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Drying of Chilli Pepper Using a Solar Dryer with a Back-Up Incinerator under Makurdi Humid Climate

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Abstract: *The drying of chilli pepper using a solar dryer with a back-up incinerator to determine the drying rate and efficiency was undertaken. The dryer was used to dehydrate the pepper during sunny (clear) and cloudy (dull) weather with the view to improve the quality of the pepper for storage. Drying was assumed to have taken place in the falling rate period so that only one drying rate constant was used. Different batches of the pepper were dried under various drying conditions. The solar dryer was used for drying during sunny weather while the incinerator assisted dryer was used during cloudy weather. Open air sun drying was carried out as control. The respective weight losses of the dried samples were measured and used to determine the reduction in moisture contents. The efficiencies of the equipment and the drying rate efficiencies were computed. The drying rate efficiencies for solar dryer and solar-incinerator dryer were obtained as 99.6 %, and 92.9 % respectively. The corresponding computed efficiencies for the equipment were 56 % and 13 % respectively. The results obtained showed that drying rate was highest during the solar drying and least during the incinerator-assisted and control drying respectively indicating good prospects for solar drying of chilli pepper in Makurdi.*

Keywords*: Solar dryer, incinerator, chilli pepper, drying rate, efficiency, humid climate*

I. Introduction

Drying is a thermal process in which heat and moisture transfer occur simultaneously. Heat is transferred by convection from heated air to the product to raise the temperatures of both the solid and moisture that is present [1]. Moisture transfer occurs as the moisture travels to the evaporative surface of the product and then into the circulating air as water vapour [2]. The heat and moisture transfer rates are therefore related to the velocity and temperature of the circulating drying air [3]. Agricultural crops need to be dehydrated by drying to moisture content suitable for storage [4 – 11].

Active drying systems for the small scale rural development are not common because of the motorised fans which calls for grid connected electricity or photovoltaic (PV) generators. While PV systems are expensive, grid connected electricity is either unavailable or unreliable or both [12 – 16]. Hence, the traditional open sun drying is still common and widespread in Nigeria. The products under the open drying are of poor quality due to the unavoidable presence of rain, wind, moisture and dust [17 – 20]. Also, they are attacked by rodents, insects and fungi among others. The process is also time-consuming and it requires a large area for spreading out the produce to dry.

Solar drying is an alternative which offers several advantages over the traditional (open sun) method of drying [21 – 23]. It is economically viable and environmentally friendly. It saves energy, time, occupies less area, improves product quality, and makes processing industries to produce hygienic, good quality food products. At the same time, it can be used to promote renewable energy sources as an in-come generating option [20]. Several attempts have been made to improve the quality of the dried agro-products by harnessing solar energy [24, 25]. Makurdi is the capital of Benue State in the middle belt region of Nigeria. The town is located on coordinates 7^{0} 43' 50"N, 8^{0}32'10"E. Several efforts have been carried out in this location to take advantage of the abundant solar radiation available [17, 22, 26].

Most crops and grains are harvested during the peak periods of raining season and preservation by sun drying proves difficult. These result in agricultural produce to be dumped in villages and major cities as waste [23, 26]. Rehydration of the crops during cloudy weather and at nights results to poor dehydrated products for storage [27].

The solar dryer with a backup incinerator therefore focuses on dehydrating agricultural produce during clear weather, cloudy weather and at nights to improve the quality of agricultural products for storage. It will enhance the dehydration of agricultural products especially during the harvest period in order to improve storage life [21, 28 – 33].

Generally, the drying of a mass of moist solid can be described under three parts namely the initial adjustment, constant rate and the falling rate periods. According to [34], natural convection drying in the falling rate period can be represented with equation 1.

$$ln(M_o - M) = Kt \quad (1)$$

where, M_o = initial moisture content and M = moisture content at time t and K = drying constant.

II. Materials and Methods

The dryer comprises of three major units namely the flat plate collector; an incinerator and the drying chamber. The incinerator is incorporated in the design for drying during cloudy weather and night periods. The schematic diagram of the complete assembly of the Solar dryer with incinerator is shown in figure 1.

