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# Determination of Kinetic Parameters for Thin Layer Drying of Corn

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***Abstract*****—***Drying is the removal of a liquid from a solid by evaporation. The main purpose of dehydration is to extend the shelf life of foods while preserving their nutritive values and seed germination properties. To achieve this purpose, the process must take place under optimum operating condition and efficient drying rate. This research work aimed at determining the kinetic parameters for thin-layer drying of corn under constant drying conditions necessary for the design of industrial dryer. An experimental work was carried out using an oven drying method which observed the drying of the grains to be in the falling rate periods at temperatures of 45$^{O}$C, 50$^{O}$C, 55$^{O}$C and 65$^{o}$C. The rate of drying was found to have a direct relationship with moisture content and temperature but an inverse relationship with time. The experimental data for corn could fairly be predicted by the Page equation. The values of A and B from the Page equation were found to be functions of temperature rather than mere constants as were used in the model and these were for A between 7.23E-04 and 6.59E-06 for the given temperature range while for B it was between 0.67 and 1.31 for the temperature range. Temperature, therefore, is then the most obvious and important parameter to be manipulated in any dryer design especially for hygroscopic grains like corn.*

***Keywords*****—** *Corn, mathematical modelling, drying rate, moisture content, temperature and drying time.*

## I. INTRODUCTION

Maize also known as corn, is a cereal grain first domesticated by indigenous peoples in southern Mexico about 10,000 years ago. Maize has become a staple food in many parts of the world, with the total production of maize surpassing that of wheat or rice. Maize and cornmeal (ground dried maize) constitute a staple food in many regions of the world. In the form of grain or cornmeal, maize is the main ingredient of most foods (Beadle, G. W. 1980). Introduced into Africa by the Portuguese in the 16th century, maize has become Africa's most important staple food crop. Maize is a major source of starch. Corn starch (maize flour) is a major ingredient in home cooking and in many industrialized food products. Maize is also a major source of cooking oil (corn oil) and of maize gluten. Maize is sometimes used as the starch source for beer. Raw, yellow, sweet maize kernels are composed of 76% water, 19% carbohydrates, 3% protein, and 1% fat (Doebley *et al.*, 1990). Drying is the removal of liquid from a solid by evaporation. Heat is applied under controlled conditions during the process. In agricultural work, drying refers to the removal of moisture until the moisture content of the product is such that decrease in quality from molds, enzymatic activity and insects will be negligible. The main purpose of dehydration is to extend the shelf life of foods by a reduction in water activity which inhibits microbial growth; however, the processing temperature is not normally sufficient to cause inactivation, hence, care needs to be taken with the product on subsequent rehydration. Drying causes deterioration in the eating quality and nutritive value of foods being dried and so the design engineer must design a plant which will minimize such detrimental effects while obtaining efficient drying rates. Grains are dried in order to reduce the moisture content and prevent spoilage before use. Proper storage of grains is achieved when the characteristics which the grain possesses are maintained after harvesting and drying. Thus, viability should be maintained for seed grain, milling and baking qualities preserved for industrially used grain, and nutritive properties sustained for grain fed to animals. Factors that affect loss in quality and quantity of grains during storage include: fungi, insects, rodents, mites, respiration and moisture, migration, air temperature etc. High heat often cracks seed coats, leading to grain breakage in handling; hence, there are maximum safe drying air temperatures for several grains. Talbot, (2001). Farmers especially in Nigeria have over the years adopted the traditional drying system of using the solar energy for grains. Grains are allowed to dry naturally after maturation to a certain reduction in moisture content before being harvested. While in the field, the grains are exposed to adverse weather conditions which reduce or even destroy the germination properties of seed, reduce food quality and increase field loss of grains due to weather, insect, rodents etc. This method causes much delay and when finally harvested, grains are either hung in the chimney or spread on the floor under uncontrolled heat temperatures. This is unhygienic and ineffective as they are still being infected by micro-organisms. The process is labour intensive, causes food wastage and prone to deterioration by biochemical reactions or microbiological or insect infestation. It does not allow for long term storage.

