MODELING LIQUID WATER ABSORPTION OF UNTREATED UKAM FIBER DURING SOAKING

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ABSTRACT

The research addresses the hydrophilic behaviors of the natural ukam plant fiber material at various studied conditions. The aim of this work was to reveal the possibilities to model the liquid water absorption characteristics of untreated ukam fiber which assists in optimizing soaking conditions. Liquid water absorption of untreated ukam fiber during soaking in liquid water at temperatures of 10, 20, 30, 40,50ºC was simulated using peleg's model. The weight-gain during soaking process was determined in terms of moisture content. Peleg's equation was adequately capable to predict water uptake of untreated ukam fiber under the experimental conditions. The peleg rate constant, k_1, decreased from $102.00*10^{-2}$ to $44.87*10^{-2}h\%^{-1}$ while capacity constant, k_2, did not with increasing temperature. The effective diffusivity was evaluated by fitting experimental absorption data to Fick's second law of diffusion. Effective diffusivity of water varied from $4.2432*10^{-9}$ to $0.8486*10^{-9}$ over the temperature range studied with an energy activation of $29{,}323.478KJmol^{-1}K^{-1}$.The temperature dependence of the diffusivity coefficient was described satisfactorily by Arrhenius-type relationship.

Keywords: Peleg's Model, Soaking, Untreated Ukam Fiber, Liquid Water Absorption.

1. INTRODUCTION

Untreated Ukam Fiber plant is an important plant in tropics of Africa and made of mainly cellulose materials for people living that area. In the developing countries the commercial processing of this locally grown plant into value added products is an important driver for economic development. Recently, there has been a growing research in ukam plant with respect to its potentials for composite production. In the composite production process, carefully arranged ukam fibers were soaked in water until saturation before composite production in order to be able to determine its water absorption capacity. In composite production process, soaking time and temperature had a highly significant effect on composite quality. Soaking in water is also both pretreatment and extraction process for the composite production process. The kinetics of water absorption has been studied extensively for traditional food fiber plant (Abu-Ghannam and McKenna, 1997: Hung et al, 1993: Sopade et al, 1992). Mathematical modeling of absorption in composite production processes is very important in the design and Optimization of its fiber liquid water hydration predictions. These models may be theoretical, empirical and semi-empirical, but despite the wide application of computers and their associated programs, empirical equations are extensively employed because of their ease of computation and simplicity (Sopade et al, 2007). Peleg's equation as a popular empirical non-exponential model with parameters of immense practical importance in hydration kinetics applicable to weight gain during rehydration (Peleg, 1988; Cunningham et al, 2007: Singh and Kulshrestha). Peleg two-parameter equation accuracy prediction during water soaking was tested with its original form as in Eq (1), rearranged to Eq. (2):

$$M_t = M_0 + \frac{t}{K_1 + K_2 t} \qquad (1)$$

$$\frac{t}{m_t - M_0} = K_1 + K_2 t \qquad (2)$$

Hence, absorption rate at the beginning of soaking process is subsequently expressed as K_1 is lined to initial liquid water absorption rate,W_0 (Peleg 1988).

$$W_O = \frac{dM}{dT} t \rightarrow o = \frac{1}{K1} \qquad (3)$$

Peleg capacity constant, K_2, relates to maximum moisture content. As $t \rightarrow \infty$, Eq. (4) shows the equilibrium moisture content (Mc) and K_2 relationship:

$$Me = M_0 + 1/ K_2 \qquad (4)$$

To authors' knowledge there is no information about soaking of untreated ukam extracted fiber. Hence, the evaluation of physical properties of untreated ukam fiber and the applicability of Peleg's equation in modeling liquid water absorption, determination of the diffusivity and activation energy at different temperatures was studied.

2.MATERIALS AND METHODS

I. Sample preparation

Ukam plant stems got from southern Nigeria in 2014 were extracted of its fiber at Geo-Mela CCRD. Samples were dried and stored at room temperature until experiments. Official AOAC(2006) methods were used to determine its biochemical properties. The experiments were conducted in five different stages at 10 rounds each.

