Research Unit of the Laboratory of New and Renewable Energy in Arid Zones (L.N.R.E.A.Z) situated in the region of Ouargla, in the south, in the Sahara. This region is distinguished by dry climate with very low precipitations attaining 70 mm [33], with heavy sandy winds in spring. The velocity of the wind varies from 2.0 m s^{-1} to 4.3 m s^{-1} [36], but can reach in some specific regions 7.4 m s^{-1} [34]. The summer in this region is a hot and dry with temperatures reaching in July and August 52 °C. The relative humidity of the air is between 6 and 14% [36].

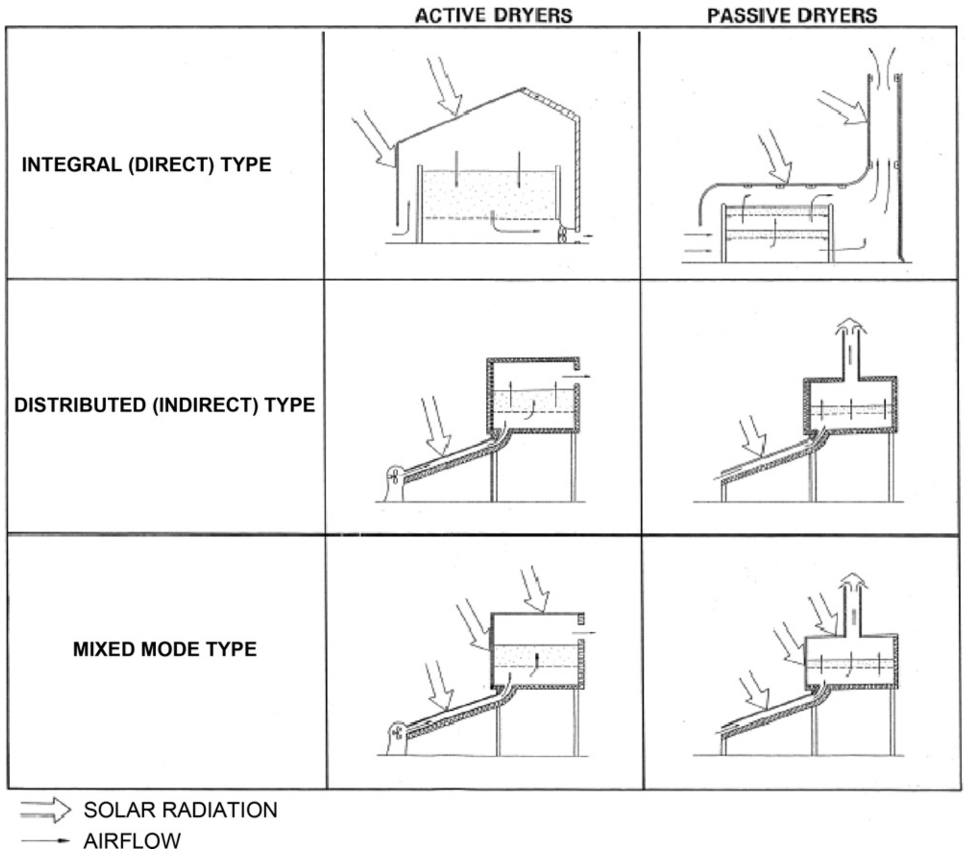

Fig. 1. Presentation of the different functioning modes and types of solar dryers [5].

We are presenting the solar dryers dependently to the mode, to the type and to the region where the dryers were tested.

2.1. Passive mode

2.1.1. Direct type solar dryer developed in D.C.R.E.

Fig. 2a shows the diagram of the simple cabinet solar dryer presented by El Mokretar et al. [37]. It is constituted of a 0.004 m thick of ordinary glass used as a cover. It is divided into three parts the first is inclined with 55°, in order to optimize the collect of radiations during winter. The optimum captivated radiations during summer are obtained with the second part, inclined with 15° and the third part is a vertical glass. The lateral, vertical and the bottom walls are isolated. As shown in the figure, its floor contains a bed of pebbles paint in black used for the unfavourable drying conditions as heat storage system. However the dimensions of the dryer were not specified. The solar dryer was tested between the 07th of July and the 20th of September. The air was stable and its velocity varies from 1.2 m s^{-1} to 2 m s^{-1}. The temperature and the flux radiations inside the drying chamber were respectively 46 °C and 653 W m^{-2}. Mint, vervain, laurel, grape, prune, banana, fig, date and pepper were dryer and the results compared to open sun drying method. The results are represented in Table 1. It is clear that we can dry from 2 to 5 times swiftly using the cabinet solar dryer than open sun drying.

