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Research Article

Experimental drying kinetics of mango slices (*Mangifera indica L.*) *Amelie* under intermittent conditions

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Abstract

The drying kinetics of food is very important for the understanding of the drying process and for optimizing the drying conditions. This work is an experimental contribution to the study of drying kinetic of mango under intermittent drying mode. Drying was carried out in a convective dryer using three inlet air temperatures (40°C; 50°C and 60°C) with 200 g of mangoes slices having an initial moisture content of 80%. During the experiments, the duration of each cycle was 120 minutes, and the intermittent mode was conducted with 60 minutes at the desired temperature and 60 minutes at the ambient temperature. The results showed that for a variation in the air drying temperature of 20°C, the drying process at 60°C ended at 90 minutes before the same operations at 40°C on an intermittent mode. Also, when the samples are stored inside the drying chamber during the tempered periods, the moisture content was almost constant, but if they are outside the drying chamber, they undergo a rehydration as soon as their moisture content is lower than 65%. Moreover, the results show that the intermittency period no longer has influence on the drying kinetics, when the moisture content of samples approaches 18 %, independently of the drying air temperature.

Keywords: *Heat flow, mango, intermittent mode, convective drying.*

1. Introduction

Drying is one of the oldest techniques used by the human being for food preservation. In the developing countries of Sub-Saharan Africa, it is a vital technique, in the direction where it makes it possible to mitigate the seasonal shift of the majority of the food crops and consequently the spreading out of consumption over all the year. However, inadequate control of this technique at the artisanal level generates substantial quantity of post-harvests losses. These losses are more significant in the wet tropical zone characterized by an average relative humidity of the air higher than 60 % which can reach 90 % and an average ambient temperature of 30°C (Amat, *et al,* 2002), (Edoun, 2010; 2014a), when it is about the drying of the products with higher moisture content such as the fruit and vegetables (moisture content ranging between 60 and 85 %). These losses estimated today at approximately 40 % in these countries (Bala, *et al,* 2003), (Edoun, *et al,* 2010; 2014b), (Takamte, *et al,* 2013) of this wet tropical zone, justifies itself by the evaporating capacity of the air is there definitely weaker (Edoun, 2010), (Derbal, *et al,* 2002).This is why artisanal drying having as principal factor of the quick transport of air shows its limits during drying of the agricultural produce with higher moisture content in an environment with higher relative humidity. In this context, we note a relatively long duration of drying process, biochemical degradations of the products, conditions favorable to the development of the pathogenic micro-organisms (El-Beltary, *et al,* 2007), (Kamil, 2007), (Madhlopa and Ngwalo, 2007), (Nganhou and Nganya, 2002).

Nowadays if with the development of the new increasingly modern techniques of drying, the problems involved in the quality of the product are quasi solved, it is not the same for the power consumption of the drying equipment even less during the drying of the products on a small scale. This set of energy themes is always of topicality in spite of many works having approached this shutter of drying. For the ones, the optimization of drier and product parameters strongly contribute to the reduction of the power consumption during the drying of some agricultural products (Kowalski and Szadzinska, 2014), (Putranto and Chen, 2013), (Oke and Omotayo, 2012), (Putranto, *et al,* 2011), (Ben Ali, *et al,* 2010), (Vaquiro, *et al,* 2009), (Baini and Langrish, 2007), (Jumah, *et al,* 2007), (Chua and Chou, 2005), (Chou, *et al,* 2000). On the other hand, for other researchers, the modification of the procedure of control of drying is an energy factor

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of optimization of drying (Jumah, *et al,* 2007), (Bon and Kudra, 2007), (Cihan, *et al,* 2007), (Cao, *et al,* 2004). This new concept gave rise to drying with variable mode with for corollary intermittent drying where the temperature oscillates in a cyclic way around two point of instruction (Chou, *et al,* 2000). In agreement with literature, Edoun, *et al,* (2010) showed that in wet tropical zones, artisanal drying on a small scale of the fruit and vegetables obey this new process of drying: drying being spread out over several days, supposes a stop of the drying operation during the night.

