ISSN:2319-6890)(online),2347-5013(print)
1 May 2016

Determination of Thin-Layer Drying Characteristics of a Plantain Sample at Different Temperatures

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Abstract : The thin-layer drying characteristics of plantain was analysed at different temperatures. The plantain sample was sliced to 5mm thickness size and dried at 40^{o}C, 50^{o}C, 60^{o}C and 70^{o}C. The moisture content (dry basis), moisture ratio, effective diffusivity and activation energy were determined within the temperature range. The moisture content of cooking plantain on dry basis was found to be 1.70g moisture/g dry sample at the beginning of the drying. The highest moisture removal of 1.58g/g dry sample occurred at the 70^{o}C drying temperature. The effective diffusivity obtained from the experimental data is within the range 2.85x10^{-10}-6.65x10^{-10}m^2/s while the activation energy is 476.54J/smol. The rate of moisture removal, moisture ratio slope, effective diffusivity and activation energy values obtained from the experimental values increase with the drying temperature.

Keywords: Cooking plantain, thin-layer, drying, moisture content, moisture ratio, effective diffusivity, activation energy

1. Introduction

Plantain is a staple carbohydrate food commonly grown in the tropical regions of the world and it can be grown in almost all types of soils provided adequate moisture is available (Adeboye et al., 2014). Specifically, plantain is a major source of carbohydrate in diets of people from most African countries, Latin America and South-East Asia (Adeboye et al., 2014). Plantains are of great nutritional importance and are known to be a great source of calcium, vitamins A, B_1, B_2, B_3, B_6,C and minerals such as potassium and phosphorus (Dzisi et al.,2012). It is consumed both as energy-yielding food and as desert, providing more than 200 calories (food energy) a day (Dzisi et al.,2012).The proximate analysis for plantain shows that per 100g edible portion ,plantains contain 67.30g water,116kcal of energy, and 31.15g of carbohydrate (Satimehin et al., 2010). There are also other minerals present as micronutrients. They are chromium (Cr), zinc (Zn), Selenium (Se), Iron (Fe), Cobalt (Co), manganese (Mn), and copper (Cu)(Danso et al.,2006). Many countries in the world today are faced with the problem of the preservation of their food products since most crops are susceptible to deterioration. This challenge is more pronounced especially in developing countries where electricity power challenge is still predominant. Plantain like other fruits and vegetables are regarded as highly perishable due to the high moisture content (Kabiru et al., 2013). The result is financial losses for the farmers and consequently the scarcity of the product. Income earnings from plantain are significantly affected as little or no economic values are obtained in the face of the wastages and losses. Therefore, the understanding of the thin-layer drying characteristics of plantain helps to develop an efficient and relatively cheap method for the preservation of this product.

2. Materials and methods

A ripe cooking plantain variety was used in the study. Cooking plantain is the plantain variety of short sizes and they closely resemble cooking banana in size and shape. The sample was purchased from Agricultural Development Project Farm, Ministry of Agriculture, Rumuodomanya, Obior-Akpor Local Government Area, Rivers State, Nigeria. The purchase of the variety from the Agriculture Development Farm (ADP) is for proper identification of the samples used for the study. The samples were transported to Bio-chemistry Laboratory, Abuja Campus, University of Port-Harcourt, Rivers State, Nigeria for the study.

2.1 Drying of the plantain samples

The plantain samples were peeled and sliced to 5mm thickness size before the drying. Thin layer drying is assumed so that the initial resistance to moisture movement within the plantain sample is ignored (Satimehin et al., 2010). Three samples of 5mm thickness size of a variety of the plantain were weighed individually by a digital balance of accuracy 300g/0.01g to determine the initial mass of the samples. Thereafter, the samples were put inside the oven dryer (TT-9023A) set at 40^{o}C and the masses were measured continually every 30mins for six hours and the average weight recorded for the sample. The whole process was repeated at 50^{o}C, 60^{o}C and 70^{o}C in the oven dryer and the weights were recorded. The samples were monitored until a constant weight value at the equilibrium moisture content is reached and the values recorded.

