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Experimental study of solar drying of Tunisian phosphate: in open sun, under greenhouse and by a parabolic concentrator

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Abstract

This work is part of operating a parabolic concentrator for drying the phosphate. This study is to analyzing the drying of Tunisian phosphate by three separate solar processes. Two experimental devices have been implemented. Three drying kinetics were set up by a parabolic concentrator, under greenhouse and in open sun, respectively. Nine thin-layer drying models were fitted to the experimental data to select a suitable drying equation. The Midilli model was found to best describe the drying behavior of phosphate for open sun, parabolic concentrator and greenhouse drying. These tests show that the drying by the parabolic concentrator gives results whose perspectives are satisfactory compared with the drying in the open sun or under greenhouses.

Keywords: open sun drying; greenhouse drying; drying kinetics; parabolic concentrator; phosphate.

1. Introduction

During recent decades, the demand for energy in its various forms has been increasing, for the development and growth of industrial activity and demand for comfort in daily life. Solar energy is transmitted by the sun in the form of light and heat [1]. It is virtually inexhaustible on the scale of human time.

Given its position, Tunisia has a significant potential of solar energy. This favorable opportunity allows Tunisia to be a pioneer in the use of solar energy in the context of energy conservation strategy and the government management programs. Indeed, essentially the southern regions of Tunisia are equipped of huge solar energy opportunity, put to use, could participate in a meaningful way to sustainable development and provide handy solutions to socioeconomic problems in these regions. In Gafsa, where the relative humidity is less than 69% during most of the year, wherein the duration of sunshine is 3000 hours/year and where the global solar radiation averages 5.4kWh/m^2/day, the use of solar energy is a very important activity [2].

The exploitation of phosphates is fundamentally centered on the production of fertilizer and phosphoric acid which represents the most important economic targets [3]. Phosphate is a high demand material in international trade. The phosphates sector occupies an important place in the Tunisian economy, both in the employment and in the trade balance. Globally, the Tunisian phosphate industry occupies the 5th place among the largest international operators in this activity [4]. Generally, the phosphates can undergo special treatments including grinding to reduce its particle sizes.

Production of marketable phosphate in Tunisia could exceed 8 million tons in 2010. Tunisia is the second country in the world to develop a large percentage of its production of phosphate (nearly 80%). This activity is more than a century for the extraction to phosphate by the Gafsa Phosphate Company (CPG) and more than fifty years in the area of its valuation in various mineral fertilizers by the Tunisian Chemical Group (GCT). CPG currently operates seven open pits and one undergrounds mine [4].

Nomenclature

a, b, c, g, h	empirical constants in the drying models
Ge	solar radiation outside the greenhouse, (W/m^2)
Gi	solar radiation inside the greenhouse, (W/m^2)
k, k_0, k_1	empirical constants in the drying models
m	mass of the material, (kg)
m_e	mass of the material water, (kg)
m_s	dry matter of the material, (kg)
n	number constants
N	number of observations
R^2	correlation coefficient
RHi	relative humidity of the air around the material (inside greenhouse), (%)
RHe	relative humidity of ambient air (outside greenhouse), (%)
RMSE	root mean square error
X	moisture content, (dry basis)
Xc	water content of phosphate placed at the focus of parabolic concentrator, (dry basis)
Xe	phosphate water content placed in open sun, (dry basis)
Xi	water content of phosphate placed inside the greenhouse, (dry basis)
X_o	initial moisture content, (dry basis)
X_{eq}	equilibrium moisture content, (dry basis)
XR	moisture ratio
XRc	moisture ratio of phosphate placed at the focus of parabolic concentrator
XRe	moisture ratio of phosphate placed in open sun
XRi	moisture ratio of phosphate placed inside the greenhouse
XR_{exp}	experimental moisture ratio
XR_{pre}	predicted moisture ratio
t	time, (hr)
Tac	air temperature at the focus of parabolic concentrator, (°C)
Tae	ambient air temperature (outside the greenhouse), (°C)
Tai	air temperature inside the greenhouse, (°C)
Tp	phosphate temperature, (°C)
Tpc	phosphate temperature placed at the focus of parabolic concentrator, (°C)
Tpe	phosphate temperature in open sun, (°C)
Tpi	phosphate temperature inside the greenhouse, (°C)
Vae	ambient air velocity (outside the greenhouse), (m/s)
Vai	air velocity inside the greenhouse, (m/s)

