

## Simple Solar Drying System for Banana Fruit

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**Abstract:** Simple solar drying system suitable for different agricultural fresh commodity was evaluated to dry banana pulp. The drying system mechanism was flexible, it was constructed from cheap and available materials (i.e. wood, glass plastic and metals). It composed solar collector, drying chamber and solar chimney and/or blower. The air type solar collector was mounted fixed all the year around at 30°. the drying chamber was flexible to be 0° and 90° with the horizon axis. Simple passive and active designs were followed to enable save energy requirement for fan operating. Banana moisture reduction rate, drying coefficient, of banana and the drying system efficiency were determined. This investigation was carried out at Ismailia, Egypt. Based on the drying constant the study found that, the horizontal dryer chamber was speeding banana drying over the vertical one for both of active and passive modes within the time of drying for the site and time of investigations. Drying system efficiency for the forced convection was higher for the first day comparing with the following days due to the fast drying in the moisture falling stage.

**Key words:** Banana fruit drying • Passive and active solar dryers

### INTRODUCTION

Insufficient food and shortage of energy supply represents the common crisis features faces Africa in spite of the natural resources of the continent. Banana fruit can provide and substitute the insufficient food for starving African people and children food factories. Banana plants is grown in tropical region all over the world near the equator [1]. Sub-Saharan Africa produces about 35% of the world's bananas (fruit and plantains). Average production of one Fadden under the Egyptian conditions 12.98 Tonnes Banana. Banana and plantains can be secures the African food, it have been estimated to supply more than 25% of the carbohydrates of approximately 70 million people in Africa's humid forest and mid-altitude regions.

Banana, is utilized in the human diet, are often sliced lengthwise, baked or broiled and served. It may be thinly sliced and cooked. Banana or plantain flour, or powder, is made domestically by sun-drying slices of unripe fruits and pulverizing [2].

Banana dietary value per 100 grams for dried powder or flakes were determined and it is given in Table 1.

Dried bananas, or so-called "banana figs" are peeled firm-ripe bananas split lengthwise, sulphured and oven-dried to a moisture content of 18 to 20%. Wrapped individually in plastic and then packed by the dozen in polyethylene bags and encased in cartons, they can be stored for a year at room temperature between 24° to 30°C and they are commonly exported. The product can be eaten as a snack [4].

Banana fruit dried to produce powder commercially, is produced by spray-drying, or drum-drying [5], it is dried at 105°C, with final moisture content of 2-5% and average drying ratio (fresh to dried weight) of 13:1 [6]. Solar energy is one of the renewable energy resources particularly for low temperature heating. Many African countries receive on average 325 days per year of bright sun light [7]. Egypt receives from 3000 to 4000 hours a year. Its lands receives from 5 to 8 kW.h/m<sup>2</sup> per day [8]. This enhances the solar energy usage in drying which is a means of banana preserving by reducing its moisture

Table 1: Banana Dietary value, per 100 gram [\*3,4]

Water*(3) %	Carbohydrates* %	Protein %	Fat %	Crude fiber %	Other %	Calories
70	23	1.2	0.2	2.6	3	88

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contents. Awady *et al.* [9] dried Banana in a solar drying system. banana was dried in their study as agricultural commodity in order to investigate the solar drying system usage all the year around.

The change in moisture content with time is proportional to the change in moisture gradient across the particle from interior to the surface. In practical terms it can be appreciated that, the rate of drying decreases with the decrease in moisture content but increase with decrease in particle size [10].

In spite of how is the simple dryer mechanism, it can be assist to alleviate the impending crisis of energy and food in some African countries. The study undertaken highlighted the significant role which solar energy could playing in the agro-industrial development of the African countries in the 21<sup>st</sup> century, as traditional energy source decline globally as climate change impacts on global agriculture.

**This Study Aims To:** drive and evaluate a simple solar dryer for a dietary banana fruit to be used either commercially or on small scale by the house wives.

## MATERIALS AND METHODS

Solar dryer mechanism was mounted and investigated for drying banana (*Musa sp.*) variety Paradica at Ismailia, Egypt (latitude of 30.5°N, longitude of 32.41°E and 17m above sea level). The dryer composes three main components: a solar air collector, where the drying air is heated, drying chamber either horizontal or vertical and flow enhancement apparatus either solar chimney as in

Fig. 1 or air blower, as in active mode. The skeleton and frames of the solar collector and the dryer cabinet was fabricated from 5cm wood thick. Solar collector of 1m long, 0.5m width and 0.1m height was mounted fixed at 30° inclined with the horizontal datum. Flexible movable drying chamber of 1 m long, 0.5 m width and 0.15 cm height were used in this study. Polyethylene foam of 5cm thick was used as insulation material underneath the 1mm thick Aluminum absorbing metal material. Aluminum sheet of 1mm thick with dimensions of 1m x 0.5m was used as absorbing material. Matt black paint was applied to the absorber plate paint. One absorbing plate was used for the solar air collector and another one with the same dimensions and material was used for the drying cabinet. A glass pane of 4mm thick with dimensions of 0.5 x 1.0m was used as a transparent cover; another pane with the same dimensions and thick was used for the cabinet cover to intensify the incident solar flux on the drying product. Meanwhile two slabs of 0.10 x 1.0 m were used for the collector side. The dryer cabinet sides slabs were, each of 0.15 x 1.0m dimension and it were used as hatch or window to spread the dried materials and collect data within the investigation.