No-load tests were carried out on the system. The tests involved measuring the temperature of the air stream and the ambient temperature using thermometer. The average velocity of air delivered into the drying chamber was also measured using a cup anemometer. The biomass (charcoal) used in the incinerator was burnt and the heat conveying fluid (water) was allowed to flow by gravity. The initial and final temperatures of the fluid were measured and the temperature of the dryer was also measured using a thermometer.

On-load tests were ran for different drying conditions for solar, solar-incinerator and control experiment of chilli pepper (*Capsicum annuum*) respectively. To compare the performance of the dryer with that of the sun drying, equal weights of control samples of chilli pepper (1000 g) to that introduced into the dryer were respectively placed on a tray beside the dryer in the open sun. Before starting the experimental runs, the whole apparatus was operated for a period of one hour to stabilize the air temperature and air velocity in the dryer each day from 09.00 hours. Drying was started after completion of loading, usually at about 10.00 hours and discontinued when it reached the final acceptable moisture content for chilli pepper of 5%. The sample was weighed every one hour to determine the moisture lost. The drying process was continued until acceptable moisture content was achieved. The same experiment was repeated for dull weather and the equipment, solar collector, incinerator and dryer connected and ran to determine the equipment efficiency and dry rate.

Weight losses of the samples during the drying process were measured using a digital weighing balance. A Vaisala humidity and temperature indicator HMI 31 was used for measuring relative humidity, ambient temperature and the temperatures of the collector and the dryer respectively. A micro processor AM 4822 Anemometer was used for measuring air speed. Temperatures of the glass cover, absorber plate of the collector were measured using thermometers at 1 hour intervals during the no-load test and 2 hours interval during the on-load test. The moisture content of the chilli pepper was determined using analytical balance moisture analyzer. The dried chilli pepper samples were collected cooled in the shade to the ambient temperature and sealed in plastic bags for storage.

III. Results and Discussions

Tables 1 to 3 show the mean mass (moisture) profile of chilli pepper for the control, solar dryer, and solar-incinerator dryer experiments respectively. The results indicate that the percentage moisture lost by the open sun drying and the solar –incinerator drying were quite close at the end of the second day (41.34 % and 48.80 % respectively). A wide gap of the moisture loss was observed at the end of the second day for the sample in the solar dryer (61.54 %). At the end of the third day (after 26 hrs), it could be said that the solar dried sample had lost all its expellable moisture content (85.96 %) whereas the open sun dried sample had lost only 51.99 % moisture content and the solar –incinerator lost only 67.91 % of its expellable moisture content. At the end of 32 hrs it could be said that the solar–incinerator dryer also lost virtually all the expellable moisture content (86.14 %) whereas the control sample lost only 80.67 %. It took (38 hrs) for the control sample to lose all its expellable moisture content (86.21 %).

Figure 2 shows that efficiency of the collector (η_c), increases with increase in ambient temperature. Figure 3 shows the drying pattern distribution rate for pepper drying. The Figure 3 shows that the drying rate is faster in solar drying, followed by solar incinerator drying, then the open sun drying. The efficiencies of the equipment were also determined using the drying distribution rates and constants of the four equipment. The drying rate efficiency for solar dryer and solar-incinerator dryer was obtained as 99.6 %, and 92.9 % respectively.

IV. Conclusion

The solar dryer can be used efficiently during cloudy, rainy and sunny weather conditions and at nights. The drying rate efficiency for solar dryer and solar-incinerator dryer was obtained as 99.6 %, and 92.9 % respectively. The computed efficiencies for the equipment were 56 % and 13 % for solar dryer and solar-incinerator dryer respectively. The solar dryer had a better drying rate. The system can be adopted in both rural and urban areas with high humid conditions such as Makurdi for drying of agricultural produce.

References

[1] Sarsavadia, P.N. (2007). Development of a solar–assisted dryer and evaluation of energy requirement for the drying of Onion, *Renewable Energy*, 32: 2529-2549

[2] Sreekumar, A. Manikantan, P.E., Vijayakumar, K.P. (2008). Performance of indirect solar cabinet dryer, *Energy Conversion and Management*, 49: 1388–1395.

[3] Madhlopa, A., Ngwalo, G. (2007). Solar dryer with thermal storage and biomass-backup heater, *Solar Energy* 81: 449–462.

