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MATHEMATICAL MODELING OF SOLAR DRYING OF TOMATOES
MODELISATION MATHEMATIQUE DU SECHAGE SOLAIRE DES TOMATES

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Abstract

Drying is one of the main techniques of preservation of agricultural and food products. Many food products are dried to increase their life and improve the appearance. In this work, the effect of different drying parameters (air drying, forced convection, solar drying and velocity drying) on drying kinetics of tomatoes are studied. For this purpose the mathematical model is developed to predict the drying behavior and activation energy on the range of temperatures usually encountered in industry. The results show that the solar drying with forced convection at temperature 55°C of and air velocity 2m/s were the best drying data of tomatoes solar drying.

Key words: Solar Drying, Tomatos, Modeling, Forced Convection.

Résumé

Le séchage est l'une des principales techniques de conservation des produits agricoles et alimentaires. De nombreux produits alimentaires sont séchés pour augmenter leur durée de vie et améliorer leur apparence. Dans ce travail, l'effet de différents paramètres de séchage (séchage à l'air, convection forcée, séchage solaire et séchage par vitesse) sur la cinétique de séchage des tomates est étudié. A cet effet, le modèle mathématique est développé pour prédire le comportement de séchage et l'énergie d'activation sur une gamme de températures habituellement *utilisée dans l'industrie. Les résultats montrent que le séchage solaire a convection forcée à une température de 55 °C et une vitesse de l'air de 2m/s étaient les meilleures données du séchage solaire des tomates.*

Mots clés: Séchage Solaire, Tomates, Modélisation, Convection Forcée.

1. Introduction

Many agricultural products, as tomato (Lycopersicon esculentum L.) are not always available during seasons. They can be easily preserved bygrowing in greenhouses, freezing, or drying[1]. Drying proves to be a simple and adequate solution. As many processes, drying techniques have been reported in literatures with their advantages and disadvantages [2, 3].They gave nutritional composition, antioxidant activity, polyphenols and carotenoids of food products.

The main objective of this study deals with the mathematical modeling of drying of tomato using an indirect solar drier functioning in forced convection. The various tests consist in the influence of the various conditions of the draining air (temperature, velocity...) on the process of drying. These parameters permit us to improve the performances of drying and consequently the quality of the product.

2. Material and Methods

Figure 1 presents different solar dryers and different modes.

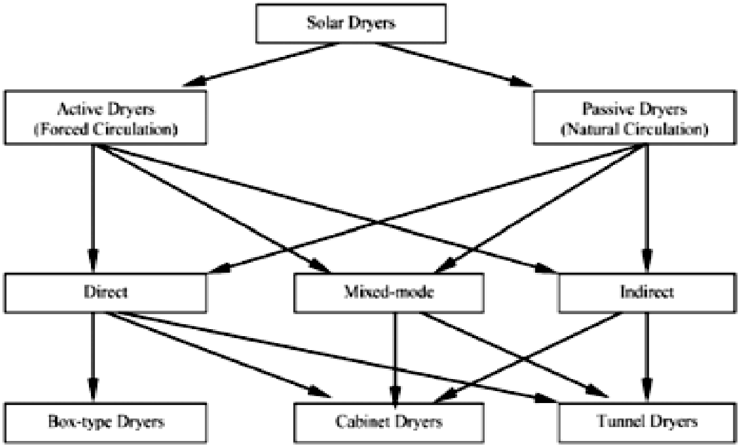


Figure-1. Classification of solar dryers drying modes [4, 5].

2.1. Choice and system description

Reasons of the choice of this process are in following points:

- The consumption of energy during operation,
- The safeguard of the product's aromatic quality,
- The preservation of air- thermal parameters,
- The kinetic drying,
- Mode of heat contribution,
- Mode of drier operation,
- Time of use,
- Quantity for dried products.

In our study, forced convection indirect solar drying (Figure 2) is assumed [4, 6].

⇒ Convection exchange 1: Hevanly vault 4: Product (tomato)
⟺ Convection exchange 2: Ambiant 5: Drying medium
→ Radiation exchange 3: Wall 6: Tray