The work already carried out on the intermittent drying of the agricultural products shows that, although the practice of this mode of drying is very old, its definition and its technique of implementation vary from author to author. Indeed, certain authors define the intermittency right by the interruption of drying and the resumption of drying, actions which are not controlled by any law or criterion (Cihan, *et al,* 2007), (Cao, *et al,* 2004), (Shei and Chen, 2002; 1998), (Pan, *et al,* 1999; 1998). Others could define it on the basis of cycle having a given duration: the intermittency is the relationship between the total duration of the cycle and the duration of temperance (Li, *et al,* 1998). In this case, parameters values are positive whole numbers. It is worth zero when drying is continuous. But it is also defines as the relationship between the duration of drying and the total duration of the cycle (Chou and Chua, 2006), (Chua, *et al,* 2003), (Chou, *et al,* 2000). Two parameters held the attention of the researchers at the time of the practice of intermittent drying: duration of drying and the final quality of the dried products. They thus highlight the positive effects of intermittent drying on the power consumption. Actually, these results are consequences of the several phenomena which proceed during this type of drying, precisely with the stops and resumptions of drying. However in extreme cases of our knowledge, the phenomena which unroll their particular during an intermittent cycle is badly described in the literature that it either in experiments that numerically.

The objective of this work is the experimental characterization of the intermittent drying of mango, so to analyze the influence of the on and off periods on drying kinetics of mango in a strongly wet environment.

2. Materials and methods

2.1 Plant material

The mangoes used in this study were the local variety *amelie* cultivated in the locality of Dang-Ngaoundere (latitude: 7°32 N and longitude: 13°58 E) in the Adamawa's region in Cameroon. It has an average weight of 310 $^{\pm 45}$ g with an average moisture content of 84 $^{\pm 2}$ % and a °Brix of 12.8 for mangos in maturity. Its great width measures between 6.4 and 7.5 cm and the height between 8.20 and 11.60 cm. With their yellowish color, these mangoes are harvests between April and June.

2.2 Experimental device

The experimental device is a convective pilot dryer with controlled air circulation (Kuitche, *et al,* 2006) installed at the Laboratory of Energetic and Applied Thermal (LETA) of the ENSAI of Ngaoundere. It is composed of an electric box, a turbine, an air heating system, a drying chamber and a compartment of recycling. The drying chamber has 10 trays superimposed with a spacing of 10 cm between them. A tray has length a 48 cm and a width of 32 cm is a surface of 0.15 m^2 per tray.

The measurement of the loss of weight of mango was taken using an electronic balance of mark Sartorius BASIC SE 622, with a precision of ± 0.01g, an infra-red thermometer (DVM8090 with 0.1°C resolution and precision ± 5°C) was used for the surface temperature product measurement. A thermocouple of the type K, a model anemometer FVAD 15 S120 and a model hygrometer ZAD 936 RAK were used for respectively to measure the temperature, the drying air velocity and the relative humidity. These characteristics of the air are recorded every 30 minutes with a power station of acquisition Almemo 2250, whose various probes are placed at 15 cm below the tray, to avoid the phenomena of turbulence. The temperature control of drying was possible thanks to the use of a thermostat of type EC.50 M/N with a precision of 0.2°C.The experimental device is presented at figure 1.

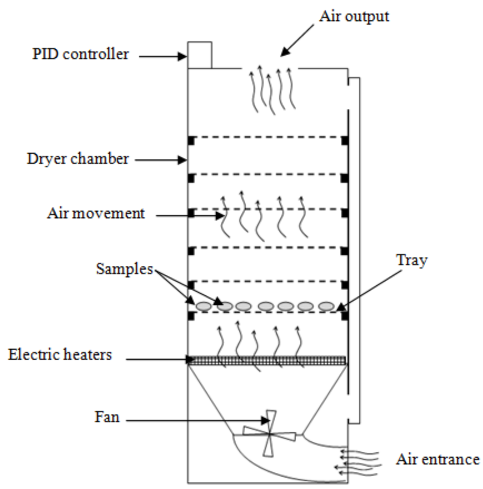

Fig.1 The laboratory convective dryer

2.3 Methods

The tests of this work were carried out according to the method of Chou and Chua, (2006); Chua, *et al,* (2003); Chou, *et al,* (2000); where the intermittency α is defined as the fraction of cycle when heating is on; i.e., (equation 1).

$$\alpha = \frac{\tau_{on}}{\tau} = \frac{\tau_{on}}{\tau_{on} + \tau_{off}} \qquad (1)$$

τ_{on} : "On" period (min)
τ_{off} : "Off" period (min)

In this study, the intermittency α is equal to ½, bother one hour of on period and an off period. Drying air temperature can obey of the following relations (equations 2 and 3)

$$T = T_h \quad \text{for } \tau.n \le t \le \tau.(n+\alpha) \tag{2}$$

$$T = T_{amb} \quad \text{for } \tau.(n+\alpha) \le t \le \tau.(n+1) \tag{3}$$

Where T_h and T_{amb} denote higher and ambient temperatures, respectively; τ is the cycle period; n : is the number of heating cycles done (n = 0, 1, 2, ...).