Modeling the solar dryer was also developed by the authors [37] and the three modes of transfers were taking place in the dryer as illustrated in Fig. 2b. Heat and mass balances lead to six differential equations presented in the following form:

Energy balance applied to the floor:

$$C_1\left(\frac{dT_1}{dt}\right) = \tau \cdot \alpha_s \cdot S_s \cdot HS(1) - Q_{cond} - Q_{16} - Qr_{12} - Qr_{13} - Qr_{14} - Qr_{15} \tag{1}$$

With:

$$C_i = (\rho Cp)_i \cdot V_i \tag{2}$$

$$Q_{ij} = h_{ii} \cdot S_i \cdot \Delta T_{ij} \tag{3}$$

$$Qr_{ij} = hr_{ij} \cdot S_i \cdot \Delta T_{ij} \tag{4}$$

Table 1
Presentation of the drying results using open sun and direct natural cabinet solar drying.

Product	Initial mass (g)	Final mass (g)	Drying time in the dryer (h)	Drying time using open sun (h)	Gain (h)
Mint	1000	83	8	48	40
Vervain	1000	430	48	72	24
Laurel	1000	427	28	72	24
Banana	1000	271	144	744	600
Grape	1000	251	268	576	312
Prune	1000	277	175	576	401
Pepper	1000	307	72	336	270
Fig	1000	205	219	960	741
Date	1000	846	214	960	746

