International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017),e-ISSN:2455-2585
International Conference on
Recent Explorations in Science, Engineering And Technology (ICRESET'19)
Volume-5, Special Issue-March, 2019.

Experimental Investigation of Drying Behaviour of Bitter Gourd in Fluidized Bed Dryer

T.A.Arun[1], J.Kaleeswaran[2], R.Barathiraja[3]

[123] Assistant professor
[12]Department of Mechanical Engineering, KGiSL Institute of Technology.
[3]Department of Mechanical Engineering, Government college of Technology

Abstract— ***This paper presents the thin layer drying experiments and mathematical modeling of bitter gourd grown in Tamilnadu, India. Drying Characteristics of bitter gourd were examined moisture content from 90 ± 1% to 14 ± 0.5% using hot air of the temperature range of 50-70^{o}C.The result have shown that, increasing the drying air temperature causes shorter drying times. The experimental drying curves obtained were fitted to number of (15) mathematical models. Comparing the determination of coefficient, reduced chi-square and values of 15 models, it was concluded that the Two term exponential, Midilli. et al and Modified Page model represents drying characteristics better than the others. The effective diffusivity coefficient of moisture transfer varied from 5.9442 X 10 -10 to 8.9163 X 10 -10 m²/s over the temperature range. The temperature dependence of the diffusivity coefficients was described by Arrhenius type relationship. The activation energy for moisture diffusion was found to be 16.3 kJ/mol.***

Keywords— ***Activation energy, Effective diffusivity coefficient of moisture transfer, reduced chi-square, Root mean square error.***

I. INTRODUCTION

Bitter gourd (Momordica charantia) is one of the most popular vegetables in Southeast Asia. It is a member of the cucurbit family along with cucumber, squash, watermelon, and muskmelon. Native to China or India, the fast growing vine is grown throughout Asia and is becoming popular worldwide. Depending on location, bitter gourd is also known as bitter melon or balsam pear. The fruit of bitter gourd fruit is similar in nutritional value compared to other cucurbits with the notable exceptions that it is much higher in folate and vitamin C. The vine tips are an excellent source of vitamin A. The medicinal value of the gourd in the treatment of infectious diseases and diabetes is attracting of scientists worldwide. In south India Bitter gourd is grown on 26004 ha area and annual production is 162196(tones) thereby productivity such that 6.23 in2010. The fruits are generally 10 -20 cm long, tapering at the ends and covered with blunt tubercles. They are green when unripe turning to an orange yellow color when ripe. Protein 2 to 3% Fat1.0 to 1.5% and Carbohydrate 8 to10% (Agricultural Research Institute, Coimbatore).

Bitter gourd is an important vegetable crop of several countries in the tropics. Bitter gourd fruit contain bioactive components with many important medicinal properties (Horax et al. 2005). Bitter gourd helps achieve positive sugar regulating effect by suppressing the neural response to sweet taste stimuli. Bitter gourd is useful in treating Diabetes and has shown significant antilipolytic and lipogenic activity and also useful as an emtic, purgative, as an anthelmentic, in piles, and jaundice.

Drying can be described as an industrial preservation method in which water content and activity of fruits and vegetables are decreased by heated air to minimize biochemical, chemical and microbiological deterioration.(Doymaz & Pala,2003).The major objective in drying agricultural products is the reduction of the moisture content to a level ,which allows safe storage over an extended period. Also, it brings about substantial reduction in weight and volume, minimizing packaging, storage and transportation Cost (Mujumber, 1995;Okos, Narsimhan, Singh, & Witnauer,1992).

The most popular drying technique applied in the fruit and vegetable industries is hot air drying in a stationary layer under forced convection.[Jayarman, K.S.; Gupta, D.K.D,1992] Another option is applying fluidized or spout–fluidized-bed–drying techniques, which offer some advantages—high heat and mass transfer coefficients and good mixing—that improve the homogeneity of the process and increase drying rates. Fluidized-bed dryers have found many applications in the food, chemical, metallurgical, and pharmaceutical industries.[Reyes. A,2002] Using a fluidized bed– drying technique can ensure good energy efficiency and homogeneity of the dry products, so the technique may also have a practical application in such food materials as cut fruit and vegetables. It has been investigated as a potential method for obtaining high-quality dried foodstuffs, including vegetables, fruit, and grains.