- *Samples preparation*

The mangos are washed and rinsed with ordinary water to eliminate the impurities possibly present at their surfaces. They are peeled, stoned and cut out in sections of average size of 40 X 15 X 10 (mm).The initial weight of the sections laid out on a tray in a layer thickness 10 mm is 200 g. At the time of the experimental countryside, the environmental conditions of the room sheltering the drier are: average temperature 23°C, average relative humidity 65 percent. After preparation, samples were taken before and after drying and were introduced into a drying oven carried for 24 h at 105°C, for the determination of the initial and final moisture content of mango using method AFNOR 1984.

- *The drying process*

The Summary of the operating conditions applied on the continuous and intermittent drying experiments of mango are given on table 1.

Table 1 Operating conditions applied on the continuous and intermittent drying experiments of mango

Parameters	Ambient	Drying mode	
		Continue	Intermittent
Temperature (°C)	22	40 ; 50 ; 60	40 ; 50 ; 60
Velocity (m/s)	0.02	0.6	0.6
Relative Humidity (%)	65	/	/
Mass of samples (g)	/	200	200
Intermittency	/	1	1/2
Period of cycle (min)	/	120	120

To follow the weight profiles of the product during drying, the weighing of the tray is carried out uninterrupted every 30 minutes thanks to an electronic balance SE 622 of precision 0.01g, located the interior of the drier. The experimental procedure is then illustrated by figure 2.

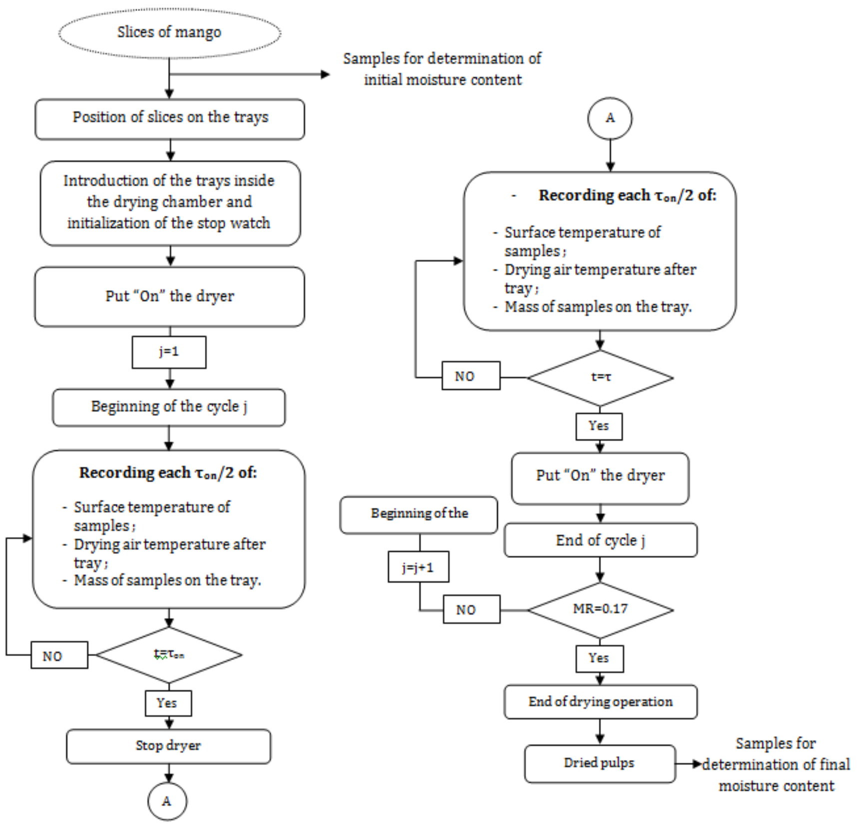

Fig.2 Experimental procedure

From the masses obtained by weighing, the moisture contents in dry base are calculated by using the equation (4) (Aghfir, *et al,* 2007).

$$X = \frac{m\,(t) - m_s}{m_s} \quad (4)$$

Where m(t) is the mass of fruit on a tray at instant t, m_s the corresponding dry mass, and X, slice's moisture content ($kg_{water}.kg_{dm}^{-1}$ d.b).