Both of active and passive modes were investigated with a fixed inclined solar collector of 30° and oriented toward the south direction while the attached drying cabinet which was also orientated to the south but with different inclination angle with the ground datum i.e. vertical and horizontal. A horizontal screen mesh shelf was fitted for the horizontal dryer cabinet, while four shelves was mounted and used for the vertical drying cabinet.

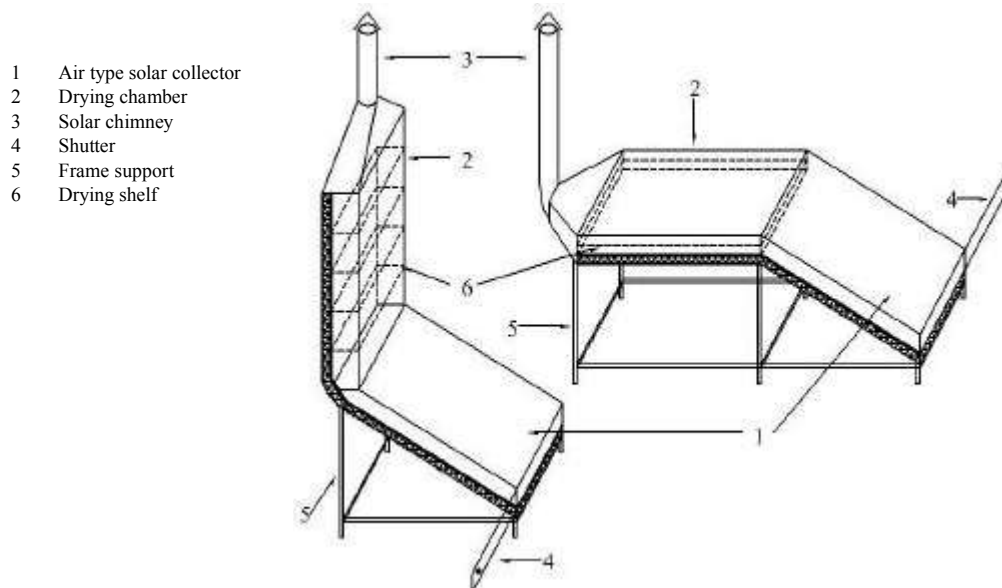


Fig. 1: Two different drying chamber position used for banana passive system in the study

Screen mesh was fitted on the entrance of the solar collector to prevent insect from getting in the dryer which affect the dried quality negatively; also, to increase the heat transfer coefficient of going inside the solar collector. Meanwhile, glass shutter was used for the entrance and exit orifices to avoid re-absorbing air humidity within the night times.

The drying system was used to dry banana under the natural convection (passive) and forced convection trials modes also under fixed tilt angle for solar collector and movable drying chamber of 0° and 90°. Blower was added and the solar chimney (of the passive design) was subtracted. Air was forced into the dryer with 0.06m³/s. Meanwhile the natural convection based on the literature reviews to be 0.005m³/s. Data were collected daily within the investigation tasks at two hours after the sun shine with two hours interval.

**Banana Preparing and Processing:** The ripe banana, *Paradica* variety were obtained from a local ripeness furnace, at Ismailia and were peeled and weighted on weighting balance. It was cut to slices from 0.5 to 1cm thick using a knife. No chemicals or discoloration substances were added to the fresh banana commodity. Forced convection with 0° was carried out within the period from 1-7 October, 16-20/10 for natural convection with the same dryer angle. When the dryer made an angle of 90° with horizontal axis it was investigated for natural convection from 17-19 /2 and forced from 14-20/10.

**Moisture Contents:** Five kilograms of Fresh banana commodity was peeled and cut on slices. To determine the initial moisture content Banana pulp sample was weighted and put in electrical oven at 60°C for 24hours and re-weight again after 24hours. Moisture content (wet basis, %) was determined for the taken samples determined according to the following simple formula:

$$Mc, (w.b, \%) = \frac{m_i - m_f}{m_i} \times 100 \quad (1)$$

Where,  $m_i$  and  $m_f$  are the initial and final mass, (kg). moisture content within the experimental campaign were determined with two hours intensive as the representative samples were put in steel mesh box on the drier shelf with the same drying thickness of 5cm. Four samples were taken from different places of the drier were represented the average dryer moisture content, one sample were considered from each shelf for the vertical dryer and one of the same destination (0.25m) for the horizontal dryer. Average moisture content was dried with moisture content with the statistical analysis for different samples.