2.2 Determination of moisture content

In determining the moisture content of the samples, the formular is applied:

$$m_t = \frac{w - w_s}{w_s} \quad (2.1)$$

Where, m_t=the moisture content at time, t. (g water/g dry samples) w_t=total product weight at each time (gram)
w_s= weight of the dry samples (gram).

2.3 Determination of the moisture ratio

The Moisture Ratio (MR) is expressed in dimensionless form and obtained by the following equation (Erenturk et al.,2004;Midilli et al.,1999;Midilli, 2001)

$$MR = \frac{m_t - m_e}{m_o - m_e} \quad (2.2)$$

Where, MR is the moisture ratio,

m_e is the equilibrium moisture content

m_o is the initial moisture content. The values of m_e are relatively small compared to m_t and m_o (Jena and Das, 2007; Doymaz, 2004; Doymaz and Pala, 2002).Therefore, Equation (2.2) becomes

$$MR = \frac{m_t}{m_o} \quad (2.3)$$

2.4 Mechanism of moisture diffusivity

The plantain is dried from the two faces and the y-direction being taken perpendicular to the drying surface. The central plane of the plantain being taken as y=0 and the plantain thickness 2l. On drying, the moisture movement inside the plantain by diffusion will be in the y-direction. The Figure 2.1 shows the sample of plantain.

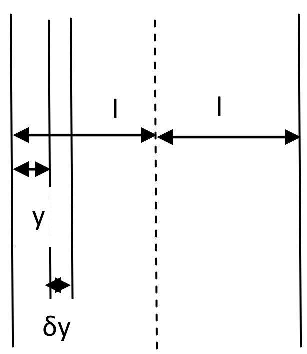

Figure 2.1: A sample of plantain of total thickness 2l being dried from both sides.

Input at y = N_A But $N_A = -D_{eff}\frac{\partial C_w}{\partial y}$

Output at $y + \delta y = [N_A + \left(\frac{\partial N_A}{\partial y}\right)\delta y]$

Accumulation$=\frac{\partial m}{A\,\partial t} = \frac{\partial C_w}{\partial t}\delta y$

Mass balance gives, Input-Output=Accumulation

Therefore, $N_A - N_A - \left(\frac{\partial N_A}{\partial y}\right)\delta y = \frac{\partial C_w}{\partial t}\delta y$

Simplifying, gives $\frac{\partial C_w}{\partial t} = D_{eff}\frac{\partial^2 C_w}{\partial y^2}$ (2.4)

C_w is the concentration of water at any point and any time in the plantain and D_{eff} is the effective diffusivity. If m_t is the concentration of water integrated over the whole thickness, m_o the initial moisture content, and m_e the equilibrium content. Applying the following initial conditions, then: At x=0, t=t, m=0

x=2l, t=t, m=0

t=0, x=x, m=m_o

The solution of the partial differential Equation of (2.4) gives

$$\frac{m_t - m_e}{m_o - m_e} = \frac{8}{\pi^2}\left\{e^{-D_{eff}t\left(\frac{\pi}{2l}\right)^2} + \frac{1}{9}e^{-9D_{eff}t\left(\frac{\pi}{2l}\right)^2} + \frac{1}{25}e^{-25D_{eff}t\left(\frac{\pi}{2l}\right)^2} + \cdots\right\}$$
(2.5)

2.5 Determination of the effective diffusivity

Moisture Ratio can be expressed as a linear equation as demonstrated by several researchers (Satimehin et al., 2010, Abano and Sam-Amoah,2011 and Ayim et al., 2012). The linear equation is obtained by taking antilogarithm of Equation (2.5)

$$\ln MR = \ln\left[\frac{8}{\pi^2}\right] - \left[\frac{\pi^2 D_{eff} t}{4L^2}\right] \quad (2.6)$$

The plot of LnMR versus time of the Equation (2.6) gives a slope:

$$Slope = -\frac{\pi^2 D_{eff}}{4L^2} \quad (2.7)$$

Where D_{eff} is the effective moisture diffusivity, L is the half thickness and t is the drying time.