Subscripts

Av	the average value
Max	the maximum value
Min	the minimum value
f	final

Greek symbol

χ^2	chi-square

Note: 1US Dollar=2.031 TD.

Drying is economically expensive, given the price of energy highly elevated. For this reason, consulting energy audit reports provided by the National Renewable Energy Agency (ANER), a study of the energy consumption of drying in the field of industry in Tunisia has allowed us to determine the weight of drying which is estimated to 266.578 kTep (1Tep = 42 10^9J) primary energy or 5.92% of total energy consumption in Tunisia and 18.5% of energy consumption in the industrial sector [5]. It should be noted, first, that this study is carried out on a total equal to 114 industries in various fields of activities. Indeed this number is according to statistics from the ANER over 90% of industrial energy consumption. The total energy consumption of mining is equal to 180.8 kTep/year; the consumption of drying in this sector is estimated at 66.896 kTep/year representing 37% of the total consumption [5].

Annually, CPG dried 1.2 million tones of phosphate, and consumes for such an operation around 17 kTep of fuel per year. This consumption weighs more and more heavily on the company's operating expenses, with an annual cost exceeding 4millionTD/year, to which must be added at least 1millionTD maintenance costs, maintenance and other expenses caused by the use of driers [6].

Faced to this serious energy situation, CPG launched in 2007 a solar drying project in the open air in the three industrial sites in the CPG, namely El M'dhila, Metlaoui and Moularès. From an initial cost of 3.3millionTD (mainly rolling stock), this project was started with semi-industrial test step during 2007, covering 25% for the production of dried phosphates, and in 2008 the project began the industrial phase with the solar treatment 60% of production (720 000 tons). In 2009, the solar drying of phosphates reached a significant rate with treating 70% of the production of dried phosphates (840 000 tons). In the coming years, the proportions to be processed in open sun will remain exactly in the same level [6]. However, there are several opportunities to dry phosphate using solar energy; there may be mentioned drying under greenhouse, drying by a parabolic concentrator and the traditional drying where the phosphate is exposed to sun and wind ... etc.

This experimental study is devoted to the determination of phosphate drying kinetics in uncontrollable conditions: outdoor, under greenhouse and by a parabolic concentrator. All three drying processes used allow enjoying free energy from the sun and constitute an economically profitable operation. It is therefore of great interest to study the various aspects of these drying processes and identify the most appropriate method.

2. Materials and methods

2.1. Sample preparation

During tests under greenhouse, outdoor and by the parabolic concentrator, we are placed in the same external conditions. In this study the phosphate used is brought from the launderette IV (CPG) in Metlaoui (a sector amongst of the five production of the phosphate of the mining region of Gafsa in southern Tunisia). The wet phosphate is introduced into a parallelepiped block in plastic. Then, one obtains a phosphate sample of 10 mm thick, length 130 mm and width 65 mm. Subsequently, this sample is placed on a polystyrene plate covered with aluminum foil (Fig. 1 (a)). To measure the material temperature, three type K thermocouples were used. The phosphate temperature being obtained by averaging the temperatures of these three thermocouples, which are positioned in different places in the material (Figs. 1 (b) and 1 (c)).

(a) (b) (c)

Figure 1. Sample preparation: (a) the phosphate in the block, (b) the phosphate sample under greenhouse, (c) the phosphate sample in open sun

2.2. Experimental devices

In this subsection we will describe the various devices used to study experimentally the phosphates drying under greenhouse, by the parabolic concentrator and in open sun.