The dimensionless form or moisture ratio can be obtained by equation (5) (Estürk and Soysal, 2010).

$$MR = \frac{X - X_{eq}}{X_0 - X_{eq}} \quad (5)$$

X the average moisture content of the product, X_0 the initial moisture content, X_{eq} the equilibrium moisture content.

By neglecting equilibrium moisture content in front of average moisture content of the product and the initial moisture content, we obtain the equation (6) (Estürk and Soysal, 2010).

$$MR = \frac{X}{X_0} \quad (6)$$

The developing of equation (6) conduct to following relation:

$$MR = \frac{m(t)}{m_i} \quad (7)$$

With m_i, m(t) mass of fruit respectively at initial instant and at instant *t* (kg)

The drying rate is calculated using the equation 8

$$\frac{dX}{dt} = \frac{X_t - X_{t+dt}}{\Delta t} \quad (8)$$

Where : t = Period drying (min), X_t = Moisture ratio at the instant t
X_{t+dt} = Moisture ratio at $t+dt$

3. Results and discussion

3.1 Dry air temperature profiles

Figure 3 presents the theoretical and experimental profiles of the drying air temperature for an inlet temperature of 40°C.

On this figure, the theoretical curve represents the behavior of the drying air at the entry of the drying chamber. For the three temperatures tested (40°C, 50°C and 60°C), this behavior is identical. The temperature of the ambient air in May was around 23°C, and drying was carried out during 570 minutes at 40°C (i.e 9 hours 30 minutes).

The duration of a cycle being fixed at 120 minutes, this figure was carried out for an intermittency α=½, it is with-statement which the product is exposed to the flow of hot air during half of the cycle, in the case of this study 60 minutes, then receives a flow of air at the ambient temperature during other half: it is a regulation of drying air temperature, one of the techniques of an intermittent mode presented by Chou and Chua, 2006.

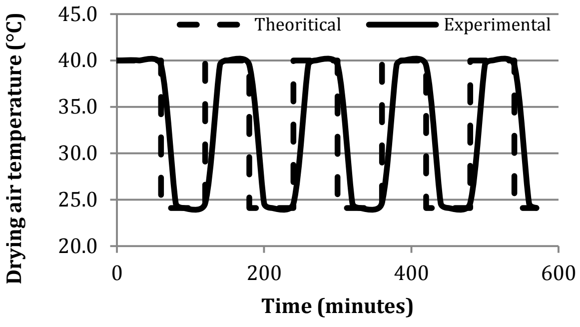

Fig. 3 Drying air temperature profiles during intermittent drying at 40°C

The experimental curve presents the real behavior of the drying air at the entrance of drying chamber. In this work, the technique used it similar to that of Biani and Langrish, (2007), which consists in leaving the product in the drying chamber for the tempered period. Thus before the starting of the drier, the products being already in the drying chamber, there is a thermal phenomenon of inertia, it is the latter which creates the shift between the theoretical temperature and the experimental temperature. However this shift being a function of the ambient temperature, is almost constant, according to weather is this temperature, and also thermal inertia is quickly overcome when the drying air temperature is larger: it is what figure 4 illustrates.

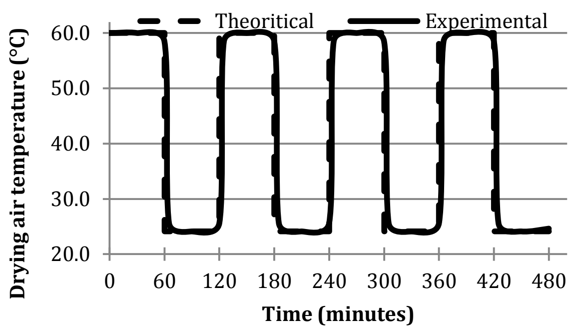

Fig.4 Drying air temperature profiles during intermittent drying at 60°C

Figure 4 presents the theoretical and experimental profiles of the drying air, between which the shift is almost null. This figure shows that thermal inertia is easily overcome for a temperature of 60°C, and also, the duration of the drying operation which was 570 minutes with 40°C is reduced to 480 minutes.