2.6 Determination of the activation energy

Arrhenius relationship can be applied to determine effective diffusivity as a function of temperature (Madamba et al., 1996, Sanjuan et al., 2003)

$$D_{eff} = D_o \exp\left[-{}^{E_a}/_{RT}\right] \quad (2.8)$$

where R, is the universal gas constant and T, is the absolute temperature. E_a is the activation energy. Activation energy is the minimum energy per mol per second required to effect moisture diffusivity from the plantain.

Taking natural logarithm of both sides of the Equation (2.8) gives, $\ln D_{eff} = \ln D_o - {}^{E_a}/_{RT}$ (2.9)

The plot of $\ln D_{eff}$ versus 1/T gives a linear equation obtained by the regression analysis of D_{eff} , slope of the straight line graph gives $-{}^{E_a}/_{R}$ and from where the activation energy can be obtained.

3.0 RESULTS AND DISCUSSION

3.1 Experimental drying results

The moisture content curves at the 40°C, 50°C, 60°C and 70°C drying temperatures are presented in Figure 3.1-3.4.

ISSN:2319-6890)(online),2347-5013(print)
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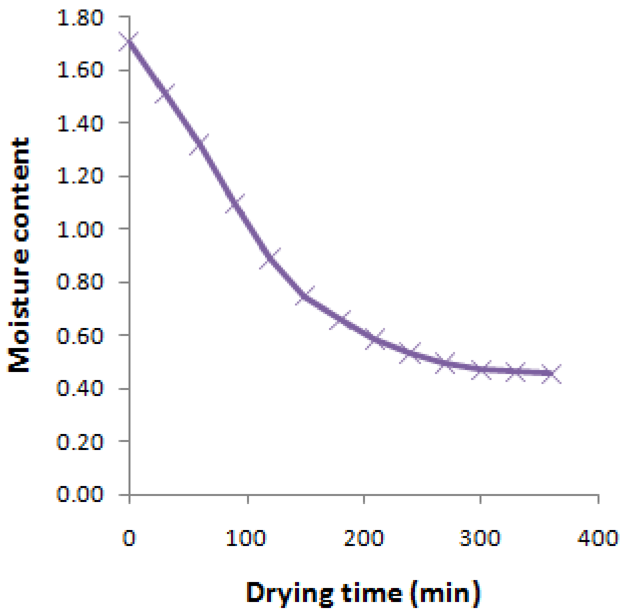

