Performance Evaluation of Forced Convection Solar Dryer and Influence of Airflow Rate on Drying Kinetics of Tomato

Kiman Silas, Gutti Babagana, Bitrus K. Highina and Mohammed D. Habiba

Abstract-The effect of air condition (airflow rate) on drying kinetics of tomato was examined. In order to select a suitable form of the drying curve, 3 different thin layer drying models were fitted to experimental data. The best model for airflow rate of 0.027, 0.054, and 0.081m3/s is Henderson and Pabis with the highest R^2 values of 0.9932, 0.9998 and 0.9998 respectively, while for airflow rate of 0.108 and 0.135, the Page model best fit with highest R^2 values 0.9979 and 0.9909 respectively. The useful heat per hour for the forced convection system was 4.33 W/m^{2}hk for drying of tomato, and the collector, pick-up and overall efficiencies were 45%, 47% and 12.4% respectively.

Keywords- Overall efficiency, Empirical models, Drying kinetics, Forced convection system, Moisture ratio, Solar dryer, Tomato

1 INTRODUCTION

Tomato (Lycopersicon esculentum L.) is one of the most popular vegetable crops grown all over the world, both for fresh marketing as well as for processing industry (Abano et al. 2011). Many developing countries still face enormous challenges of postharvest losses of tomatoes due to inadequate processing and storage facilities. Tomatoes produced in the peak seasons are either consumed fresh, sold at relatively cheap prices, or are allowed to go waste (Shukula and Sharma, 2010).

The most popular method of drying tomato in the tropics is hot air drying (Aslan and Ozcan, 2011). The convectional sun drying is commonly practiced in most of the developing countries like Nigeria where, vegetable processing/storage facilities and solar dryers are either not available, or are too expensive for the local farmers to afford (Gutti et al. 2012).

Drying of agricultural products is an essential process in their preservation which normally provides longer shelf-lighter weight for easy transportation and small space for storage. It is a process of moisture removal due to simultaneous heat and mass transfer (Babagana et al. 2012). Many applications of drying have been successfully applied to decrease physical, biochemical and microbiological deterioration of food products due to the reduction of the moisture content to the level (Abano et al. 2011). daSilva et al. (2014), reported that medicinal benefits of tomatoes include reduction of cholesterol, improvement of vision, maintenance of gut, lowering of hypertension, alleviation of diabetes, protection of the skin, prevention of urinary tract infections and gallstones. Lycopene is used in cosmetics and pharmaceutical products and is an excellent natural colourant in several food formulations.

In this paper, forced convection mode solar dryer was evaluated in terms of its performance especially, the determination of collector, pick-up and overall efficiencies. Also, this work described the thin layer drying kinetics of tomato, using empirical models and the analysis of the influence of air flow rate condition on the kinetic constants of some proposed models.

2 MATERIALS AND METHODS

2.1 Drying Procedure

The performance of a solar dryer is determined by the amount as well as the rate of moisture it can remove from the products (Mohammed, 2008). Knowing the initial weight and the final weight at point when no further weight loss of the product was attained. The moisture content was determined using the weight loss method with the aid of a sensitive balance with range of 0-500g The drying process was stopped after no further change in weights was observed. At this point moisture content decreased considerably (Mirzaee et al. 2010). The samples were dehydrated in an experimental air dryer, who consists of sections: air flow rate control, collector unit and drying test compartments. Experiments to determine the influence of process variables on the drying kinetics were performed. Air was supplied to the system by the five air circulation units, the airflow rate was controlled by adjusting to 0.027, 0.054, 0.081, 0.108 and 0.135 m3/s i.e each air circulation unit can produce 0.027 m3/s airflow rate.

