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*Full Length Research Paper*

# Drying of Lavander (*Lavandula officinalis* L.) flowers

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**Drying is the most common food preservation, particularly for medicinal plants and herbs because of reduction of essential oils and changes of qualitative properties such as color, which both of them influence on the economical value of the products. Drying process of *Lavandula officinalis* L. flowers was studied and modeled in this investigation. Independent variables were temperature at three levels (40, 50 and 60°C), air velocity at two levels (0.5 and 1 m/s) and product depth at three levels (1, 2, and 3cm). The experimental data was fitted to a number of thin layer drying equation such as Yagcioglu, modified Page, Page, Henderson and Pabis, Lewis, two-term and Verma. Based on the results, the Page equation showed the best fit.**

**Keywords:** Drying; Mathematical model; *Lavandula officinalis* L.

## INTRODUCTION

The main aims of drying of agricultural products are to increase the shelf life, to prevent from biological activities including microbial and enzymes, and to reduce the weight and volume of the materials in order to facilitate packaging, transporting and less storage space (Simal et al., 2005). During drying process it is important to preserve the texture, color, flavor, and nutritional value of the product. It means to reach moisture at safety level to minimize the quantity and quality losses during storage (Hall, 1980). Lavander is an important medicinal plant of the Labiatae family. Linalool and linalyl acetate are the main component of lavender oils. Panchariya examined the drying conditions of black tea at temperature ranging from 80 to 120°C and air velocity from 0.25 to 0.65 m/s. Experimental data was evaluated using Lewis, Page, modified Page, Two-term, and Handerson & pabis drying models with non-linear regression, and the Lewis model was selected as the best model (Panchariyaet al., 2002). Arabhosseini examined drying of *Artemisia dracunculus* L. leaves at temperature range of 40 to 90°C, different relative humidities and air velocity of 0.6 m/s. Although the Diffusion approach equation showed the best fit, but Page model was chosen since it had almost a similar performance but the equation is simpler as it has only two parameters instead of three in Diffusion approach model (Arabhosseini et al., 2009). Doymaz assessed the drying behavior of mint leaves at temperatures of 35, 45, 55, and 65°C and air velocity of 1m/s. He reported that drying time reduced significantly at higher temperature. Four drying models were selected to fit the experimental data and the logarithmic model described satisfactorily the drying behavior of mint leaves (Doymaz, 2007).

This research was based on thin layer drying with heated air. The main objective of this study was to evaluate the best model for drying of *Lavandula officinalis* L. flowers to preserve quality properties and effective chemical compounds.

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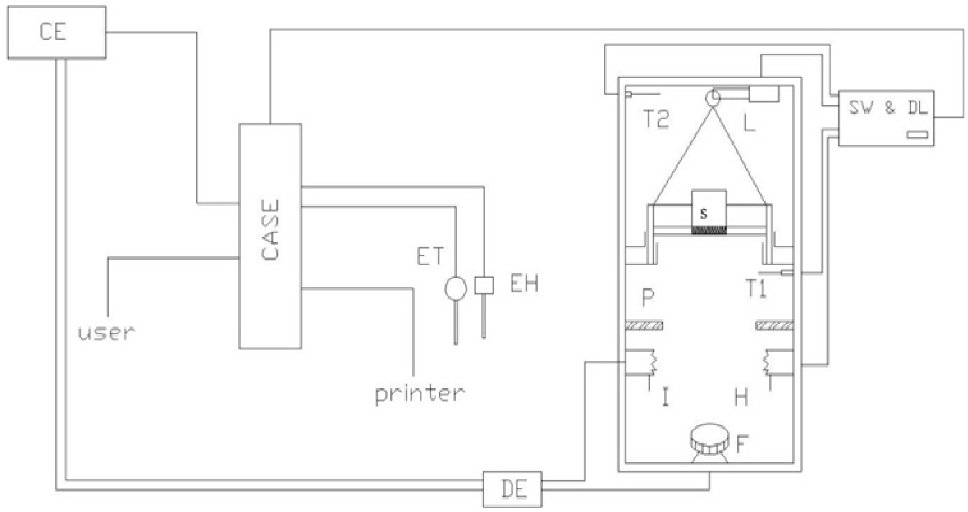


**Figure 1.** Experimental dryer

(F) fan, (H) heat generator, (S) sample – hold mesh, ($T_1$) thermometer before(s), ($T_2$) thermometer after(s), (Sw) switches, (DL) data logger, (CE) control electronic system, (DE) electronic driver, (EH) environment humidity sensor, (ET) environment temperature sensor.

