Study and simulation of the behaviour of a direct solar dryer under the climate of Bou-Ismail

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Abstract –**In order to study the thermal performance of a greenhouse -type solar dryer devoted to food drying and wastes from the food industry, we conducted an experimental and numerical study to examine the thermal efficiency of a direct solar dryer prototype manufactured at UDES laboratory. The numerical simulation take account the initial condition, ambient and weather conditions. The kinetics of drying and energy balance on the various walls have been obtained by the software fluent 6.3.26. The experiments and calculations were conducted under conditions of the Bou-Ismail city (located at latitude of 36°39', longitude of 2°42' and an altitude of 10 m). The tests were carried out during the day of 20th August 2013 under a daily solar radiation received on an inclined plane of 35 ° and varying within the range 564 to 920 W/m2 and an ambient temperature varying from 24.9 to 25.6 °C with a wind speed ranging from 0.9 to 2.2 m/s. The experimental results and numerical simulation permit to illustrate the profile of thermal radiation and temperatures at the internal surfaces, glass and air coolant inside the dryer, horizontal and vertical walls. The temperatures of the absorber plates are highest. These results can be justified without any doubt by the right choice of following design parameters: isolation, absorber, materials used, inclinations and orientation.**

Keywords – direct solar dryer, efficiency, radiation, temperature, simulation.

I. NOMENCLATURE

Symbols	Designations	Units
DNI	Direct normal irradiation	$w.m^{-2}$
Dif	Diffuse radiation	$w.m^{-2}$
T_i , T_{pr}	Temperature	°C
φ_e	Inlet flux	w
φ_g	Generated flux	w
φ_{st}	Stored flux	w
φ_s	Outlet flux	w
t	Time	s
ρ	Density	kg/m^3
C_p	Specific heat capacity	j/kg k
λ	Thermal conductivity	w/k.m
Qr_{ij}	Heat flux exchanged by radiation	w
Qcv	Heat flux exchanged by convection	w
S	Surface	m^2

II. INTRODUCTION

Drying is a means of preservation, is a step in the processing of certain products. It is used both in rural areas in the industrial world through food, textile ... etc. Solar dryers are easy to build with tools and locally available materials and can function by natural convection [5]. Obviously the amount of sun and humidity affect the performance of the dryer. Solar dryers are divided into two models, direct and indirect types. Also, these systems can be active or passive. All notices examined agree drying temperatures between 35 and 82°C are the most common. Some drying methods [6]:

- Artificial solar drying;
- Drying by ventilation;
- Drying infrared radiation;
- Conventional solar drying;
- Drying superheated steam;
- Drying by a combustion source.

There are two problems to be solved are:

- Find a heat source to heat the air;
- Create the ventilation (natural or forced), which causes the air out of the dryer.

We solved these two problems as follows:

- Heat source: the sun, the ambient air;
- Ventilation: created between the bottom and top of the dryer temperature variation that allows the draw [3].

Solar drying as a means of preserving food was considered the most widely used system of solar energy. Quantities processed by this method are extremely important for facilities that are inexpensive using the action of solar radiation as a source of heat and depend on the temperature, humidity and natural air ventilation. The traditional drying method suffers from many problems, among them, the lack of ability to control the drying process properly, the uncertainty of the time, the cost of labor higher work, the need for large areas, the infection by insects and other foreign matter. A properly designed solar dryer can alleviate the drawbacks of open sun drying and quality of the dried product (final) can be improved. Many scientists have studied the modeling of solar drying of agricultural products and there are also simulation studies of solar dryers (direct, indirect) and the behavior of various vegetables and fruit, characterized by drying kinetics [1]. To use free, renewable and non-polluting source as the main energy provided by the sun, the introduction of solar dryers in developing countries can reduce losses of food waste and improve significantly the quality of the dried product compared to traditional drying methods. In recent years, many attempts have been made to develop solar drying, mostly to preserve food. The solar drying systems must be correctly designed to assemble the requirements of drying, particularly, the specific crops and to give acceptable performance concerning energy demand [2]. Drying characteristics of particular materials being dried and simulation models are needed in the design, construction and operation of drying systems. Several researchers have developed simulation models for systems with natural and forced convection. The objective of our work is to simulate the dryer in three dimensions, the contribution to the experimental study of the direct solar dryer natural convection. The selection of a direct solar dryer for drying specific products is determined by [4]:

- Thermal Performance;
- Quality of dried product;
- Physical characteristics of the dryer;
- Cost dryer and amortization period.