Available techniques have not been able to adequately bring solutions to this problem especially in West African Region. The gap between harvesting and processing of grain needs to be bridged. This can be achieved through the design of an appropriate dryer with efficient drying rate and optimum operating temperature. The design of this dryer is possible only when the kinetic parameters for drying is accurately determined. However, to achieve this purpose, there is a need to develop mathematical models which can predict accurately the drying behavior of sample in the dryer. Therefore, a mathematical model anchored on drying kineticswhich is based on the physical mechanisms of internal heat and mass transfer to the material being dried which controls the process resistance as well as on structural and thermodynamic assumptions must be considered. Sun drying under natural convection is widely used as the conventional method of corn drying. It has a low cost heating source (Doymaz and Ismail, 2011) but having some inherent disadvantages (Khawas *et al*. 2013) such as slowness of the process, weather uncertainties especially long rainy seasons, high man power costs, large area requirement, insects' infestation and contamination with foreign materials are prominent draw backs of sun drying. The drying characteristic curves of most of these food materials were modeled using different drying models such as the Newton model (O'Callaghan *et al*., 1971), Page model (Akpinar *et al*., 2003, Iminabo *et al*., 2018), Henderson and Pabis model (Karathanos and Belessiotis, 1999), logarithmic model (Yaldiz *et al*., 2001), two term exponential model (Akpinar *et al*., 2003). For example, the page model was found to be best in describing the drying behavior of potato, red pepper, plantain chips and tomato under hot air drying (Akpinar *et al*., 2003; Simal *et al*., 2005; Iminabo *et al*., 2018; Doymaz, 2007). Hence, this research seeks to determine the kinetic parameters for thin-layer drying of corn for the design of industrial dryer.

## II. MATERIALS AND METHOD

### *2.1 Experimental Investigation*

Thin-layer drying test was performed using fresh-shelled corn in the laboratory of the Chemical/Petrochemical Engineering of the Rivers State University.

### *2.1.1 Raw materials*

Fresh corn sample was obtained from the Enugu State Main Market. The specie of corn used was the locally harvested yellow-colored type.

### *2.1.2 Procedure*

- A gravity-convection oven was used to dry the grain at 45°C, 50°C, 55°C, and 65°C.
- The sample material was first shelled and cleaned of dirt and other impurities.
- The moisture cans were dried, weighed and the samples placed in them and reweighed and the weight of the sample was taken.
- The oven was set at a specified temperature and when stabilized, the sample was placed in there and allowed to dry for 30 minutes.
- The sample was brought out of the oven after 30 minutes, cooled in desiccators without a drying agent and weighed, then placed back into the oven.
- Subsequent weighing and drying at every 30 minute internal was done till weight lost became negligible at that particular temperature. It was then left in the oven overnight to get the bone dry weight at the point where equilibrium moisture content is zero.
- This was done at the various temperatures of tests (45°C, 50°C, 55°C, and 65°C).
- Knowledge of the weight of the sample at the different drying times and its dry matter weight, allowed the construction of the sample drying curve. During the thin layer drying tests, the temperature was monitored.

### *2.2 Mathematical Modelling*

The grain drying model was developed based on fundamental principles and experimental results. The model for solids described the drying characteristics of the solids and predicted the drying rate as a function of moisture in the solids and the temperature and humidity of the drying air.

### *2.2.1 Assumptions*

- The initial moisture content of material grain is uniform.
- The temperature gradient within kernel is negligible.
- The dryer walls are adiabatic and no heat losses.
- The airflow and grain flow are plug type and constant.
- The kernel-to-kernel condition is negligible
- The volumetric shrinkage of grain is negligible

### *2.2.2 Drying kinetics*

The drying of grains in thin layers where each and every kernel is fully exposed to the drying air was expressed thus: Proctor (1994).

$$M_R = f\ (T,h,t) \tag{1}$$

$$M_R = \frac{M_C - M_{C_e}}{M_{C_o} - M_{C_e}} \tag{2}$$

where:

$M_R$ = Moisture Reduction Ratio

$M_C$ = Moisture content of the grain at any level and at any time, % dry bases (%*db*)

$M_{C_e}$ = Equilibrium moisture content (%*db*)

$M_{C_o}$ = initial moisture content of the wet grain (%*db*)

T = air temperature (°C)

h = air relative humidity and

t = drying time

Relationship between drying rate and air conditions for the grains' thin-layer drying was first developed by the Page model (1949), used by Sharaf-Eldeen (1980), and recommended in ASAE standards (2000a). The model is:

$$M_R = \frac{M_C - M_{C_e}}{M_{C_o} - M_{C_e}} = \exp(-At^B) \tag{3}$$

where:

A and B are used as constants in their model.

Simplifying equation (3) to determine their values thus:

$$In\,M_R = -At^B \tag{4}$$

$$In\ (-In\,M_R) = InA + BInt \tag{5}$$

A plot of $In\ (-In\,M_R)$ against $Int$ gives a straight line graph with a high relational coefficient which shows a perfect relationship (Figures 1- 4),from the slope and intercept of the graph values of A and B can be determined.

Rearrangement of equation (3) gives:

$$M = (M_{C_o} - M_{C_e})exp\ [-A(T)t^B(T)] \tag{6}$$

Using an appropriate curve fitting technique, the dependence of A and B on air temperature is obtained with a perfect correlation coefficient of $R_2 = 1$.