## MATERIALS AND METHODS

### Drying equipment

Three experimental dryers of Kiln type were used for drying experiments. The experiments were performed at research complex of Asr-e- Enghelab, Tehran, Iran. This kind of dryer consists of two floors and usually use for drying of seeds, food stuffs, fruits and vegetables. In the first floor there is a heat generator and in the second floor, there is a container, with dimensions of 40 by 40 cm and 165cm height, to put the products for drying. At the bottom of this floor there are some holes to pass hot air generated in the first floor (Fig. 1). About 40 cm above the samples, there is a port to escape the moist air. Each dryer has two electric elements to generate required heat which one of them was controlled by a digital thermostat and the other one was controlled manually. The current flow of the hot air was produced by a blower which is located under the elements. The aeration rate of the blowers is adjustable by a dimmer in the range of 180 to 220 $m^3/h$. Two sensors are in the upper and lower parts of the container to measure the temperature of the drying air just before and after the samples location.

Before starting of each experiment, the temperature was adjusted by the thermostat and the dryers were activated to reach the required heat. Having turned off the element by the switcher, means that the dryer's temperature was balanced then the samples were placed in the container. Data collection for thin layer drying experiments was performed through samples weighting at 5min time intervals using a digital balance (Sartorius, model PT210, Germany) with an accuracy of ±0.001g and then the results were recorded. Weighting of the samples continued until three consecutive readings showed the same value. Sample moisture was measured before and after drying experiment. The mean value of the samples dry weight was used for computations. The final moisture content of the samples was determined by drying in a vacuum dryer (model Galen Kamp) at 70°C, 150 mbar, for 8hours (Tsami et al., 1990). The air velocity of drying air was adjusted to the desired level by adjusting the blower motor and measured by an anemometer (AM- 4201, Lutron) with an accuracy of ±0.1m/s. During the experiments the ambient air temperature and RH variations in the lab were measured to be between 25 to 29°C and 31- 33%, respectively. Given the small size of the samples, 35 by 35 cm metal micro-pore meshes were used as tray to keep the samples in the dryers. Aluminum frames of 35 by 35 cm cross section with 1, 2 and 3cm height were placed on the porous plates to obtain the desired bed depths.

### Drying process

The lavender variety was collected from medicinal herb research collection of Jahad-e-Daneshgahi in May and June, 2009. After harvesting the flowers were immediately removed from the stems. The separated flowers were cut and then the samples were stored separately in plastic bags and refrigerated at temperature of 4± 1°C to prevent from microbial spoilage. Moisture content of the flowers

**Table1**. Mathematical equations used for modeling of drying process

| Model name | Model equation | Reference |
|---|---|---|
| Lewis | MR=exp(-kt) | [Lewis, 1921] |
| Henderson and Pabis | MR=a exp(-kt) | [Westerman et al., 1973] |
| Page | MR=exp(-kt$^n$) | [Page, 1949] |
| Modified Page | MR=exp(-(kt)$^n$) | [White et al., 1981] |
| Yagcioglu | MR=a exp(-kt)+c | [Yagcioglu et al., 1999] |
| Verma | MR=a exp(-kt)+(1-a) exp(-gt) | [Verma et al., 1985] |
| Two-term | MR=a exp(-$k_0$t)+b exp(-$k_1$t) | [Arabhosseini et al., 2009] |

In the above equations, k, n, a, b, c, g, $k_0$ and $k_1$ are the model coefficients.