II. Determination of Physical properties

In order to determine dimensions, untreated ukam fibers were chopped at same lengths and possess same thickness (Diameters), all were measured with the help of an electronic digital caliper having a resolution of 0.01mm.Untreated ukam fiber geometric mean diameter (G_{md}) and degree of sphericity (ϕ) were calculated using the relationship below (Kashaninejad et al, 2006):

$$Gmd = (LWH)^{1/3} = (AL)^{1/3} \qquad (5)$$

$$\Phi = \pi^{1/3}(6Vp)^{2/3}/Ap(6)$$

III. Determination of liquid water absorption kinetics

To determine the kinetics of liquid water absorption, one gram of sample was weighed and soaked in a known weight of distilled water at five different temperatures 10, 20, 30, 40 and 50^{o}C for a known period of time. At the soaking processes, samples were periodically removed from the incubator and weighed using an electronic balance (END, 0.0001gr, China). At each five minutes interval, the water content of the untreated ukam fiber were calculated as the percentage ratio of the difference between the weight of the dry solid and wet samples to the weight of the dry samples. The variations of the moisture content of the samples with time were used to plot the kinetic curve of samples moisture.

IV. Determination of the effective diffusivity and activation energy

The elimination of the effect of the fiber radius on the constant rate of diffusion, the effective diffusivities were calculated in analogy to the analytical solution of one dimensional Fick's law of diffusion with constant moisture diffusivity for sphere/cylinder given by (Kaptso et al,2008). With respect to this, the equation below was used:

$$K = \frac{\pi . D_{eff}}{r^2} \qquad (7)$$

The reciprocal of absolute temperature were correlated with the obtained diffusivity according to Arrhenius type Equation and the activation energy was calculated by linear regression of Ln (D_{eff}) verse 1/T:

3. RESULTS AND DISCUSSION

I. Physico-chemical Properties of Ukam Fiber

Few physico-chemical properties of ukam fiber are in table 1 below. The length, radius, area, sphericity and geometric mean diameter of the fiber sample were calculated as in the table 1 respectively.

Table 1: Average Physico-chemical Analysis of Ukam Fiber

Parameters	Analyzed quantity
Moisture content	2.366%
Ash	0.963%
Length	100mm
Radius	2×10^{-3}mm
Area	1.2569×10^{-5}mm^2
Sphericity	5%
Geometric mean diameter	0.8565mm

II. Kinetics of Liquid Water Absorption

The moisture content (on a dry weight basis) of ukam fiber calculated at five soaking temperatures (10^{o}C-50^{o}C) during hydration processes are shown in Figures below. A regular increase in water absorption was observed as temperature and soaking time increased. This phenomenon is due to high rate of water diffusion at higher temperature and time. The same observations goes with other studies on cellulosic materials (Obekpa et al, 1990;Tangratanavalee et al, 2002; Chiang et al, 2002; Moreira *et al.*, 2008 and Kaptso *et al.*, 2008). These figures depicts that the rate of water absorption is initially rapid and then slows down as equilibrium approaches showing some can of asymptotic behavior relative to the decrease of driving force in liquid water transfer hydration system close to equilibrium. These effects were similar during liquid water soaking of cellulosic materials (Bello *et al.*, 2004 and Solomon, 2007) as the liquid water absorption data of the ramie fiber samples in terms of moisture content and its soaking time under the experimental conditions were fitted to Peleg's equation (Eq.1).

