Journal of Physical Sciences, Vol. 20, 2015, 97-110
ISSN: 2350-0352 (print), www.vidyasagar.ac.in/journal
Published on 24 December 2015

The Investigation of Tea Leaves Drying Model in Tray Dryers

M.Yousefzadeh[1*] and H.Mighani[2]

[1]Department of Chemistry, Islamic Azad University of Shahrood, IRAN
[2]Department of Chemistry, University of Golestan, Gorgan, P.O.Box 155, IRAN
[1]E-mail: m_yousefzadeh257@yahoo.com
[2]E-mail: h.mighani@gu.ac.ir

Received 08 September 2015; accepted 13 November 2015

ABSTRACT

Tea is an important and strategic product in Iran. One of the most important part of tea production processes is drying process. Basis of products drying includes heat production for evaporating of water and transferring the evaporated water from the dryers. It can be implied that solids drying is a heat transfer process. Energy used in many industries is about triple than the last three decades patterns in Iran and it means competition impossibility for Iranian products in these industries in global market. Energy losses, specially in drying section are very highline industry of Iran. The main problem of these dryers sun evenly heat distribution in dryers. That makes crops dry unevenly and consume fuel more than international standards and also produced unfavorable products. The process of tea leaves drying in laboratory tray dryers examined by mathematical model used in references. In the following, the equilibrium moisture content in three sample of friction phase 1,2,3is calculated to introduce the most suitable semi-theoretical model in the tea drying process in tea industry. Mathematical models which have been studied include Henderson – Pabis , Lewis, Page, Re Page and Two Term.

Keywords: Dry, tray dryer, mathematical models drying

1. Introduction

The concern for energy consumption optimization in the world has begun since 1970. Nowadays, the energy consumption management and optimization is considered as one of the new energy sources besides the physical available source. Energy losses is significant in Iran. According to statistics, it has increased in last 30years. In 1960, energy consumption has been 3.3 Gtoe. In 1990, this value increased to 8.8 which has 3.3 percent growth yearly that shows it increased 166 percent. To achieve the aims of this research, the following test were performed and the results were examined. At first, samples were prepared from eight of dryer, at beginning, first, second, third, fourth, fifth, sixth, seventh tray and finished product. In each tests, the time that tea leaves enter the dryer to each point that sampled is measured. Samples were transferred to biochemistry lab and were examined individually in five tests. In the lab, at first, first moisture is obtained in each sample. One these, just a constant factor was considered and that was outflow air temperature because of according to information that obtained from resources, to prevent in fermentation process, leaves should be exposed to air with 60° C temperature. So thickness of leaf on tray as independent variable set out that exhaust air temperature remain stable about 60 °C and the residence time in dryer was about 22 min. Results of organic tests which are done on conducted final products sampling has been reported.

2. Tray dryers

Tea dryer consists of heating parts with hot air furnaces, hot air blower ventilator and box including grid trays which carry the fermented leaves through the tank. Conveyors distribute equally on moving- grid trays, fermented leaves trough divider small tank called hoper with regulators help. At the same time of entering leaves into dry container, the inside temperature rises and the leaves lose their water gradually. In the first steps of drying process, fermented leaves act as wet objects and the leaves heat rises in the primary trays of third about 60%, in the trays of third class about 25% and in fifth class about 10% and in seven class about 5% and in lost part to 3% reduced by reducing the moisture and increasing the warm air blowing from furnace in each classes, temperatures will be different between 120 F to 130 F for the first part and entrance of fermented leaves, 155 to 165 F in third class trays and at last about 184 F in sixth class trays and at last about 195 F or 90 C in last class will increase. Warm air sources fuels are Gas, Gasoil or another fuel like coal or rice hull. Warm air temperature in dryer has been controlled by a thermostat. Warm air in module is blown from under the tray. Food placed on trays. In systems, the tray are designed in such a way that movement direction of warm air is in zigzag pattern form and it makes warm air and food have more contact with each other and increase the efficiency and reduce the pressure. This way is very effective in reducing the costs [2.5.6.12].