3.2 Influence temperature on the kinetics of drying

a. Moisture content profiles

The moisture content profiles on continue and intermittent modes are represented by figures 5, 6 and 7 respectively at 40°C, 50°C and 60°C.

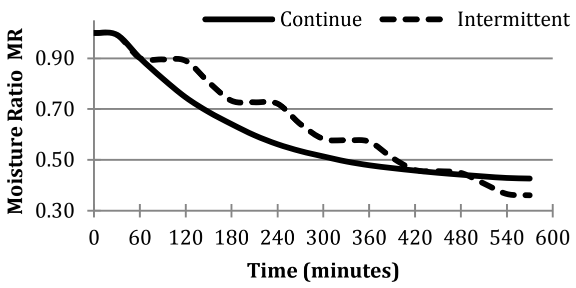

Fig.5 Moisture ratio profiles of mango on continuous and intermittent modes at 40°C

On figure 5, with 40°C in continuous mode as in intermittent mode, the variation of the moisture content during the first 30 minutes is very weak. This is because when a product is exposed to a flow of hot air, it appears a first phase called phase of temperature setting, of which the duration depends on the parameters such as the moisture content of the product, its thickness and temperature, the temperature, relative humidity and velocity of drying air. Thus taking into account these various parameters associated with the moment of statement of the first measurement, this observation is normal. In addition, the environment in which drying being at an ambient temperature is carried out around 23°C, the evaporation of the water from the product for an operation of drying to 40°C is very slow. After 570 minutes, the moisture content reduces to 36 %. The later is higher than the value of the residual water content recommended by Kuitche, *et al,* 2007 and O' Mahony, *et al,* 1986 for the fruit and vegetables conservation, which must lie between 15 to 28 %.

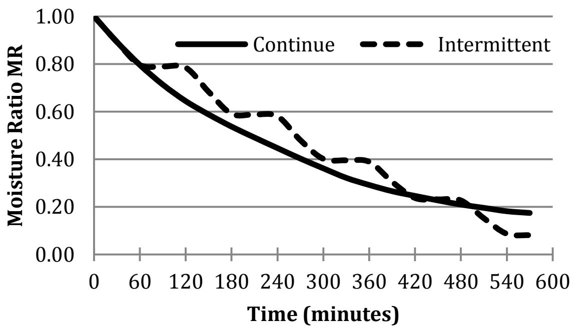

Fig.6 Moisture ratio profiles of mango on continuous and intermittent modes at 50°C

The analysis of figure 6 shows that over 420 minutes total duration, the samples already reached the final moisture content for two cases. After 60 minutes additional of exposure to the flow of hot air, the products reached the minimal value of this water content residual. The comparison between figures 5 and 6 shows which one needed 10°C additional of drying air for a saving time and the quality of dried products.

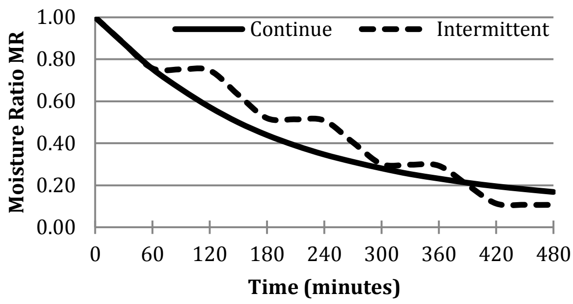

Fig.7 Moisture ratio profiles of mango on continuous and intermittent modes 60°C

On figure 7, one also raises the impact of the drying air temperature on the duration and the final moisture content of the samples.

Generally, of these three figures, we noticed that the final moisture content of the product during intermittent drying carried out is always lower than that of drying in continuous mode. This behavior of the product can be justified in the following way: drying being a thermal operation, when the product is exposed to a flow of hot air, evaporation is carried out surface towards the center of the product. Thus, longer is this exposure of the product to the hot air, which led to the shrinkage, and thus prevents water from evaporating product, and consequently slows down the operation of drying. On the other hand, if at a given moment, the product comes to be exposed to a flow of ambient air (weak compared to the temperature retained for the operation of drying), then it is carried out a distribution of water in the product. Indeed, for the period of exposure to the ambient temperature, the variation in temperature between the product and the air, obligate the migration of the water of the center of the product towards its surface, which softened then the latter. This description will be illustrated better by the layout of the drying rate profiles. These results obtained are in agreement with those of Da Silva, *et al,* (2015); Cihan and Ece,(2001); Chou, *et al,* (2000).