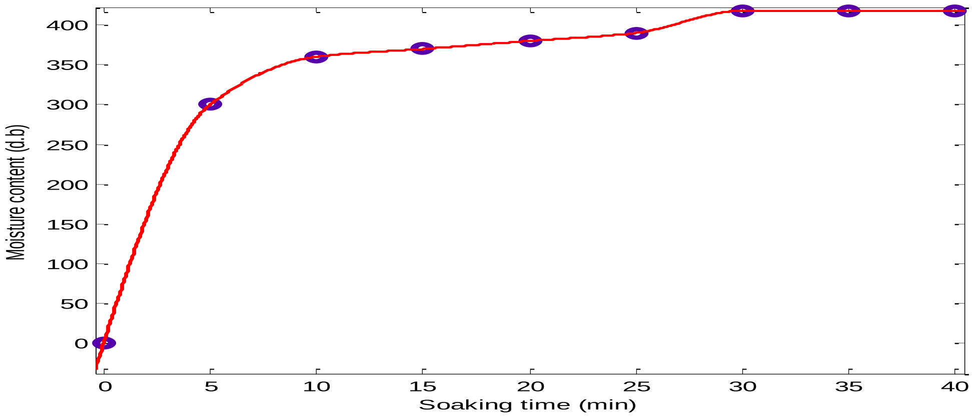

Figure 1: Variation Of Moisture Content vs Soaking Time

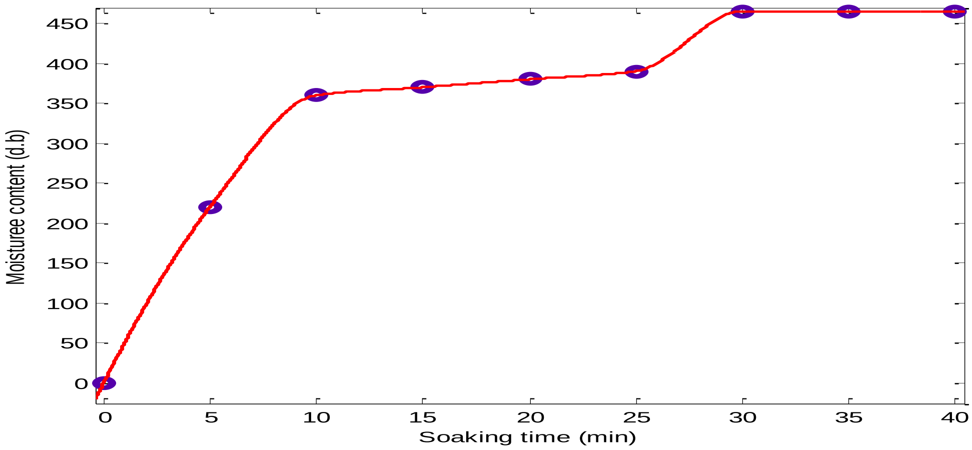

Figure 2: Variations Of Moisture Content vs Soaking Time

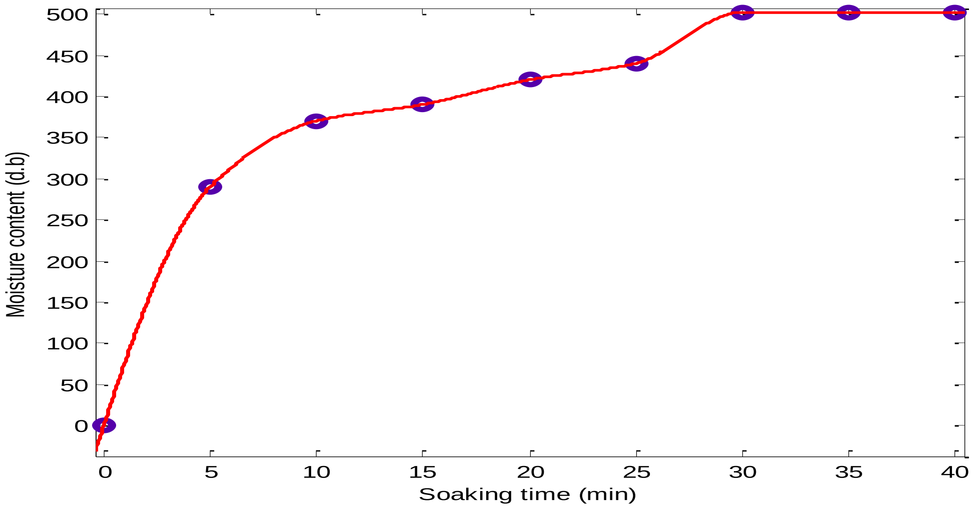

Figure 3: Variations Of Moisture Content vs Soaking Time

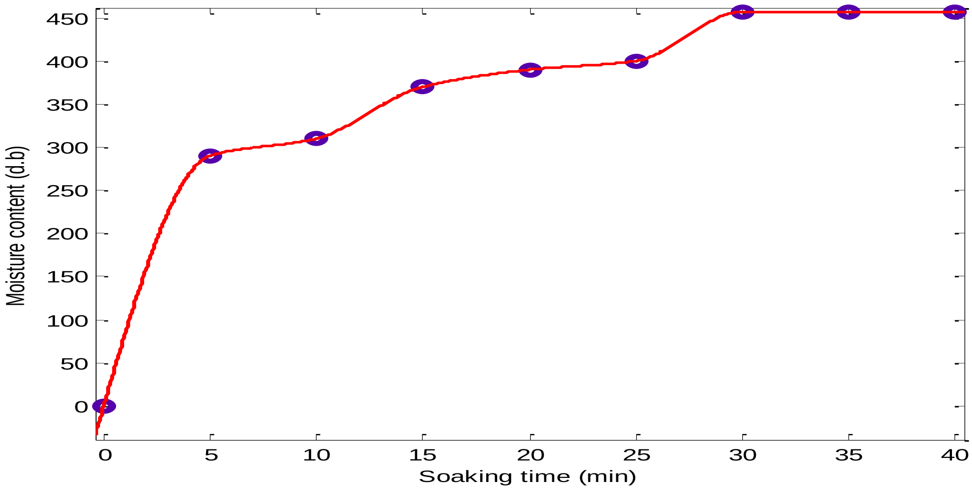

Figure 4: Variations of Moisture Content vs Soaking Time

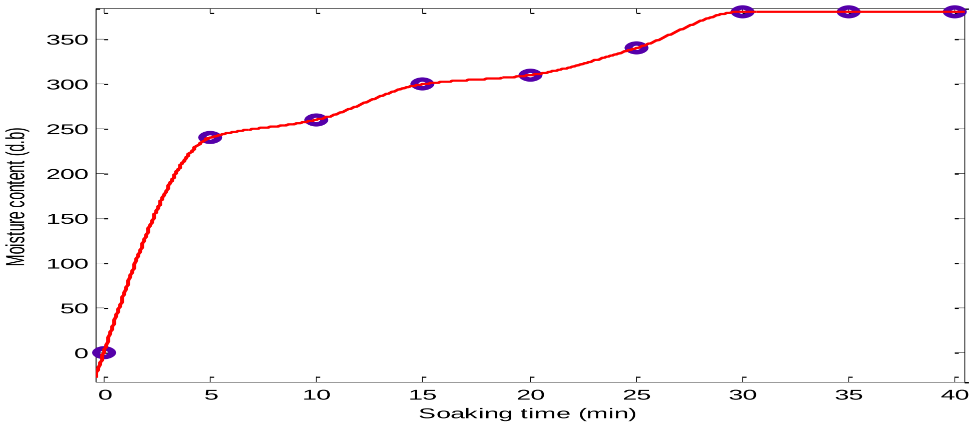

Figure 5: Variations of Moisture Content vs Soaking Time

III. The constant rate of water absorption

The Plots of t/(Mt -Mo) versus soaking time (t) in the figures below allows to study the characteristics of Peleg's constants. The Peleg's rate constant (k_1) and capacity constant (k_2) determined at different temperatures are presented in Table 2. The f-statistic and t-statistic values from the optimization process confirm the adequacy of the model for describing the water absorption kinetics of untreated ukam fiber within the studied temperature range. In this work, K_1 values were inversely related to temperature indicating the increase in the water absorption rate at higher temperatures. This result is in agreement with previous studies (Obekpa et al, 1990; Sopade *et al.*, 1992; Hung *et al.*, 1993; Abu-Ghannam and McKenna 1997; Turhan *et al.*, 2002; Resio*et al.*, 2006).