3. Calculation of drying time

Kinetics of drying production generally is calculated empirical by measuring the dry product weight as a function of time. Humidity level in variable times, drying speed in variable times and drying speed in medium moisture are different theories that have been studied. By humidity reduction in drying processes, drying speed will be increased. And also by increasing the temperature, the time of arriving to equilibrium state will be reduced [9, 10].

3.1. Drying time

The following equation is used for drying intensity:

$$\int dt = \frac{ls}{A}\int_{M1}^{M2}\frac{dM}{WD} \qquad (1)$$

On this equation M_1 and M_2 are the amount of moisture at t=0 and t respectively. WD is constant for drying phase.

$$t_1 = \frac{L_x}{A.WD_l}\left(M_1 - M_{cr}\right) \qquad (2)$$

That $M_2 = M_{Cr}$, crop moisture in last phase of drying and Debbie is constant. Drying time In the case of descending Debbie it will be counted the following equation.

$$tu = \frac{l_s}{A}\int_{M1}^{M2}\frac{dM}{WD_u} \tag{3}$$

In this formula, M_2 shows the final moisture of crops. Modeling of drying time has been done in two phases with constant intensity and descending intensity.

3.1.1. Constant intensity phase

The initial moisture was M_1 and it must be noticed that $M_2 \rangle M_{Cr}$, so drying time equation is:

$$t = \frac{l_s}{AN_c}\left(M_1 - M_2\right) \tag{4}$$

3.1.2. Descend ring intensity phase

If M_1 and M_2 is less than M_{Cr}, N will be variable, so two mode may happen.

A: general mode: solving by graphical approach. It means draw the changes of $\frac{1}{N}$ and M also obtained area under the curve between M_1 and M_2 is favorable answer.

B: private mode: If N and M changes suppose with lineal-logic error percentage, we have that:

$$N = am + b \tag{5}$$

For drying time in this mode we have:

$$t = \int dt = \frac{-L_s}{A}\int\frac{dm}{am+b} = \frac{L_s}{a.A}Ln\frac{aM_1+b}{aM_2+b} \tag{6}$$

Every drying equation expressed that M_1 as an initial moisture and M_2 as a final moisture and M_C as critical moisture and According to Fick's law:

$$\frac{\delta c}{\delta t} = D_{AB}\left(\frac{\delta^2 C}{\delta X^2}\right) \tag{7}$$

C: partial density in two partial phases A and B.

t= permeate time.

x= distance in direct permeate.

D_{AB} = Diffusivity in joint capture of A and B phases.

This equation expresses permutation in solid, liquid and gas. In the following equation, it is assumed that the surface is dry or it was in equilibrium moisture and initial moisture distribution was uniform [5, 9, 11]:

$$\frac{M - M_e}{M_c - M_e} = \frac{8}{\pi^2}\left[\sum_{n=1}^{n=\infty}\frac{1}{(2n+10)}e^{-(2\pi+1)2D_L^t\left(\frac{\pi}{2d}\right)^z}\right] \tag{8}$$

M, M_e and M_c are the moisture average contents based on drying at t.

D_L is liquid permeate and it assumed constant.

t is the start time.

D is the half of solid layer thickness from where permutation has been occurred.

This equation is for long period in the above equation:

$$\frac{M - M_e}{M_{c-}M_e} = \frac{8}{\pi^2}\left(e - D_L^{t\left(\frac{\pi}{2d}\right)^z}\right) \tag{9}$$

By solving this equation, differential the drying time was measured:

$$\frac{dM}{dt} = \frac{\pi^2 . D_L}{4d^2}\left(M - M_e\right) \tag{10}$$

And for final time we have this:

$$t_f = \frac{4d^2}{D_L \pi^2} Ln \frac{M_c - M_e}{M - M_e} \tag{11}$$

4. Experiment results

An example of the first experiment, of kind friction tea 3 and rubbing, the drying it has not taken enough care and in terms of color, taste is weak.

Sampling location	C0	C1	C2	C3	C4	C5	C6	C7
Time(second)	0	130	220	400	535	715	860	970
Moisture percent based on drying content	128	115	85.2	68.1	60	17.6	2	4.7

Table 1: First experiment results

Second experiment tea sample, is with think leaves in appearance and on the Sift method that adequate care is not taken in drying and it has bad color and perfume and taste.