The study of drying behaviour of various vegetables has been subject of interest of different researchers. There have been many studies on the drying behavior of various vegetables such as soybeans and white beans (Hutchinson & Otten, 1983; Kitic & Viollaz, 1984), green beans (Senadeera, Bhandari, Young, & Wijesinghe,2003), red pepper (Akpinar, Bicer, & Yildiz,2003; Doymaz & Pala, 2002), carrot (Doymaz, 2004),eggplant (Ertekin & Yaldiz, 2004), and pumpkin, green pepper, stuffed pepper, green bean and onion (Yaldiz &Ertekin, 2001).

1.1 MATHEMATICAL MODELING

It has been accepted that drying phenomenon of biological products during the falling rate period is controlled by the mechanism of liquid and/or vapour diffusion. Thin-layer drying models that describe the drying phenomenon of biological materials mainly fall into three categories namely, theoretical, semi-theoretical and empirical. The first takes into account only internal resistance to moisture transfer while the other two consider only external resistance to moisture transfer between product and air (Fortes & Okos, 1981; Henderson, 1974; Whitaker et al., 1969). Assuming that the resistance to moisture flow is uniformly distributed throughout the interior of the homogeneous isotropic material, the diffusion coefficient, D is independent of the local moisture content and if the volume shrinkage is negligible, Fick's second law can be derived as follows:

$$\frac{\partial M}{\partial t} = D\nabla^2 M \quad (1)$$

The semi-theoretical models are generally derived by simplifying general series solutions of Fick's second law or modification of simplified models and valid within the temperature, relative humidity, air flow velocity and moisture content range for which they were developed (Fortes & Okos, 1981). Among semi-theoretical thin-layer drying models, the Two-term model (Eq. (2)), the Henderson and Pabis model (Eq. (3)), the Lewis model (Eq. (5)), the Page model (Eq. (6)) and the Modified Page model (Eq. (7)) are used widely. Sharaf-Eldeen, Blaisdell, and Hamdy (1980) presented a two-term model to predict the drying rate of shelled corn fully exposed to air. This model is the first two terms of general series solution to the analytical solution of Eq. (1). However, it requires constant product temperature and assumes constant diffusivity. The Two-term exponential model has the form

$$MR = \frac{M - M_e}{M_0 - M_e} = a\exp(-k_0 t) + b\exp(-k_1 t) \quad (2)$$

where M, M0 and Me are the material, initial, and equilibrium moisture contents in dry basis, respectively, and a, k0, b, k1 are the empirical coefficients. The Henderson and Pabis model is the first term of a general series solution of Fick's second law (Henderson & Pabis, 1969)

$$MR = \frac{M - M_e}{M_0 - M_e} = a\exp(-kt) \quad (3)$$

This model was used successfully to model drying of corn (Henderson & Pabis, 1969), wheat (Watson & Bhargava, 1974) and peanut (Moss & Otten, 1989). The slope of this model, coefficient k, is related to effective diffusivity when drying process takes place only in the falling rate period and liquid diffusion controls the process (Madamba et al., 1996). The Lewis model (Lewis, 1921) is a special case of the Henderson and Pabis model where intercept is unity. Lewis described that the moisture transfer from the agricultural materials can be seen as analogous to the flow of heat from a body immersed in cold fluid. By comparing this phenomenon with Newton's law of cooling, the drying rate is proportional to the difference in moisture content between the material being dried and the equilibrium moisture content at the drying air condition as

$$\frac{dM}{dt} = -k\,(M - M_e) \quad (4)$$

or after integrating yields

$$MR = \frac{M - M_e}{M_0 - M_e} = \exp(-kt) \quad (5)$$

The Page model is a modification of the Lewis model to overcome its shortcomings. This model has produced good fits in predicting drying of grain and rough rice (Wang & Singh, 1978), shelled corn (Agrawal & Singh, 1977) and barley (Bruce, 1985)

$$MR = \frac{M - M_e}{M_0 - M_e} = \exp(-kt^n) \quad (6)$$

Overhults, White, Hamilton, and Ross (1973) also modified the Page model to describe the drying of soybean

$$MR = \frac{M - M_e}{M_0 - M_e} = \exp(-kt)^n \quad (7)$$

The empirical models derive a direct relationship between average moisture content and drying time. They neglect the fundamentals of the drying process and their parameters have no physical meaning. Therefore, they cannot give a clear and accurate view of the important processes occurring during drying, although they may describe the drying curve for the conditions of the experiment (Keey, 1972). Among them, the Wang and Singh model (Eq. (8)) was used to describe the intermittent drying of rough rice (Wang & Singh, 1978)

