Global Journal of Researches in Engineering
Mechanical and Mechanics Engineering
Volume 13 Issue 5 Version 1.0 Year 2013
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 Print ISSN:0975-5861

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Keywords : compressed air motor (cam)/ pneumatic wrench, compressed air technology, eco-friendly, global conditions, renewable energy handling.
GJRE-A Classification : *230199p , 290501p*

MATHEMATICAL MODELING OF DRIED BANANA SLICES WITH MCHPDRYER

Strictly as per the compliance and regulations of :

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Saeed Faal [α], Teymour Tavakoli [σ], Barat Ghobadian [ρ], Gholamhassan Najafi [Ѡ], Hashem Samadi[¥] & Mohammad Zarein[§]

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Keywords : drying, modeling, banana, combined heat and power.

I. Introduction

Interest in combined heat and power technologies has grown among energy customers, regulators, legislators, and developers over the past decade as consumers and providers seek to reduce energy costs while improving service and reliability. combined heat and power technology is a specific form of distributed generation, which refers to the strategic placement of electric power generating units at or near customer facilities to supply onsite energy needs. combined heat and power technology enhances the advantages of distributed generation by the simultaneous production of useful thermal and power output, thereby increasing the overall efficiency.

Internal combustion engines are capable of burning a variety of fuels, including natural gas, oil, and alternative fuels to produce shaft power or mechanical energy. About two-thirds of the energy inputs to the engine wasted through exhaust gas and cooling system. Waste heat is generated in a process by the way of fuel combustion or chemical reaction, and then dumped into the environment even though it could still be reused for some useful and economic purpose [1]. Mechanical energy from the prime mover is most often used to drive a generator to produce electricity. Thermal energy from the system can be used in direct process applications or indirectly to produce steam, hot water, hot air for drying. In this study thermal energy of system was used for drying banana.

Banana have been part of humans' diets for many years. Production and consumption of banana have come to stay with many people around the globe. However, bananas contain about 70% moisture and therefore very susceptible to post-harvest losses and considerable weight loss during transportation and storage. This in turn causes serious economic losses as a result of reduction in weight and quality. Post-harvest losses are a major challenge for tropical products such as mango, pineapple, banana, etc especially in Iran. Fruits and vegetables are regarded as highly perishable food due to their high moisture content [2]. Drying is one of the methods that is widely used to preserve fruits and vegetables. Longer persistence, product diversity and reduction in the size is the main reasons for drying fruits and vegetables and this can be expanded with improving product quality and drying methods. Drying of moist materials is a complicated process involving simultaneous heat and mass transfer [3]. Many researches have attempted for drying the Food products especially banana. Mathematical modeling of drying process is a good way to analysis and describing the products drying treatment. All parameters used in the model are directly related to drying conditions. It is directly related to drying conditions drying time and energy required [4]. This process is very useful because doing all the experimental tests will be difficult, time consuming and costly. There are so many investigations about mathematical modeling of thin layer drying behavior of agricultural products, for example, apricot [5], olive [6], carrot [7], eggplant [8], apple pomace [9], plum [10], white mulberry [11] and walnut [12].

II. Materials and Methods

In this study, banana slices were used to conduct the experiments. The study samples were freshly provided. Banana slice were placed on the drying bed after preparing and setting the CHP dryer for different experimental levels. An IC Engine and a

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generator set with the following specifications were showed in table 1. Air parameters were adjusted by measuring temperature and velocity using thermometer (Lutron, TM-925, Taiwan) and anemometer (Anemometer, Lutron-YK, 80AM, Taiwan). The drying process continued until the weight of samples did not change. During the drying experiments, the variation range of ambient temperature was 23±3˚C and of ambient relative humidity was 24±4 percent. Initial moisture content of the banana was determined by drying in an air convection oven. About 32 g sample was placed in the oven at the 80 ℃ for 12 hours till the sample weight did not change anymore and the initial moisture was obtained to be 71% (w.b.). All the experiments were performed three times.