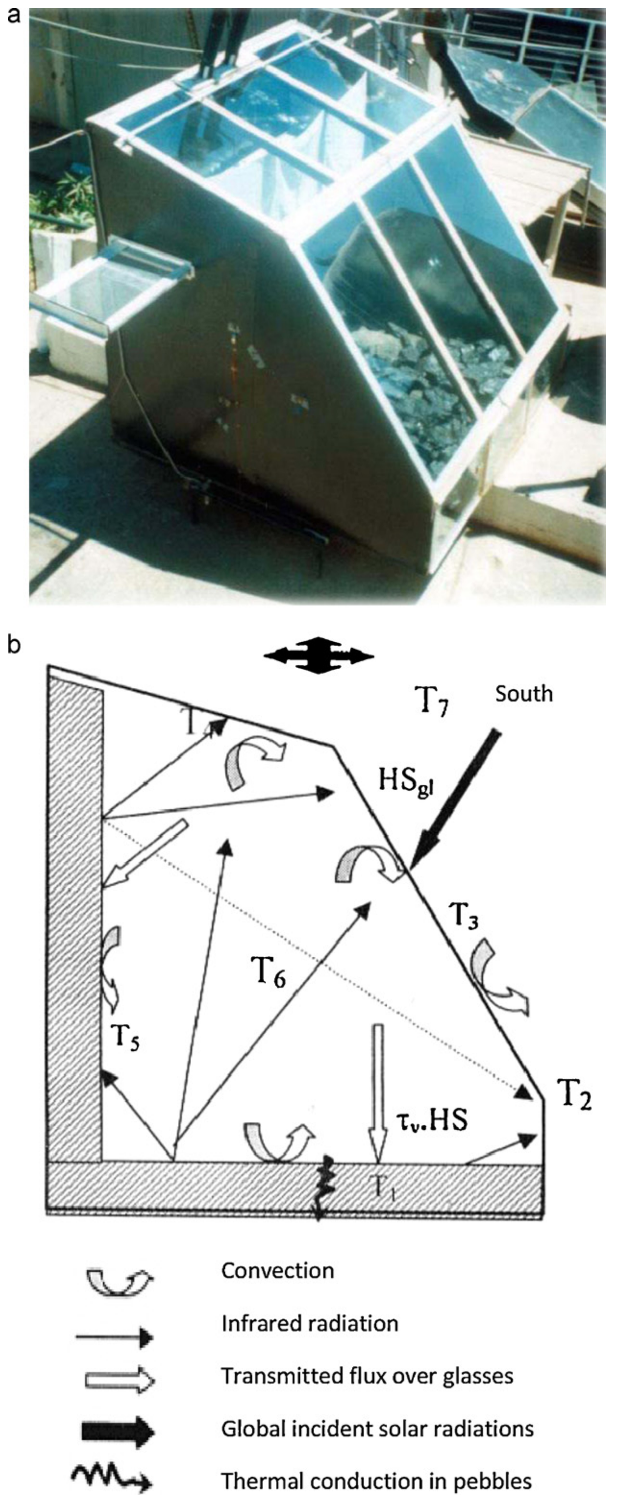

Fig. 2. (a) Direct solar cabinet dryer developed in D.C.R.E. [37]. (b) Different heat transfer modes happened in the cabinet solar dryer. (1) Floor (bed of pebbles), (2) the vertical glass, (3) the 55° inclined glass, (4) the 15° inclined glass, (5) the north wall, (6) the interior air, (7) the ambient air [37].

Balances applied for the different parts of the glass cover are represented by the three following equations:

$$C_2\left(\frac{dT_2}{dt}\right) = \alpha_V \cdot S_{v1} \cdot HS(2) + Q_{62} + Q_{12} + Qr_{32} + Qr_{42} + Qr_{52} - Q_{27} \quad (5)$$

Fig. 3. Natural convection solar dryer – indirect type developed in D.C.R.E. [38].

$$C_3\left(\frac{dT_3}{dt}\right) = \alpha_V \cdot S_{v2} \cdot HS(3) + Q_{63} + Q_{13} - Qr_{32} + Qr_{43} + Qr_{53} - Q_{37} \quad (6)$$

$$C_4\left(\frac{dT_4}{dt}\right) = \alpha_V \cdot S_{v3} \cdot HS(4) + Q_{64} + Q_{14} - Qr_{42} - Qr_{43} + Qr_{54} - Q_{47} \quad (7)$$

Heat balance applied to the north wall noted by (5):

$$C_5\left(\frac{dT_5}{dt}\right) = \tau \cdot \alpha_n \cdot S_n \cdot HS(5) + Qr_{15} - Qr_{52} - Qr_{53} - Qr_{54} - Q_{56} \quad (8)$$

Balance applied to the interior air noted by (6):

$$C_6\left(\frac{dT_6}{dt}\right) = Q_{16} + Q_{56} - Q_{62} - Q_{63} - Q_{64} - Q_{67} \quad (9)$$

Depending on the surfaces: i and j vary from (1) to (6).

These equations have allowed following the variations of the temperatures of the different parts constituting the cabinet solar dryer. The comparison between the theoretical and the experimental results shows a great agreement with a deviation no more than 20%. It should be caused by the use of some empirical relations, such as the exchange coefficients. The use of an inverse method will lead to more appropriate coefficients.

2.1.2. Indirect type solar dryer developed in D.C.R.E.

Miri et al. [38] have developed an indirect solar dryer working on natural convection. The chart of this solar dryer is illustrated in Fig. 3. It is constituted of two essential parts: the solar collector and the drying chamber. The solar collector is heating air with double circulation; the first between the glass cover and absorber and the second between the absorber and the bottom part. This last part and the lateral walls are thermally isolated. The collector has the

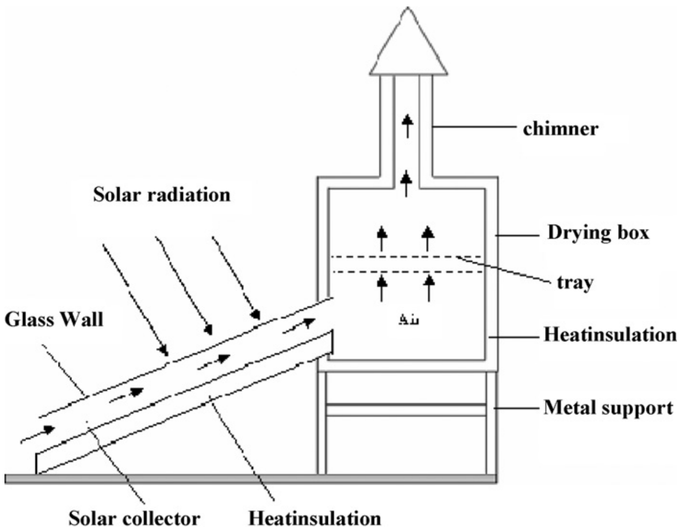

Fig. 4. Indirect natural solar dryer developed in L.N.R.E.A.Z. [40,41].