Fig. 2 (a) illustrates the entire experimental device used for drying phosphate under greenhouse and outdoors. This device consists mainly of a balance inserted into a wooden box. For tests in the open air, the tray covered by aluminum foil containing the phosphate was surrounded by these four sides by a bell formed of four pieces of thin ordinary glass, to avoid deterioration caused by excessive air currents (Fig. 2- (a)). The small greenhouse used for drying the phosphate is built in our Department in the Gafsa Faculty of Sciences, with ground surface of 2.25 m^2 (its base is a square of 1.5 m side), height 1,8 m from its base to its summit and its axis is parallel to the east-west direction (Fig. 2 (c)). To protect it the prevailing wind (North-West), we have installed this greenhouse in an internal space of the Faculty of Sciences of Gafsa. The greenhouse is coated with a plastic blanket (low density polyethylene of thick 180 µm) (Fig. 3 (b)).

The parabolic concentrator was built in the Physics Department of the Gafsa Faculty of Sciences operating with a manual tracking system in two axes vertical and horizontal. Both axes can track the sun in its racing and also to maximize the concentrated solar radiation to the absorber. It has a rigid support posing on the ground. It consists of two parts, namely: the reflector and the receiver (Fig. 3- (a)). The opening of this solar concentrator is ϕ =2.80 m with a total surface (reflector) is 2.92 m^2. It is constituted by 1825 mirrors (the thickness of a mirror being 3 mm with surface is limited to 4cm × 4cm) which are bonded with silicone on the entire parabolic surface (Figure 3- (a)). All rays issued by sun is reflected by the mirrors and gathered in one point called the focus (Receiver: holder-sample of phosphate of h =60 cm height from the center of the parabolic solar concentrator) for supporting the high temperature and thus the heat that will be used thereafter for drying the phosphate. To analyze and identify the receiver position, we have displaced a cardboard in different positions until the appearance of a flame that burns the card after 5 min, indicating at the focus.

(a) (b) (c)

Figure 2. Phosphate drying: (a) in the open air, (b) by a parabolic concentrator (c) under greenhouse.

(a) (b)

Figure 3. Experimental device: (a) parabolic concentrator (b) Greenhouse

2. 3. Drying procedure and data acquisition

In the drying tests, the drying parameters (incident radiation, air velocity, humidity and air temperature) are continuously variable in time (variable conditions). The incident radiation is measured using a calibrated photovoltaic solar panel with a pyranometer of type Kipp-Zonen (Model CM3) and ± 5% accuracy. The air speed is measured by an anemometer (TESTO 435) for the velocity measurements in the range of 0-15m/s, with ± 0.1ms^{-1} accuracy. The relative humidity and the air temperature were measured by a sensor HMP35C (Vaisala Model HMP35C). The HMP35C errors are ± 0.1°C of temperature and ± 3% of humidity. The thermocouples were connected to the multimeters. The measurement error is ± 0.2 °C. The sample mass during time is measured by a scale of capacity 7000 g and precision of ± 0.1 g. The sensitiveness was obtained from catalogs of the instruments.

The material temperature on the tray, air temperature, relative humidity of the air above the material surface and the sample mass were measured at intervals of 20 min during the experiments. The recordings were made manually.

Once the drying operation is complete, the sample was placed in an oven at 120°C for 12 hours, and then weighed to determine the corresponding dry matter (m_s).

3. Mathematical modeling of drying curves

Phosphates water content was estimated on dry basis. Dry matter value of the samples was calculated. The material water content at different drying stages was then expressed according to the following relation:

$$X = \frac{m_e}{m_s} = \frac{m - m_s}{m_s} \qquad (1)$$

Where m_e is the mass of the material water, X the water content in dry basis, m the mass of the material and m_s the corresponding dry matter.