[4] Thirugnanasambandam, M., Iniyan, S., Goic, R. (2010).A review of solar thermal technologies. *Renewable and Sustainable Energy Reviews*, 14: 312–322

[5] Fudholi, A. Sopian, K., Ruslan, M.H., Alghoul, M.A., Sulaiman, M.Y. (2010). Review of solar dryers for agricultural and marine products. *Renewable and Sustainable Energy Reviews*, 14: 1–30

[6] Çakmak, G., Yıldız, C. (2009). Design of a new solar dryer system with swirling flow for drying seeded grape. *International Communications in Heat and Mass Transfer*, 36: 984–990

[7] Afriyie, J.K., Rajakaruna, H., Nazha, M.A.A., Forson, F.K. (2011). Simulation and optimisation of the ventilation in a chimney-dependent solar crop dryer. *Solar Energy*, 85: 1560–1573

[8] Bennamoun, L. (2011). Reviewing the experience of solar drying in Algeria with presentation of the different design aspects of solar dryers. *Renewable and Sustainable Energy Reviews*, 15: 3371– 3379

[9] Amer, B.M.A., Hossain, M.A., Gottschalk, K. (2010). Design and performance evaluation of a new hybrid solar dryer for banana, *Energy Conversion and Management*, 51: 813–820

[10] Afriyie, J.K., Nazha, M.A.A., Rajakaruna, H., Forson, F.K. (2009). Experimental investigations of a chimney-dependent solar crop dryer, *Renewable Energy*, 34: 217–222

[11] Murthy M.V.R. (2009). A review of new technologies, models and experimental investigations of solar driers, *Renewable and Sustainable Energy Reviews*, 13: 835–844

[12] Montero, I., Blanco, J., Miranda, T., Rojas, S., Celma, A.R. (2010). Design, construction and performance testing of a solar dryer for agro-industrial by-products, *Energy Conversion and Management*, 51: 1510–1521

[13] Li, Z. Zhong, H., Tang, R. (2006). Experimental investigation on solar drying of salted greengages, *Renewable Energy*, 31: 837–847.

[14] Jairaj, K.S., Singh, S.P., Srikant, K. (2009). A review of solar dryers developed for grape drying, *Solar Energy*, 83: 1698–1712

[15] Janjai, S., Lamlert, N., Intawee, P., Mahayothee, B., Bala, B.K., Nagle, M., Müller, J. (2009). Experimental and simulated performance of a PV-ventilated solar greenhouse dryer for drying of peeled longan and banana, *Solar Energy*, 83: 1550–1565

[16] Singh, S., Kumar, S. (2012). Testing method for thermal performance based rating of various solar dryer designs, *Solar Energy*, 86: 87–98

[17] Edeoja, A.O., Kucha, E.I., Itodo, I. N. (2009). Development of an active solar crop dryer with a manually-tracking concentrating collector. Int. Journal of Electrical & Elect. 1(1).

[18] Barki, E., Ibrahim, J. S., Eloka-Eboka, A. C. (2012). Performance Evaluation of an Efficient Solar Dryer with a Backup Incinerator for Grated Cassava under Makurdi Humid Climate. *International Journal of Environment and Bioenergy*. 1(2): 118-125

[19] Bal, L. M., Satya, S., Naik, S.N. (2010). Solar dryer with thermal energy storage systems for drying agricultural food products: A review. *Renewable and Sustainable Energy Reviews*, 14: 2298–2314

[20] Sharma, A., Chen, C.R., Vu Lan, N. (2009). Solar-energy drying systems: A review. *Renewable and Sustainable Energy Reviews*, 13: 1185–1210

[21] Ibrahim, J. S., Eloka-Eboka, A. C., Barki, E. (2014). Comparative Analysis and Performance of Solar Dryers with Backup Incinerators for Nsukka Sub-tropical and Makurdi Humid Locations Using Selected Farm Produce. *British Journal of applied science and technology*, 4(3): 525-539.

[22] Ibrahim, J. S., Edeoja, A. O., Barki, E. (2013). Comparative Performance Analysis of Solar Dryers with Backup Incinerators under Subtropical and Humid Climate Using Cassava Grates. *Jurnal Mekanikal*, 36: 24-33

[23] Bala, B. K., Mondol, M. R. A., Biswas, B. K., Chowdury B. L. K., Janjai S. (2003). Solar Drying of Pineapples using solar Tunnel Drier, *Renewable Energy*, 28: 183-190.