Sampling location	C0	C1	C2	C3	C4	C5	C6	C7
Time(second)	0	90	215	400	540	725	880	990
Moisture percent based on drying content	143	129	104	98	54	26	2.7	1.6

Table 2: Second experiment results

Third experiment s result, it is friction 3 tea kind and has low friction. It has anomalistic weak leaves. This tea has suitable color, perfume and taste.

Sampling location	C0	C1	C2	C3	C4	C5	C6	C7
Time(second)	0	160	315	580	770	1010	1215	1365
Moisture percent based on drying content	139	118.3	92.4	43.4	41	1.5	0.82	1.08

Table 3: Third experiment results

Fourth experiment tea sample, is friction 3 tea kind that Due to the season, it has the favorable color but it has not good smell and taste.

Sampling location	C0	C1	C2	C3	C4	C5	C6	C7
Time(second)	0	120	260	470	640	845	1051	1140
Moisture percent based on drying content	144	132	110	86	65	9.2	2	2.6

Table 4: Fourth experiment results

Fifth experiment tea sample, is friction 3 kind of tea with on the Sift method that has thick leaves and has good taste and dried in suitable condition, in terms of quality.

Sampling location	C0	C1	C2	C3	C4	C5	C6	C7
Time(second)	0	150	300	560	755	1000	1200	1345
Moisture percent based on drying content	133	95	58	13	504	2.7	2	1.8

Table 5: Fifth experiment results

As is evident from organic experiments result, in all them friction 3 and on the Sift method are used. When five series of experiments was done as they mentioned above, and the optimum conditions of friction 3 and Sift, tea drying sampling of each 3 kind (friction 1 , 2 and 3) was found under the same condition, different kinds of tea can be compared in drying process.

Sampling location	time(s)	Humidity percent	Humidity percent	Humiditypercent (friction 3)

		(friction 1)	(friction 2)	
Arrival beginning	0	123.7	124.4	115.47
Tray 1	120	100.8	102.6	70.15
Tray 2	290	85	58.68	64.1
Tray 3	560	61.1	40.7	19.27
Tray 4	750	36.2	40.76	14.1
Tray 5	1020	5.24	7.2	6.61
Tray 6	1210	2.05	6.34	6.42
Final product	1355	1.98	5.2	6.39

Table 6: Experiment results

5. Kinds of models used in this research

Black tea drying models divided to three general categories including theoretical, semi theoretical and experiential. Semi theoretical models are: Tow Term- Pabis & Henderson-Lewis- Page- Re Page. These models fitness according the difference between moisture, primary equilibrium moisture and final moisture. Among these semi theoretical models of tea drying, some of them will be mentioned following [3, 8, 1].

-In 1980 Sharaf- Eldeen, Blaisdell and Hamdy introduced a two term model that predicted fully the corn crust drying speed in the air. Equation of this model is as follows.

$$MR = \frac{M - M_e}{M_0 - M_e} = A_0 \exp(-k_0 t) + A_1 \exp(-k_1 t) \quad (12)$$

M, M_0 and M_e are amount of moisture, primary moisture and final moisture, respectively. A_0, k_0, A_1 and k_1 are empirical Coefficients.

-Henderson and Pabis model is one of the first basic solutions for Fick second law. In 1969 this model used for corn, wheat and peanut drying model successfully.

$$MR = \frac{M - M_e}{M_0 - M_e} = A_0 \exp(-k_0 t) \quad (13)$$

-Lewis model. Lewis in 1921 introduced one of the special kind of Henderson and Pabis model. Results show that moisture transferring from foods and crops, maybe seen like heat flow of floated body in cold liquid. With Comparison between this phenomenon and Newton's cooler law, drying rate with difference in dried food and equilibrium moisture content in dry air situation is proportional.

$$\frac{dM}{dt} = -k_0 (M - M_e) = \exp(-k_0 t) \quad (14)$$

- Page model: in 1985 Bruce introduced this model by overcoming the Lewis model defects and also using this model to study on the grain drying process.