2.2 MATHEMATICAL MODELING OF DRYING CURVES

2.2.3 Drying kinetics Expressed in Terms of Empirical Models

To describe the thin layer drying of an agricultural product the empirical and diffusion models are used (daSilva et al. 2014).The drying kinetics of tomato slices was expressed in terms of empirical models, where the experimental data obtained for the five different airflow rates were plotted in the form of moisture ratio against drying time in accordance with the work of (Abano et al. 2011). Drying curves were fitted to 3 thin layer drying models which were given in Table 1. Goodness of the fit was determined using the statistical parameter called the coefficient of determination (R2) according to Ogawa and Tagawa (2007).

$$R2= N(\sum_{i=1}^{n} - MR\sum_{i=1}^{n} Pr)/(N\sum_{i=1}^{n} Pr - \sum_{i=1}^{n} Pr) \quad (1)$$

Where, MR is moisture ratio, Pr is predicted moisture ratio, N is number of observation.

According to Gokhan et al. (2009), the moisture ratio can be expressed as:

MR = Mt- Me / Mo- Me (2)

Where, Mt denotes moisture content after drying time t, Mt stands for equilibrium moisture content and Mo is the initial moisture content. The values of Me are relatively small compared to those of Mt or Mo, hence the error involved in the simplification is negligible, hence moisture ratio is calculated as (Amin et al. 2011):

MR = Mt / Mo (3)

Moisture content data were converted to moisture ratio and then fitted (Mirzaee et al. 2010) to the drying models.

TABLE 1: DRYING MODELS TO DESCRIBE DRYING KINETICS

Model name	Model	Reference
Page	MR = exp(-kta)	Yurtlu (2011)
Henderson and Pabis	MR = a exp(-kt)	Ogawa and Tagawa (2007)
Newton	MR = a(-kt)	Chung et al. (2010)

2.3 SOLAR COLLECTOR EFFICIENCY

The thermal efficiency of a collector is defined as the ratio of useful energy gain by the air to solar radiation incident on the absorber of solar collector (Yousef and Adam, 2008).

$$\eta = Qg/AcIt \quad (4)$$

Where, Qg is heat gain by the air from the absorber (W/m2K), Ac is area of transparent cover (m2), It is total incident solar radiation (W/m2), Joe (1980) defined the total incident solar energy as:

$$Qs = Qa + Qr + Qc \quad (5)$$

Where, Qr is rate of radiation losses from absorber (W), Qa is rate of convection and conduction losses

Where, Qg = Heat transferred per unit time.

from absorber (W) and Qc is rate of useful heat by the absorber (W). Bukola and Ayoola (2008) reported that the three heat losses terms are usually combined into one term given as:

$$Ql = Qco + Qcv + Qr \ (6)$$

Where, Ql is rate of losses from the absorber (W/m2K) while Duffie and Beckman (1974), defined the rate of the losses as:

$$Ql = UlAc(Tc - Ta) \ (7)$$

Where, Ul is overall heat transfer coefficient of the absorber. Also according to Mukhersee and Chakrabarti (2005):

$$Qg = UlAc(Tc - Ta) \ (8)$$

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Tiwara (1978) defined the rate of heat absorption by the collector as:

$$Qab = (\tau\alpha)Io \quad (9)$$

Where, Io is incident solar radiation, τ is transmittance and α is absorptance. Tiwara (1978) presented the useful heat by the absorber as:

$$Qu = Ql + Qab \quad (10)$$

2.4 OVERALL EFFICIENCY (η_d)

The overall efficiency is defined as the ratio of the energy required to evaporate the moisture to the energy required to evaporate the moisture to the heat supplied to the dryer and it is expressed as (Perry and Green, 1984).

$$\eta_d = wL/Ic\ Ac \quad (11)$$

Where, w is weight of moisture content evaporated (kg), L is latent heat of vaporization of water (kg/kg), Ic is Insolation on the collector surface (kg/m2) and Ac is collector area (m^2).

2.5 PICK-UP EFFICIENCY (η_P)

Yurtlu (2011), defined the pick-up efficiency as the ratio of the moisture pick-up by the air in the drying cabinet to the theoretical capacity of the air to absorb moisture. It is expressed as:

$$\eta_P = ho - hi/has - hi \quad (12)$$

Where, ho is absolute humidity of air leaving the drying cabinet, hi is absolute humidity of air entering the drying cabinet and has is adiabatic saturation humidity of the air entering the dryer.