The moisture ratios (XR) of Phosphates during drying were calculated using the following equation:

$$XR = \frac{X - X_{eq}}{X_0 - X_{eq}} \qquad (2)$$

Where X, X_0 and X_{eq} (kg water/kg dry matter) are, respectively, the moisture content at a specific time, the initial moisture content, the equilibrium moisture content.

The moisture ratio XR is simplified by some investigators [7- 9] to X/X_0 because the equilibrium moisture X_{eq} content is significantly less than the initial moisture content X_0. In this case, Eq. (2) becomes:

$$XR = \frac{X}{X_0} = \frac{m - m_s}{m_0 - m_s} \qquad (3)$$

Where m_0 is the water mass of the initial material.

For mathematical modelling, the thin layer drying equations in Table 1 were tested to select the best model for describing the drying curve equation of phosphate during drying by the parabolic concentrator, under greenhouse and in open sun. Regression analysis was performed using the Statistica computer program. The correlation coefficient (R^2) was the primary criterion for selecting the best equation to describe the drying curve equation. In addition to R^2, the reduced χ^2 as the mean square of the deviations between the experimental and calculated values for the models and the root mean square error analysis (RMSE) were used to determine the goodness of the fit. Higher values of R^2 and lower values of χ^2 and RMSE indicate better goodness of fit [8- 14]. These can be calculated as:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(XR_{exp,i} - XR_{pre,i}\right)^2}{\sum_{i=1}^{N}\left(\overline{XR}_{exp,i} - XR_{pre,i}\right)^2} \quad (4)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(XR_{exp,i} - XR_{pre,i}\right)^2}{N-n} \quad (5)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(XR_{exp,i} - XR_{pre,i}\right)^2\right]^{\frac{1}{2}} \quad (6)$$

Where $XR_{exp,i}$ is the *i*th experimental moisture ratio, $XR_{pre,i}$ is the *i*th predicted moisture ratio, $\overline{\mathbf{XR}}_{\mathbf{exp,i}}$ the mean experimental moisture ratio, N the number of observations, and n the number of constants in each regression model.

Table 1. Mathematical models widely used to describe drying kinetics

Model no.	Model name	Model	Reference
1	Newton	XR = exp(-kt)	[15]
2	Henderson and Pabis	XR = aexp(-kt)	[16]
3	Page	XR = exp(-kt^n)	[17]
4	Logarithmic	XR = aexp(-kt) + c	[18]
5	Modified Page	XR = exp(-(kt)^n)	[19]
6	Midilli et al.	XR = a exp(-kt^n) + bt	[20]
7	Two-term	XR = aexp(-k$_0$t) + bexp(-k$_1$t)	[21]
8	Wang and Singh	XR = 1 + at + bt^2	[22]
9	Modified Henderson and Pabis	XR = aexp(-kt) + bexp(-gt) + cexp(-ht)	[23]

4. Results and discussion

4. 1. Drying conditions

The atmospheric conditions (solar radiation, ambient temperature, ambient humidity and wind speed) are factors that can drive and steer outstandingly the drying operation. The drying tests of phosphate in the open sun, by the parabolic concentrator and under greenhouse are realized jointly under the same weather conditions, on the same time of 04/29/2014.

4.1.1. Solar radiation

Climatic conditions during this day of 04/29/2014 are characterized by a perfect sunshine (Fig. 4). Solar radiation in open air reaches its maximum about 1050 W/m² at midday. However, the solar radiation under the greenhouse is less intense than that outside. We recorded 20% reduction of radiation penetrating in the greenhouse. The maximum solar radiation reaches under greenhouse was about 850 W/m².