From equation (3)

$$M_C - M_{C_e} = (M_{C_o} - M_{C_e})exp\ (-At^B) \tag{7}$$

Using;

$$t = \frac{x}{u} \tag{8}$$

substituting (8) into (7) and rearranging, we have

$$M_C = M_{C_e} + (M_{C_o} - M_{C_e}) exp\ (-A\left(\frac{x}{u}\right)^B)$$

Let $z = A\left(\frac{x}{u}\right)^B$ (9)

Hence, simplifying further and taking differential with respect to z we have:

$$\frac{dM_C}{dz} = -\frac{A * B(M_{C_o} - M_{C_e})}{U^B} x^{B-1} exp\left[A\left(\frac{x}{u}\right)^B\right] \tag{10}$$

In summary, the form of the thin layer drying equation used for the development of the model is the Page (1949), Sharaf-Eldeen model (1980) which was recommended in ASAE standards (2000a). To validate the equilibrium moisture content equation of Sharaf-Eldeen *et al.,* (1980), the temperature of the oven was recorded during the processes.

The drying kinetics data obtained from the experiment was used to plot graphs of drying rate against moisture content which showed a common trend for all the items.

Drying was found to be in the falling rate period for all the grains since the initial moisture content, Mc, is less than the critical moisture content, Cr. Rate of drying was found to have a direct relationship with moisture content and temperature but an inverse relationship with time.

## III. RESULT AND DISCUSSION

### *3.1 Results*

The results of the experiment are presented in Tables 1-4 for 45°C, 50°C, 55°C and 65°C respectively. Drying curves of drying rate over drying period were constructed to depict drying profile graphically.

TABLE 1. Result of Drying Kinetics data for Corn at 45°C

| **Drying Time (sec)** | **Mass of Sample (g)** | **Moisture an Sample (g)** | **Moisture Content (db g/g)** | **Difference in Moisture Content (db g/g)** | **Drying Rate (glg.sec)** |
|---|---|---|---|---|---|
| 0 | 10.1474 | 4.5308 | 0.8067 | 0.0613 | |
| 1800 | 9.8030 | 4.1864 | *0.7454* | 0.0504 | 0.0000341 |
| 3600 | 9.5202 | 3.9036 | 0.6950 | 0.0478 | 0.000028 |
| 5400 | 9.25 19 | 3.6353 | 0.6472 | 0.0399 | 0.0000266 |
| 7200 | 9.0275 | 3.4109 | 0.6073 | 0.0373 | 0.0000222 |
| 9000 | 8.8182 | 3.2016 | 0.5700 | 0.0372 | 0.0000207 |
| 10800 | 8.6345 | 3.0179 | 0.5373 | 0.0328 | 0.0000182 |
| 12600 | 8.4502 | 2.8336 | 0.5045 | 0.0299 | 0.0000182 |
| 14400 | 8.2822 | 2.6656 | 0.4746 | 0.0342 | 0.0000166 |
| 16200 | 8.0899 | 2.4733 | 0.4404 | 0.0267 | 0.000019 |
| 18000 | 7.9402 | 2.3236 | 0.4137 | 0.0237 | 0.0000148 |
| 19800 | 7.8070 | 2.1904 | 0.3900 | 0.0203 | 0.0000132 |
| 21600 | 7.6932 | 2.0766 | 0.3697 | 0.0195 | 0.0000173 |
| 23400 | 7.5838 | 1.9672 | 0.3502 | 0.268 | 0.0000108 |
| 76500 | 6.0782 | 0.4616 | 0.3265 | 0.00605 | 0.000005 |
| 80100 | 6.0443 | 0.4277 | 0.2875 | 0.07615 | 0.0000017 |
| 83700 | 5.6166 | 0.0000 | | 0 | 0.0000212 |

Bone Dry Mass = 5.6166g

TABLE 2. Result of Drying Kinetics data for Corn at 50°C

| **Drying Time (sec)** | **Mass of Sample (g)** | **Moisture an Sample (g)** | **Moisture Content (db g/g)** | **Difference in Moisture Content (db g/g)** | **Drying Rate (glg.sec)** |
|---|---|---|---|---|---|
| 0 | 10.0146 | 4.4715 | 0.8067 | 0.0695 | |
| 1800 | 9.6297 | 4.0866 | 0.7372 | 0.0569 | 0.0000386 |
| 3600 | 9.3139 | 3.7708 | 0.6803 | 0.0489 | 0.00003 16 |
| 5400 | 9.0432 | 3.5001 | 0.63 14 | 0.0432 | 0.0000272 |
| 7200 | 8.8036 | 3.2605 | 0.5882 | 0.041 | 0.000024 |
| 9000 | *8.5763* | 3.0332 | 0.5472 | 0.0384 | 0.0000228 |
| 10800 | 8.3632 | 2.8201 | 0.5088 | 0.0375 | 0.0000213 |
| 12600 | 8.1553 | 2.6122 | 0.4713 | 0.032 | 0.0000208 |
| 14400 | 7.9782 | 2.4351 | 0.4393 | 0.029 | 0.0000178 |
| 16200 | 7.8173 | 2.2742 | 0.4103 | 0.0265 | 0.0000161 |
| 18000 | 7.6703 | 2.1272 | 0.3838 | 0.025 | 0.0000147 |
| 19800 | 7.5320 | 1.9889 | 0.3588 | 0.0222 | 0.0000139 |
| 21600 | 7.4087 | 1.8656 | 0.3366 | 0.2629 | 0.0000123 |
| 90000 | 5.9628 | 0.4197 | 0.3125 | 0.001 | 0.0000038 |
| 93600 | *5.9460* | 0.4029 | 0.2875 | 0.0727 | 0.0000003 |
| 99000 | 5.5431 | 0.0000 | | 0 | 0.0000135 |