3 RESULTS AND DISCUSSION

Influence of airflow rate on drying kinetics of tomato slices. Figure 1-5 show the plot of moisture ratio versus drying time for the various airflow rates i.e 0.027, 0.054, 0.081, 0.108 and 0.135m3/s respectively. The plot is for the experimental data and the thin layer drying models listed in Table 1. The moisture ratio of the samples decreased continually with drying time. As expected, there is an acceleration of the drying process due to the increase of the airflow rate. The drying rates were higher in the beginning of the drying processes and they gradually decreased through the end of the drying process. These results are in agreement with other findings reported for drying of tomato.
The drying process was stopped after no further change in weights was observed. At this point moisture content decreased considerably. Moisture content data were converted to moisture ratio and then fitted to the three thin layer drying models.

TABLE 2.0: PARAMETER ESTIMATION AND COMPARISON CRITERIA OF THE SELECTED MODELS

Air flow Rate (m3/s)	Page			Henderson and Pabis			Newton		
	a	k	R2	a	k	R2	a	k	R2
0.027	0.2087	0.0101	0.9863	0.3750	0.2941	0.9932	0.7100	0.2525	0.9663
0.054	0.4688	0.9700	0.9812	0.2500	0.1360	0.9998	0.7100	0.0615	0.9832
0.081	0.9473	0.2750	0.9941	0.0200	0.0585	0.9998	0.9600	0.0413	0.9857
0.108	0.1626	0.0990	0.9979	0.2000	0.0680	0.9891	0.4100	0.0150	0.9632
0.135	0.1626	0.0990	0.9909	0.2000	0.0680	0.9882	0.4100	0.0150	0.9362

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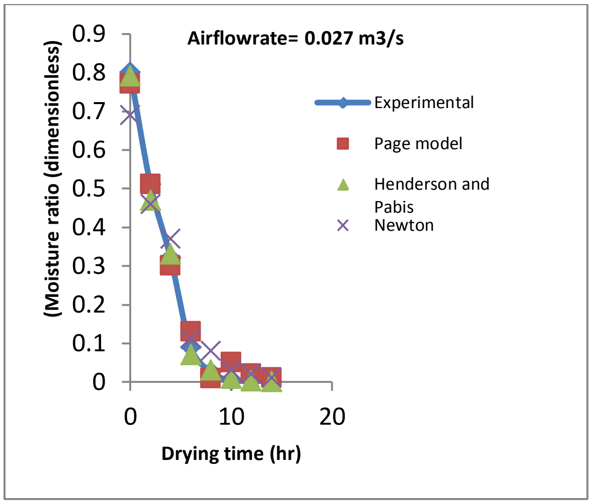