**Table 2.** Equations of indicators for evaluation of the drying models [8]

| Indicator | Equation |
|---|---|
| P- value | $P = \frac{100}{N}\sum \frac{\lvert M_i - M_{pre}\rvert}{M_i}$ |
| $\chi^2$ | $\chi^2 = \frac{\sum_{i=1}^{n}(MR_{exp} - MR_{pre})^2}{N-n}$ |
| *RMSE* | $RMSE = \sqrt{\frac{\sum_{i=1}^{n}(MR_{pre} - MR_{exp})^2}{N}}$ |

In Table2 $M_i$ is moisture content of matter, $M_{pre}$ is predicted moister by the model, N is number of observations, n is number of model constants, $MR_{exp}$ is moisture ratio of experimental data, $MR_{pre}$ is predicted moisture ratio.

was found to be 59% db. In this study the independent variables were temperature at 40, 50, and 60°C, air velocity at 0.5 and 1 m/s and bed depth of 1, 2, and 3cm. Dependent variable was drying time in order to determine the best equation for thin layer drying of *Lavandula officinalis* L. flowers.

## Mathematical modeling of drying

The moisture ratio (MR) of *Lavandula officinalis* L. flowers during the drying experiments was calculated by using equation 1 (Doymaz, 2007).

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad (1)$$

In which: MR is moisture ratio (dimensionless), $M_t$ is moisture content at time t (d.b%), $M_0$ is initial moisture content (d.b%), $M_e$ is equilibrium moisture content(d.b%). The final moisture content of samples was determined by using equation 2 on the dry basis.

$$M_C = \frac{W_w - W_d}{W_d} \quad (2)$$

In which: $M_C$ is moisture content (d.b%) $W_w$ is weigh of sample (kg) and $W_d$ is dry matter weight (kg). Table 1 shows a list of drying equations is made based on the literature.

A non-linear regression program in Matlab was used to fit the equations to the experimental data to find the coefficients of the equations. For evaluating the goodness of fit, three statistical indicators were used in addition to $R^2$ (Table 2). The model having the highest $R^2$ and the lowest Root Mean Squares Error (RMSE), $\chi^2$, and P-value was thus determined as the best model.

## RESULTS AND DISCUSSION

Tables 3 to 5 show the obtained statistical results of $R^2$, RMSE, p-value and $\chi^2$ for fitting the experimental data to selected drying models in order to determine the best model. The Verma, Yagcioglu and Two-term models were eliminated for having $R^2$ values lower than 0.9 while the Henderson and Pabis and Modified Page models were omitted because of undesirable $\chi^2$ values. The Lewis model was eliminated due to very high RMSE. Overall, the Page model showed the best fit having highest $R^2$ and lowest $\chi^2$, RMSE and P-value.

Table 6 shows the fitness of obtained data from experimental treatments using the Page model. The $R^2$ values are above 0.99 and p-values are below 10% for all

**Table3**. Evaluation of the models at 40°C and air velocities of 0.5 and 1 m/s

| Model | RMSE $\times 10^{-1}$ | $\chi^2 \times 10^{-2}$ | $R^2$ | P- value (%) |
|---|---|---|---|---|
| $v$=0.5 m/s | | | | |
| Lewis | 25 | 15 | 0.99 | 10.22 |
| Henderson and Pabis | 22 | 40 | 0.95 | 13.75 |
| Page | 7 | 8 | 0.99 | 5.02 |
| Modified Page | 25 | 47 | 0.88 | 21.22 |
| Yagcioglu | 31 | 19 | 0.89 | 15.18 |
| Verma | 31 | 26 | 0.85 | 13 |
| Two – term | 47 | 32 | 0.88 | 14.31 |
| $v$=1.0 m/s | | | | |
| Lewis | 31 | 15 | 0.90 | 11.25 |
| Henderson and Pabis | 47 | 43 | 0.98 | 17.75 |
| Page | 8 | 9 | 0.99 | 8.39 |
| Modified Page | 43 | 39 | 0.98 | 18.39 |
| Yagcioglu | 40 | 18 | 0.85 | 18.83 |
| Verma | 36 | 12 | 0.89 | 19.17 |
| Two – term | 30 | 22 | 0.85 | 20.64 |