Banana peels was determined as a ratio from the total fruit weight. Those byproduct is proposed to feed the biogas unit and the released energy to be used for banana ripping, as it will be given in a separate study.

**Solar Radiation Intensity, (G):** Intensity of the incident solar radiation was derived mathematically for the site of investigation which was assured by the measurements. Measurements was carried out by a simple pyranometer apparatus composed a solar cell and multi-meter according to Mujahed and Almoud [11] and Duffie and Beckman [12] which validated against previously well calibrated Pyranometer.

**Temperatures of the Absorbing Surfaces and Drying Air:** Three points were selected to measure the absorbing surfaces of the solar collector and the drying chamber were determined and averaged. Points were located at the longitudinal central axis for each of the collector and the drying chamber, with 0.25m apart. The ambient, air at the entrance of the solar collector out the exit air from the collector and the drying chamber were determined and averaged.

**Air Relative Humidity,  $R_h$ :** Relative humidity for the inlet ambient air and the outlet air from the drying chamber were determined using psychrometer (dry and wet bulb thermometers). A digital psychrometric chart was used to determine the air relative humidity from the obtained dry and wet temperatures of the psychrometer.

**Drying System Efficiency,  $\eta_{ds}$ :** Total efficiency for the drying system which composed two parts of the useful thermal energies i.e. a part of the energy was consumed in evaporating water from banana crop while other part which is less than the latent heat of evaporation it was consumed in raising up temperature of crop. It is given by the following expression [9].

$$\eta_{ds} = \frac{m.L_{ev} + m_c c_{pa} \Delta T}{AGt} \quad (2)$$

where  $c_{pc}$  the banana crop specific heat capacity given as 3.35kJ/kg°C (0.8kCal/kg°C).  $m$  is released vapor mass in kg,  $L_{ev}$ , the latent heat of evaporation;  $m_c$  banana crop mass determined at time  $t$  in seconds,  $G$  the intensity of the incident solar radiation on the drying system aperture,  $Wm^{-2}$  and  $A$  is the dryer aperture area in  $m^2$ .

**Nocturnal Moisture Re-Absorption,  $R_n$ :** The nocturnal moisture re-absorption or loss is defined as the ratio of the rise in moisture content over the night period to the

moisture content value at the sunset of the preceding day. Positive values of  $R_n$  mean moisture re-absorption, but negative values indicate further moisture loss.  $R_n$  can be expressed in percentage as Zaman and Bala [13]

$$R_n = \frac{M_{sr} - M_{ss}}{M_{ss}} \times 100 \quad (3)$$

Where,  $M_{ss}$  is the moisture content at the sun-set, decimal, while,  $M_{sr}$  is the decimal moisture content at sunrise next day.

**Banana Drying Constant "K" for Different Drying Concepts:** The criteria used to evaluate the performance of the solar drying system with different positions and flow modes in this study was "the drying constant. The drying constant,  $k$  was based on Woods *et al.* [14] empirical arches formula which represents the constant  $k$  of banana to the dryer temperature as:

$$k = 0.6854 \exp(-3316.1/(T + 273.15)) \quad (4)$$

Where  $T$  was considered for the average drying air temperature between the inlet and the out in Celsius degrees.

## RESULTS AND DISCUSSION

**Solar Radiation Intensity, (G):** the incident solar radiation is shown in Figure 2 in  $\text{Wm}^{-2}$  for the all day from the sun-rise till sun-set for different investigation days (1<sup>st</sup> till 7<sup>th</sup> October). The solar radiation intensity in the figure is given for the fixed inclined solar air collector with

inclination angle of  $30^\circ$  in A and for the horizontal dryer chamber of  $0^\circ$  with the horizontal axis (in B).

**Air Relative Humidity, Rh:** Relative humidity of air at the dryer inlet and outlet are shown in Figures 3-6 for the different trials. Figures 3 and 4 represents the relative humidity versus drying time for the forced convection mode when the drying chamber created  $0^\circ$  and  $90^\circ$  with the horizon, respectively. It is also represented in Figures 5 and 6 for the natural convection mode for drying chamber of  $0^\circ$  and  $90^\circ$ , respectively. Forced convection mode enhanced removing evaporated water from banana commodity, resulted on reducing the outlet relative humidity above the inlet as shown in Figures 3 and 4. The same effect was happened when the natural convection mode for  $0^\circ$  drying chamber. This reflects higher drying constant ( $k$ ) and fast drying rate compared with the other drying methods.