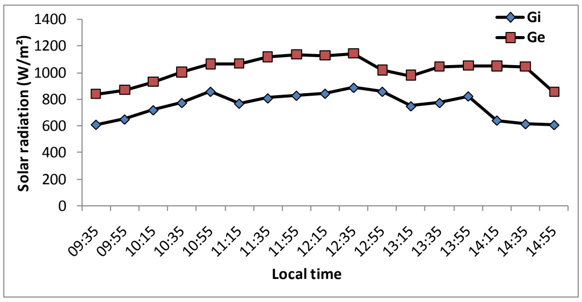

Figure 4. Evolution the outside solar radiation (Ge) and under greenhouse (Gi) versus time of 04/29/2014

4.1.2. Relative humidity

The relative humidity of the outside air and under the greenhouse are approximately the same, it is varied between 15.1 and 33.4% (Fig. 5). They are slightly reduced during time. Yet, the relative humidity of air under greenhouse is imperceptibly lower than outside. We recorded 7% decline in the relative humidity of the air in the greenhouse compared to outside.

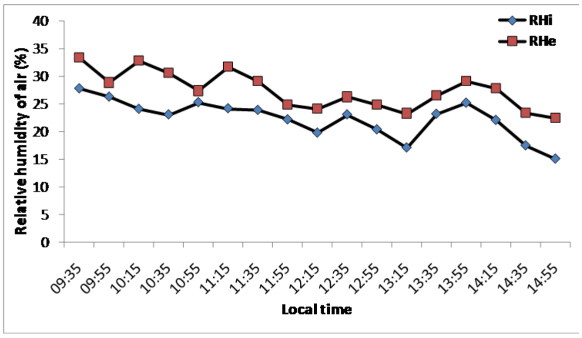

Figure 5. Evolution of relative humidity of the outside air (RHe) and under greenhouse (RHi) versus time of 04/29/2014

4.1.3. Air velocity

During the course of phosphate drying tests, the outside air velocity around the material samples is low enough; it ranges from 0.13 to 1.14 m/s. Nevertheless, air under greenhouse is almost stagnant (Fig. 6). Indeed the air velocity has little influence on the drying kinetics.

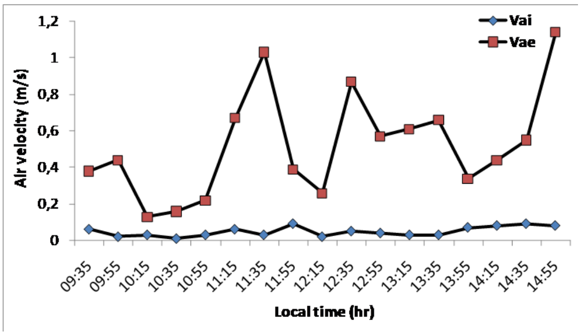

Figure 6. Evolution the outside air velocity (Vae) and under greenhouse (Vai) versus time of 04/29/2014.

4.1.4. The air and the material temperatures

During the day of 04/29/2014, the air temperature at the vicinity of the focus of the parabolic concentrator is considerably higher than that of the ambient air and the air inside the greenhouse; it reaches 484°C, while the air temperature inside the greenhouse reaches only a maximum of 50°C and ambient air temperature 40°C (Figs. 7a and 7b). However air temperature under greenhouse is higher than at outside (Fig. 7a).

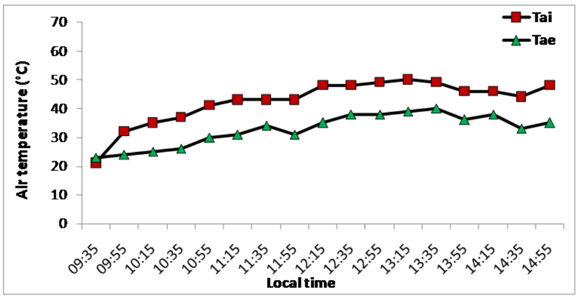

Figure 7a: Evolution of the air temperature at outside (Tae) and under greenhouse (Tai) versus time of 04/29/2014.