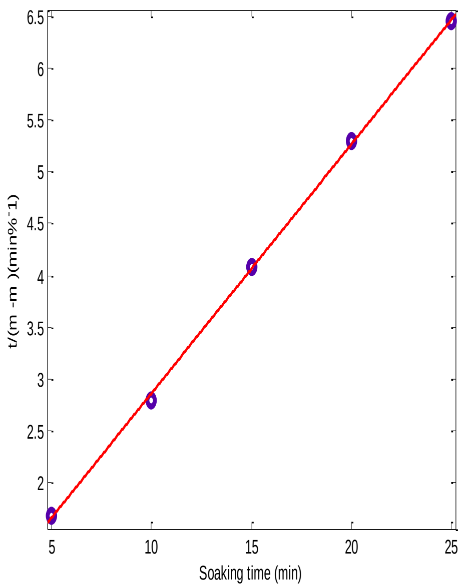

Fig: 1 $\frac{t}{M_t - M_0}$ $vs\ t$

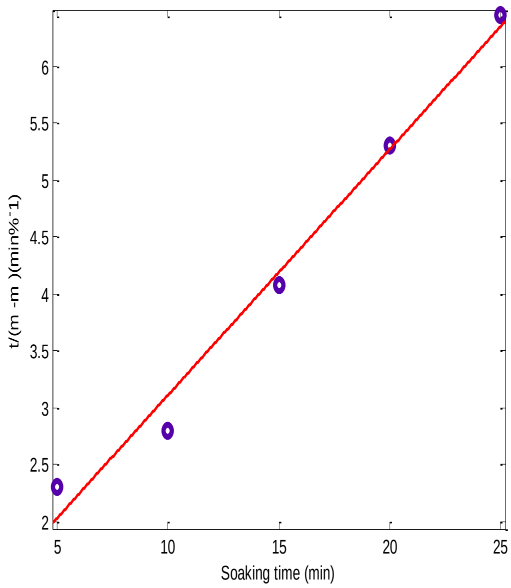

Fig: 2 $\frac{t}{M_t - M_0}$ $vs\ t$

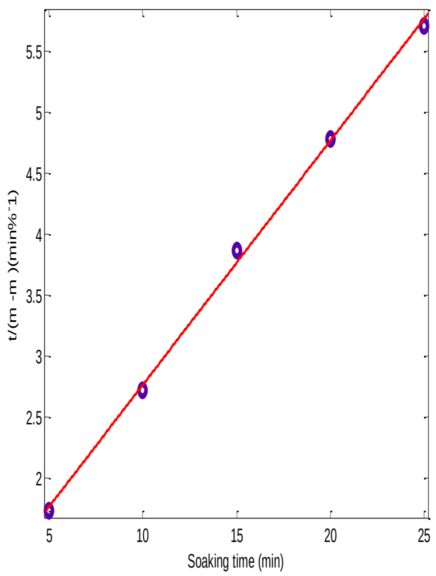

Fig: 3 $\frac{t}{M_t - M_0}$ $vs\ t$

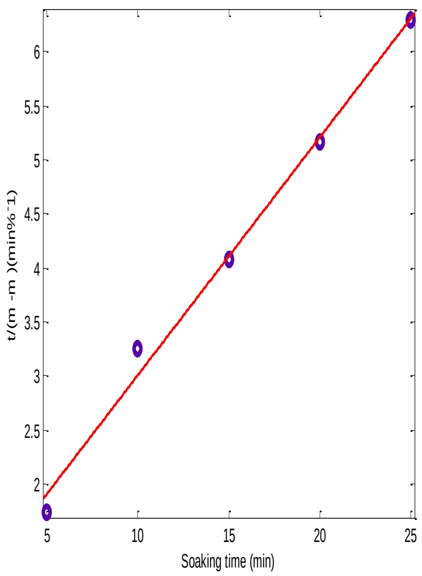

Fig: 4 $\frac{t}{M_t - M_0}$ $vs\ t$

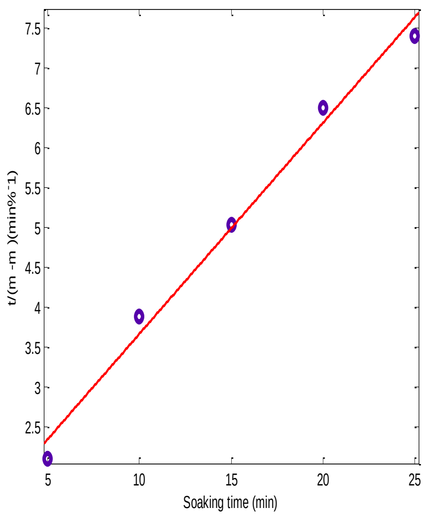

Fig: 5 $\frac{t}{M_t - M_0}$ $vs\ t$

Table 2: Average Peleg's constants and equilibrium moisture content of untreated ukam fibers.