$$MR = 1 + at + bt^2 \quad (8)$$

Modelling the drying behavior of different products often requires the statistical methods of regression and correlation analysis. Linear & non-linear regression models are important tools used to find the relationship between different variables, especially those for which no established empirical relationship exists. In this study, the constants and coefficients of the best fitting model were determined, involving drying variables such as air temperature, humidity, velocity and product thickness. The effects of these variables on the constants and coefficients of the drying expression were also investigated by multiple linear regression analysis.

1.2 DATA ANALYSIS

The average moisture ratio of bitter gourd dried at different temperatures was test verified with fifteen different drying models to find out their suitability to describe the drying process. The correlation coefficient and results of statistical analyses obtained from non linear regression analysis using MATLAB (version 6.5) software package are summarized in Table 3. The coefficient of determination (R^2), reduced chi-square (χ^2), and root mean square error (RMSE) were used in this study to evaluate the goodness of fit. For quality fit,R2 value should be higher and c2, MBE and RMSE values should be lower (Demir et al., 2004; Erenturk et al., 2004 ;Pangavhane et al., 1999; Sarsavadia et al., 1999; Togrul and Pehlivan, 2002). These parameters can be calculated by using the following equations:

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{N - z}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{\exp,i}\right)^2\right]^{1/2}$$

In these equations, N is the number of observations, z is the number of constants, MRexp and MRpre are the experimental and predicted moisture ratios, respectively. Higher values of R^2 and lower values of χ^2 and RMSE indicate better goodness of fit.(Menges HO et.al ,2006., Meisami-asl E.et.al.,2010 and Kirmaci V.et.al.2008., Kaleta A.et.al.2010)

II. MATERIALS AND METHODS

2.1.MATERIALS AND APPARATUS

Good quality fresh bitter gourd (Momordica charantia) were purchased from local market in Coimbatore, India. Damaged and Immature were removed manually by visual inspection.3-4^{o}C for one day for equilibration of moisture and then used for experiments. Average diameter of bitter gourd samples was measured as 4±0.5 cm. Samples washed and cut top and bottom parts of its and cut in the form of slices of 4±0.5 mm thickness with a knife. The average Moisture content of the bitter gourd sample was about 90±1% (on a wet weight basis),as determined by drying in an oven at 105^{o}C for 4h, the tests being performed in triplicate.

After Drying **Before drying**

2.2 DRYING EXPERIMENTS

A Blower(1.5 hp) sucked air from atmospheric before that was heated by LPG burner. After that hot air supply to the plenum chamber through a 180*130 mm rectangular pipe. The air flow rate can be controlled by the gate valve. The flow rate can be calculated from the water column manometer connected to the venturimeter. The venturimeter is fixed at a distance of 500 mm away from the outlet of the blower and the gate valve is located at outlet of blower at the distance 200 mm. This ensures that uniform flow in the venturimeter. A electronic digital meter arrangement helps to measure the readings on the manometer without error. The entry of air in to the plenum chamber is made tangential to it so as to have a clockwise air circulation within this chamber. This is to reduce the pressure loss at entry in the distributor, as the inclined hole perforated distributors were also designed to have a clockwise air entry into the bed.
The cylindrical stainless steel plenum chamber has an internal diameter of 350 mm and height of 300 mm. A flange has been provided on the top of the plenum chamber for attaching the bed column. The cylindrical bed column has an internal diameter of 350 mm and a height of 600 mm. This is made of stainless steel cylinder so as to have visual observations while conducting experiments. A flange, made of 10 mm thick mild steel, was made at the bottom of the bed column for fixing it to the plenum chamber.
A distributor holder has been made to place the distributor in position. This is made from a 12 mm thick circular plate of size 350 mm and is provided 1000 holes with triangular pitch 10mm and airtight assembly of the distributor. A calibrated temperature sensor of type RTD has been located within the pipe just after the venturimeter, for the purpose of measuring the temperature of air flowing through the bed chamber. This temperature can be measured to an accuracy of 0.1 ^{0}C with a digital temperature indicator. Another one temperature sensor located at before that chevron separator.