following dimensions: 2 m length, 0.94 m width and 0.12 m height, without specifying what sorts of materials are used. The drying chamber has a cubic form, with a 1 m^3 volume, surmounted by a "v" roof. Polystyrene was used as insulator for the lateral walls. On the other hand, glass wool was used for the roof and the door existing at the back of the drying chamber. In addition, a black plastic was covering the whole drying chamber, in order to increase the attraction of the solar radiations and it was used against rain. A 1 m height chimney with 0.08 m diameter was added to the drying chamber in order to simplify the exit of the humidified air. The connection between the solar collector and the drying chamber is effectuated due a simple tube, as shown in the figure. The drying chamber is supported by a metallic support at 2.2 m height from the ground. It is supporting 3 perforated cube trays and the distance between them is 0.20 m. The results obtained by the collector with double circulation were compared with one with simple circulation. Hence, the temperature of the absorber of simple circulation has attained 103.31 °C and was 96.55 °C for double circulation. The most important temperature to be known is one of the heated air that goes to the drying chamber. It was around 60 °C, for a simple circulation collector and around 50 °C for a double circulation. Mint, pepper, grape, laurel and vervain were the dried products between the 15th and the 16th of August. The obtained results compared to those obtained by open sun drying are presented in Table 2. The calculated efficiency of the solar dryer was around 40% which was an encouraged result. However, its application is restricted to the domestic use.

A comparison between the direct natural solar cabinet dryer and the indirect natural one was made by Benkhelfellah et al. [39]. The results were relatively favourable to the direct solar cabinet dryer, as we register 70% of extracted pepper humidity in 72 h against 243 h for the indirect dryer. Also drying grapes needed 268 h using direct dryer against 318 h for the indirect solar dryer. But 67% of the humidity of vervain was extracted in 48 h using direct natural solar dryer and it was only 30 h for extracting 75% of its humidity using the indirect natural solar dryer.

Table 2
Presentation of the drying results using open sun and indirect natural solar drying.

Product	Initial mass (g)	Final mass (g)	Drying time in the dryer (h)	Drying time using open sun (h)	Gain (h)
Mint	200	40	30	50	20
Pepper	300	60	243	342	99
Grape	500	150	318	580	262
Laurel	300	120	28	52	24
Vervain	300	75	30	52	22

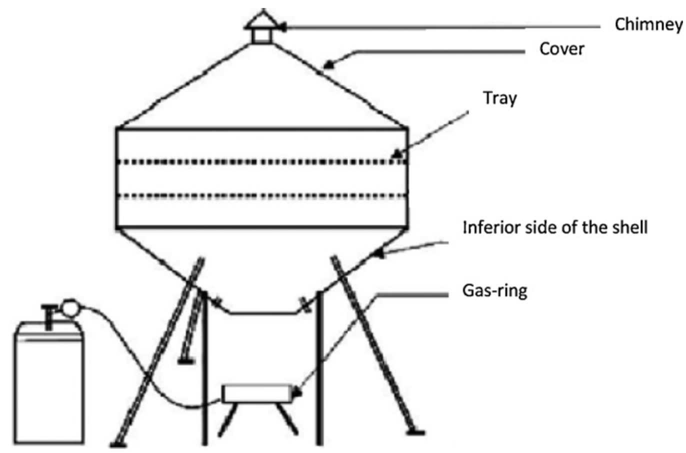

Fig. 5. Indirect shell natural solar dryer developed in N.I.A. [42].

2.1.3. Indirect type solar dryer developed in L.N.R.E.A.Z.

The developed indirect natural solar dryer is shown in Fig. 4 [40,41]. The solar air collector is a simple one, it has the following dimensions: 2 m length, 1 m width and 0.13 m height, inclined of an angle of 16° with respect to the horizontal and directed to the south. The air collector is composed by glass plate having a thickness of 0.004 m, used as a cover. Then we find an aluminium plate painted in black in order to increase the absorption properties. The distance of 0.06 m is separating the cover from the absorber. The lateral sides and the bottom parts are thermally isolated with polystyrene. The drying chamber has the following dimensions: 1.0 m × 0.8 m × 0.8 m, it is made with coated sheet and thermally isolated with polystyrene for all the external surfaces. The drying chamber is dotted with a chimney made with galvanized sheet. It has the following dimensions: 1.0 m × 0.02 m × 0.02 m. Its sides

Fig. 6. Indirect forced convection dryer developed in D.C.R.E. [43,44].