## Temperatures of the Absorbing Surfaces and Drying Air:

Temperatures of the absorbing surfaces for the solar air collector ( $T_{sc}$ ) and the drying chamber ( $T_{dc}$ ) are represented in Figures 7 and 8 for the drying chamber of  $0^\circ$  applying the natural and forced convection, respectively. Meanwhile, Figures 9 and 10 represent temperatures of drying chamber  $90^\circ$  for natural and forced convections modes, respectively. Also, temperatures of the ambient air ( $T_{amb}$ ), outlet air temperature from the solar air collector ( $T_{ca}$ ) and exit air from the drying chamber ( $T_{da}$ ). Mean average temperatures represented in Table 2 beside the relative humidity of the ambient air ( $RH_{amb}$ ) and the relative humidity of the outlet air from the drying chamber.

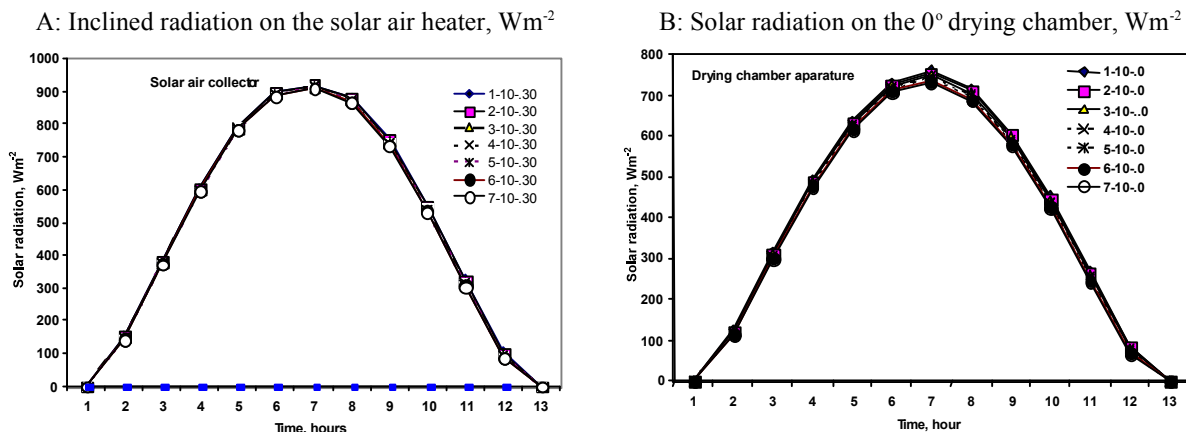


Fig. 2: Solar radiation intensity ( $\text{Wm}^{-2}$ ) on fixed inclined solar collector of  $30^\circ$  and  $0^\circ$  drying chamber for the period from the 1<sup>st</sup> till 7<sup>th</sup> October

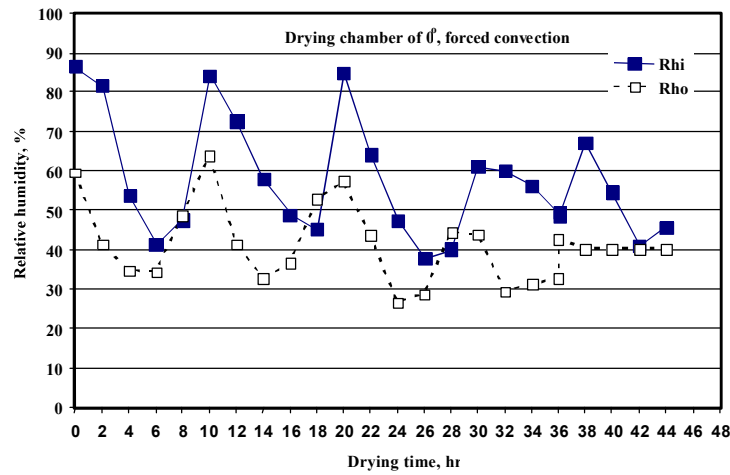


Fig. 3: Inlet and outlet relative humidity for drying chamber creates an angle of  $0^\circ$  with the horizontal plan when the forced convection mode was applied

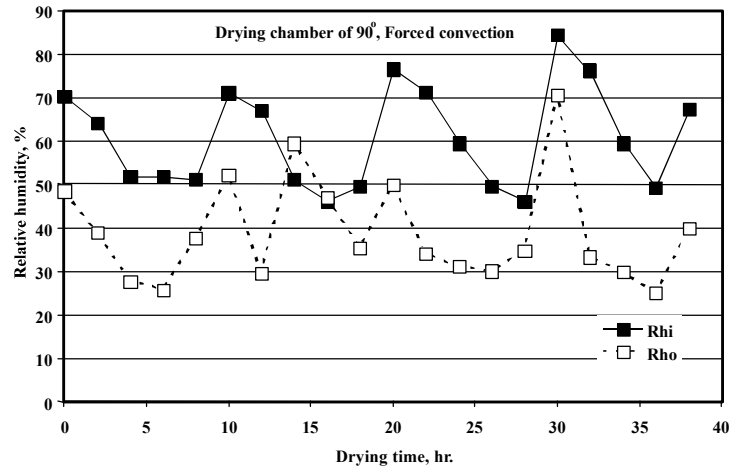


Fig. 4: Inlet and exit relative humidity for drying chamber loaded with banana and creates an angle of  $90^\circ$  with the horizontal plan when forced convection mode was applied