III. DESCRIPTION OF THE DRYER

The greenhouse dryer is a drying chamber (1) in the form of housing, although closed to prevent the dissipation of the heat outdoors. It has six walls, left, right, front, back, top and bottom. The upper face is glazed (2) and inclined at the latitude (36 deg). The internal faces of left, right and bottom walls are covered with an aluminium plate painted black to ensure the absorption of the solar rays which pass through the glass, as a result basis the dryer effect in the drying chamber. The walls are thermally insulated sandwich panels compounds of polystyrene sheet and wood plates to minimize losses to the outwards and resistance to moisture produced during the drying operation. The rear and left side walls are fitted with doors (3) allowing access to the drying chamber for filing trays (4) containing the product to dry. The front has an opening (5) for the inlet of cold air and the rear face is provided with a further opening (4) in the upper portion for the outlet of the hot air charged with moisture outwardly. These openings are equipped with an opening / closing pivot on an axis of rotation (0 to 90 deg) and the system to allow monitoring and controlling the temperature through the flow control of the air entering and out depending on the type of product to be dried. The dryer is equipped with this device to prevent overheating of the product to dry which can cause alteration of the chemical composition, color and flavor and guarantee thus obtaining products of high quality. Drying trays (4) are screened surface plates equal to 0.54 m² allow easy passage of air that carries the moisture contained in the product. They are arranged in staircase separated from each other. These metal structures (6) are drying trays with feet through the bottom wall through holes to drop on the scales located outside just below the dryer (7). Electronic scales are placed on a plate welded to the structure which is supported by feet provided with wheels (8). Each is provided with a scale display (9) mounted on the right side of the dryer [3].

IV. THEORETICAL PART

The theoretical study that we conducted on the dryer trays empty and allowed us to study the temperature evolution of the various walls of the system and especially the interior air. There are several methods for drying of agricultural products. However, the convection drying, also called training remains the most widely used technique and more [4]. If a wet body is placed in a chamber where reigns a warm and dry gas flow, differences in temperature and partial pressure of water will be found between the body and thus leading to gas following phenomena:

- A heat transfer gas to the wet body under the effect of the existence of an temperature gradient,
- Mass transfer (water) takes place from the body to the gas under the effect of a partial pressure gradient.

Supposed drying is isenthalpic if the energy required to vaporize the water is exactly equal to that provided by the hot gas stream [7]. According to the first law of thermodynamics:

$$\mathrm{Qe} + \mathrm{Qg} = \mathrm{Qst} + \mathrm{Qs} \qquad (1)$$

$$(\rho \mathrm{C_p})_\mathrm{i} * V_i * \left(\frac{dT_i}{dt}\right) = -\frac{T_{pr} - T_{i'}}{\frac{e_v}{\lambda_v}} + \alpha_v\, S_{ij} G_{ij} + \mathrm{Qr}_{\mathrm{ij.ciel}} + \mathrm{Qr}_{\mathrm{ij.sol}} + \mathrm{Qcv}_{\mathrm{ij.air.ext}} \qquad (2)$$

T_i and T_{pr}: Temperature of horizontal / vertical plane, air coolant inside the dryer , the interior surface and glass.

t : time (s).

ρ : Density (kg/m^3).

$\mathrm{C_p}$: Specific heat capacity (j/kg k).

λ: Thermal conductivity of the material (w/k m).

$\mathrm{Qr_{ij}}$: Heat flux exchanged by radiation between the surface ij (w).

Qcv: Heat flux exchanged by convection between the surface ij (w).

In our case:

$$\mathrm{Qg} = 0 \qquad (3)$$

The two openings (inlet and outlet) are critical elements that ensure the heat exchange by natural convection inside the dryer to dry the product. Increasing the temperature of the air coolant inside our dryer allows for better speed drying. Changes in temperature and humidity with time are ignored before the axial variations [3].