Table 1 : Engine and generator specification

	Engine
Type	single cylinder- 4-stroke Air-cooled
power	6.5 hp @ 1200 rpm
Displacement	196 CC
Bore x Stroke:	68×54 mm
Fuel Types	Natural gas (N), LPG(L)
Ignition system	Transistor Coil Ignition (T.C.I)
Oil capacity	0.55 L
Sound level	70 dB
	Generator
Type	Single-Phase AC Synchronous
Frequency	50 HZ
Current (A) / DC voltage (V)	12V/8A
Maximum power	2.3 kW
Power rating	2 kW

In this research work waste heat from exhaust an engine-generator was used for drying process. Equipment used in this dryer consist of a single cylinder IC engine that works with natural gas fuel, a generator that produces 2 kW of electricity, gas flow meter for measuring fuel consumption, a dryer chamber which samples placed in it, a fan to remove hot air of the dryer chamber, a digital balance for weighing samples, temperature sensor for measuring temperature and a PC to record hot air temperature and sample weight. The schematic diagram of this CHP dryer system is shown in Fig. 1. Waste heat from the engine exhaust was directed into the dryer chamber. The produced heat is approaches under the chamber tray directly and the dryer's chamber is warmed. Hot air is circulated inside the chamber and is removed from the chamber by a fan. Engine was run for a few minutes to reaches steady state condition. The drying experiments were performed at constant speed and four load levels, 25%, 50%, 75% and full load (100%). About 32g samples with thickness of 3, 5 and 7 mm were placed in the dryer chamber and were dried. Samples were weighed automatically by the digital balance with ±0.01 accuracy for 5 min.

To evaluate the characters of the drying process, it is highly important for modeling the drying process. Therefore in this study, the drying curves obtained from experiments were fitted with 3 different models that commonly were used for describing the thin layer drying behavior (Table 2).

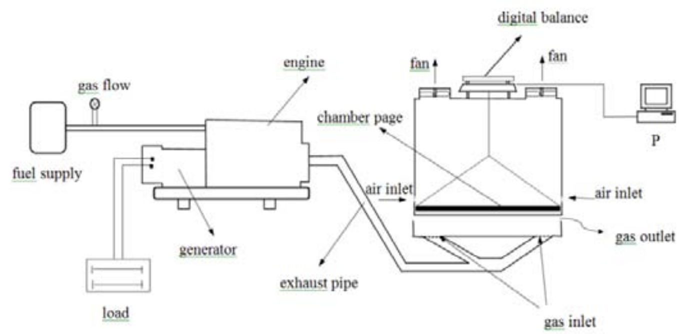

Figure 1 : Schematic diagram of drying equipment

Table 2 : Mathematical models applied to the drying curves

No	Model name	Model	References
1	Lewis	MR = exp(-kt)	[13]
2	Page	MR = exp(-kt^n)	[14]
3	Logarithmic	MR=a.exp(-kt)+c	[15]

To find the best mathematical model, the moisture content data at different engine output powers were converted to (MR) that presents the dimensionless moisture ratio using Eq (1)

$$MR = \frac{M - M_e}{M_0 - M_e} \tag{1}$$

where, M is the instantaneous moisture content (kg $_{water}$ kg^{-1} $_{dry\ matter}$) of the product, M_0 is the initial moisture content of the product and M_e is the equilibrium moisture content. The values of M_e are relatively negligible compared with M and M_0 for long drying time. Thus Eq (1) has been simplified to Eq (2) [16].