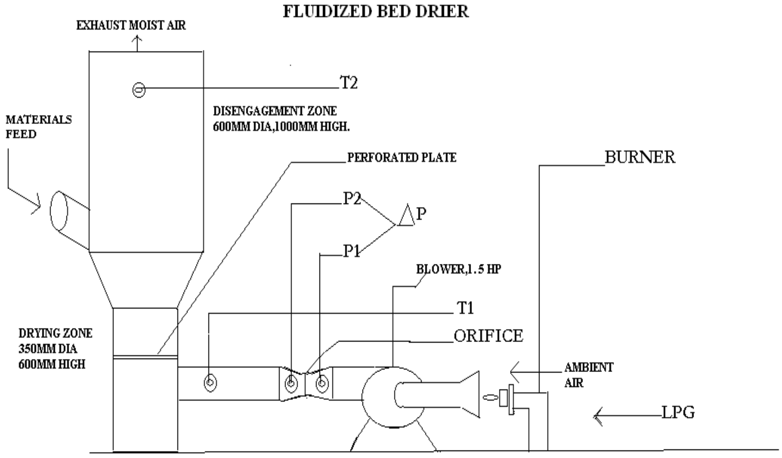

Figure .1. Schematic diagram of the experimental set-up

Figure 2.Experimental setup photograph

III. RESULTS AND DISCUSSION

3.1 DRYING CURVES

The bitter gourd slices were dried as single layer with thicknesses of 4 mm at the drying air temperatures of 40, 50 and 60 0C in a fluidized bed dryer. The bitter gourd slice of initial moisture content of around 9 kg water per kg dry matter was dried to the final moisture content of about 0.16 kg water per kg dry matter until no further changes in their mass were observed. Fig3.1.1 present the variations in the moisture content as a function of drying time at various drying air temperatures for the slice thickness of 4 mm, respectively. From these, it can be seen that moisture content decreases continually with drying time. As expected for these drying curves, the drying air temperature had much more effect on the moisture content of bitter gourd slices. In other words, the increase in drying air temperature resulted in a decrease in drying time. The drying time to reach the final moisture content for the bitter gourd thickness of 4 mm were 90, 75 and 60 min at the drying air temperatures of 50, 60 and 70 0C, respectively. The decrease in drying time with increase in the drying air temperature have been observed by Vergara, Amezaga, Barcenas, and Welti (1997) for apple,Ramaswamy and van Nieuwenhuijzen (2002) for apple slices and Wang and Chao (2002) for apple slices.

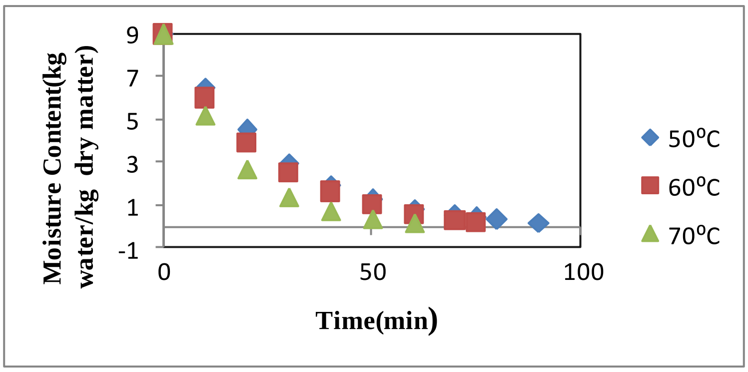

Fig.3.1.1.Effect of drying air temperature on moisture content for bitter gourd

Drying rate is defined as the amount of water removed and time is shown in Fig3.1.2 for bean samples during thin layer drying at 50, 60 and 70^{0}C. It is apparent that drying rate decreases continuously with improving drying time. In this curves, there was not constant-rate period but it seen to occur the falling-rate period. The results indicated that diffusion is the most likely physical mechanism governing moisture movement in the bean samples. The results were generally in agreement with some literature studies on drying of various food products (Madamba, Driscoll, & Buckle, 1996; Senadeera et al., 2003; Yaldiz & Ertekin, 2001).