Bone Dry Mass = 5.5431g

TABLE 3. Drying Kinetics Data for Corn at 55ºC

| **Drying Time (sec)** | **Mass of Sample (g)** | **Moisture in Sample (g)** | **Moisture content (db g/g)** | **Difference in Moisture Content (dbg/g)** | **Drying Rate (glg.sec)** |
|---|---|---|---|---|---|
| 0 | 10.0303 | 4.4785 | 0.8067 | | |
| 1800 | 9.3982 | 3.8464 | 0.6928 | 0.1139 | 0.0000633 |
| 3600 | 8.9451 | 3.3933 | 0.61 12 | 0.0816 | 0.0000453 |
| 5400 | 8.5345 | 2.9827 | 0.5372 | 0.074 | 0.0000411 |
| 7200 | 8.1725 | 2.6207 | 0.4720 | 0.0652 | 0.0000362 |
| 9000 | 7.8666 | 2.3148 | 0.4169 | 0.0351 | 0.0000306 |
| 10800 | 7.6551 | 2.1033 | 0.3789 | 0.038 | 0.0000211 |
| 12600 | 7.4053 | 1.8535 | 0.3339 | 0.045 | 0.000025 |
| 14400 | 7.1949 | 1.6431 | 0.2960 | 0.0379 | 0.0000211 |
| 16200 | 7.0126 | 1.4608 | 0.2631 | 0.0329 | 0.0000183 |
| 18000 | 6.8455 | 1.2937 | 0.2330 | 0.0301 | 0.0000167 |
| 19800 | 6.7109 | 1.1591 | 0.2088 | 0.0242 | 0.0000134 |
| 21600 | 6.6280 | 1.0762 | 0.1938 | 0.015 | 0.0000083 |
| 23400 | *6.5258* | 0.9740 | 0.1754 | 0.0184 | 0.0000102 |
| 25200 | *6.4354* | 0.8836 | 0.1592 | 0.0162 | 0.0000090 |
| 27000 | *6.3552* | 0.8034 | 0.1447 | 0.0145 | 0.0000081 |
| 79680 | 5.5518 | 0.0000 | 0.0000 | 0.1447 | 0.0000003 |

Bone Dry Mass = 5.5518g

TABLE 4. Drying Kinetics data for Corn at 65°C

| **Drying Time (sec)** | **Mass of Sample (g)** | **Moisture in Sample (g)** | **Moisture Content (dbg/g)** | **Difference in Moisture Content (dbg/g)** | **Drying Rate (g/g.sec)** |
|---|---|---|---|---|---|
| 0 | 10.0623 | 4.4928 | 0.8067 | | |
| 1800 | 9.2439 | 3.6744 | *0.6597* | 0.147 | 0.0000817 |
| 3600 | 8.5744 | 3.0049 | 0.5395 | 0.1202 | 0.0000608 |
| 5400 | 7.9805 | 2.4110 | 0.4329 | 0.1066 | 0.0000592 |
| 7200 | 7.5185 | 1.9490 | 0.3499 | 0.083 | 0.0000461 |
| 9000 | 7.0977 | 1.5282 | 0.2744 | 0.0755 | 0.0000419 |
| 10800 | 6.7677 | 1.1982 | 0.2151 | 0.0593 | 0.0000329 |
| 12600 | *6.5075* | 0.9380 | 0.1684 | 0.0467 | 0.0000259 |
| 14400 | 6.3159 | 0.7464 | 0.1340 | 0.0344 | 0.0000191 |
| 16200 | 6.1715 | 0.6020 | 0.1081 | 0.0259 | 0.0000144 |
| 18000 | 6.0558 | 0.4863 | 0.08730 | 0.0208 | 0.0000116 |
| 19800 | 5.9737 | 0.4042 | 0.0723 | 0.015 | 0.0000083 |
| 70200 | 5.5695 | 0.0000 | 0.0000 | 0.0723 | 0.0000014 |

Bone Dry Mass = 5.5695g

The plots of $In(-InM_R)$ against $Int$ for each of the temperature values are shown in Figures 1 – 4. Also, the graph of drying curve for each of the temperatures are presented in Figures 5 - 12 which shows the moisture content variation with drying rate and drying time.