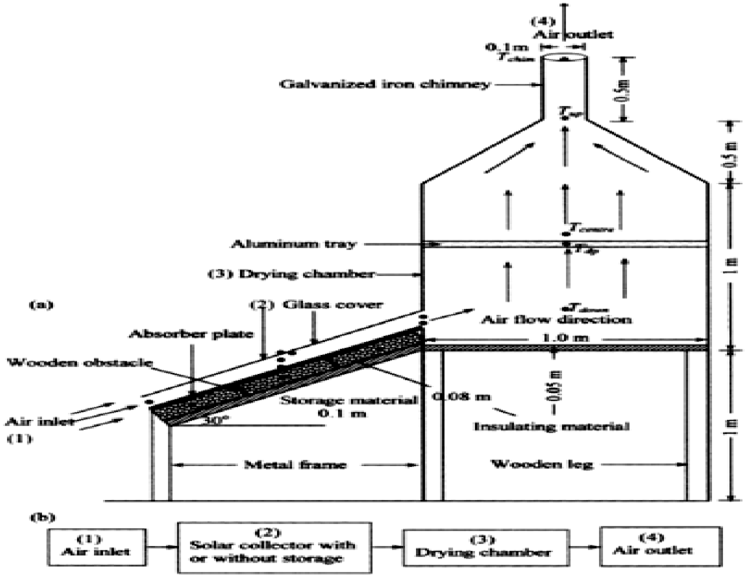


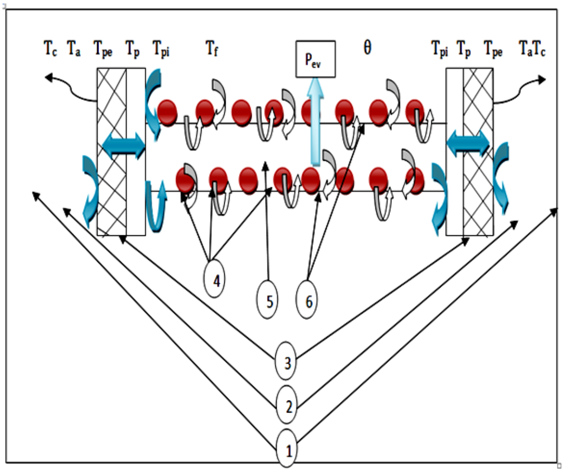
Figure 2. (a) Cross-sectional view of the indirect type natural convection solar dryer; (b) Air flow diagram. [6]

The following assumptions are considered.

- radiative exchanges inside the drier are neglected,
- heat exchange relating to the trays are neglected (conduction tray-product),
- thermal and pressure losses in the piping of connections are neglected,
- dry air and water vapor are assumed as perfect gas,
- air flow is supposed to be uniform and in one-way,
- Temperature and the water content are supposed uniform inside the product.

2.2. Energy and mass balance for room drying

Modeling the drying unit: Mathematical formulation



2.2.1. Product energy balance (tomato)

$$m_f \cdot Cp_f \left(\frac{dT_f}{dt}\right) = h_{air,pr} \cdot S(\theta_{(j-1)} - T_f) - P_{ev} \tag{1}$$

Using the product surface, we get:

$$\frac{m_f \cdot Cp_f}{S} \left(\frac{dT_f}{dt}\right) = h_{air,pr} (\theta_{(j-1)} - T_f) - P_{ev} \tag{2}$$

The evolution of energy balance of tomato over time is given by the system of equation 3:

$$\begin{cases}
\dfrac{m_{pe}\cdot Cp_{pe}}{S_p}\left(\dfrac{T_{pe}^{t+\Delta t}(j)-T_{pe}^{t}(j)}{\Delta t}\right)=h_{ce}(T_a-T_{pe}^{t+\Delta t}(j))+h_{re}(T_c-T_{pe}^{t+\Delta t}(j))+h_{cd,p}(T_p^{t+\Delta t}(j)-T_{pe}^{t+\Delta t}(j)). \\
\dfrac{m_{pi}\cdot Cp_{pi}}{S_p}\left(\dfrac{T_{pi}^{t+\Delta t}(j)-T_{pi}^{t}(j)}{\Delta t}\right)=h_{cd,pi}(T_p^{t+\Delta t}(j)-T_{pi}^{t+\Delta t}(j))+h_{air,pi}(\theta^{t+\Delta t}(j-1)-T_{pi}^{t+\Delta t}(j)). \\
\dfrac{m_{pe}\cdot Cp_{pe}}{S_p}\left(\dfrac{T_{p}^{t+\Delta t}(j)-T_{p}^{t}(j)}{\Delta t}\right)+h_{cd.p}\left(T_p^{t+\Delta t}(j)-T_{pe}^{t}(j)\right)=\dfrac{m_{pi}\cdot Cp_{pi}}{S_p}\left(\dfrac{T_{p}^{t+\Delta t}(j)-T_{p}^{t}(j)}{\Delta t}\right)+h_{cd.pi}\left(T_{pi}^{t+\Delta t}(j)-T_p^{t}(j)\right) \\
Q\cdot C_p(\theta^{t+\Delta t}(j)-\theta^{t+\Delta t}(j-1))=h_{air,pi}\cdot S_p(T_{pi}^{t+\Delta t}(j)-\theta^{t+\Delta t}(j-1))+h_{air,pr}\cdot S(T_f^{t+\Delta t}(j)-\theta^{t+\Delta t}(j-1)). \\
\dfrac{m_{f}\cdot Cp_{f}}{S}\left(\dfrac{T_{f}^{t+\Delta t}(j)-T_{f}^{t}(j)}{\Delta t}\right)=h_{air,pr}(\theta^{t+\Delta t}(j-1)-T_f^{t+\Delta t}(j))-P_{ev}
\end{cases} \quad (3)$$