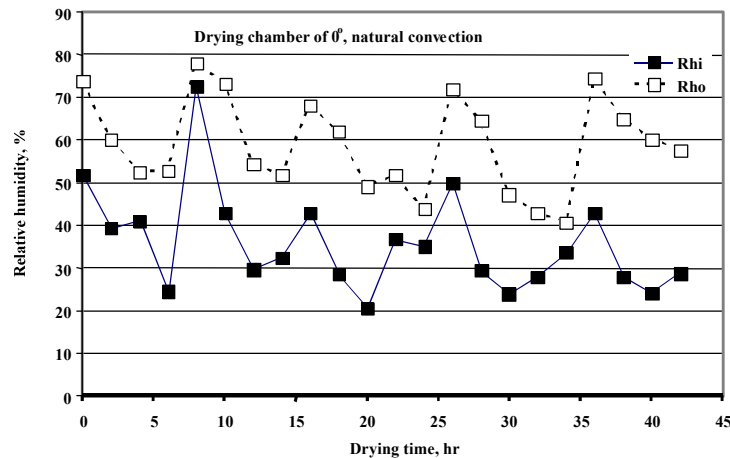


Fig. 5: Inlet and outlet relative humidity to the drying system for drying chamber of  $0^\circ$  with the horizontal plan when the natural convection mode was applied

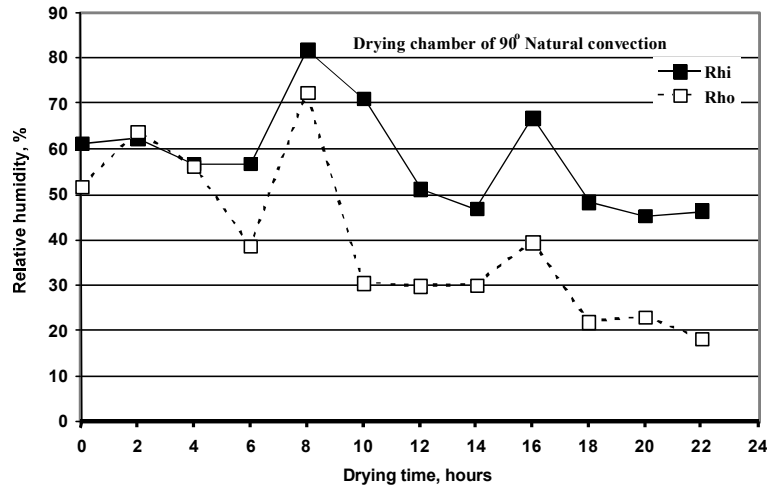


Fig. 6: Inlet and exit relative humidity for drying chamber of 90° with the horizontal plan and natural convection mode was applied

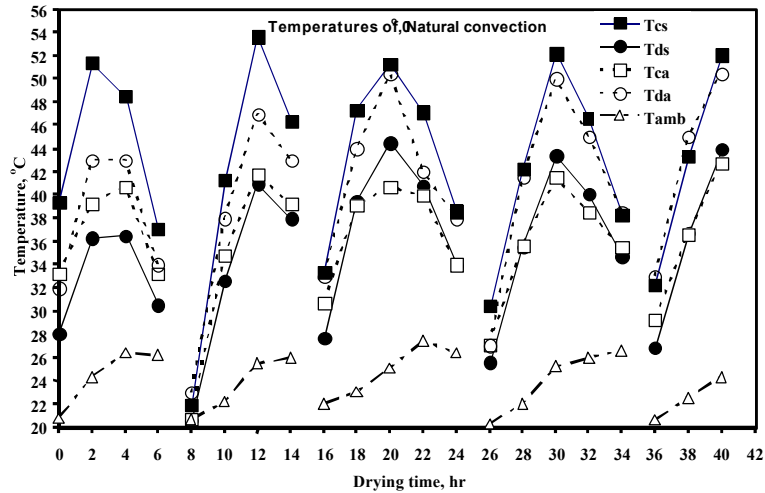


Fig. 7: Measured temperatures for the different drying days for 0° drying chamber and natural convection mode