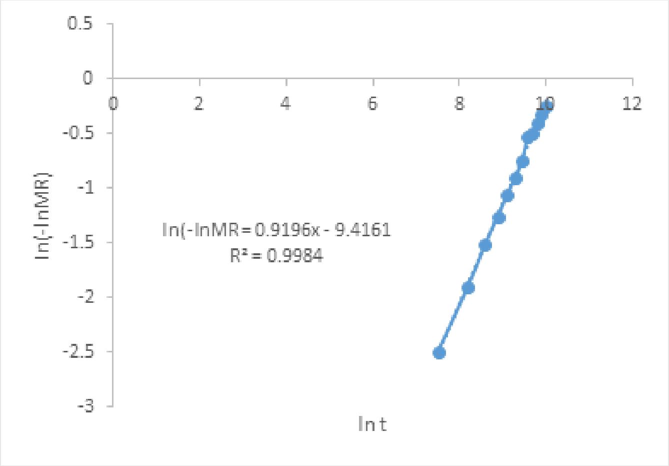

Fig. 1. Plot of $In(-lnM_R)$ against Int at 45°C

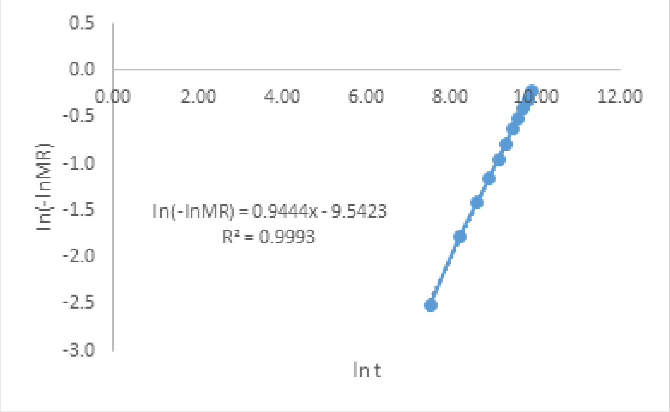

Fig. 2. Plot of $In(-lnM_R)$ against ln t at 50°C

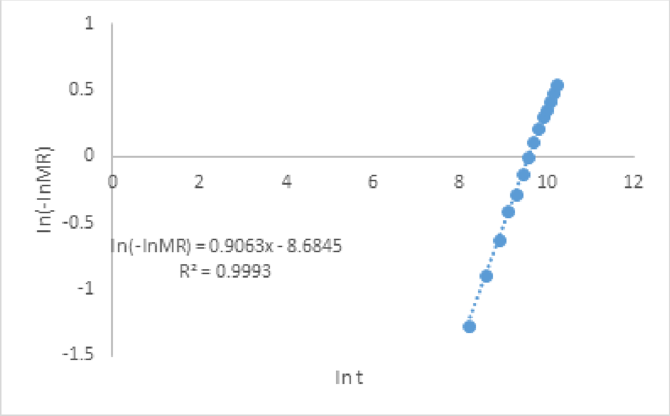

Fig. 3. Plot of $In(-lnM_R)$ against ln t at 55°C

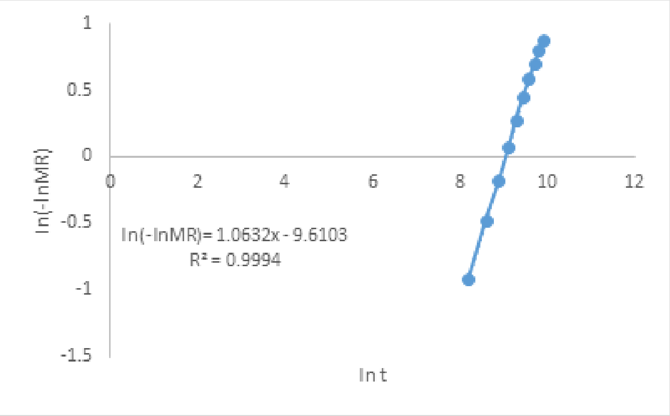

Fig. 4. Plot of $In(-lnM_R)$ against ln t at 65°C

Figures 1 – 4 are straight line graphs showing the variation of $\ln(-InM_R)\, against\, lnt$ with a high relational coefficient which shows a perfect relationship. Using the curve fitting technique, the dependence of A and B on air temperature is obtained with a perfect correlation coefficient of $R_2 = 0.999$ for each temperature values.