$$MR = \frac{M_t}{M_0} \tag{2}$$

Regression analyses for determining the most suitable model for drying thin layer apricots with combined heat and power dryer was carried out with using the conventional statistical calculations namely the chi-square (χ^2), root mean square error (RMSE) and modeling efficiency (EF). The highest values of EF and the lowest values of χ^2 and RMSE, represent the best fitness with experimental data and mathematical model [17]. These statistical values can be calculated as follows:

$$x^2 = \frac{\sum_{i=1}^{n}(MR_{exp,i} - MR_{per,i})^2}{N-n} \quad (3)$$

$$RMSE = \left[\frac{\sum_{i=1}^{n}(MR_{per,i} - MR_{exp,i})^2}{N}\right]^{\frac{1}{2}} \quad (4)$$

$$EF = 1 - \frac{\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^{n}(MR_{exp,i} - MR_{exp,i_{mean}})^2} \quad (5)$$

where, $MR_{exp,i}$ is the *i*th experimental moisture ratio, $MR_{pre,i}$ is the *i*th predicted moisture ratio, N is the number of observations, n is the number of constants in the drying model and $MR_{exp,i_{mean}}$ is the mean value of experimental moisture ratio.

III. Results and Discussion

Figs. 2 till 5 show the time required for drying different banana slices at different temperatures (different engine operation powers). According to curves in this figures, the minimum drying time of apple slices occurred at full engine load (80˚C) and 3mm thickness while its maximum was at 25% of engine load (50˚C) and 7mm thickness. As shown in this curves, increasing the engine operation power and, consequently, the temperature of the leaving gas from exhaust at fixed air velocity, the drying time is decreased since both the thermal gradient inside the object and the evaporation rate of the product increase. In the drying of banana slice with hot air flow (drying using the leaving heat from the engine's exhaust), the time required for heating up the whole mass of the thin layer banana to reach the evaporation point via thermal conduction inward the product's layer is prolonged due to its low thermal conduction.