[24] Mumba, J. (1995). Economic analysis of a photovoltaic, forced convection solar grain drier, *Energy*, 20(9): pp. 923–928.

[25] Okonkwo, W. I., Okoye, E. C. (2004). Integrated pebbled Bed passive solar energy crop dryer, proceedings of 5th international conference and AGM of the Nigerian Institution of Agricultural Engineers, 26: 417 - 423.

[26] Itodo, I.N., Obetta, S.E., Satimehin, A.A. (2002). Evaluation of a solar crop dryer for rural application in Nigeria, *Botswana .J. Tech.*, 11(2): 58 – 62.

[27] Ayensu, A. (1997). Dehydration of food crops using a solar dryer with convective heat flow, *Solar Energy* 59 (4/6): 121–126.

[28] Unachukwu, G.O., Anyanwu, C.N. (2010). Small-scale Incinerator for Domestic Hot Water Generation from Municipal Solid Wastes. Vol, 39; pp 430-439.

[29] Kaewkiew, J., Nabnean, S., Janjai, S. (2012). Experimental investigation of the performance of a large-scale greenhouse type solar dryer for drying chilli in Thailand. *Procedia Engineering*, 32: 433 – 439

[30] Aktaş, M., Ceylan, İ., Yilmaz, S. (2009). Determination of drying characteristics of apples in a heat pump and solar dryer, *Desalination*, 239: 266–275

[31] Boughali, S., Benmoussa, H., Bouchekima, B., Mennouche, D., Bouguettaia, H., Bechki, D. (2009). Crop drying by indirect active hybrid solar–Electrical dryer in the eastern Algerian Septentrional Sahara, *Solar Energy*, 83: 2223–2232

[32] Maiti, S., Patel, P., Vyas, K., Eswaran, K., Ghosh, P. K. (2011). Performance evaluation of a small scale indirect solar dryer with static reflectors during non-summer months in the Saurashtra region of western India, *Solar Energy*, 85: 2686–2696

[33] Banout, J., Ehl, P., Havlik, J., Lojka, B., Polesny, Z., Verner, V. (2011). Design and performance evaluation of a Double-pass solar drier for drying of red chilli (*Capsicum annum L.*), *Solar Energy*, 85: 506–515

[34] Coulson J. M., Richardson J. F. (1977). Chemical Engineering Vol. 1, 3rd Ed. A wheaton and CO, Exeter, G.B.

Table 1: Mean Mass (Moisture) Profile of Pepper Sample (Control)

Time (Hrs)	Mass before drying, W (g)	Mass after drying, W_s (g)	M (%)	M_o-M (%)	$In(M_o - M)$	Time (days)
1000 – 1200	1000	824	21.30	65.30	4.17	1
1200 – 1400	824	805	24.08	62.52	4.13	
1400 – 1600	805	809	23.50	63.10	4.14	
1600 – 1800	809	786	27.09	59.51	4.08	
0800 – 1000	786	773	29.31	7.29	4.05	2
1000 – 1200	773	765	30.60	56.00	4.02	
1200 – 1400	765	761	31.33	55.27	4.01	
1400 – 1600	761	722	38.49	48.11	3.87	
1600 – 1800	722	707	41.34	45.26	3.81	
0800 – 1000	707	677	47.60	39.00	3.66	3
1000 – 1200	677	671	48.98	37.62	3.62	
1200 – 1400	671	683	46.30	40.30	3.69	
1400 – 1600	683	657	51.99	34.61	3.54	
1600 – 1800	657	611	63.43	23.17	3.14	
0800 – 1000	611	595	67.89	18.71	2.93	4
1000 – 1200	595	553	80.67	5.93	1.78	
1200 – 1400	553	556	79.23	7.37	1.99	
1400 – 1600	556	552	81.13	5.47	1.69	

Table 2: Mean Mass (Moisture) Profile of Pepper Sample (Solar Dryer)