$$MR = \frac{M - M_e}{M_0 - M_e} = \exp\left(-k_0 t^n\right) \tag{15}$$

-Re Page model (repaired model), in 1973 Overhults, White, Hamilton and Ross describe soya drying process with this model successfully.

$$MR = \frac{M - M_e}{M_0 - M_e} A_0 \exp\left(-k_0 t\right)^n \tag{16}$$

In this research, semi- theoretical models is surveyed and applied. Ratios obtained from different experiments in provided models fit out with Matlab software and Coefficient of Determination (R^2), and radical mean square of errors (RMSE) criterions are used to selected the best model. Results are shown in tables and calculation section. Coefficient of determination content and radical meal square of errors was obtained from the following equation [1,2,3,4,7,10].

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N} \left(MR_c - MR_{\exp}\right)^2}{\sum_{i=1}^{N} \left(\overrightarrow{MR_c} - MR_{\exp}\right)^2} \right] \tag{17}$$

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^{N} \left(MR_c - MR_{\exp}\right)^2 \right]^{\frac{1}{2}} \tag{18}$$

In these equations, $MR_{\exp}$ is moisture content in experimental results and MR_C is moisture content in calculated results and N is number of experimental observations. Maximum Coefficient of Determination and minimum mean square of errors are selected as a fit out criterion.

5.1. Results of modeling calculations

After the Matlab programs running for Semi-Theoretical models that noted in last chapter, The following results were obtained according to the data obtained from experiments namely times referred to tea position than every one of samples friction 1, 2 and 3.

	Henderson& Pabis	Lewis	Page	Re Page	Two Term	
T	MRc	MRc	MRc	MRc	MRc	MRexp
0	138.7158	1	1	132.625	137.5034	128
130	104.3121	1.2267	25.47156625	96.4822	86.9319	115
220	85.6314	1.5048	25.47156625	55.6877	54.2713	85.2
400	57.7072	2.1444	25.47156625	15.5759	22.6275	68.1
535	42.9218	2.7969	25.47156625	4.8881	10.5257	60
715	28.9251	0.3905	25.47156627	0.9322	2.4563	17.6
860	21.0474	0.5128	25.47156628	0.2085	-0.9634	2
970	16.5368	0.6248	25.47156628	0.0654	-2.4529	4.7

Table 7: First experiment results

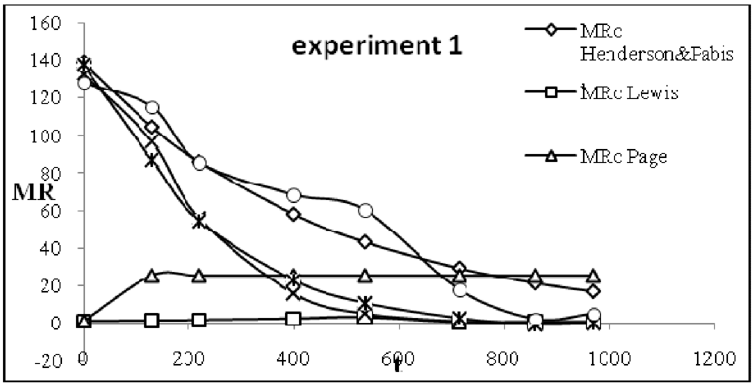

Figure 1: Calculations of moisture changes model equations in proportion to the time curves in the first experiment.

	Henderson& Pabis	Lewis	Page	Re Page	Two Term	
T	MRc	MRc	MRc	MRc	MRc	MRexp
0	154.1165	1	1	132.625	137.5034	143
90	127.9003	1.226722	25.471566	96.4822	86.9319	129
215	98.7195	1.504847	25.471566	55.6877	54.2713	104
400	67.2898	2.144466	25.471566	15.5759	22.6275	98
540	50.3482	2.7969793	25.471566	4.8881	10.5257	54
725	34.3186	3.905183	25.471566	0.9322	2.4563	26

880	24.8925	5.1282559	25.471566	0.2085	-0.9634	2.7
990	19.8196	6.2482398	25.471566	0.0654	-0.2452	1.6