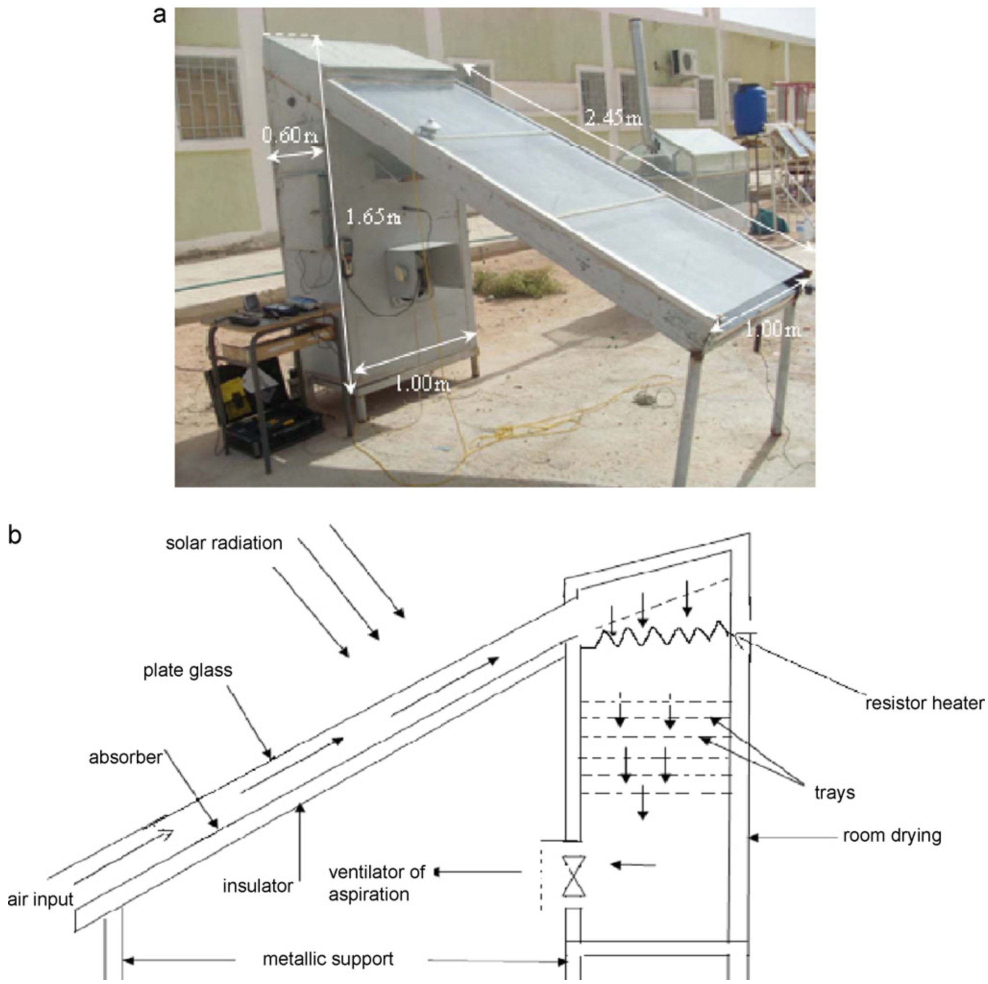

Fig. 7. (a) Indirect forced convection dryer developed in L.N.R.E.A.Z. and its dimensions [47]. (b) Detailed diagram of the indirect forced convection dryer developed in L.N.R.E.A.Z. [47].

are thermally isolated with polystyrene, too. Date fruit is used as dried product. The mathematical modeling studies presented by the authors were not to simulate the behaviour of the solar dryer but to put models that describe well the drying kinetics happened with non-controlled process conditions. The first proposed model is an exponential one written in the form:

$$Xr(t) = A_0 + A_1 \ \exp(-bt) \tag{10}$$

where the coefficients A_0, A_1 and b are presented as functions of the drying conditions.

The second proposed model is taking the following form:

$$Xr(t) = \exp(-\sqrt{k}t) \tag{11}$$

k is a coefficient presented as a function of the drying conditions (temperature and velocity) and some product characteristic (initial moisture).