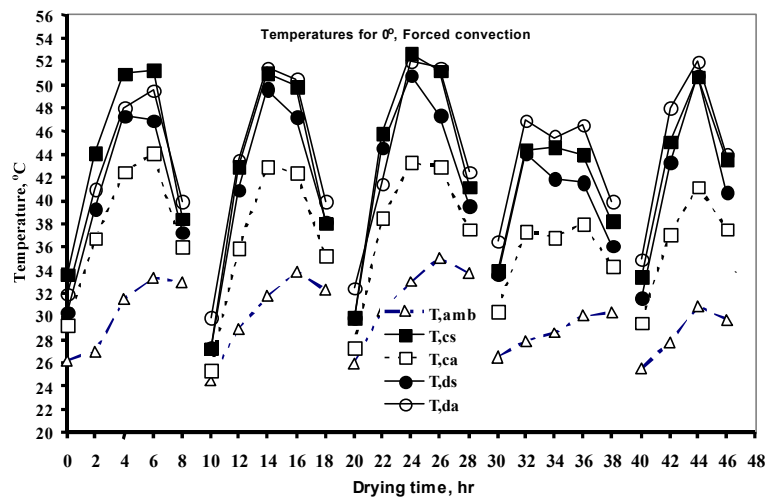


Fig. 8: Measured temperatures for the different drying days for 0° drying chamber and forced convection mode

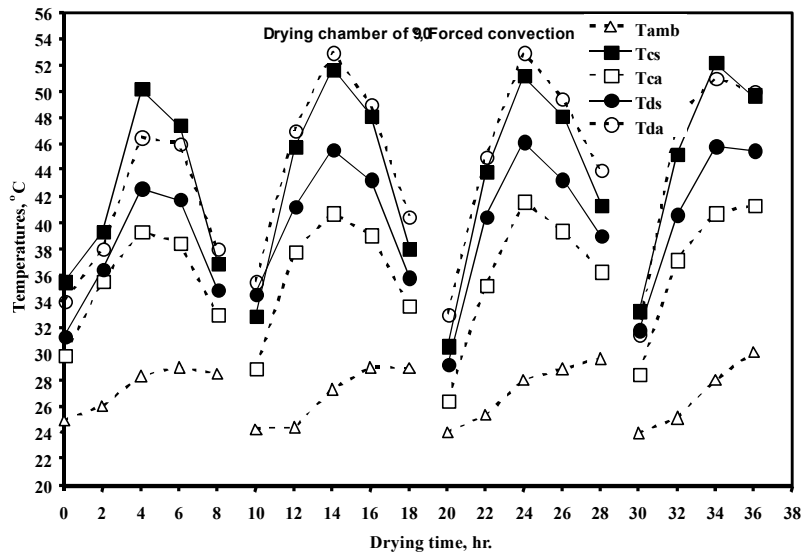


Fig. 9: Measured temperatures for the different drying days for 90° drying chamber and natural convection mode

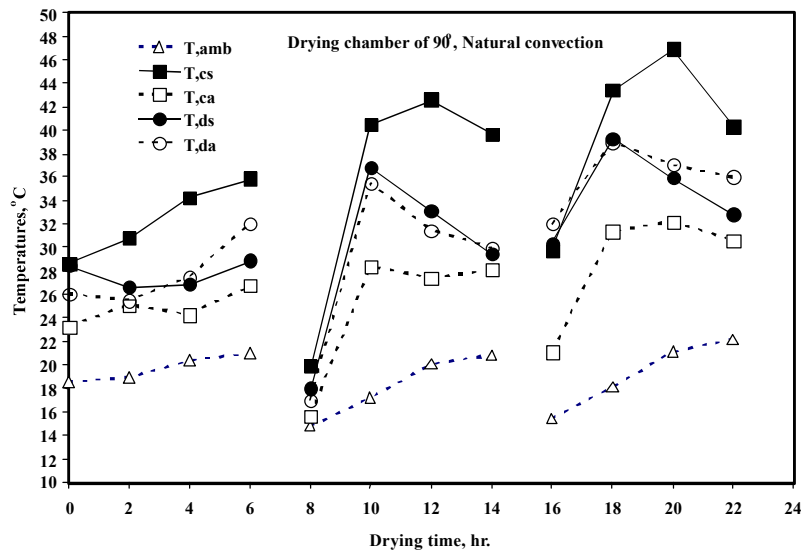


Fig. 10: Measured temperatures for the different drying days for 90° drying chamber and natural convection mode

**Banana Moisture Content vs. Drying Time:** Wet basis moisture content (%), versus drying time in hours for two convection modes and drying chamber inclination angle is shown in Figure 11. Averages for the different samples represented for different shelves of vertical or different places of 0° were averaged and showed in the figure. For all the followed method that was used to dry banana fruit in the solar dryer, it was noticed that the banana moisture contents was faster and lower contents than that dried under the direct sun rays samples. This was noticed for all the drying period.