Table 8: Second experiment results

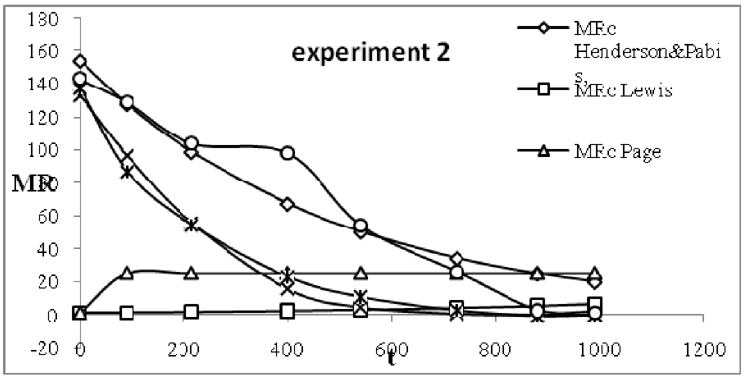

Figure 2: Calculation of moisture change model equations in proportion to the time curves in second experiment

	Henderson& Pabis	Lewis	Page	Re Page	Two Term	
T	MRc	MRc	MRc	MRc	MRc	MRexp
0	138.5622	1	1	132.625	137.5034	139
160	85.4553	1.2267	25.471566	96.4822	86.9319	118.3
315	52.7027	1.5048	25.471566	55.6877	54.2713	92.4
580	22.8032	2.1444	25.471566	15.5759	22.6275	43.4
770	12.1651	2.7969	25.471566	4.8881	10.5257	41
1010	5.5242	3.9051	25.471566	0.9322	2.4563	1.5
1215	2.9002	5.1282	25.471566	0.2085	-0.9634	0.82
1365	1.8175	6.2482	25.471566	0.0654	-0.2452	1.08

Table 9: Third experiment results

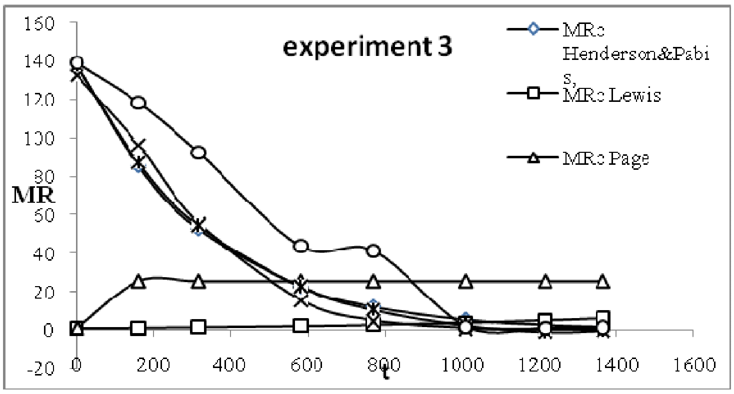

Figure 3: Calculation of moisture change model equations in proportion to the time curves in third experiment.

	Henderson& Pabis	Lewis	Page	Re Page	Two Term	
T	MRc	MRc	MRc	MRc	MRc	MRexp
0	138.5622	1	1	132.625	137.5034	144
120	85.4553	1.226722	25.471566	96.4822	86.9319	132
260	52.7027	1.504847	25.471566	55.6877	54.2713	110
470	22.8032	2.144466	25.471566	15.5759	22.6275	86
640	12.1651	2.7969793	25.471566	4.8881	10.5257	65
845	5.5242	3.905183	25.471566	0.9322	2.4563	9.2
1051	2.9002	5.1282559	25.471566	0.2085	-0.9634	2
1140	1.8175	6.2482398	25.471566	0.0654	-0.2452	2.6