The use of the indirect natural solar dryer has given good results with a marketable quality of the obtained dried dates.

2.1.4. Shell indirect solar dryer developed in N.I.A.

The form of the shell solar dryer is shown in Fig. 5 [42]. The upside of the dryer is constructed with metallically sheet painted in black representing the opening part of the dryer. This part is dotted with a chimney to facilitate the evacuation of the humidified air. The inferior part of the dryer has a conical form which gives the form of a shell-fish from where the name of the dryer. The interior of the dryer has perforated trays that let the circulation of the heated air inside the chamber. The upside part of the dryer receives the solar radiations which will be transferred to the product. The dryer is also dotted with a control system; so if the temperature of the heated air is under a fixed one, a gas-ring starts working. The supplement heat penetrates to the drying chamber by means of holes made at the end of the inferior part. The dryer has a 0.91 m^2 as a surface and can support 8 kg of grapes, which are the tested products. The process was performed with an air heated to a constant temperature of 65 °C and its flow was about 50 m^3 h^{-1}. The decrease of the product humidity from 76.82% to 22.60% necessitates 6.71 kWh and the efficiency of the solar collector was more than 52%. However, the authors have found that increasing the surface of the dryers to 1.72 m^2 will give better results.

2.2. Active mode

2.2.1. Indirect forced convection solar dryer developed in D.C.R.E.

Benaouda and Belhamel [43] and Boulemtafes-Boukadoum et al. [44] have developed the solar dryer shown in Fig. 6. As well this dryer is constituted of 2 main parts; the solar collector and the drying chamber. The solar collector is a simple one with simple air circulation, its dimensions were: 2 m × 0.94 m, built with galvanized sheet-iron. The same matter painted in black (in order to increase the absorption properties) is used as absorber. It has a 0.0005 m thick and the value of its thermal conductivity was 54 W m^{-2} K. The collector is covered with a 0.003 m thick of ordinary glass. The collector is inclined by 36°. The drying chamber has a cubic form with a volume about 1 m^3 and can contain 3 perforated trays, allowing a good circulation of the heated air and 0.25 m separates the trays. The drying chamber is made with 0.002 m thick of sheet-iron steel and then covered with 0.04 m thick of polystyrene used as insulator. The drying chamber is equipped with a chimney used for the evacuation of the humidified air. As, illustrated in the figure, the connection between the solar collector and the drying chamber is effectuated by means of a tube. The flow of the ambient air is controlled by fans which allow having from 50 $m^3 h^{-1}$ to 300 $m^3 h^{-1}$. In addition, an electrical heater that gives a power of 1 kW is added. It plays the role of an auxiliary source of energy and it is used when the temperature of the heated air is less than a fixed one or during unfavourable climatic conditions. The use of a thermo regulator tool allows performing drying with air heated to a constant 50 °C. Several products were tested such as tomatoes, tobacco, figs, mint and laurel and depending on the product; the drying time varies from 5 to 10 h. The dryer has given satisfactory results, however the quantities were not important.

The authors have made mathematical modeling of the dryer through heat and mass balances represented by the two following equations:

Heat balance effectuated at the air level:

$$D_a Cp_a \Delta z \frac{\partial T_a}{\partial z} = h_{cp} S_{pr}(T_a - T_{pr}) - h_{ci} \Delta S_{pr}(T_a - T_{pi}) \tag{12}$$

Product heat and mass balance:

$$m_{pr} Cp_{pr} \frac{\partial T_{pr}}{\partial t} = h_{cp} S_{pr}(T_a - T_{pr}) - L\nu \cdot \overline{\overline{m}} \tag{13}$$

These two equations allow following the variations of the temperatures of both the air and the dried product.

Nowadays, there are investigations for the amelioration of the efficiency of the solar dryer by recycling the humidified air [45,46]. Laurel product was tested and we have found that only 26 h were necessary to dry the products which gives better results than natural convection solar drying (Tables 1 and 2). 65% of the humidified air was recycled and re-injected inside. During recycling operation, 65% of the recuperated air was re-injected inside the drying chamber and 35% was taken from the ambient air. The authors registered a 10% of economy in energy expenses.