Figure 1 shows a detailed diagram type solar dryer emission composed of: drying chamber (1), glass (2) doors (3), trays shaped grid (4), inlet and outlet openings air (5), the supporting structures of the trays (6), measurements of weight balances (7), wheels (8), displays (9).

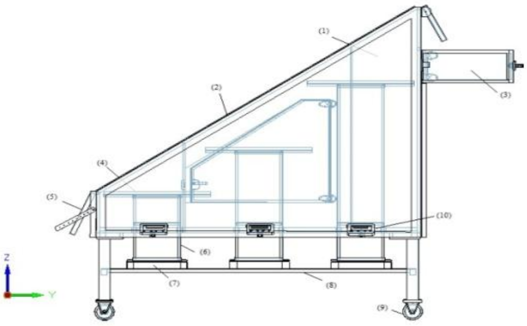

Fig.1 General description of the solar dryer with three trays.

The temperature difference between inside and outside may reach 29 to 70°C. The dryer is efficient even with flow rates generally low and laminar.

Fig.2 Actual photo of the greenhouse

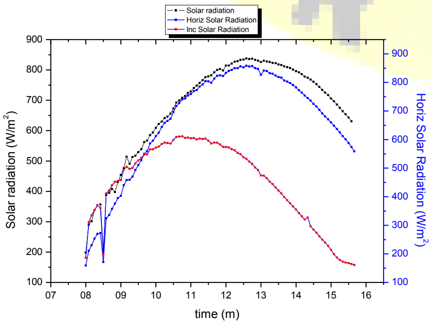

Fig.3 The variation of solar radiation during the day of the test.

V. SIMULATION PART

The numerical simulation is predestined to evaluate the performance of our dryer without the three trays.

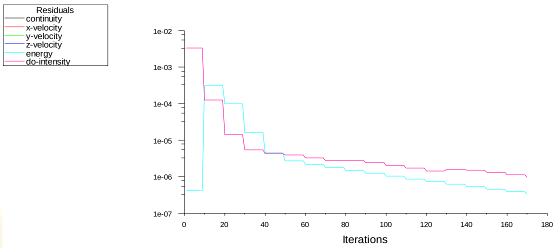

Fig.4 Convergence test with fluent 6.3.26.

To complete the simulation, we must also determine the boundary conditions (average temperatures of the outer surfaces), the initial conditions and environmental conditions associated.

I. The distribution of radiation incident on the different planes of the dryer

Figures 5, 6 and 7 show respectively the variations of the surfaces radiation incident on the different planes of the dryer realized. The three figures show that there is a difference between the profiles of radiation following the axis Y. This gradient is caused by the effect of the heat flux exchanged at each radiation surface.

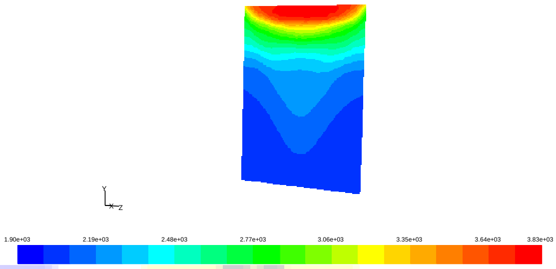

Fig.5 Contours of surfaces incident radiation (outlet and north).

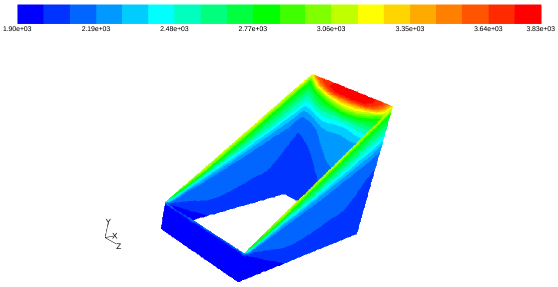

Fig.6 Contours of surfaces incident radiation.

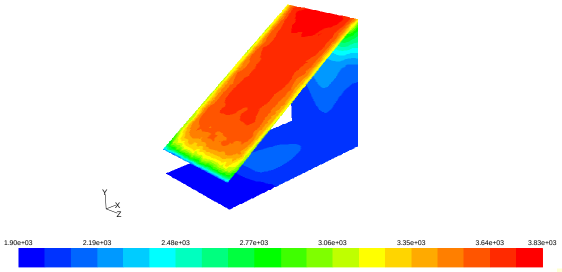

Fig.7 Contours of surfaces incident radiation (north, board, glass and outlet).