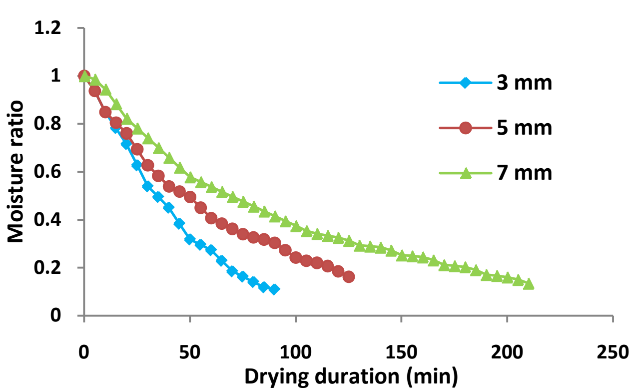

Figure 2 : Thin-layer drying curves of banana slice in 25% of engine load

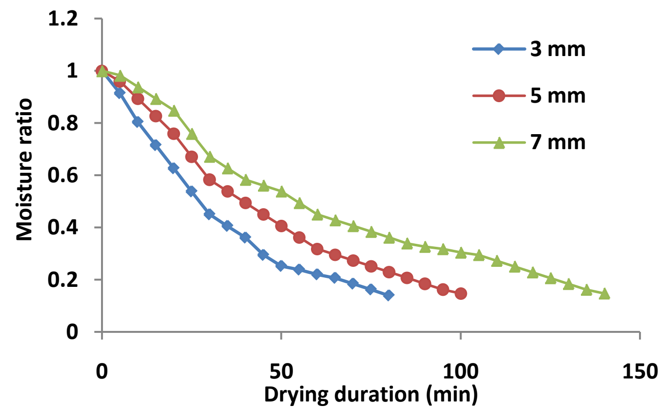

Figure 3 : Thin-layer drying curves of banana slice in 50% of engine load

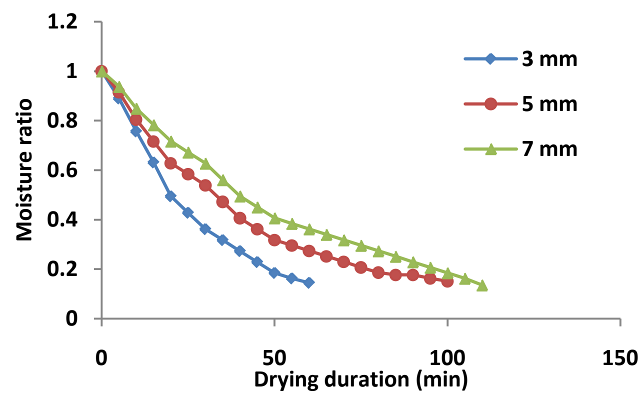

Figure 4 : Thin-layer drying curves of banana slice in 75% of engine load

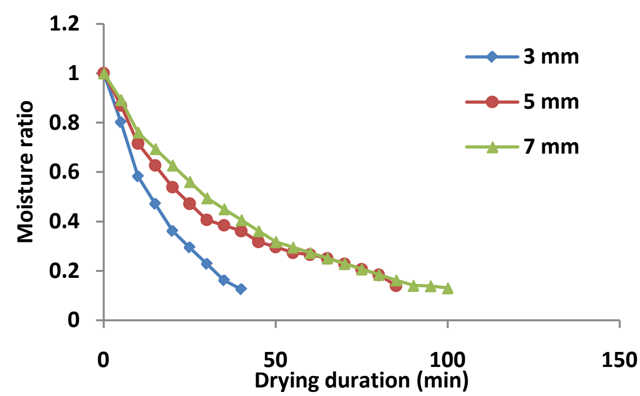

Figure 5 : Thin-layer drying curves of banana slice in 100% of engine load

The results showed that the reduction in drying time did not happen in the equal interval. In Figs. 6 till 11 it can be seen that a constant drying rate was not observed in drying the apricot samples and the moisture loss at beginning was faster comparing it with the end of drying process.

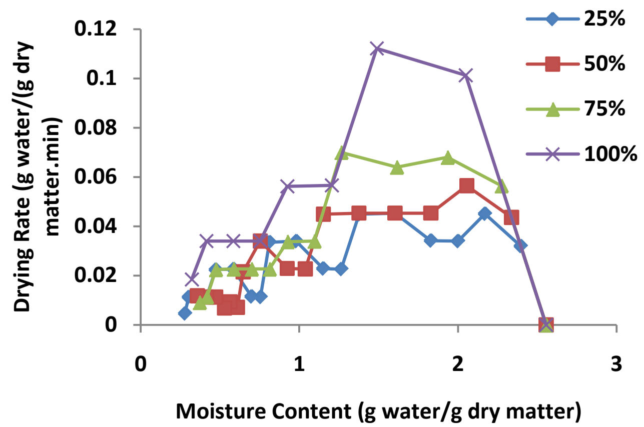

Figure 6 : Drying rate versus moisture content of banana (3 (mm) thickness) at different engine output power

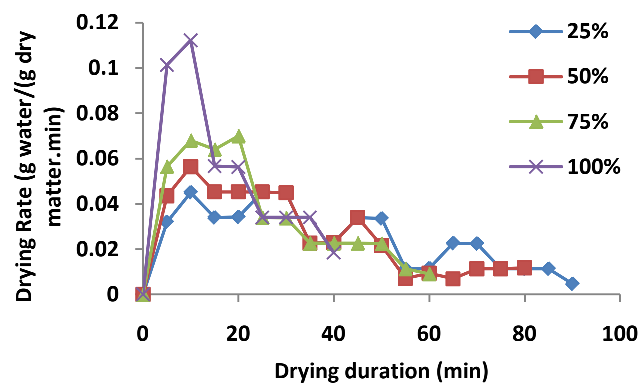

Figure 9 : Drying rate versus drying duration of banana (3 (mm) thickness) at different engine output power