Moreover, at 50°C and 60°C, all the curves in intermittent mode tend to become punts after 450 minutes. This generally means for these two temperatures that, when the product already reached its residual moisture content, the intermittency does not influence any more drying. These results were also obtained by Putranto, *et al,* (2011); Baini and Langrish, (2007).

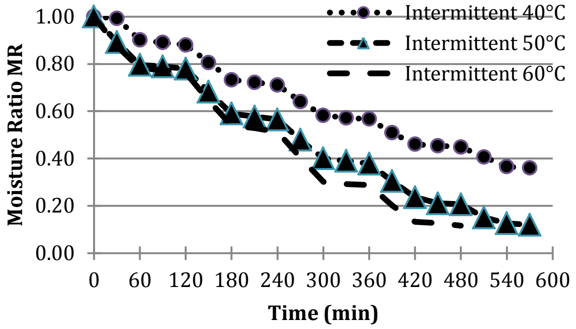

Fig. 8 Moisture ratio profiles of mango in an intermittent mode at 40°C, 50°C and 60°C

At the intermittent mode, for the three temperatures tested (figure 8), we note that the intermittency has a significant impact, so much over the duration of drying than on the final moisture content of the product.

During the first 60 minutes of drying, the moisture content reduced of the product with 50°C and 60°C are almost close. But after the first tempered period, these curves open gradually, thus put forward the influence of the temperature of drying over the duration of drying. At 60°C, the samples reached their residual moisture content after 420 minutes, i.e after 240 minutes of exposure to the flow of hot air, whereas it took 90 more minutes more for drying at 50°C to reach this residual moisture content, that is to say one 570 minutes total duration.

Moreover, being in the wet tropical zone where the air relative humidity is very high all along the year, and particularly in May, the choice to leave the products in the room of drying is justified. Because, if those had been suddenly exposed to the ambient air, they would have tendency to rather rehydrated itself. Thus, figure 9 shows that for the tempered periods at 60°C, the moisture content of the products left in the room of drying is constant.

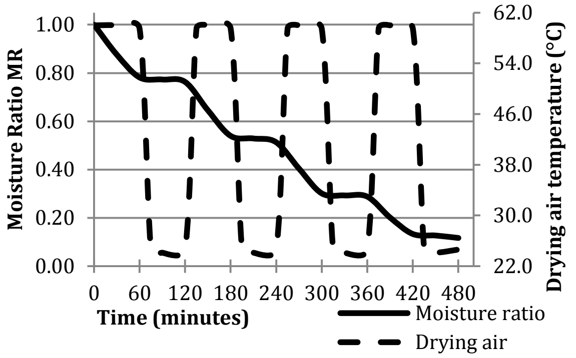

Fig.9 Moisture ratio of mango and drying air temperature profiles at 60°C (Intermittency inside drying chamber)

Figure 9 shows the influence of the presence of the samples in the drying chamber for the tempered periods. Indeed, it is noted that after the second cycle, that is to say 240 minutes after the beginning of drying, the moisture content of the product is around 50 %, therefore lower than the relative humidity of the day around 65 %. In spite of that, for the other tempered periods, the moisture content remained constant. These results were also obtained by Putranto and Chen, (2013). Whereas if these samples had been suddenly exposed in the ambient air, those would tend to rehydrated, thus reversing the process of drying (figure 10).

Figure 10 presents the moisture content profiles reduced of the samples of mangos dried in intermittent mode, if the samples are exposed to the ambient air for the tempered period. It is the technique used by Da Silva, *et al,* (2015) and Pan, *et al,* (1998).

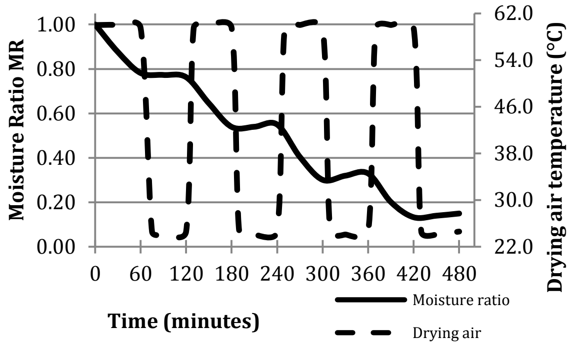

Fig.10 Moisture ratio of mango and drying air temperature profiles at 60°C (Intermittency outside the drying chamber)