Consequently, and always staying in the same concept, we can justify the reason for the presence of the highest incident radiation on the glass amount. We are assured that the radiation of the glass is higher. The three figures show that there is a big difference between the profiles of the incident radiation of the glass and the side walls to the other side. So the horizontal wall receives the largest portion of the solar radiation.

II. The temperature distribution on the different surfaces of the greenhouse

Figures 10 and 11 show the evolution of the radiation temperature in different surfaces of the dryer, they cover a range between 29°C and 87°C. Measured temperatures are indicated in Figures 8 and 15.

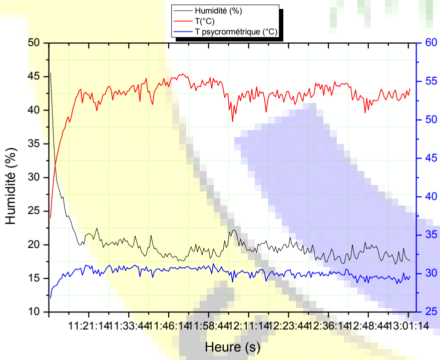

Fig.8 The distribution of the temperature and humidity inside the dryer during the test period

Both figures 10 and 11 show that the radiation temperature of the horizontal wall (glass or plate) is even higher than the temperature of the vertical surface. These results are certainly suitable to the inclination of the horizontal plate (0°) which is the closest to the optimum inclination relative to the (90°) of the vertical surface. We can ensure that there is always a temperature gradient between two surfaces in the same plane (north surface and outlet). This gradient is caused by the effect of the heat flux exchanged by the three modes (conduction, convection and radiation) at the level of each type of surface. In this case, the outlet temperature of the air coolant inside the solar dryer with a laminar flow can reach the value of 60°C.

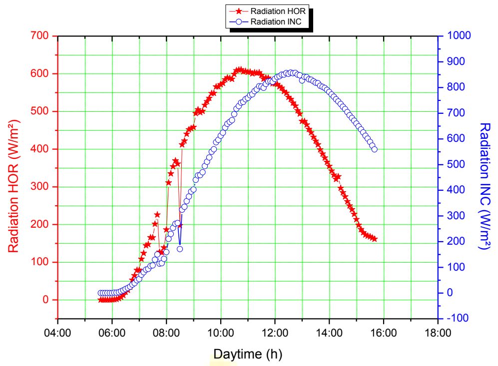

Fig.9 Solar radiation on horizontal and inclined surfaces.

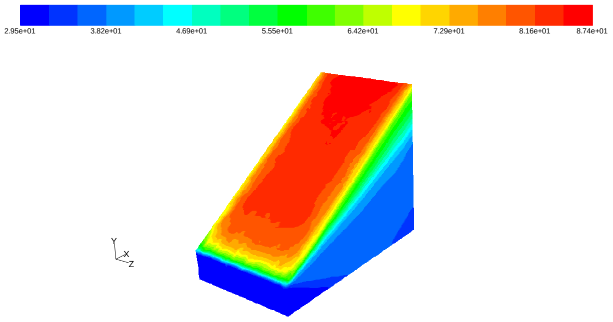

Fig.10 Contours of the surfaces radiation temperature.

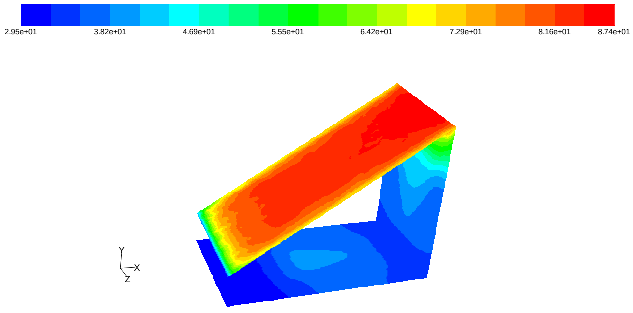

Fig.11 Contours of the surfaces radiation temperature (north, board, glass and outlet).