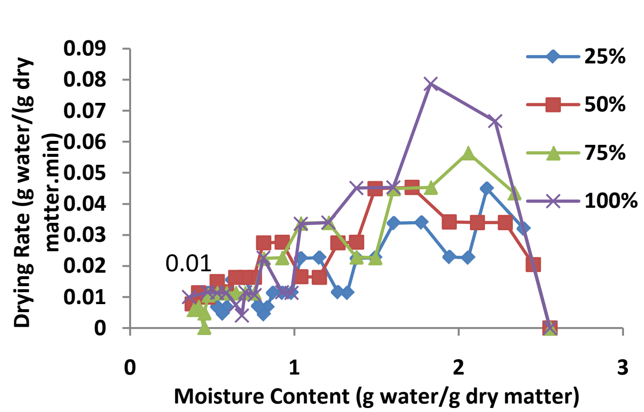

Figure 7 : Drying rate versus moisture content of banana (5 (mm) thickness) at different engine output power

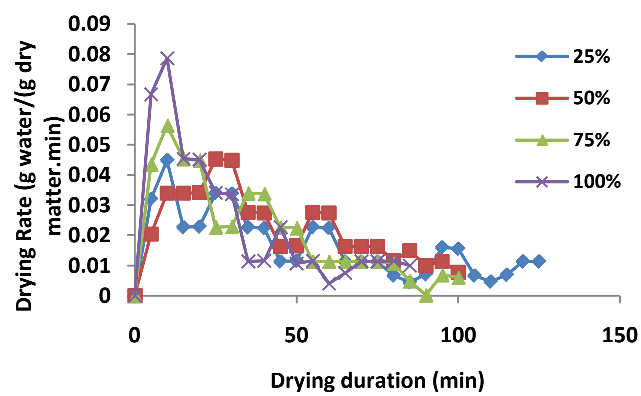

Figure 10 : Drying rate versus drying duration of banana (5 (mm) thickness) at different engine output power

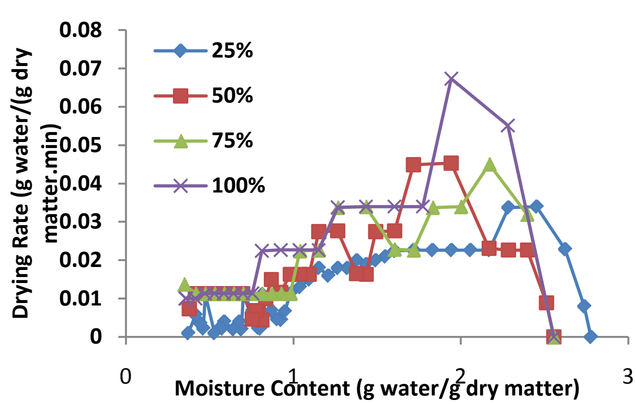

Figure 8 : Drying rate versus moisture content of banana (7 (mm) thickness) at different engine output power

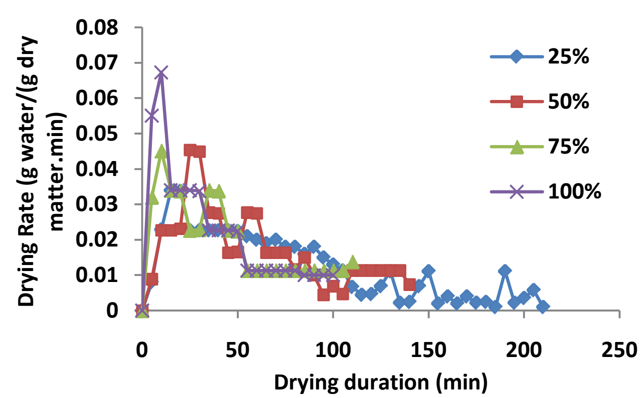

Figure 11 : Drying rate versus drying duration of banana (7 (mm) thickness) at different engine output power

MATLAB 2011, curve fitting toolbox environment was employed to run standard drying curve fitting (Table 2) on the experimental data. The statistical results including models coefficients and equations used to assess the excellence model namely EF, RMSE and χ^2 are presented in Table 3. The average values of R^2, χ^2 and RMSE for all drying models are shown in Fig. 5. For banana with 3 (mm) thickness page model offering maximum average value of EF and minimum average value of RMSE and χ^2 namely 0.99745, 0.01473875 and 0.000208443 and for banana slice with thickness of 5 and 7 (mm) Logarithmic model offering maximum average value of EF and minimum average value of RMSE and χ^2 namely 0.9966, 0.01472 and 0.00022 respectively as shown in Table 3.