Time (Hrs)	Mass before drying (W) (g)	Mass after drying Ws (g)	M (%)	M_o-M (%)	$In(M_o - M)$	Time (days)
1000 – 1200	1000	816	22.42	64.18	4.16	1
1200 – 1400	816	812	23.04	63.56	4.15	
1400 – 1600	812	800	24.94	61.66	4.12	
1600 – 1800	800	767	30.30	56.30	4.03	
0800 – 1000	767	756	32.17	54.43	3.99	2
1000 – 1200	756	730	36.93	49.67	3.91	
1200 – 1400	730	717	39.29	47.31	3.86	
1400 – 1600	717	643	55.40	31.20	3.44	
1600 – 1800	643	619	61.54	25.06	3.22	
0800 – 1000	619	600	66.59	20.01	2.99	3
1000 – 1200	600	582	71.76	14.84	2.69	
1200 – 1400	582	564	77.28	9.32	2.23	
1400 – 1600	564	537	85.96	0.64	- 0.44	

Table 3: Mean Mass (Moisture) Profile of Pepper Sample (Solar-Incinerator Dryer)

Time (Hrs)	Mass before drying W (g)	Mass after drying W_s (g)	M (%)	M_o-M (%)	$In(M_o - M)$	Time (days)
1000 – 1200	1000	821	21.8	64.74	4.17	1
1200 – 1400	821	794	25.81	60.79	4.11	
1400 – 1600	794	802	24.61	61.99	4.13	
1600 – 1800	802	789	26.61	59.99	4.09	
0800 – 1000	789	775	29.03	57.57	4.05	2
1000 – 1200	775	755	32.45	54.15	3.99	
1200 – 1400	755	719	39.01	47.59	3.86	
1400 – 1600	719	702	42.36	44.24	3.79	
1600 – 1800	702	672	48.80	37.80	3.66	
0800 – 1000	672	668	49.50	37.10	3.61	3
1000 – 1200	668	606	64.89	21.71	3.07	
1200 – 1400	606	650	53.66	32.94	3.49	
1400 – 1600	650	595	67.91	18.69	2.93	
1600 – 1800	595	555	80.11	6.49	1.87	
0800 – 1000	555	544	83.66	2.94	1.08	4
1000 – 1200	544	537	86.14	0.46	- 0.77	