**The Moisture Re-Absorption or Losses,  $R_n$ :** Moisture re-absorption by Banana fruit under drying was determined for the different treatments according to equation (3) and it is represented in Table 3. From the table (within the investigation conditions), it is noticed that, banana lost its weight (moisture) during the first night (between first and second drying day) for all the convection modes or the drying chamber inclination angle.

**Drying Constant,  $k$ :** Banana solar drying constant was correlated with temperature using Arrhenius equation as Woods *et al* [14]:

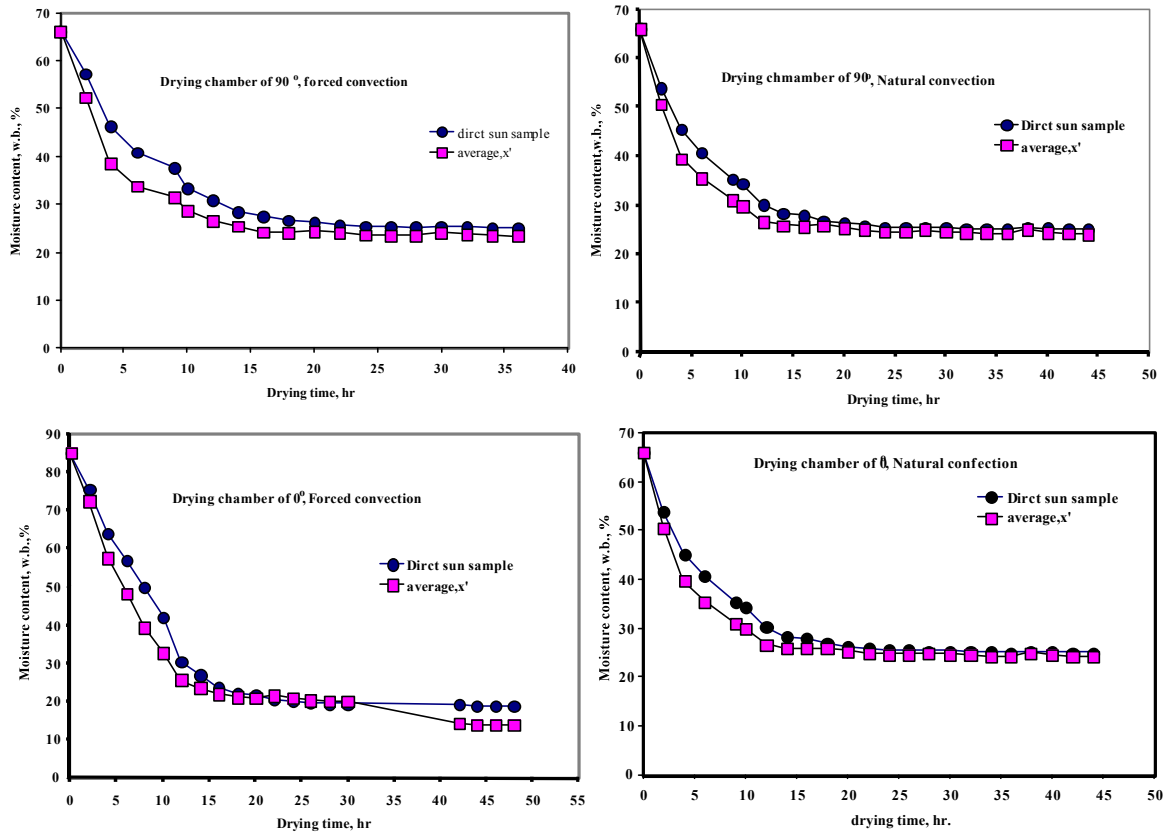


Fig. 11: Average moisture content (%) versus drying time, hours for vertical dryer cabinet

Table 2: Average temperatures and relative humidity for different drying chamber-inclinations and different convection modes used with banana drying

Chamber angle	Convection mode	$T_{amb}$	$RH_{amb}$	$T_{cs}$	$T_{ca}$	$T_{ds}$	$T_{da}$	$RH_{sd}$
0°	natural	24.05	59.42	42.82	36.14	35.21	40.26	36.09
	forced	29.88	57.30	42.81	36.79	40.91	43.41	41.23
90°	natural	19.05	58.00	36.06	26.18	30.57	30.75	39.71
	forced	27.03	60.86	43.33	34.16	39.52	43.88	39.12

Table 3:  $R_n$  values for different treatments, %

	Forced, active designs			Passive			
	1-2d	2-3d	3-4d	1-2d	2-3d	3-4d	4-5d
D. Sun sample	-11.59	-2.42	1.19	-10.15	-20.91	-12.30	-
90°	-8.57	1.69	2.82	-8.98	-19.33	5.50	-
S.D	±0.85	±0.27	±0.21	±1.23	±4.90	±24.86	-
D. Sun sample	-15.63	-2.15	-0.36	-15.09	-4.42	-0.28	0.91
0°	-17.07	-1.30	-0.26	-14.76	-1.53	0.96	3.96
S.D.	±0.62	±0.29	±0	±1.46	±2.18	±0	±1.42