Figure 3.1: Moisture content curve at 40°C

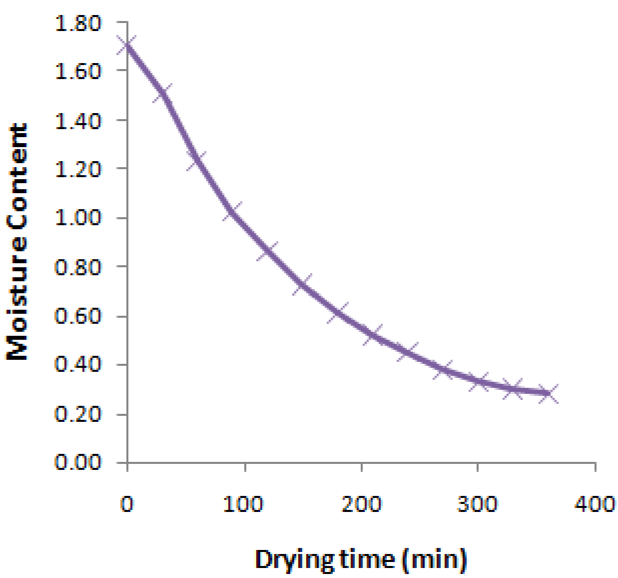

Figure 3.2: Moisture content curve at 50°C

From Figure 3.1, it can be seen that the moisture content at the beginning of the drying is 1.70g moisture/g dry sample and after 6hrs of drying at 40°C, the value falls to 0.46 g moisture/g dry sample. From the difference between the initial moisture content and the final value, it can be seen that the amount of moisture removed from the cooking plantain is 1.24 within the period of six hours of drying. At 50°C drying temperature given in Figure 3.2, it can be seen that the moisture removal is higher with value 1.42 g moisture/g dry sample. This is because of higher diffusivity of moisture takes place at 50°C than 40°C drying temperature.

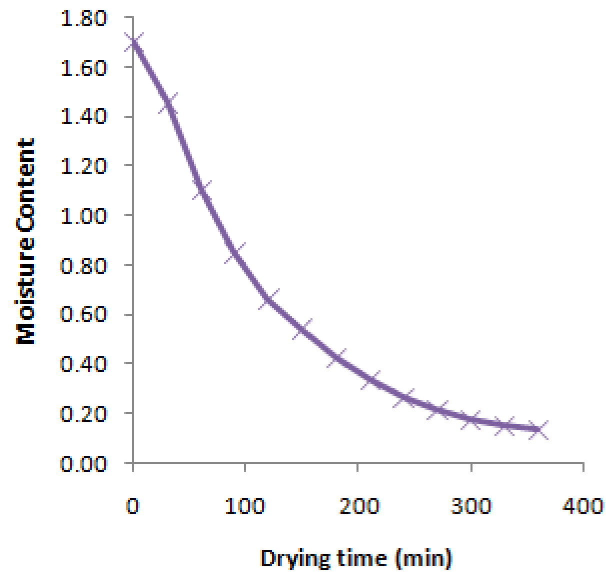

Figure 3.3: Moisture content curve at 60°C

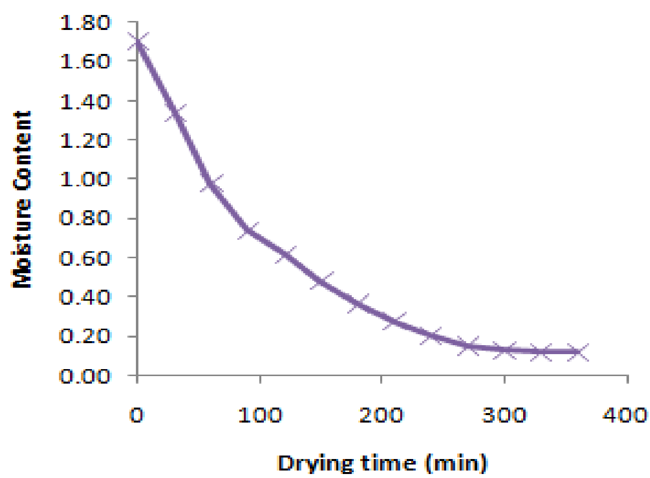

Figure 3.4: Moisture content curve at 70°C

Figure 3.3 shows the moisture content curve of the plantain at 60°C. At the end of the six hours of drying, the moisture removed is 1.56 g moisture/g dry sample. At the 70°C drying temperature shown in Figure 3.4, It can be seen that cooking plantain has the highest moisture removal of 1.58 g moisture/g dry sample during the 6hrs of drying. The moisture contents of the varieties are initially high and decrease as the drying time increases. Therefore, the drying process occurred in the falling rate period, starting from high initial moisture content to the final moisture content. This means that the drying process was mainly controlled by diffusion mechanism. Similar results have been reported by various researchers, pomegranate arils (Motevali et al.,2010), egg plant (Erketin and Yaldiz, 2004),peach slices (Kingsley et al.,2007) and cassava chips (Tunde-Akinthunde and Afon, 2010).