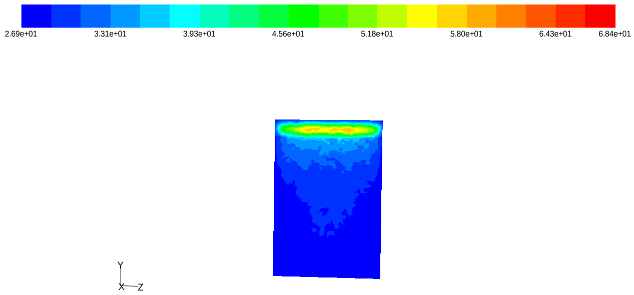

Fig.12 Contours of the total temperature (outlet and north).

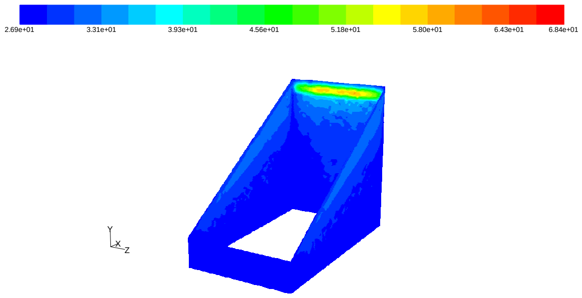

Fig.13 Contours of the total temperature (north, East, West, inlet and outlet).

Note that Figures 12 and 13 show a contour of different total temperature evolution in all surfaces of dryer, can justify the reason for the increase in the mass of hot air out of the emissions rate.

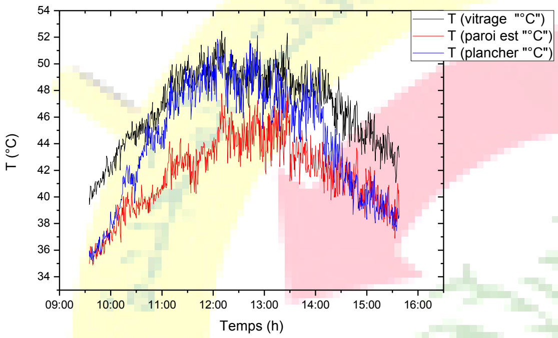

Fig.14 The temperature distribution in the different surfaces of the greenhouse.

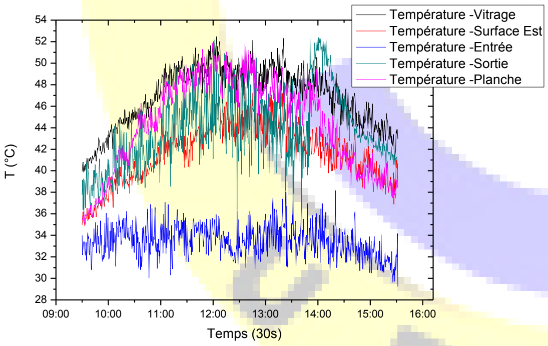

Fig.15 The temperature distribution on the glass, inlet, plane north, East, West, and outlet of the dryer.

VI. CONCLUSION

The greenhouse type solar dryer works by convection and does not require energy input making it completely autonomous. In fact, solar energy is the only energy that ensures the operation input. The openings for the entry of cold air and the hot air outlet have adjustment devices for controlling and adjusting the amount of air passing through the dryer and allow for the control and regulation of conditions inside the dryer. This dryer can be easily used for the enhancement of food waste as feed for poultry. Provided wheel mobile making, it can be transported directly from the place of accumulation of waste to be fitted value of the product on the drying racks. It is intended to be used in rural and remote areas [4].

The weight measurement system installed outside the drying chamber for monitoring the process of reducing the weight of the product is ingenious. Indeed, the dryer suffers no external disturbance by any opening of the chamber. The advantage of this device is digital weight indicator to inform the user of the dryer at the end of the drying process without the need for quality control in the laboratory. The greenhouse type solar dryer can handle large quantities of products to be dried. It is recommended for production plants, agricultural farms or large plantations. The greenhouse type solar dryer is designed to dry products in a completely protected against dust, insects, animals, the rain and atmosphere, thereby guaranteeing a finish of a very high quality product. The operation of the solar greenhouse dryer type is fully autonomous and does not require skilled labor.

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