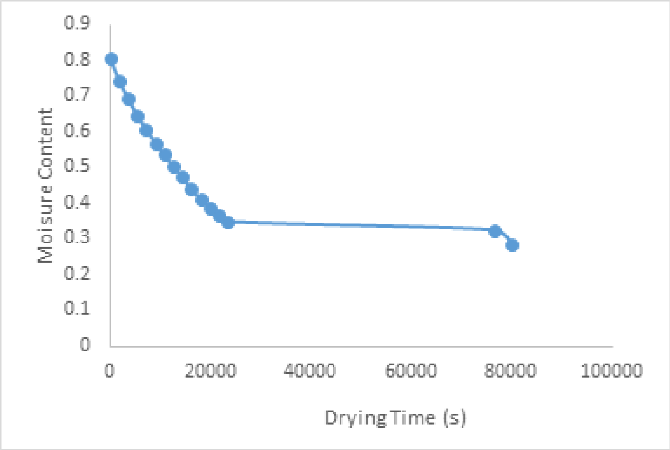

Fig. 5. Variation of Moisture Content with Drying time at 45°C

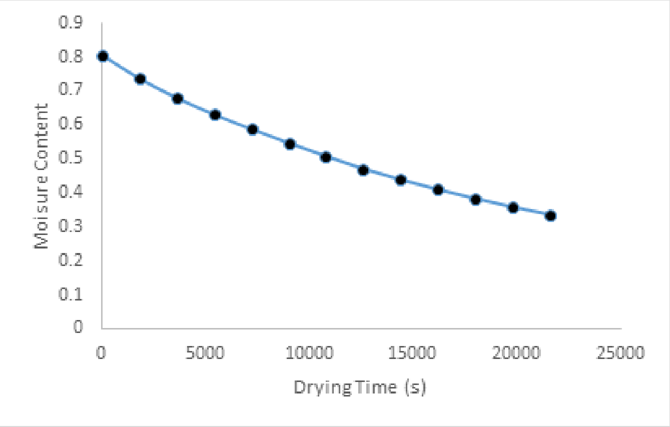

Fig. 6. Variation of Moisture Content with Drying Time at 50°C

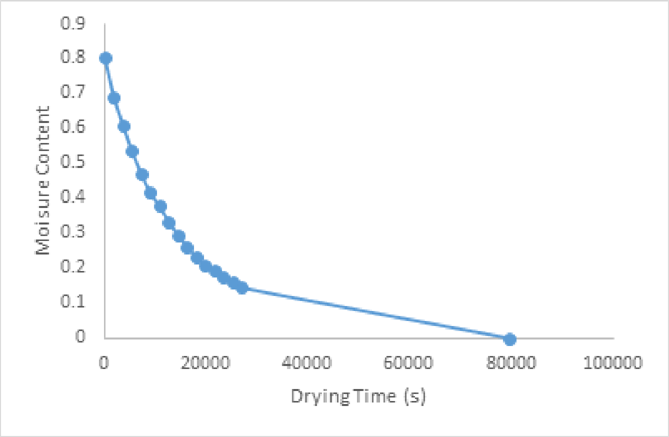

Fig. 7. Variation of Moisture Content and Drying Time at 55°C

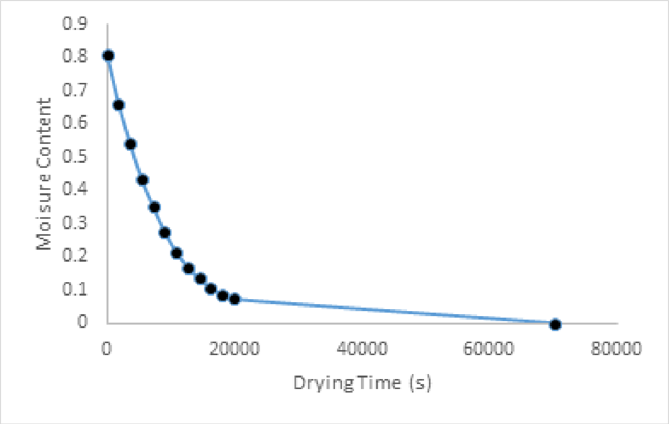

Fig. 8. Variation of Moisture Content with Drying Time at 65°C

Figure 5 - 8 shows the Variation of Moisture Content with Drying time at temperatures of 45°C, 50°C, 55°C and 65°C respectively. From the plots, it is seen that as the drying time increases the moisture content of the sample in the four cases decreases. This is as a result of increased residence time of the sample in the oven. Also, it was observed that the moisture content decreases with an increase in temperature from 45°C to 65°C. Hence, it can be concluded that the moisture content is a function of temperature and it is inversely proportional to the drying time.