In Fig. 12, the data predicted by the page model versus the experimental data is plotted. As can be seen the points have been arranged on a straight line with angle of 45° to the horizontal axis that shows the good agreement between the calculated and experimental results. Accordingly, the page model is selected as a suitable model to describe the characteristics of banana slice with 3(mm) thickness which dried in combined heat and power dryer.

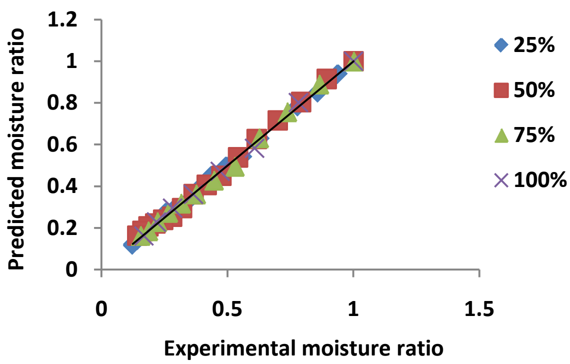

Figure 12 : Experimental and predicted moisture ratio values at different engine output power for the page model (3 (mm thickness)

In Fig. 13 and 14, the data predicted by the logarithmic model versus the experimental data for banana slice with thicknesses of 5 and 7 (mm) is plotted. As can be seen the points have been arranged on a straight line with angle of 45° to the horizontal axis that shows the good agreement between the calculated and experimental results.

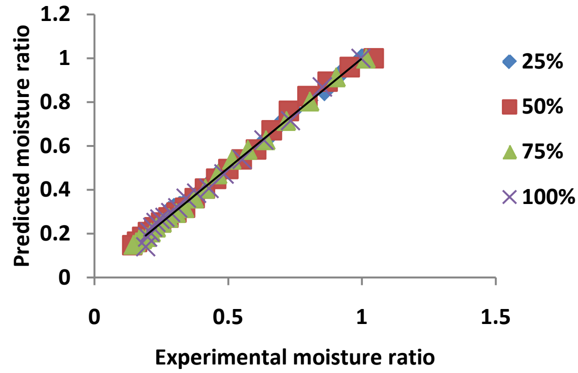

Figure 13 : Experimental and predicted moisture ratio values at different engine output power for the logarithmic model (5 (mm) thickness)

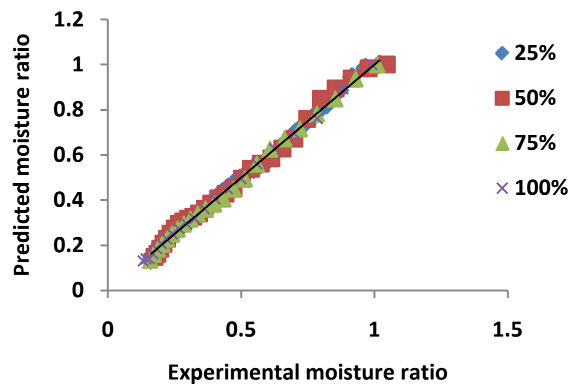

Figure 14 : Experimental and predicted moisture ratio values at different engine output power for the logarithmic model (7 (mm) thickness)