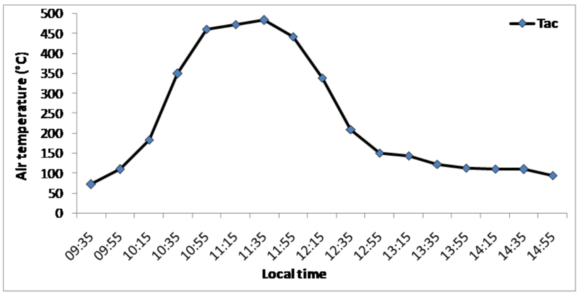

Figure 7b: Evolution of the air temperature at the focus of parabolic concentrator (Tac) versus time of 04/29/2014.

Thus, the phosphate temperature in open sun is greater than that of air; it reaches a maximum of 50°C. However, the phosphate temperature under the greenhouse reached a maximum of 59°C while that of the sample placed at the focus of the parabolic concentrator reached a maximum of about 102°C at solar noon (Table 2). Under direct solar radiation (in open air and under greenhouse) the material temperature exceeds that of the surrounding air. This result is in agreement with the researchers observations during drying of agricultural products [24-26].

Table 2: The air temperature and the phosphate temperature of 04/29/2014

Drying process	Air temperature			Phosphate temperature		
	Ta_{Min} (°C)	Ta_{Max} (°C)	Ta_{Moy} (°C)	Tp_{Min} (°C)	Tp_{Max} (°C)	Tp_{Moy} (°C)
Open sun	23	40	32,71	27	50	40,23
Greenhouse	21	50	42,53	27	59	49,19
Parabolic concentrator	73	484	234,18	26	102	66,15

Indeed, the phosphate temperature under greenhouse is consistently higher than that the phosphate dried outside (Fig. 8). However, the temperature curve of material placed at the focus of the parabolic concentrator in the course of time reaches a maximum of 102°C at midday-sun. Thus, the parabolic concentrator allows the phosphate reaching the air temperature of the artificial dryers drying used by CPG [27]. The phosphate temperatures at the end of the drying process are similar for the three methods (Fig. 8).

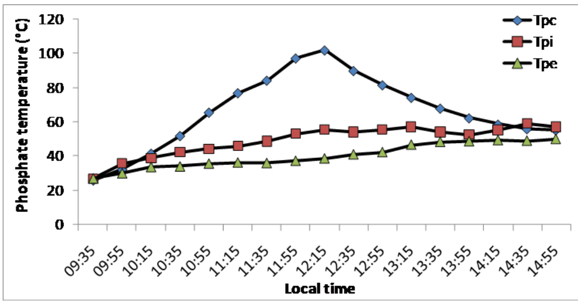

Figure 8. Evolution of the phosphate temperature (Tpe) in open air, at the focus of the parabolic concentrator (Tpc) and under greenhouse (Tpi) versus time of 04/29/2014.

4. 2. Drying kinetics

In Fig. 9 is shown the phosphate drying kinetics when it is placed respectively at the focus of parabolic concentrator, under greenhouse and in open sun. In fact, the phosphate dries faster when placed at the focus of the parabolic concentrator (Fig. 9).

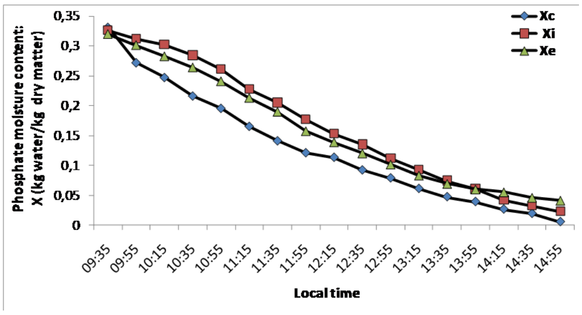

Figure 9. Variation of the water content of phosphate in open sun (Xe), by parabolic concentrator (Xc) and under greenhouse (Xi) versus time of 04.29.2014.