The equations system of five unknown factors is obtained, these unknown factors are T_{pe}, T_{pi}, T_p, T_f and θ where:

T_p : Temperature between the two walls [K],

T_{pe} : Temperature of the outer wall [K],

T_{pi} : Internal wall temperature [K],

θ : Drying air temperature [K],

T_f : Product temperature [K],

3. Results and discussion

To solve the model equations, we chose the numerical solution of MATLAB simulation tool. In this method, all the unknowns are expressed in time (t) so that the end result is a system of five equations with five unknowns.

3.1. Evolution of the product's temperature during drying

Figure 3. presents the variation of temperature of the product versus the time. At the beginning of drying, the temperature of the product is 290K. Its increases in a significant and fast way until reaching a maximum value (about 305K); this increase is a both-way exchange (forced convection and conduction); the convection is between the product and the draining

air and conduction phenomenon is between the product and the dryer wall chart [7].

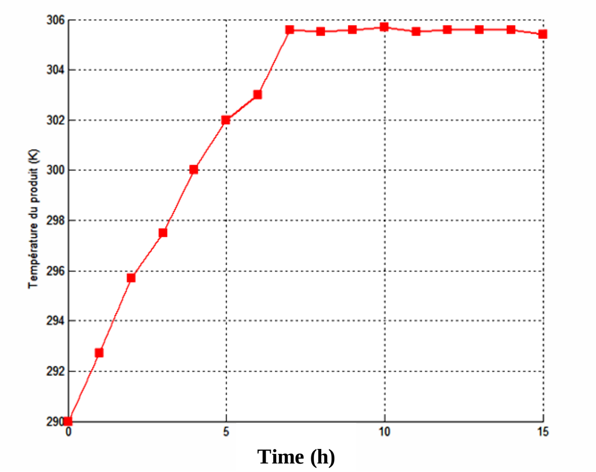


Figure 3: Variation the temperature product vs time

3.2. Variation of the absolute Humidity of tomato during drying

The humidity decreases strongly until reaching a more stable pace; starting from 11h (Figure 4). In fact, the air enters dry and warm with low water content, passes through the various trays, moistening and cooling because of heat and mass transfer with the product.

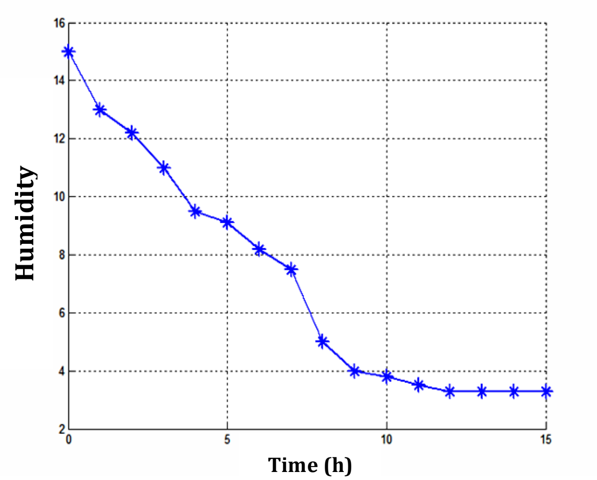


Figure 4. Evolution of the absolute humidity vs time.

3.3. Variation of drying velocity with time

In table n°1, different velocities are reported. As the temperature increases, the velocity of drying increases and becomes high. Indeed, absolute humidity drops quickly and the drying speed becomes high and consequently time drying is reduced [8, 9].

Table n°1: Variation the drying velocity

V(m/s)	0	2	2.2	2.3	2	1.25	0.65
Time (h)	0	1	1.82	2.80	5	6.10	0.71
V(m/s)	0.34	0.29	0.28	0.28	0.28		
Time (h)	10	11	12	13	15		

3.4. Variation of moisture (water content) for various trays

According to Figure 5, ones notes that the product dries faster in the first racks, compared to the product placed on the last. As air moves into the dryer, its temperature decreases and its humidity increases. The explanation is that, the wet product gives up its water to the air since it governs a partial pressure of water vapor lower in the air than the surface of the tomato. The increase of the temperature makes it possible to give more heat to the product, thus more evaporation of water. For the first screen (tray), the heat brought by the air is important and for the second screen the air temperature will drop, which will reduce the amount of evaporation of the water, the same phenomenon being reflected in the other racks [10].