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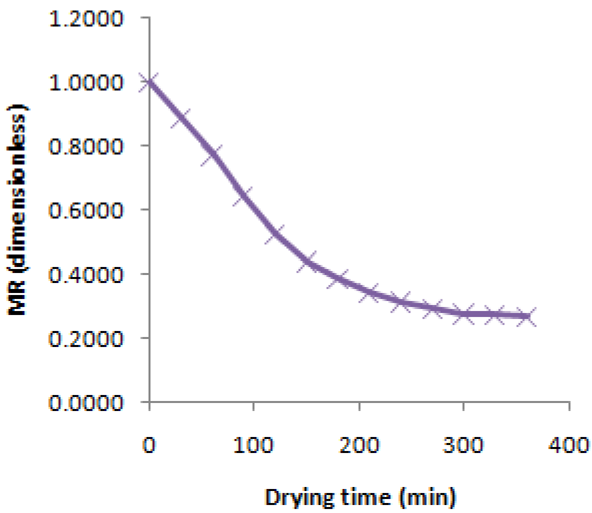

Figure 3.5: Moisture Ratio curve at 40°C

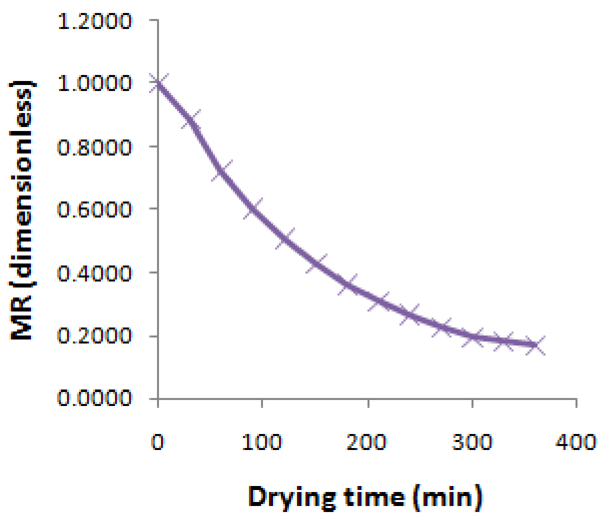

Figure 3.6: Moisture Ratio curve at 50°C

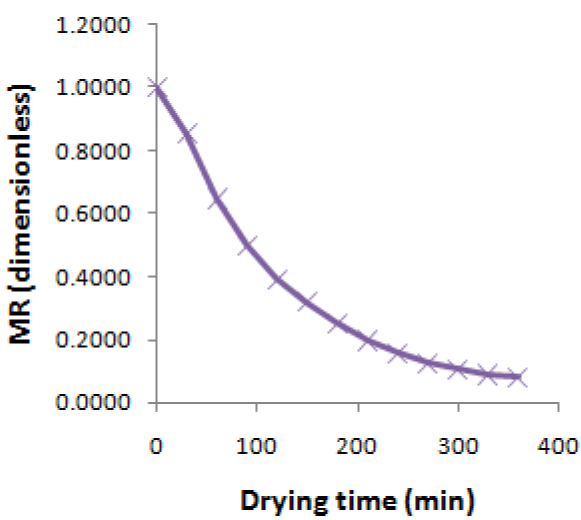

Figure 3.7: Moisture Ratio curve at 60°C

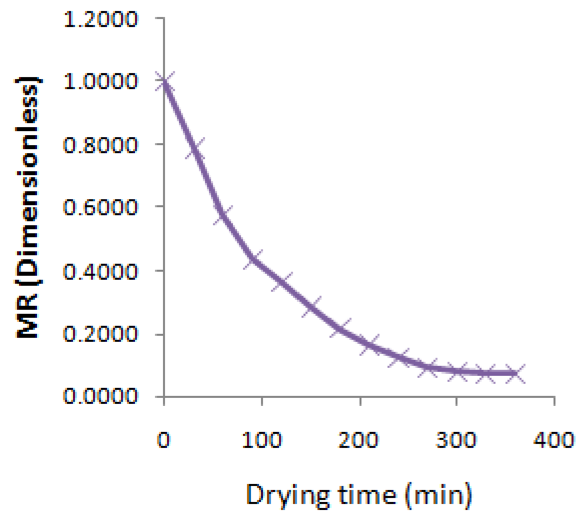

Figure 3.8: Moisture Ratio curve at 70°C

The Moisture Ratio Curve versus time plots given in Figures 3.5-3.8 show the average rate of drying of the plantain at the given temperatures. The MR is the ratio of M_t to M_o and the value approaches the minimum value asymptotically. The determination of the average rate is based on the slope of the curves since all the curves have the same initial value of 1. It can be seen that the steepness of the MR curves increases as the temperature increased from 50°C to 70°C .Therefore, the rate of drying of the plantain samples is highest at 70°C. This observation agrees with previous literature studies on the convective drying of banana at different drying temperatures (Maskan, 2000).