It accomplished 05 hr 20 min to dry to a water content Xc_f = 0.006 kg water/kg dry matter. However, the drying under greenhouse and in the open air does not reach to this value. We remark that phosphate moisture content curve under greenhouse is nearly than that of the open sun (Fig. 9). Under greenhouse, the phosphate puts 05 hr 20 min to dry to a water content value Xi_f = 0.022 kg water/kg dry matter. However in the open air, the phosphate is dried to a water content value Xe_f = 0.042 kg water/kg dry matter. Drying the phosphate in the open sun is profitable. The phosphate drying kinetics in open sun and under greenhouse join and become assemblies.

In order to normalize the drying curves, the experimental data were transformed to a dimensionless parameter called the moisture ratio versus time (Fig. 10). The moisture ratios (XR) versus drying time were fitted to the nine drying models presented by previous workers (Table 1). The results of the statistical analysis undertaken on these models for solar drying by the parabolic concentrator, in open sun and under greenhouse are given in Tables 3, 4 and 5, respectively. The models were evaluated on the basis of R^2, χ^2 and RMSE. The model that best predicts the drying process will have higher value of R^2 and lower values of χ^2 and RMSE. The Midilli model was found to be the most suitable model for describing drying curve of the thin layer of phosphate by the three drying process, as shown in Tables 3, 4 and 5. For the solar drying of phosphates by parabolic concentrator, the Midilli model gave R^2=0.99858, χ^2=1.48 10^{-4}, RMSE =0.01216. For the solar drying of phosphates in open sun the Midilli model gave R^2 =0.99912, χ^2=0.98 10^{-4} and RMSE=0.00990. For the solar drying of phosphates under greenhouse the Midilli model gave R^2=0.99969, χ^2 =0.78 10^{-4}, RMSE =0.00886.

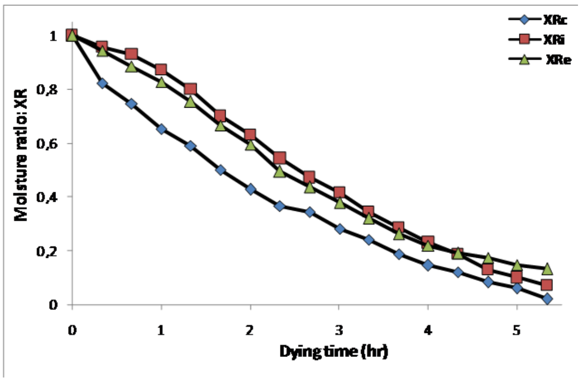

Figure 10. Variation of the moisture ratio in open sun (XRe), by parabolic concentrator (XRc) and under greenhouse (XRi) versus drying time of 04.29.2014.

Table 3: Modeling of moisture ratio according to drying time for thin layer parabolic concentrator drying of phosphates.

Model no.	**Model constants**	**R^2**	**χ^2**	**RMSE**
1	k=0.44603	0.98730	10.8 10^{-4}	0.03289
2	a=1.00581, k=0.44877	0.98736	11.5 10^{-4}	0.03389
3	n=1.0944, k=0.40851	0.98995	9.13 10^{-4}	0.03021
4	a=1.16498, k=0.30313, c=-0.19832	0.99724	2.69 10^{-4}	0.01640
5	k=0.44129, n=1.09498	0.98995	9.13 10^{-4}	0.03021
6	**a=0.9943, k=0.36939, n=0.82661, b=-0.03917**	**0.99858**	**1.48 10^{-4}**	**0.01216**
7	a=-40.29188, k_0=0.69413, k_1=0.68528, b=41.25687	0.99241	7.95 10^{-4}	0.02820
8	a=-0.2402, b=0.01314	0.98978	9.90 10^{-4}	0.03147
9	a=0.26964; k=0.4481; b=0.36808; g=0.44873; c=0.36808; h=0.44873	0.98735	15.7 10^{-4}	0.03958

Table 4: Modeling of moisture ratio according to drying time for thin layer open sun drying of phosphates.