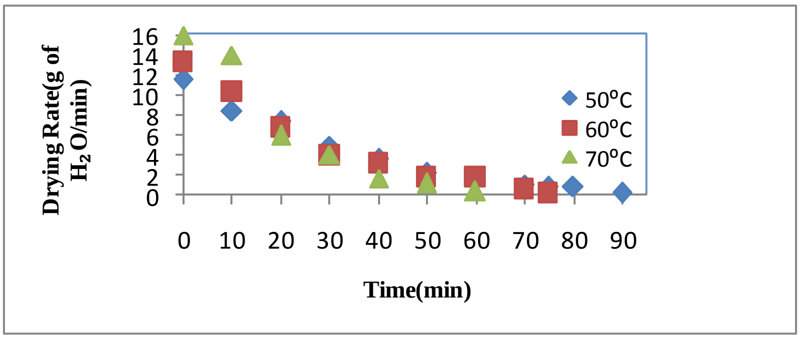

Fig .3.1.2 drying rate curves for bitter gourd at selected temperature with 2.3 m/s air velocity

As expected from Fig. 3.1.2, increasing the air temperature increases the drying rate (consequently decreases drying time). The experimental results were showed that air temperature is considered as the most important factor affected drying rate. Different authors reported similar results on drying of vegetables (Hatamipour & Mowla, 2003; Hutchinson & Otten, 1983).

3.2. MODELLING OF THE THIN-LAYER DRYING CHARACTERISTICS

Experimental results of moisture ratio with drying time were fitted to Thin-layer drying models that describe the drying phenomenon of biological materials mainly fall into three categories namely, theoretical, semi-theoretical and empirical. The models were evaluated based on R^2, χ^2 and RMSE (Ertekin & Yaldiz, 2004; Ozdemir & Devres, 1999). These curve fitting criteria for the there models were shown in Table 1. In all cases, R^2 values were greater than 0.90, indicating a good fit (Madamba et al., 1996). The Two term exponential, Midilli et al and Modified Page model was the best descriptive model as shown in Table 1. Generally, R^2, χ^2 and RMSE values were varied between 0.9971–0.9999, 0.000733–0.000010 and 0.04521–0.003172, respectively. Hence, Two term exponential, Midilli et al and Modified Page model represents drying characteristics better prediction than other models, and satisfactorily described drying characteristics of bitter gourd. Variation of experimental and Two term exponential, Midilli et al and Modified Page model predicted moisture ratio by with drying time are shown in Fig. 3.2.1,3.2.2and 3.2.3. As can be observed in this figure, good agreement between the former variables is observed. Similar findings were reported by Senadeera et al. (2003) for green bean drying and Doymaz (2004) for carrot drying.

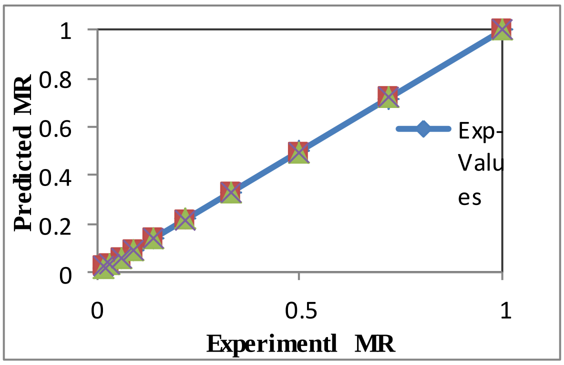

Fig.3.2.1.Comparison of experimental and predicted moisture ratio by established models for slice thickness 4mm at 50^0C

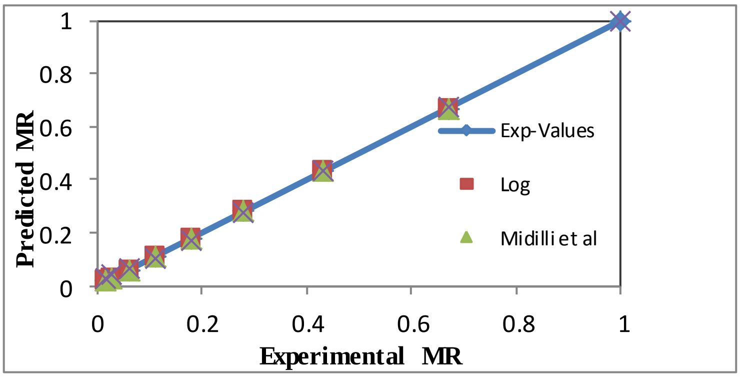

Fig.3.2.2.Comparison of experimental and predicted moisture ratio by established models for slice thickness 4mm at 60^0C