On figure 10, we see that during the first tempered period, the water content reduced of the samples remained constant; therefore it did not have rehydration of the product there. This is justified by the fact that the moisture content reduced around 80 % is still higher than the relative humidity of the ambient air which was around 65 %. But as of the second intermittency, this moisture content grows slightly, and intensifies with the third intermittency. It is noticed whereas as soon as the product reached moisture content reduced lower than the relative humidity of its environment, the process of drying is reversed, and the product is rehydrated rather. This phenomenon was illustrated per none the researchers whose work was found in the literature.

b. Surface temperature product

Figures 11 and 12 present the surface temperature product profiles and the drying air at the entrance of the drying chamber during the intermittent mode respectively at 40°C and 60°C.

On figure 11, we see that the drying air temperature at the entrance of the drying chamber follows a harmonic. In continuous mode, the temperature of the samples grows gradually progressively when the moisture content of the product decreases, until approaching the temperature of the drying air. These results are largely presented in the literature.

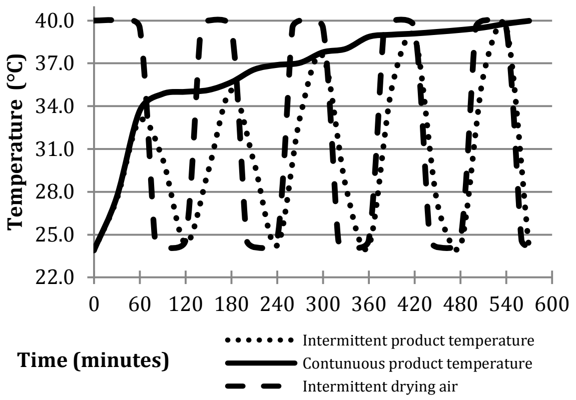

Fig.11 Surface temperature product and drying air profiles at 40°C

In intermittent mode, we note firstly that the temperature of product and the drying air have the same pace. Only, each rise of the temperature of the product is higher than the preceding one, proof that the moisture content decreases. These results are similar to those of Putranto and Chen (2013). As, it is observed as the samples temperature at each tempered period, approaches the ambient temperature. This is justified by the fact that the variation in temperature between the samples and the drying air is weak, compared to a drying at 50°C or 60°C.

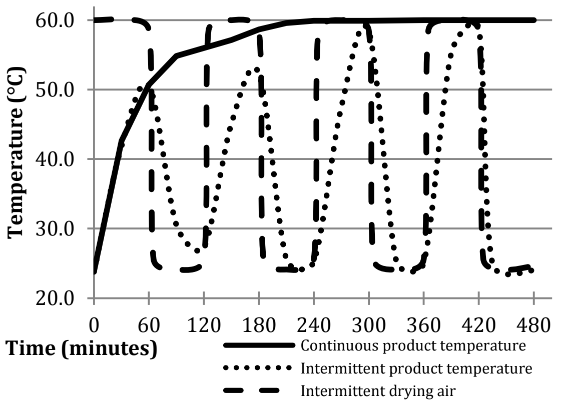

Fig.12 Surface temperature product and drying air profiles at 60°C

On figure 12, during the first 60 minutes, we remark that the two profiles of temperatures are almost identical, even report that with 40°C. Only with the first tempered period, the surface temperature product is still higher than that of the ambient air temperature. This is justified by the fact that the temperature of the drying air being sufficiently high relatively the ambient temperature, the downtime identical to that of figure 10, is short. However, as of the second tempered period until the end of drying, i.e. as from 180 minutes, this time becomes sufficient so that the surface temperature product is equal to the ambient temperature, because moisture content of the products to be decreased. Thus the temperatures of the samples balance quickly as soon as there is variation in the temperature of the drying air. Towards the end of drying, one notices that an abrupt variation of the temperature of the drying air induced also an abrupt variation of the samples temperature, because those do not contain enough moisture.

c. Drying rate profiles

On intermittent mode of drying, the drying rate profiles are described by function of a sinusoidal type whose amplitude decreases in the course of time. It should be noted that after each phase of drying at the ambient temperature, the drying rate increases in the course of time to reach values higher than those obtained at the same moment in mode of continuous drying. It is observed that the difference between the values the speed of drying obtained in continuous mode and intermittent mode increases with time (figure 13).This result is due mainly to the redistribution of moisture inside the product at the time of the phase of drying at the ambient temperature, which leads to one rebalances moisture in the product. The observation of the sections of mango dried in intermittent mode shows that this distribution continues moisture in the product makes it possible to avoid the abrupt contracting of the product and to reduce the phenomenon of shrinkage which is very frequent during the drying of the agro-alimentary products in general and with higher moisture content of have in particular. These results are similar to those of Ben Ali, *et al,* (2010) and Pan, *et al,* (1999).