Table 10: Forth experiment results

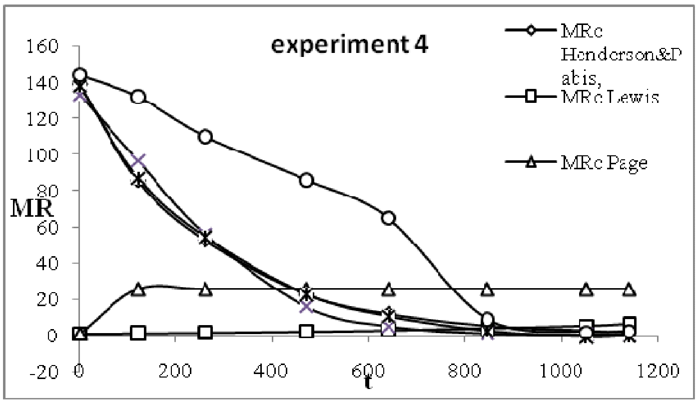

Figure 4: Calculation of moisture change model equations in proportion to the time curves in forth experiment

	Henderson& Pabis	Lewis	Page	Re Page	Two Term	
T	MRc	MRc	MRc	MRc	MRc	MRexp
0	138.5622	1	1	132.625	137.5034	133
150	85.4553	1.226722	25.471566	96.4822	86.9319	95
300	52.7027	1.504847	25.471566	55.6877	54.2713	58
560	22.8032	2.144466	25.471566	15.5759	22.6275	13
755	12.1651	2.7969793	25.471566	4.8881	10.5257	5.4
1000	5.5242	3.905183	25.471566	0.9322	2.4563	2.7
1200	2.9002	5.1282559	25.471566	0.2085	-0.9634	2
1345	1.8175	6.2482398	25.471566	0.0654	-0.2452	1.8

Table 11: Fifth experiment results

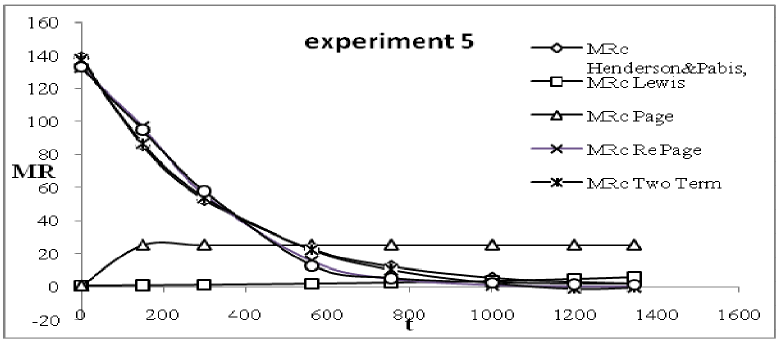

Figure 5: Calculation of moisture change model equations in proportion to the time curves in fifth experiment

6. Effective penetration calculation equations

Drying of black tea only happens in rate falling period. Fick's second law can be used to describe the black tea particles drying. Fick's second law general phase solution shows in following spherical coordinate. Tea spherical particles are considered with 0.0005 m diameter in each permeation invariant

$$Mr = \frac{M - M_e}{M_0 - M_e} = \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp\left(-\frac{n^2 Deff\, \pi^2}{R^2} t \right)$$
(19)

In here D is effective penetration (m^2/s) and R is tea particles radius (m). The first step of above equation is known as Henderson and Pabis model. The tilt is k factor in this model that related to effective penetration

$$k = \frac{Deff\ \pi^2}{R^2} \tag{20}$$

Effective penetration is calculated by equation k. By using of obtained domains from linear regression, LnMR than time data series shows in shape. Since the most appropriate decreased moisture than time to be considered in fifth experiment, following results achieve with considering varieties obtained from tests and with equations of diffusivity calculations.

Time (s)	MRexp	lnMRexp	K	R	Deff
0	133	4.890349	-0.003	0.00025	-1.901 * 10^-11
150	95	4.553877			
300	58	4.060443			
560	13	2.564949			
755	5.4	1.686399			
1000	2.7	0.993252			
1200	2	0.693147			
1345	1.8	0.587787			