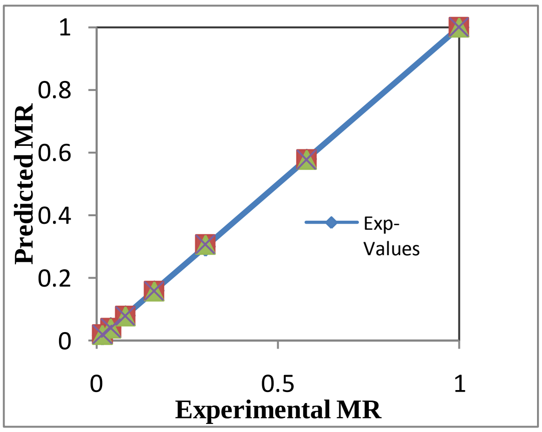

Fig.3.2.3.Comparison of experimental and predicted moisture ratio by established models for slice thickness 4mm at 70^0C

3.3. DETERMINATION OF THE EFFECTIVE DIFFUSIVITY COEFFICIENTS

The experimental drying data for the determinationof diffusivity coefficients were interpreted by using Fick_s second diffusion model. Fick's second law was applied to describe the effective moisture diffusivity of dried bitter gourd. Moisture ratio is used as a dependent variable as described in Eq. (1), which relates the initial moisture content (M_0), equilibrium moisture content (Me), and moisture content at any time during drying (Mt). The effective moisture diffusivity (Deff) is determined by using Fick's second law of diffusion:

$$\frac{\partial M}{\partial t} = D\nabla^2 M$$

The analytical solution of Fick's second law Equation of unsteady-state diffusion in a spherical coordinates with the assumptions of moisture migration being by diffusion, negligible shrinkage, constant effective diffusivity, and temperature during the drying process is given as follows:

$$MR = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left(-n^2\pi^2\frac{D_{eff}\,t}{r^2}\right)$$

For long drying periods, the above Equation can be further simplified to only the first term of the series. Thus, Equation is written in a logarithmic form as follows:

$$\ln\left(MR\right) = \ln\left(\frac{6}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}\,t}{r^2}\right)$$

The effective moisture diffusivity is obtained by plotting the experimental drying data in terms of ln(MR) versus time (min). From above equation, a plot of ln(MR) versus time gives a straight line with a slope of (K), in which:

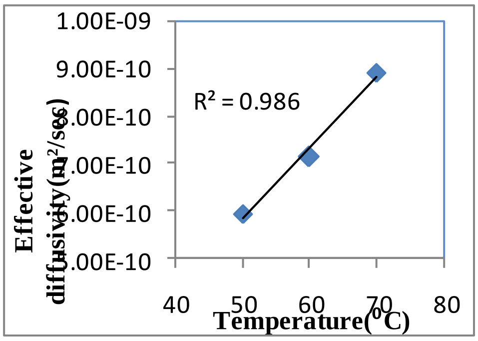

Fig.3.3.Air temperature effect on the effective diffusivity

$$K = \frac{\pi^2 D_{eff}}{r^2}$$

The effective diffusivity is derived from the slope. Calculated values of Deff for different temperatures are given in Fig. 3.3 The Deff of bitter gourd were 5.944x10-10, 7.133x10-10 and 8.916x10-10 m2/sec at 50, 60 and 70^{o}C, respectively. The values lie within the general range of 10-11 to10-9m2/s for food materials (Madamba et al., 1996). It can be seen that the values of Deff increased greatly with increasing temperature. Drying at 70 ^{0}C gave the highest Deff value. Similar variations were also observed during drying of garlic (Madamba et al., 1996), drying of carrot (Doymaz, 2004) and drying of green bean (Rosello´ , Simal, SanJuan, & Mulet, 1997).

3.4. COMPUTATION OF ACTIVATION ENERGY

The dependence of the effective diffusivity on temperature is generally described by the Arrhenius equation:[Simal, Femenia, Llull, &Rosello, 2000)

$$D_{eff} = D_0 \exp\left(-\frac{E_a}{R(T+273.15)}\right)$$

Here D_0 is the pre exponential factor of the Arrhenius equation (m²/s), Ea is the activation energy (kJ/mol), R is the universal gas constant (kJ/mol.K), and T is temperature (^oC).