Table 3 : Statistical results obtained from different thin-layer drying model

Number	Load	Coefficient Constants			RMSE	χ^2	R^2
			3 mm				
1	25%	k = 0.02147			0.035450	0.001257	0.985100
	50%	k = 0.02515			0.019500	0.000380	0.995100
	75%	k = 0.03274			0.019160	0.000367	0.995500
	100%	k = 0.05046			0.013370	0.000179	0.998000
2	25%	k = 0.009002	n = 1.226		0.009915	0.000093	0.998900
	50%	k = 0.02057	n = 1.055		0.017930	0.000301	0.996100
	75%	k = 0.02655	n = 1.061		0.017060	0.000267	0.996700
	100%	k = 0.04824	n = 1.015		0.014050	0.000173	0.998100
3	25%	k = 0.01647	c = -0.1865	a = 1.215	0.015960	0.000226	0.997300
	50%	k = 0.02708	c = 0.02001	a = 1.01	0.017780	0.000277	0.996400
	75%	k = 0.03394	c = 0.003585	a = 1.022	0.017980	0.000269	0.996700
	100%	k = 0.05005	c= -0.00677	a= 1.011	0.015110	0.000171	0.998100
			5 mm				
1	25%	k = 0.0143			0.013800	0.000183	0.996800
	50%	k = 0.01788			0.028770	0.000828	0.989200
	75%	k = 0.02138			0.019160	0.000220	0.995500
	100%	k = 0.02529			0.045870	0.002104	0.964400
2	25%	k = 0.01742	n = 0.9528		0.011680	0.000126	0.997800
	50%	k = 0.009493	n = 1.16		0.015220	0.000499	0.997100
	75%	k = 0.02577	n = 0.9518		0.017060	0.000160	0.996700
	100%	k = 0.0577	n = 0.7778		0.021490	0.000435	0.992700
3	25%	k = 0.0158	c = 0.05104	a = 0.9493	0.011860	0.000124	0.997800
	50%	k = 0.01687	c = -0.06435	a = 1.108	0.018340	0.000303	0.996000
	75%	k = 0.02518	c = 0.067554	a = 0.9466	0.017980	0.000162	0.996700
	100%	k = 0.03773	c = 0.1572	a = 0.8382	0.020010	0.000353	0.994000
			7 mm				
1	25%	k = 0.009549			0.018800	0.000353	0.994200
	50%	k = 0.01245			0.026810	0.000719	0.989400
	75%	k = 0.01679			0.013110	0.000172	0.997400
	100%	k = 0.0222			0.016350	0.000267	0.996000
2	25%	k = 0.01283	n = 0.9364		0.015540	0.000236	0.996100
	50%	k = 0.009616	n = 1.06		0.025480	0.000626	0.990800
	75%	k = 0.01574	n = 1.016		0.013160	0.000165	0.997500
	100%	k = 0.03075	n = 0.9157		0.007821	0.000058	0.999100
3	25%	k = 0.0116	c = 0.08088	a = 0.9377	0.013290	0.000168	0.997200
	50%	k = 0.01392	c = 0.03029	a = 1.016	0.023130	0.000497	0.992700
	75%	k = 0.01703	c = 0.001694	a = 1.008	0.013300	0.000161	0.997600
	100%	k = 0.02473	c = 0.05354	a = 0.9372	0.009181	0.000076	0.998900

IV. Conclusion

The drying behavior of banana slice under four different engine loads for four temperature levels (50, 60, 70, and 80°C) and three sample thicknesses (3, 5 and 7 mm) at constant air velocity (0.5 m/s) was studied. With increased load on the engine and decreased the banana thickness, the drying time was reduced. The drying process of apple slices occurred in the falling rate period. The results from the mathematical modeling showed that the page model gave the best fit to the experimental data of banana with 3(mm) thickness and logarithmic model gave the best fit to the experimental data of banana with 5 and 7 (mm) thickness.

V. Acknowledgement

The authors wish to thank the Iranian Fuel Conservation Organization (IFCO) of NIOC for the research grant provided to complete this project and Tarbiat Modares University for providing of laboratory facilities.

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