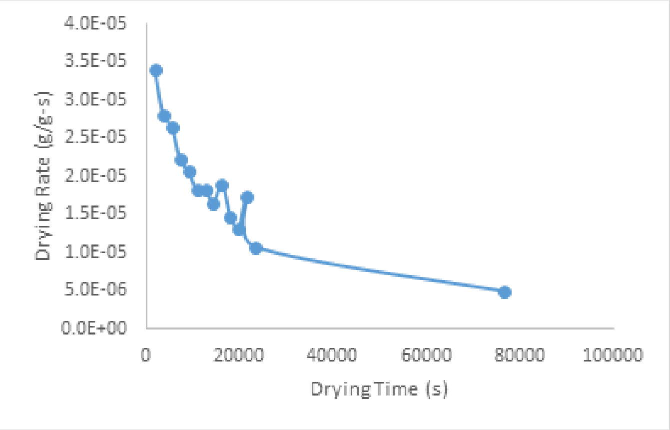

Fig. 9. Variation of Drying Rate and Drying Time at 45°C

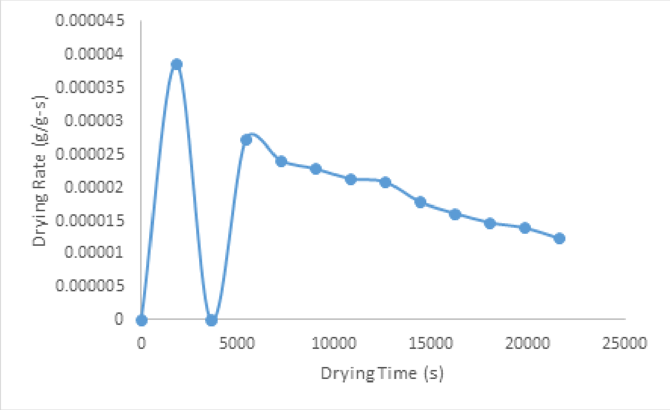

Fig. 10. Variation of Drying Rate and Drying Time at 50°C

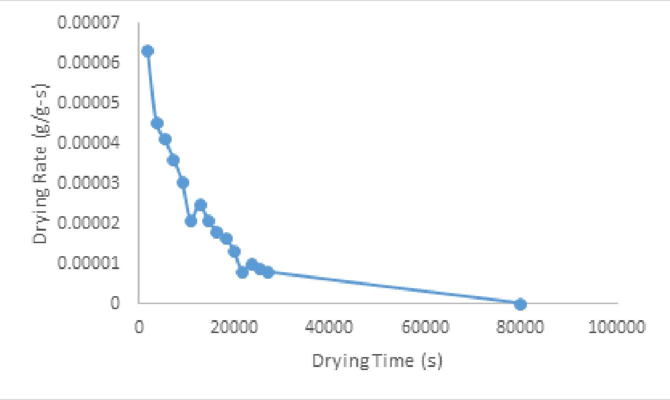

Fig. 11. Variation of Drying Rate and Drying Time at 55°C

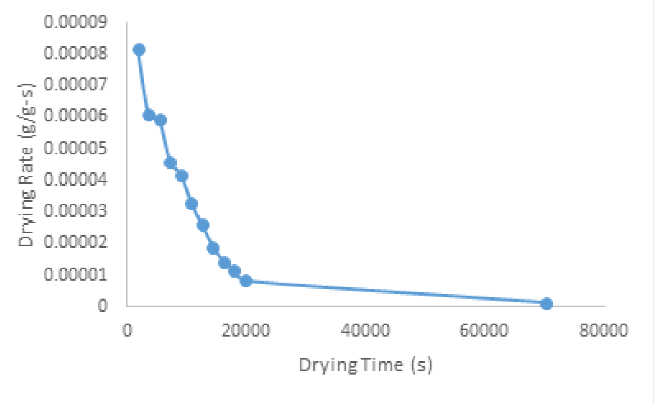

Fig. 12. Variation of Drying Rate with Drying Time at 65°C

Figures 9 - 12 depicts the variation of Drying Rate and Drying time at 45°C, 50°C, 55°C and 65°C respectively. From the plots, it is seen that the drying rate decreases with an increase in drying time which is as a result of increased residence time of the sample in the oven. It was observed also, that the drying rate increases with an increase in temperature as shown in Figures 9 - 12 for temperatures 45°C - 65°C. Hence, it can be concluded that the drying rate is a function of temperature and it is inversely proportional to the drying time.

## IV. CONCLUSION

The purpose of drying is achieved when an optimum operating condition and efficient drying rate is determined.

This work has achieved this objective through the investigation of the kinetic parameters for the thin layer drying of corn for further purposes under constant drying conditions. The drying of the grain was observed to be in the falling rate period. The experimental data for corn could fairly accurately be predicted by the Page equation. The values of A and B for corn respectively are:

| T°C | A | B |
|---|---|---|
| 45 | 0.000722969 | 0.6752 |
| 50 | 0.0013036374 | 0.6193 |
| 55 | 4.6907E-05 | 1.039 |
| 65 | 6.58972E-06 | 1.31 |

The contribution of this work to knowledge is the discovery of the dependence of A and B on air temperature which can be used in the design of industrial dryers for corn under constant drying conditions and also enable the development of dryer models over a wide range of temperatures.

## REFERENCES

[1] Akpinar, E.K., Bicer, Y., Yildiz, C., (2003). Thin Layer Drying of Red Pepper. *Journal of Food Engineering,* 59, 99–104.