2.2.2. Indirect forced convection solar dryer developed in L.N.R.E.A.Z.

Fig. 7a and b shows the studied solar dryer and its compounds and dimensions. It consists mainly of a flat plate solar collector, drying chamber, electrical fan, electrical resistance used as a heater and considered as an auxiliary source of energy, it delivers a power equal to 3.75 kW, and finally a temperature controller.

The solar collector has an area of 2.45 m^2, and inclined by 31° with the horizontal and directed to the south all the time. The absorber is made of galvanized metal painted in black; it has a 0.002 m thick. It is protected from the top by a 0.005 m thick of glass. For the lateral and the bottom sides, polystyrene is used, constituting the insulator part of the collector. It is connected directly to the drying chamber without any ducts and the air is flowing between the glass cover and the absorber. The drying chamber has the form of a box and is fabricated with a galvanized iron and its walls are insulated using polystyrene. The chamber has 1.65 m height, 1.00 m width and 0.60 m depth. It contains six perforated trays with the possibility of extension to eight trays. Each tray has a surface of about 0.4 m^2 and can support a mean value of 2 kg, depending on the bulk density of the dried product. In order to obtain a uniform circulation of the air inside the chamber, a distance of 0.12 m is let between the different trays. The door of the chamber is properly sealed to prevent the air escape and also loading the products inside the cabinet. The used fan has a 0.02 m diameter and gives a 1400 rpm velocity. It insures a volumetric flow of the air around 0.325 $m^3 s^{-1}$ and the option of controlling the air flow was applicable. The added heater is functioned if the temperature of the air given by the collector is less than a fixed one. The system is controlled by a temperature controller. Depending on the time of the day and the velocity of the heated air, the efficiency of the solar collector was ranged from 19% to around 52%. The overall efficiency of the solar dryer varies from 13% to 47.5%. The life of the dryer was estimated to 15 years which gives a payback around 1.3 years, which makes the dryer very useful. The tested product was slices of tomato.

a

b

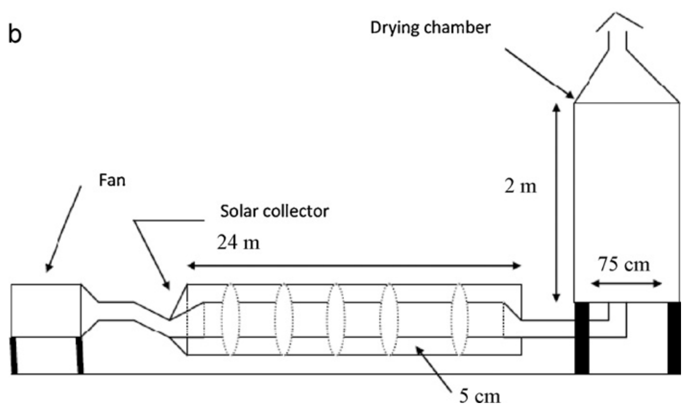

Fig. 8. (a) Overall view of the indirect forced convection solar dryer developed in N.I.A. [48]. (b) Detailed diagram of the forced convection solar dryer developed in N.I.A. [48].

2.2.3. Indirect forced convection solar dryer developed in N.I.A.

The solar dryer is illustrated in Fig. 8a and Fig. 8b gives more details about the compounds and dimensions of the apparatus [48]. As shown in Fig. 8b, the solar dryer is divided into three distinct parts; the solar collector, the drying chamber and the fan. The solar collector is realised within two plastic films of polyethylene having a thickness equal to 0.00015 m. The first plastic film is a transparent one and has a length of 24 m and its width is around 3.4 m. The second plastic film is painted in black for using it as an absorber. It has the same length as the transparent one, but the width is equal to 3 m, it is supported by metallically circles having a 0.9 m as a diameter, giving a cylindrical form to the absorber. The same method