Table 4: Banana drying constant " $k$ " for different treatments,  $S^{-1}$ 

Vertical drying chamber, 90°		horizontal drying chamber, 0°	
Active	Passive	Active	passive
$1.7475 \times 10^{-5}$	$1.1561 \times 10^{-5}$	$1.91861 \times 10^{-5}$	$1.6529 \times 10^{-5}$

Table 5: Drying system efficiency, (%) for 1<sup>st</sup> three successful days of forced convection for the drying chamber of 90° and 0°

1 <sup>st</sup> drying day	Drying time, hr	angle of DC	2 (10:00)	4 (12:00)	6 (14:00)	8 (16:00)	Daily Average
	Drying system efficiency, %	90°	7.61	10.43	10.03	45.02	18.27
		0°	5.09	7.1	15.42	40.59	17.05
2 <sup>nd</sup> drying day	Drying time, hr		10	12	14	16	Daily Average
	Drying system efficiency, %	90°	5.40	5.04	5.70	21.82	9.49
	Drying system efficiency, %	0°	3.46	3.73	3.51	10.46	5.29
3 <sup>rd</sup> drying day	Drying time, hr		18	20	22	24	Daily Average
	Drying system efficiency, %	90°	1.78	3.50	6.78	35.35	11.85
	Drying system efficiency, %	0°	1.98	3.42	3.78	10.34	4.88

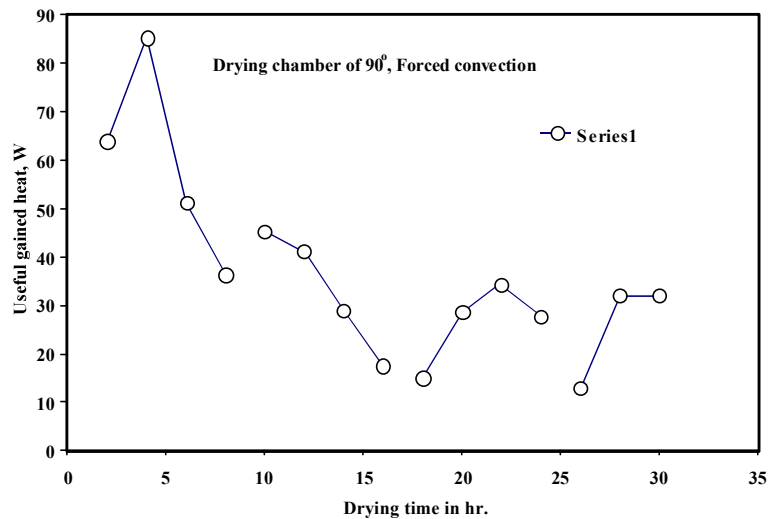


Fig. 12: Useful heat determined for 90° drying chamber position and forced convection

$$k = 0.6854 \exp(-3316.1/(T + 273.15))$$

Where  $T$  was considered for the average drying air temperature between the inlet and the outlet in Celsius degrees. The drying constant  $k$  is presented in Table 4:

From the table the drying constant was found as  $1.1561 \times 10^{-5} \text{ S}^{-1}$  for passive banana drying for Vertical drying chamber, 90°; average drying air temperature between the dryer inlet and outlet as 28.47°C. Meanwhile the constant was found as  $1.7475 \times 10^{-5} \text{ S}^{-1}$  for active drying when the average drying temperature was 37.89°C. the constant for active dryer with 0° was found as  $1.91861 \times 10^{-5} \text{ S}^{-1}$  for average drying temperature of 43.16°C with Standard deviation of  $\pm 0.83$ . It was also found as  $1.6529 \times 10^{-5} \text{ S}^{-1}$  for 0° when the passive natural convection solar drying was applied with standard deviation of  $\pm 1.76^\circ\text{C}$  for average air temperatures of 38.2°C.

**Drying System Efficiency:** Drying system total efficiency was determined according to equation (2) and represented in Table 5 for the first three drying days. For two hours intervals and within the forced convection mode. The

system efficiency was higher compared to the following days for both of the drying chamber inclination angle with the horizon. This may be attributed to the fast drying in the falling moisture stage at the first drying day, as it is shown in Figure 11. Figure 12 represents the useful heat within banana drying when the drying chamber at 90° with the horizontal datum.

## CONCLUSIONS

### The Study Revealed the Following Conclusions:

- Drying constant was found denoted fast drying processes for the forced convection against the passive.
- Also, drying constant denoted that, horizontal dryer chamber was speeding banana drying over the vertical one for active and passive within the time of drying for the site of investigation.
- Drying system efficiency for the forced convection was higher for the first day comparing with the following days due to the fast drying in the moisture falling stage.

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