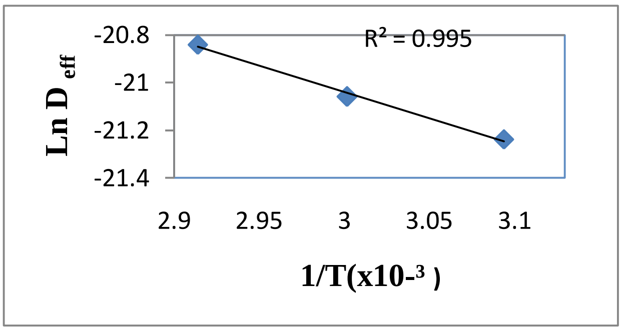

Fig3.4. Arrhenius-type relationship between effective diffusivity coefficient and temperature

The calculated effective diffusivities were plotted as a function of the absolute air-drying temperature (Fig. 3.4).The plot was found to be essentially a straight line in the range of temperatures investigated, indicating Arrhenius dependence. From the slope of the straight line described by the Arrhenius equation, the activation energy was found to be 16.3kJ/mol, where the Arrhenius factor (D_0) was 2.94 x 10-7m2/s. It is lower than the activation energies of carrot drying (28.36kJ/mol) (Doymaz, 2004) and soybeans drying (28.80kJ/mol) (Kitic & Viollaz, 1984) and green bean drying (39.47kJ/mol) (Senadeera et al., 2003).

IV. CONCLUSIONS

The influence of drying air temperature in the range of 50 to70 ^oC and 2.3 m/s of air velocity for bitter gourd was studied. The values of calculated effective diffusivity coefficients ranged from 5.9442 X 10 -10 to 8.9163 X 10 -10 m²/s. The drying rate and effective diffusivity increases with air temperature increases (consequently drying time decreased). Temperature dependence of the diffusivity coefficients was described by Arrhenius-type relationship. The activation energy for moisture diffusion was found as 16.3 kJ/mol. Two term exponential, Midilli et al and Modified Page model represents good fit curves and better than the others models(15).

REFERENCES

[1] Adnan Midilli, Hayati Olgun, Teoman Ayhan. 1999. *Experimental studies on mushroom and pollen drying. International Journal of Energy Research*. 23(13): 1143-1152.
[2] Afzal TM, Abe T. 2000. *Simulation of moisture changes in barley during for infrared radiation drying. Computers and Electronics in Agriculture*. 26: 137–145
[3] Agarwal YC, Singh RP.1997. *Thin layer drying studies on short grain rough rice. ASAE* Paper No: 3531.
[4] Aguerre R, Suarez C and Viollaz PE. 1982. *Drying kinetics of rough rice grain. .Journal of Food Technology*. 17: 679-686.
[5] Ahmet Can. 2000. *Drying Kinetics of pumpkinseeds. International Journal of Energy Research. 24*(11): 965-975.
[6] Akpinar EK, Midilli A, Bicer Y. 2003. *Single layer drying behavior of potato slices in a convective cyclone dryer and mathematical modelling. Energy Conversion and Management*. 44: 1689-1705.
[7] Akpinar EK, Saras1lmaz C, Yildiz C. 2004. *Mathematical modelling of a thin layer drying of apricots in a solar energized rotary dryer. International Journal of Energy Research.* 28 (8): 739-752.
[8] Akpinar EK. *Mathematical modeling and experimental investigation on sun and solar drying of white mulberry. J Mech Sci Technol* 2008;22:1544–53.
[9] *Association of Official Analytical Chemists. Official Methods of Analysis*, 15th ed.; Association of Official Analytical Chemists: Arlington, VA, 1990.
[10] Bruce D. 1985. *Exposed layer barely drying-three models fitted to new data up to 150 °C. Journal of Agricultural Engineering Research.* 32: 337-347.
[11] B. Vijarajan, R. Saravanan and S. Renganarayanan (2007)." *Studies on Thin Layer Drying of Bagasse". International Journal of Energy Research*, Vol: 31, Issue: 4, pp 422-437.
[12] Demir V., Gunhan T., Yagcioglu A.K., and Degirmencioglu A., 2004. *Mathematical modelling and the determination of some quality parameters of air-dried bay leaves. Biosystems Eng.*, 88, 325-335.
[13] Diamante LM, Munro PA. 1993. *Mathematical modelling of the thin layer solar drying of sweet potato slices. Solar Energy*. 51: 271-276.

[14] Dincer I, Dost S. 1996. *A modelling study for moisture diffusivities and moisture transfer coefficients in drying of solid objects. International Journal of Energy Research*. 20(6): 531-539

[15] Dincer I, Hussain MM, Yilbas BS. 2002. *Development of a new drying correlation for practical applications. International Journal of Energy Research.* 26(3): 245-251.