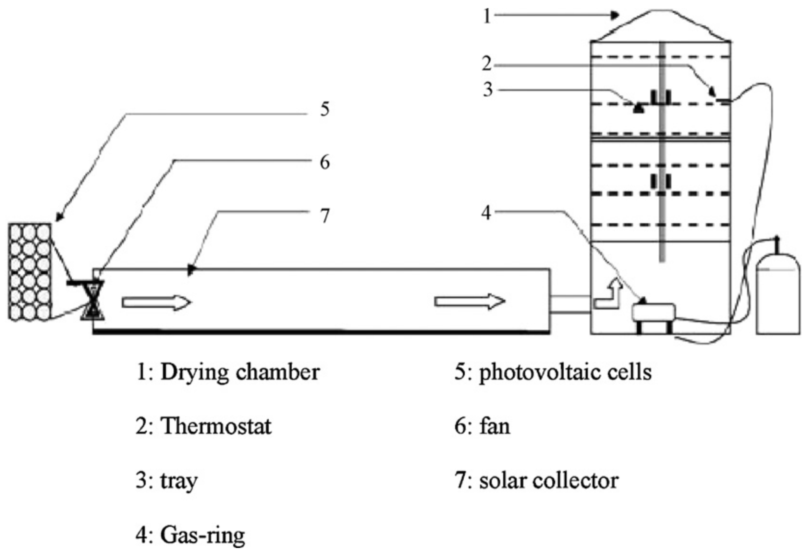

Fig. 9. Diagram of the ameliorated forced convection solar dryer developed in N.I.A. [49].

is used with the transparent film by means of metallically circles having a diameter equal to 1 m, creating a space of 0.05 m between the two plastic films. A tube is used to connect the solar collector to the drying chamber, allowing the flow of the heated air. The drying chamber has the following dimensions: 2 m height and a surface of 0.75 m × 1 m. The top of the chamber contains a chimney with two holes oriented to the north. The chamber contains twelve trays and each one can support 3 kg of product. The ambient air is aspired by fan that has a velocity of 1500 rpm, placed at the entrance of the collector, as shown in Fig. 8b. The mean value of the temperature of the heated air that goes to the drying chamber was 46 °C. However, the velocity of the air was $2\,m\,s^{-1}$. The calculated efficiency of the collector has given the feeble value of 11.36%. The tested product was apricot and around 300 min were necessary to extract 50% of the product humidity. In order to ameliorate the performances of this solar dryer and to give it independence against electrical energy, photovoltaic cells were added in order to aliment the fan. A temperature controller system was also used; it consists on a gas-ring that works until obtaining the desired temperature [49]. The graph of the ameliorated solar dryer is represented in Fig. 9. This method has proofed its efficacy by increasing the efficiency of the solar collector to 49.23%. In spite of the obtained results and the important dried quantities, the solar dryer cannot be easily manipulated also the reserved surface make it not practical to the farmer.

3. Conclusion

In spite of the new Algerian experience in solar drying, many successful solar dryers were developed. We register for the passive mode the development of only one direct natural conversion solar dryer dotted with a heat storage system. However, three, indirect type, of natural convection solar dryers were developed, just one of them has used auxiliary source of energy. On the other hand and concerning the active mode, we list the realisation of three forced convection solar dryers and all of them were indirect type. Regarding the solar collectors used in this type, all of them were directed to the south and inclined with different angles from horizontal to 36 °. The one with simple air circulation has given better results, as the temperature of the heated air at the exit from the collector was higher. Also, we register for indirect active solar dryers, the utilization of fans, electrical heater or gas-ring with control systems of the air flow or its velocity and its temperature. In general manner, the comparison of performances between forced and natural convection solar dryers was favourable to forced convection due to the utilization of fans which allows having a better distribution of the air inside the drying chamber [26]. As well, the quality of the final dried product was better [50]. Nevertheless, the comparison between direct and indirect type for the same mode was not clearly defined and can changes depending on the drying products. In addition to the solar collectors and independently to the regions where the dryers were tested, one or multiple auxiliary sources of energy were necessary (5 of the 7 studied cases), in order to increase the efficiency of the dryer, to give it independence regarding electrical energy or to decrease drying time.

In one hand, the studied solar dryers were made with cheap and available materials, which permit to deduce that the feedback and the investment return may be acceptable. On the other hand, in the majority of the studied cases, solar dryers were easy for manipulation and for maintenance. These reasons guarantee the feasibility of the development of passive and active solar dryers in Algeria.

Exploring mixed type of solar dryers will be an original work done in Algeria as during our review we have not found any experimental work dealing with this theme, at the exception of one simulation work which has studied the behaviour of a mixed mode solar dryer using forced convection [51]. Whole studies were done during summer and it should be constructive to know the behaviour and the efficiency of the studied solar dryers in different seasons and for different products. Also, whole the studies were dealing with thin layer drying and it could be interesting to perform thick bed drying which permits the optimization of the space inside the drying chamber and by this the quantities of the dried product should increase.

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