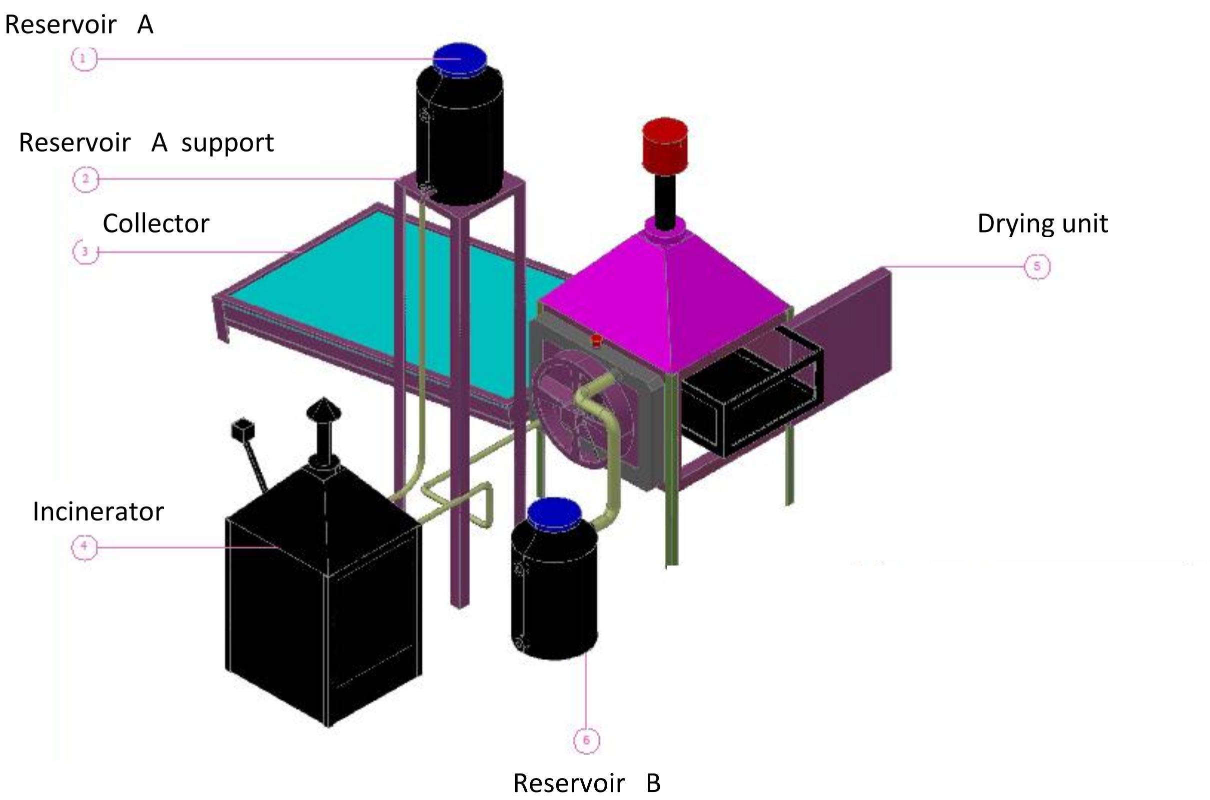

Fig. 1: Solar dryer with a back-up incinerator

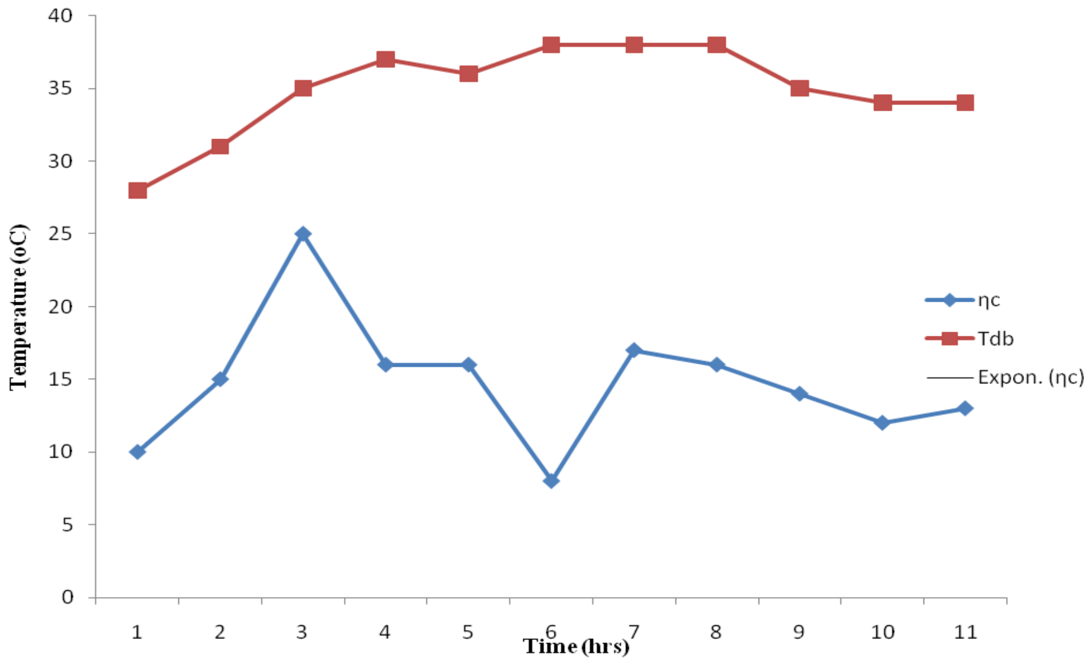

Fig. 2: Effect of Ambient Temperature on the Efficiency of Collector during No-load test