[16] Dinen K. Ghosh. 2003. *Bagasse burning principle and care. Proceedings of Sugar Technology Association of India.* 65: 13-20.

[17] Doymaz, I., & Pala, M. (2003). *The thin-layer drying characteristics of corn. Journal of Food Engineering*, 60, 125–130

[18] Ertekin, C., & Yaldiz, O. (2004). *Drying of eggplant and selection of a suitable thin layer drying model. Journal of Food Engineering,* 63,349–359.

[19] Erenturk S., Gulaboglu M.S., and Gultekin S., 2004. *The thinlayer drying characteristics of rosehip. Biosystems Eng*., 89,159-166.

[20] Fortes M, Okos MR. 1981. *Non-equilibrium thermodynamics approach to heat and mass transfer in corn kernels. Transactions of ASAE*. 22: 761–769

[21] Freire F, Figueiredo A, Ferrao P. 2001. *Modelling high temperature thin layer drying kinetics of olive bagasse. Journal of Agriculture Engineering Research*. 78 (4): 397-406.

[22] Hatamipour, M. S., & Mowla, D. (2003). *Experimental investigation of drying behavior of carrots in a fluidized bed with energy carrier.Engineering Life Science, 3, 43–49.*

[23] Henderson SM. 1974. *Progress in developing the thin layer drying equation. Transactions of the ASAE*. 7: 1167-1172.

[24] Henederson, SM, Pabis S. 1969. *Grain drying theory-I:Temperature effect on drying coefficient. Journal of Agriculture Engineering Research*. 6(3): 169-174.

[25] Holman JP. 2001. *Experimental methods for engineers. New York: McGraw-Hill*. Page: 48–143.

[26] Horax, R.. N. Mettiarachchy, and S. Islam. 2005- *Total phenolic contents and phenolic acid constituents in 4 varieties of hitter melons (Momordico chomntia) and antioxidant activities of their extracts, J. Food Sci*. 70:275-280.

[27] Hussain MM, Dincer I. 2003. *Analysis of two-dimensional heat and moisture transfer during drying of spherical objects. International Journal of Energy Research*. 27(8):703-713.

[28] Hutchinson, D., & Otten, L. (1983). *Thin layer air drying of soybeans and white beans. Journal of Food Technology*, 18, 507–524.

[29] Jayarman, K.S.; Gupta, D.K.D. *Dehydration of fruits and vegetables—Recent developments in principles and techniques. Drying Technology*1992, 10 (1), 1–50.

[30] Jorge Barroso, Felix Barreras, Hippolyte Amaveda, Antonio Lozano. 2003. *On the optimization of boiler efficiency using bagasse as fuel. Fuel*. 82: 1451-1463.

[31] Kaleta A, Gornicki K. Some remarks on evaluation of drying models of red beet particles. Energy Convers Manage 2010;51:2967–78.

[32] Keey RB. 1972. Drying principles and practice. New York: Pregoman Press.

[33] Kirmaci V, Usta H, Menlik T. An experimental study on freeze-drying behaviour of strawberries. Dry Technol 2008;26:1570–6.

[34] Kinoshita CM. 1991. Flue Gas Drying of Bagasse. Applied Engineering in Agriculture. 7(6): 729-734.

[35] Kitic, D., & Viollaz, P. E. (1984). Comparison of drying kinetic of soybeans in thin layer and fluidized beds. Journal of Food Technology, 19, 399–408.

[36] Lewis WK. 1921. The rate of drying of solids materials. Industrial Engineering Chemistry. 13: 427.

[37] Madamba PS, Driscoll RH, Buckle KA. 1996. Thin layer drying characteristics of garlic slices. Journal of Food Engineering. 29: 75–97.

[38] Menges HO, Ertekin C. Modeling of thin layer drying of Golden apples. J Food Eng 2006;77:119–25.

[39] Meisami-asl E, Rafiee S, Keyhani A, Tabatabaeefar A. Drying of apple slices (var.Golab) and effect on moisture diffusivity and activation energy. Plant Omics J2010;3(3):98–102.

[40] Midilli A, Kuck H. 2003. Mathematical modelling of thin layer drying of pistachio by using solar energy. Energy Conversion Management. 11:11-22.