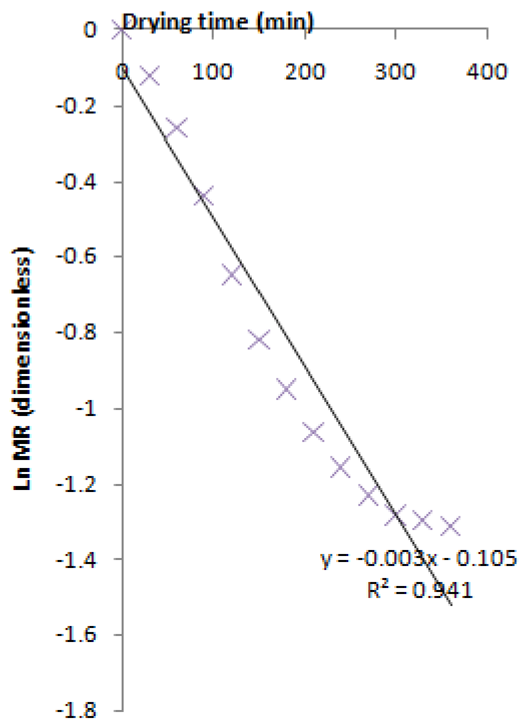

Figure 3.9: Regression analysis of MR at 40°C

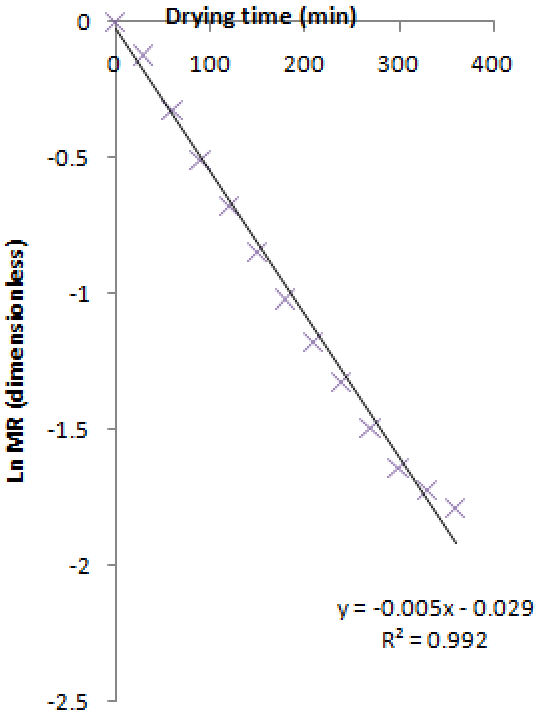

Figure 3.10: Regression analysis of MR at 50°C

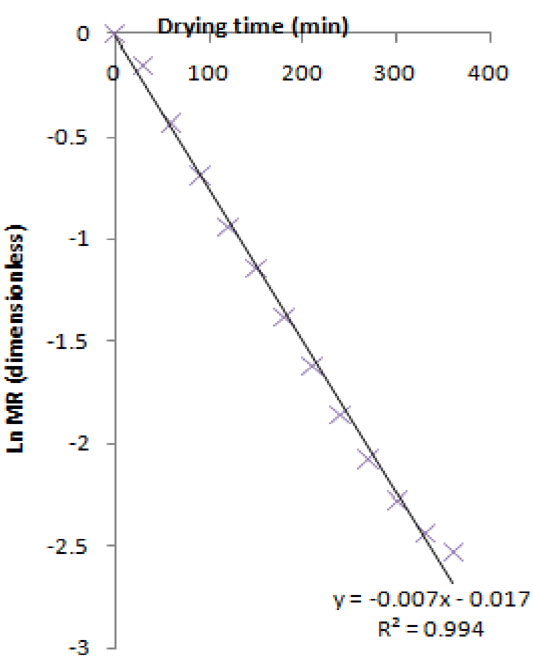

Figure 3.11: Regression analysis of MR at 60°C

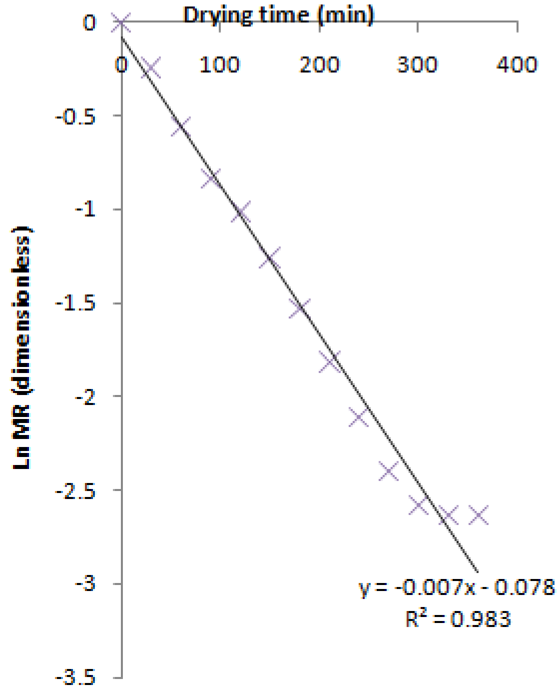

Figure 3.12: Regression analysis of MR at 70°C

The fitting of the MR straight line equation given in Equation (2.6) is determined by the data with the highest value of R^2. The trend line regression analysis is used because the patterns of the values are known and in this case linear. Figure 3.9 shows the trend line regression analysis of the 5mm thickness size of the cooking plantain at 40°C. The value of the R^2 is 0.9410. The R^2 value at 50°C drying temperature given in Figure 3.10 is 0.992. The R^2 value at 60°C given in Figure 3.11 is 0.994 while the value at 70°C given in Figure 3.12 is 0.983. The effective diffusivity is calculated from Equation (3.5) from the values of the slope. The values of the effective diffusivity, D_{eff} calculated at 40°C and 70°C is $2.85x10^{-10}m^2/s$ and $6.65x10^{-10}m^2/s$ respectively. It can be seen that the effective diffusivity increases with temperature with the average D_{eff} of $5.22x10^{-10}m^2/s$ within the drying temperature range. The activation energy is obtained from Equation (2.9) and the activation energy of the cooking plantain calculated from the experimental data is 476.54J/smol.

4. CONCLUSION

It can be seen from the experimental results that cooking plantain has high moisture content of 1.70g moisture/g dry sample (dry basis) but also high moisture removal rate. The 1.58g moisture/g dry sample removed at the 70°C drying temperature indicates relatively low moisture content for the sample at the equilibrium moisture condition.

ISSN:2319-6890)(online),2347-5013(print)
1 May 2016

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