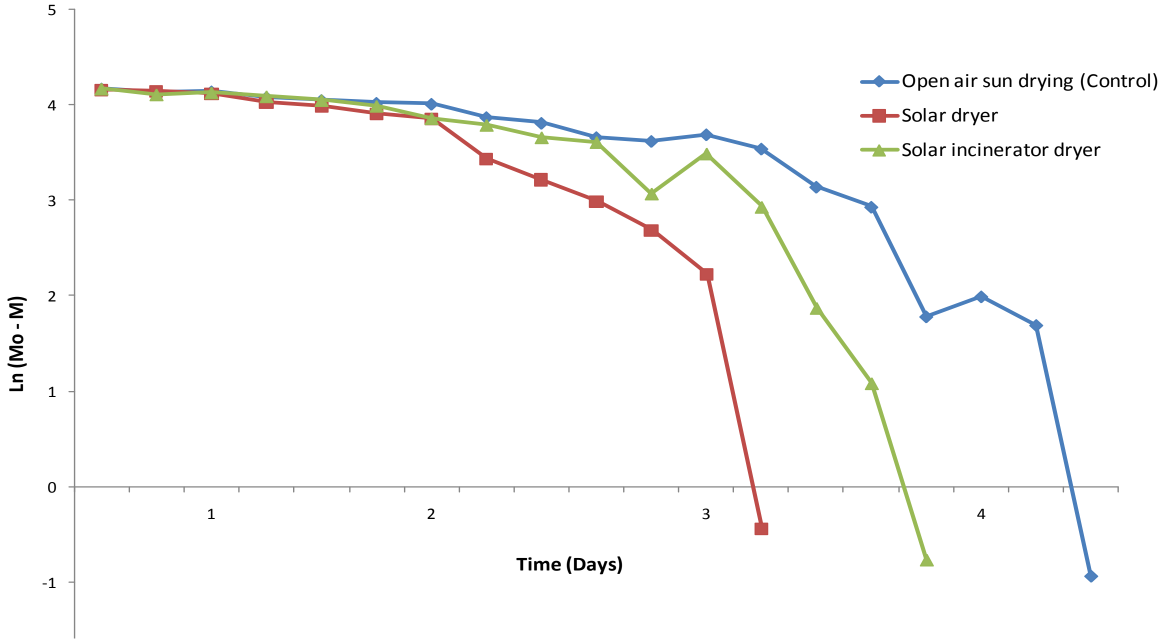

Fig. 3: Drying rates of Pepper for various drying conditions

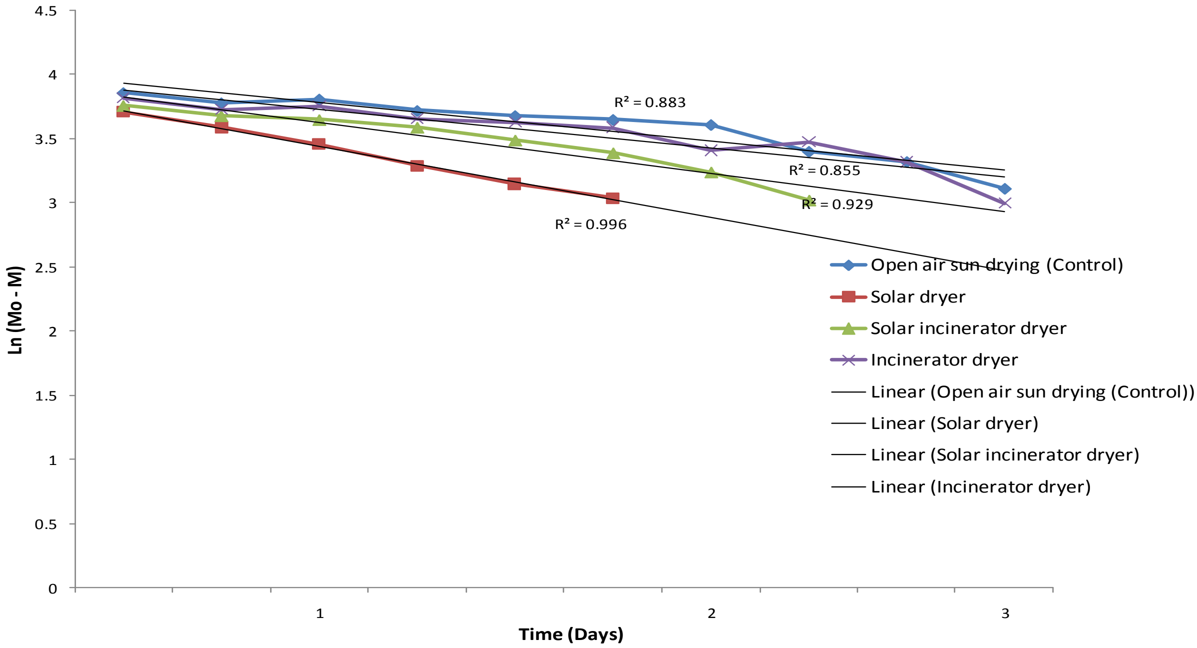

Fig. 4: Drying distribution rates and constants of the four Equipment