[2] American Society of Agricultural Engineers, (2000a). Thin — layer Drying of Grains and Crops. *ASAE, Data Standard 5448.* St. Joseph, MI Publication. 221-235.

[3] Arslan, D &Özcan, M.M. (2010). Study the effect of Sun, Oven and Microwave Drying on Quality of Onion Slices. *LWT* - Food Science and Technology 43, 1121-1127.

[4] Baker, C. G. (1999). Predicting the Energy Consumption of Continuous Well Mixed Fluidized Bed Dryers from Drying Kinetics Data. *Journal of Drying Technology*. (17) 1533-1555.

[5] Beadle, G. W. (1980). The ancestry of corn. *Scientific American, 242* (1), 112-119.

[6] Beltagy, A., Gamea, G. R. &AmerEssa, A. H. (2007). Solar Drying Characteristics of Strawberry. *Journal of Food Engineering,* 78 (2), 456 – 464.

[7] Bessarabov, A., Shimiehev, V., Menhutina, N. (1999). Microwave drying of multicomponent solids. *Journal of Drying Technology,* (17) 3, 379 — 394.

[8] Bradly P. M., Nicholas R. F., and Fred W. B. (2003). Drying Rate of Individual Ears of Corn. *ASAEAnnua1 International Journal* Las Yegas, Nevada USA, 27 — 30.

[9] Cao C. L., Qiang, M. Z. (2000). Research on modeling and simulation of grain drying systems. Faculty of Mechanical Engineering, China Agricultural University Beijing, 100083, China (ICET 2000. Session 6. Technology Innovation and Sustainable Agriculture).

[10] 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. Biosys. Engineering 88 (3):325- 335.

[11] Dissa, A.O., Bathiebo, D.J., Desmorieux, H., Coulibaly, O. &Koulidiati, J. (2011). Experimental characterisation and modelling of thin layer direct solar drying of Amelie and Brooks mangoes. Energy 36, 2517-2527.

[12] Doymaz, I., Ismail, O., (2010). Drying and rehydration behaviors of green bell peppers. Food Science Biotechnology, 19 (6), 1449–1455.

[13] Doymaz, I., Ismail, O., (2011). Drying characteristics of sweet cherry. Food Bio-production Process. 89, 31–38.

[14] Doymaz, I., Pala, M., (2002). Hot-air drying characteristics of red pepper. *Journal of Food Engineering,55, 331–335.*

[15] Doebley, J. &Stec, A. (1993). Inheritance of the morphological differences between maize and teosinte: comparison of results for two F2 populations.*Genetics, 134*, 559-570

[16] Francturk, S., Gulaboglu., M.S. and Guitekin, S. (2004). The thin-layer drying characteristics of rosehip. Biosy.Engineering, 89 (2):150-166.

[17] GŐkhanGŰrlek, NecdetOzbalta, Ali GŰngŐr, (2008), Solar tunnel drying characteristics and mathematical modeling of tomato.Food Science Biotechnology, 14(8), 149–155.

[18] Iminabo, John; Iminabo, Misel and Dagde, Kenneth (2018). “Modeling the drying kinetics of plantain chips under forced and free convection,” *International Research Journal of Advanced Engineering and Science*, (3) 2: 1-6.

[19] Karathanos, V. T. &Belessiotis, V. G. (1999). Application of thin layer equation to drying data of fresh and semidried fruits. *Journal of Agricultural Engineering Research, 74, 355 – 361.*

[20] Khawas,P., Das,A.J,Dash,K.K. and Deka,S.C. (2013).Thinlayer drying characteristics of Kachkal banana peel (Musa ABB) of Assam, India. *International Food Research Journals*, 21(3): 1011-1018.

[21] Simal, S. Garau, C. Femenia, A. and Rossello, C. (2005). Drying of red pepper (Capsicum annum): water desorption and quality. *International Journal of Food Engineering,* 1(4): 1 -14.

[22] Sharaf - Edeen, Y. L, Blaisdell, J. L. and Hamdy, M.Y. (1980). A Model for Ear Corn Drying. *Transactions of the ASAE*, 23 (5): 1261 - 1271.

[23] O’Callaghan, J.R., Menzies, D.J. & Bailey, P.H., (1971). Digital simulation of agricultural dryer performance. *Journal of Agricultural Engineering Research,* 16, 223–244.

[24] Page, C. (1949). Factors Influencing the Maximum Rate of Drying Shelled corn in layers.M.Sc thesis, Purdue University, West Lafayette IN.

[25] Proctor D.L. (1994). Grian Storage Techniques Evolution& Trends in Developing countries FAO Agricultural Services Bulletin. 109

[26] Yaldiz, O., Ertekin, C. &Uzun, H.B. (2001). Mathematical modelling of thin layer solar drying of sultana grapes. Energy, 26, 457–465.