Fig.1: M_R vs T for airflow rate of 0.027 m^3/s

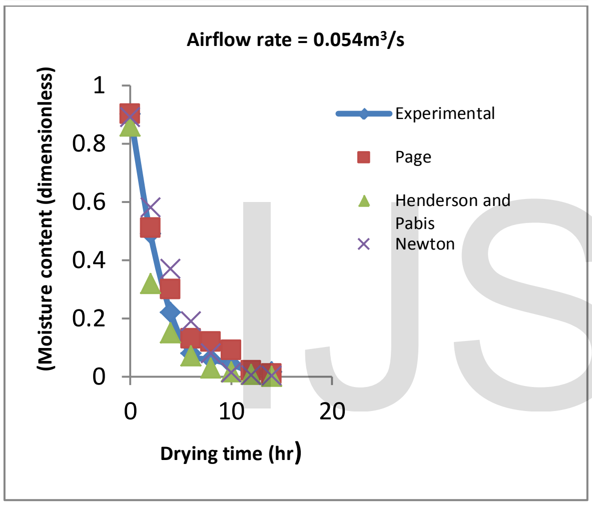

Fig.2: M_R vs T for airflow rate of 0.054 m^3/s

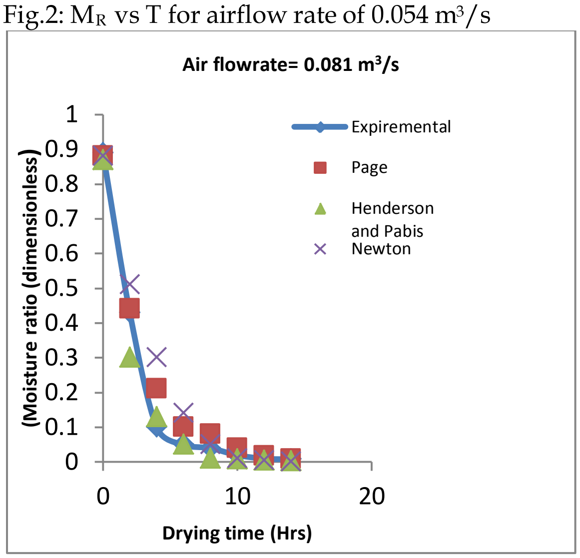

Fig.3: M_R vs T for airflow rate of 0.081 m^3/s

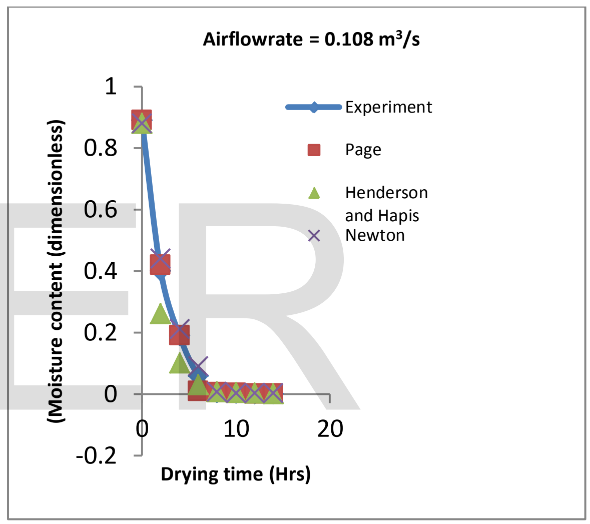

Fig.4: M_R vs T for airflow rate of 0.108 m^3/s

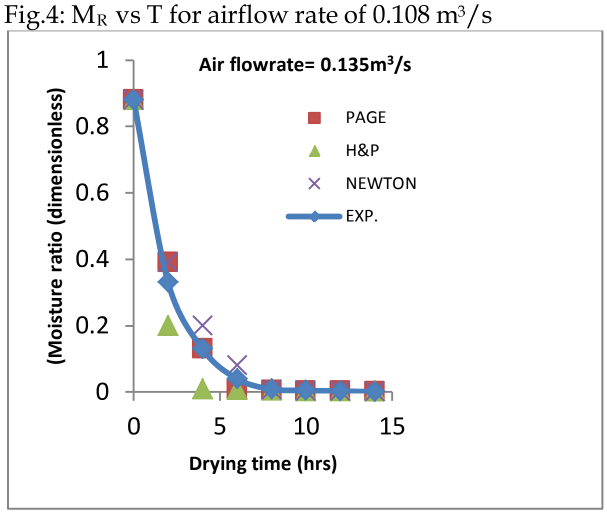

Fig.5: M_R vs T for airflow rate of 0.135 m^3/s

4 CONCLUSION

The forced convection mode was used to dried tomato with varying the airflow rate. The useful heat per hour of forced convection system was 4.33 W/m2hk for drying of tomato, with collector efficiency, pick-up efficiency and overall efficiency of 45, 47 and 12.4% respectively.

In order to explain the drying behavior of tomato cultivated in Maiduguri, 3 models in the literature were applied and fitted to the experimental data. According to the statistical analysis applied to all models, it can be concluded that among these models, that the best model for airflow rate of 0.027 m^3/s, 0.054 m^3/s, and 0.081 m^3/s is the Henderson and Pabis with the highest R^2 values of 0.9932, 0.9998 and 0.9998 respectively, while for airflow rate of 0.108 m^3/s and 0.135 m^3/s, the Page model best fit with highest R^2 values 0.9979 and 0.9909 respectively. The results showed good agreement with the experiment data. This result indicates that the influence of airflow rate on drying time cause decrease in drying time.

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