Model no.	**Model constants**	**R^2**	**χ^2**	**RMSE**
1	k=0.31942	0.96011	36.3 10^{-4}	0.06024
2	a=1.09257, k=0.35403	0.97520	24.1 10^{-4}	0.04906
3	n=1.43106, k=0.2013	0.99837	1.58 10^{-4}	0.01259
4	a=1.51642, k=0.18643, c=-0.47126	0.99118	9.17 10^{-4}	0.03028
5	k=0.32624, n=1.43078	0.99837	1.58 10^{-4}	0.01259
6	**a=0.98377, k=0.18825, n=1.5783, b=0.01079**	**0.99912**	**0.98 10^{-4}**	**0.00990**
7	a=0.54625, k_0=0.35402, k_1=0.35402, b=0.54631	0.97520	27.8 10^{-4}	0.05270
8	a=-0.2402, b=0.01314	0.98979	9.90 10^{-4}	0.03147
9	a=0.3642; k=0.35402; b=0.36419; g=0.35402; c=0.36417; h=0.354021	0.97520	32.8 10^{-4}	0.05729

Table 5: Modeling of moisture ratio according to drying time for thin layer greenhouse drying of phosphates.

Model no.	Model constants	R^2	χ^2	RMSE
1	k=0.30671	0.92329	79.6 10^{-4}	0.08992
2	a=1.13055, k=0.35279	0.95046	54.8 10^{-4}	0.07405
3	n=1.70234, k=0.14136	0.99891	1.21 10^{-4}	0.01100
4	a=2.91269, k=0.08062, c=-1.86043	0.99285	8.47 10^{-4}	0.02911
5	k=0.31686, n=1.70216	0.99890	1.21 10^{-4}	0.01100
6	**a=0.99698, k=0.13778, n=1.64228, b=-0.00842**	**0.99969**	**0.78 10^{-4}**	**0.00886**
7	a=-53.61188, k_0=0.74239, k_1=0.72667, b=54.58721	0.99594	5.17 10^{-4}	0.02276
8	a=-0.19588, b=0.00246	0.98901	12.2 10^{-4}	0.03487
9	a=0.37684; k=0.35277; b=0.37684; g=0.35277; c=0.37684; h=0.35275	0.95046	74.8 10^{-4}	0.08648

5. Conclusion

This study extends to briefly explore the foundations of the combined Radiative-Convective drying of phosphate under uncontrolled and varying climatic conditions. This study is attended in part by the construction of a mini-greenhouse and a parabolic concentrator, on the other hand a series of measurements carried out on the drying of phosphate in open sun, under greenhouses and by a parabolic concentrator. Indeed, under continuous and intense solar radiation, the results of experimental tests have shown that the drying kinetics of phosphate in open sun and under greenhouse join and become assembly. The intensity of the radiation acts directly on the material temperature through the flow of heat conveyed by the radiation which accordingly promotes the mass internal transfers. Both of the solar drying process (open sun and greenhouse) puts a period of 05 hr 20 min to drying the phosphate.

Indeed, the air temperature at the focus of parabolic concentrator is much higher than that under greenhouse and than that in open air. The phosphate temperature under greenhouse is lower than with solar concentration at the focus of parabolic concentrator, accordingly this last phosphate dries more quickly. However, drying in open sun has advantages. It allows better productivity because large surface areas that may be put in works and requires a very small investment compared to the price and the maintenance cost of parabolic concentrators.

The parabolic concentrator allows the phosphate reaching the air temperature of the artificial dryers drying used by CPG. The phosphate drying by a parabolic concentrator appears to us as one of the means to a greater availability over time and more economically profitable in the production of phosphate by the CPG. Indeed, a special search effort should be used to adopt new processes of solar drying of phosphate.

Acknowledgments

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