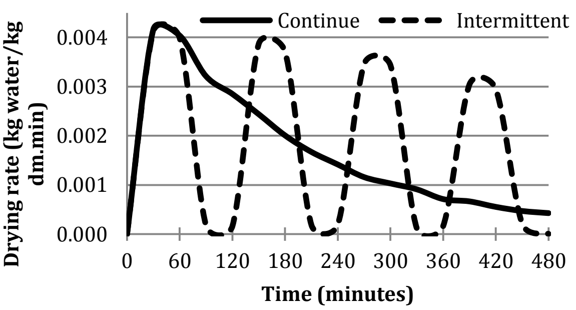

Fig.13 Drying rate profiles on continuous and intermittent mode at 60°C

Figure 14 shows that the drying rate is a function of the drying air temperature, and is reversed when the product of brings closer its residual moisture content.

Compared to the drying rate profiles at 50°C and 60°C, the drying rate profiles at 40°C varies very slightly at the beginning of the drying operations. This comes to justify the initial behavior of figures 5 and 8 for drying at 40°C.Generally, it is noted that the drying rate at 40°C is almost constant and relatively low. The drying has a long duration at this temperature. At 60°C, after 480 minutes, the kinetics of drying does not exist; this shows that the samples reached their residual moisture content.

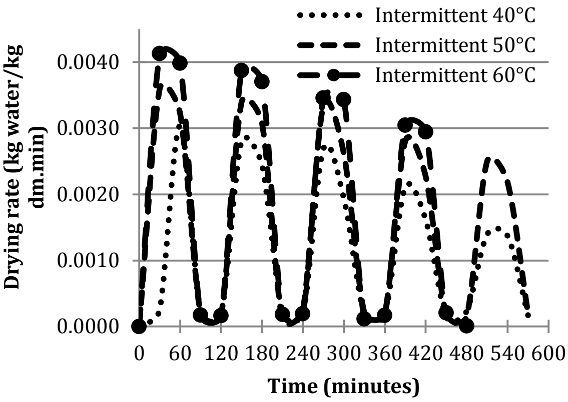

Fig.14 Drying rate profiles on intermittent mode at 40°C, 50°C and 60 °C

Figure 15 shows that for the periods of drying at the ambient temperature, the drying rate is almost null, because the temperature variation is very weak.

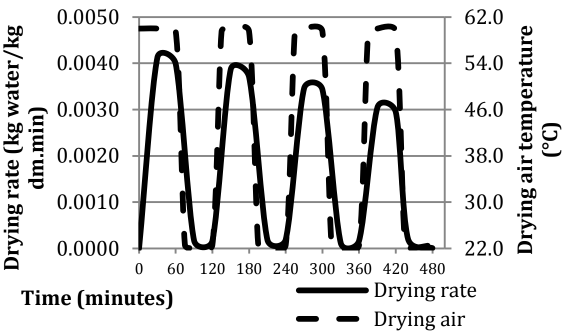

Fig.15 Drying rate and drying air temperature profiles on intermittent mode at 60°C

By making the comparison of figures 12 and 15, at 40°C, the drying rate does not fall abruptly as at 60°C. Indeed, since evaporation is weaker at 40°C, the samples still contain sufficient water, at every moment compared to 60°C, which translates that they store also more heat. Towards the end of drying, the drying rate profile tends to merge with the drying air profile, because there is not almost more water in the samples.

Conclusion

The results presented in this work were obtained from an experimental study mango drying on continuous and intermittent modes in the wet tropical climate, which is characterized by a higher relative humidity. Drying in intermittent mode makes it possible to maintain a sufficiently high the drying rate of mango throughout the operation of drying. In fact, for an intermittency α=½, the drying at 60°C conduct at a gain of 90 minutes, i.e 1 hour 30 minutes, comparatively at a drying at 50°C, for the same initial moisture content of product. Moreover, it contributes to shrinkage reduction at the surface of the dried products. The continuity of this work will be the modeling of the diffusion of heat and matter within the product at the tempered periods of drying.

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