Table 12: Penetration Coefficient calculation

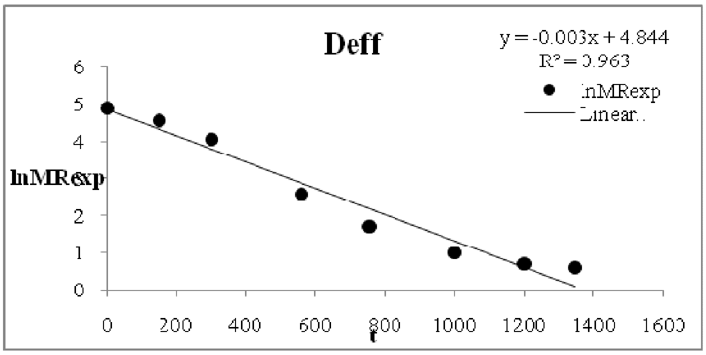

Figure 6: Ln $MR_{\exp}$ in proportion to the time for effective diffusivity Coefficient calculation

Models	Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5
	RMSE	RMSE	RMSE	RMSE	RMSE
H&P	12.5503	15.8224	6.1314	6.1314	6.131
Lewis	60.7914	60.7914	60.791	60.791	60.79
Page	56.4694	56.4629	56.462	56.462	56.46
Re Page	1.72933	1.72933	1.7293	1.7293	1.729
Two Term	5.5359	5.53590	5.5359	5.5359	5.535

Table 13: Statistical results of different thin- layer modeling in drying

7. Conclusion

By studying the graphs and performed experiments results and according to Curve nearby to each other, we can present the fifth experiment as the most appropriate method to reduce the tea leaves moisture in less time. By modeling calculations, as obvious in experiments results and provided shapes in this part, in every samples among the Page, Lewis, Re Page, Two Term, Henderson and Pabis models, we can present the Re Page and Two Term and Henderson and Pabis as best models. Due to the curves shapes of Page and Lewis, these two models are not appropriate for this section.

REFERENCES

1. H. AhmadiChenarbon and S.M. Hasheminia, Modeling of drying Lavandula officinalis L. leaves, *Journal of American Science*, 7(7) (2011) 204-208.
2. R. Amiri, C. Hayjan and M. Kaveh, PHysical parameters and kinetic modeling of fix and fluid bed drying of terebinth seeds, *Journal of Food Processing and Preservation*, 6 (2013) 1-14.
3. A. Cihan, K. Kahveci and O. Hacihafizoglu, Modelling of intermittent drying of thin layer rough rice, *22030 Edirne*, 79(1) (2007) 293-298.
4. S.H. GHatrehsamani, M. Dadashzadeh and A. Zomorodian, Kinetics of apricot thin layer drying in a mixed and indirect mode solar dryer, *International journal of Agriculture Sciences*, 4(6) (2012) 262-267.
5. Intermediate Technology Development Group, Tray dryers, (2002) 1-6.
6. M. Javanmard, K.A. Abbas and F. Arvin, A Microcontroller-Based Monitoring System for Batch Tea Dryer, *Journal of Agricultural Science*, 1(2) (2009) 101-106.
7. W.A.M. McMinn, Thin-Layer modeling of the convective, *Microwave, microwave-convective and microwave-vacuum drying of lactose powder*, 72(2) (2006) 113–123.
8. A. Motevali, S. Younji, R. Amiri CHayjan, N. Aghilinategh and A. Banakar, Drying kinetics of dill leaves in a convective dryer, *International Agrophysics*, 27 (2013) 39-47.
9. P.C. Panchariya, D. Popovic and A.L. Sharma, Thin-layer modelling of black tea drying process, *Journal of Food Engineering*, 52 (2002) 349-357.
10. I.E. Saeed, K. Sopian and Z.Z. Abidin, Drying characteristics of Roselle (1): Mathematical Modeling and Drying Experiments, *The CIGRE journal*, (2008) 1-25.

11. W. Senadeera, B.R. Bhandari, G. Young and B. Wijesinghe, Influence of shapes of selected vegetable materials on drying kinetics during fluidized bed drying, *Journal of Food Engineering*, 58 (2003) 277-283.
12. S. Syahrul, I. Dincer and F. Hamdullahpur, Thermodynamic modeling of fluidized bed drying of moist particles, *International Journal of Thermal Sciences*, 42 (2003) 691-701.