**Table4**. Evaluation of the models at 50°C and air velocities of 0.5 and 1 m/s

| Model | RMSE $\times 10^{-1}$ | $\chi^2 \times 10^{-2}$ | $R^2$ | P- value (%) |
|---|---|---|---|---|
| $v$=0.5 m/s | | | | |
| Lewis | 18 | 18 | 0.95 | 10.12 |
| Henderson and Pabis | 31 | 43 | 0.89 | 13.41 |
| Page | 8 | 7 | 0.99 | 5.30 |
| Modified Page | 24 | 40 | 0.98 | 18.93 |
| Yagcioglu | 45 | 14 | 0.85 | 14.20 |
| Verma | 33 | 15 | 0.85 | 13.15 |
| Two – term | 52 | 35 | 0.95 | 26.69 |
| $v$=1.0 m/s | | | | |
| Lewis | 20 | 14 | 0.99 | 10.40 |
| Henderson and Pabis | 36 | 54 | 0.85 | 19.65 |
| Page | 7 | 8 | 0.99 | 4.35 |
| Modified Page | 62 | 19.21 | 0.98 | 15.65 |
| Yagcioglu | 35 | 12.12 | 0.85 | 23.39 |
| Verma | 27 | 35.15 | 0.89 | 18.85 |
| Two – term | 32 | 40.12 | 0.85 | 18.37 |

temperature and air velocities which statistically shows the good fit.

In a research Park found the Page model as the best model for drying mint leaves because it showed the best fit (Park et al., 2002). The study on drying *Artemisia dracunculus* L. leaves at air temperatures and relative humidities in the range of 40 to 70 °C and 11 to 84% respectively, and constant air velocity of 0.6 m/s showed that the Diffusion approach model was the best while Page model came second. However, since the Page model has

**Table5**. Evaluation of the models at 60°C and air velocities of 0.5 and 1 m/s

| Model | RMSE ×$10^{-1}$ | $\chi^2$ ×$10^{-2}$ | $R^2$ | P- value (%) |
|---|---|---|---|---|
| *v*=0.5 m/s | | | | |
| Lewis | 17 | 10 | 0.97 | 8.31 |
| Henderson and Pabis | 39 | 20 | 0.95 | 17.25 |
| Page | 7 | 7 | 0.99 | 3.35 |
| Modified Page | 30 | 26 | 0.85 | 20.11 |
| Yagcioglu | 41 | 16 | 0.85 | 18.31 |
| Verma | 50 | 26 | 0.88 | 19.45 |
| Two – term | 30 | 20 | 0.88 | 12.31 |
| *v*=1.0 m/s | | | | |
| Lewis | 13 | 17 | 0.89 | 20.23 |
| Henderson and Pabis | 41 | 21 | 0.98 | 25.45 |
| Page | 6 | 4 | 0.99 | 4.37 |
| Modified Page | 30 | 35 | 0.85 | 15.43 |
| Yagcioglu | 31 | 14 | 0.85 | 20.37 |
| Verma | 64 | 15 | 0.85 | 19.41 |
| Two – term | 56 | 29 | 0.85 | 35.22 |

**Table 6** Coefficient of the Page equation fitted to drying data

| Temperature (°C) | Velocity, m/s | k | n | RMSE ×$10^{-1}$ | P- value (%) | $\chi^2$ ×$10^{-2}$ | $R^2$ |
|---|---|---|---|---|---|---|---|
| 40 | 0.5 | 0.013 | 0.425 | 7 | 5.22 | 3.17 | 0.999 |
| | 1 | 0.028 | 0.673 | 9 | 8.11 | 9.11 | 0.999 |
| 50 | 0.5 | 0.017 | 0.017 | 8 | 5.31 | 7.65 | 0.999 |
| | 1 | 0.011 | 0.0385 | 7.45 | 4.22 | 8.49 | 0.999 |
| 60 | 0.5 | 0.021 | 0.112 | 7.32 | 3.07 | 7.23 | 0.998 |
| | 1 | 0.037 | 0.503 | 6.45 | 4.11 | 4.65 | 0.998 |

one less parameter, it was selected as the better model (Arabhosseini et al., 2009). Also, in a research about thin-layer drying of onions using x-ray, the Page model was proposed as the best one for having the highest $R^2$ and the least $\chi^2$ (Sharma et al., 2007).

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