The drying time of the product increases from the first to the last rack, because the air flow in the cabinet is from bottom to top. Moving from a lower rack to a rack

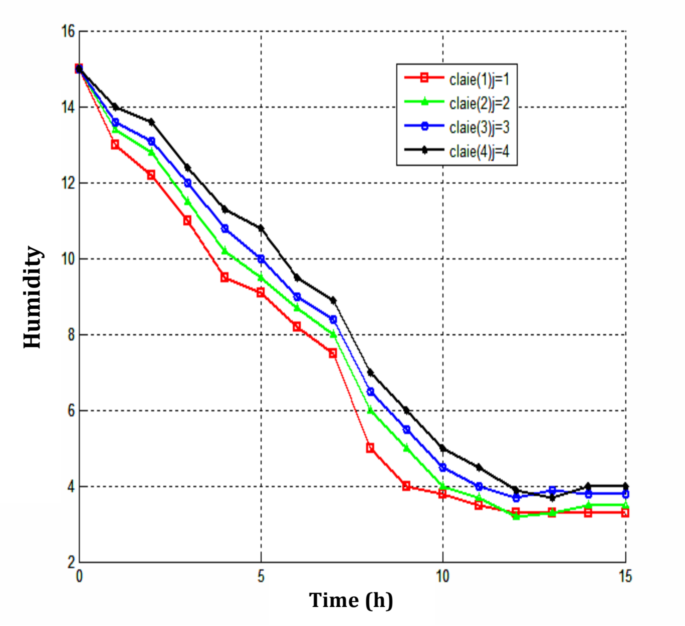


Figure 5: variation of the absolute humidity vs time with various trays

3.5. Influence of the drying air temperature on the moisture of the product

Figure 6 shows the influence of the drying air temperature (between 313 and 328K) depending on the moisture of the product, for a mass of 1 kg of tomato placed on each rack. For the first time, the increase in the temperature of the drying air makes it possible to give more heat to the product, thus more water evaporation due to the increase of the water pressure inside the product which accelerated the migration of product water to the outside.

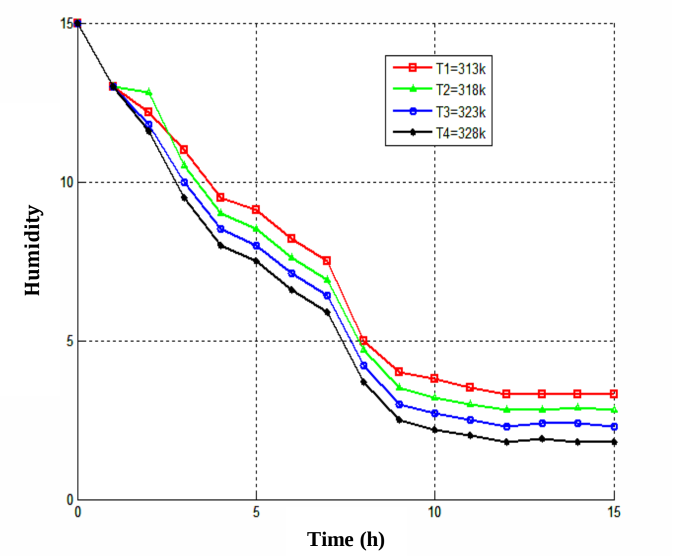


Figure 6: Effect of the air drying temperature on moisture of tomato

Conclusion

Tomatoes (Lycopersicon esculentum L.) are essentially and widely consumed as components of diet in the world. They are nutritionally beneficial and contain antioxidant compounds which play important roles in inhibiting the formation and progression of Reactive Oxygen Species (ROS) that are responsible for degenerative diseases.

In this study, a mathematical model has been applied to the indirect solar dryer to improve its effectiveness. The theoretical study of the drying chamber permit to distinguish a difference in drying of the product that is on the various screens of the dryer. The progression of the heated air in height, leads to the increase of the water content of the product of trays. The increase in temperature and velocity of the drying air (increase of the evaporative power of the drying air) makes it possible to increase the heat and mass exchanges and consequently it makes it possible to raise the quantities of evaporated water and the temperature of the product to be dried. At the end, this model proved its effectiveness.

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