T(°C)	$K_1*10^{-2}(h\%^{-1})$	$K_2*10^{-2}(\%^{-1})$	Me(d.b)
10	102.00	26.44	380.5808
20	94.27	21.61	465.1147
30	80.11	22.01	456.7049
40	76.07	20.03	501.6171
50	44.87	24.08	417.6484

It is observed that the Peleg's constant $K_2$for untreated ukam fiber cannot be a function of temperature (Fig. 3).Similar trends have been observed for other workers (Sopade and Obekpa, 1990; Hung *et al.*, 1993) that reported that K_2 can be independent of temperature.

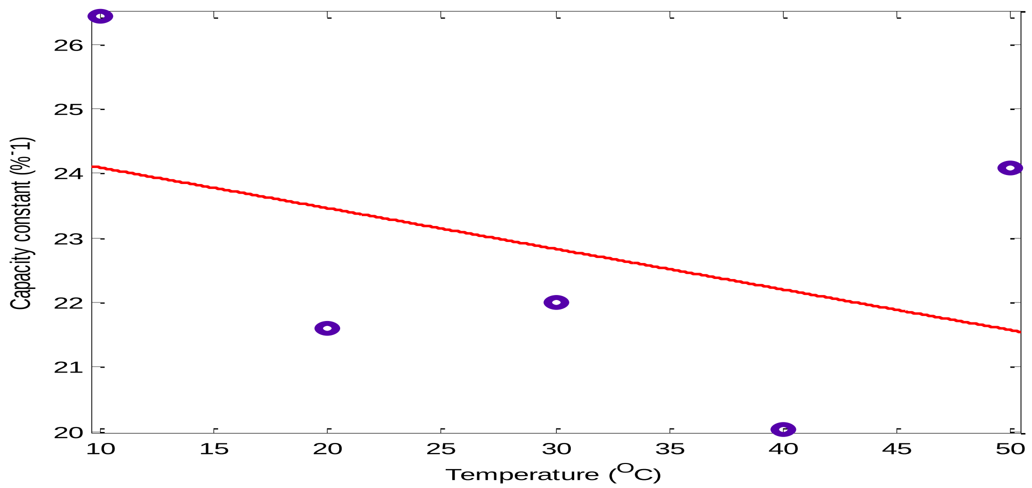

Figure3. Effect of temperature on the Peleg's capacity constant (K_2) during soaking of untreated ukam fibers

Table 2 shows the constant K_2fluctuating from26.44 to 20.03 while the soaking temperature increased from 10 to 50°C. This is due to the uncertainty in liquid water absorption capacity of ukam fiber with increasing of temperature. This statement clearly confirms that as soaking temperature increases the equilibrium moisture content of ukam fibers may or may not increase (Table 2).

IV. Effective diffusivity and activation energy

The effective diffusivity of fibers calculated by Eq. (G)is shown in Table 3. The effective diffusivity of the fibers increased from 0.8486×10^{-9} to 4.2432×10^{-9} m^2s^{-1} as the soaking temperature increased from 10 to 50ºC. The comparison of the diffusion coefficients for water soaking obtained in this study for ramie fiber with those reported in the literature for cellulosic materials depicts that the effective diffusivity of ramie fiber is very similar to other agricultural materials (Resio*et al*, 2006; Bello *et al*, 2004).

Table3. Arrhenius parameters for liquid water absorption of untreated ukam fiber

Temperature(^{O}C)	Diffusion coefficient (m^2s^{-1})
10	$0.8486*10^{-9}$
20	$1.0609*10^{-9}$
30	$1.4144*10^{-9}$
40	$2.1209*10^{-9}$
50	$4.2432*10^{-9}$

The logarithm of Deff as a function of reciprocal of absolute temperature (T) is plotted below. The results show a linear relationship between (log Deff) and (1/T)or an Arrhenius-type relationship. The diffusivity constant (D_0) and activation energy (Ea) calculated from the linear regression were $1.8764*10^{-4}$(m^2s^{-1}) and29,323.478($KJmol^{-1}K^{-1}$), respectively. The obtained activation energy is reasonable data comparable with several authors, for instance (Kaptso,*et al*2008),(Resio*et al.* 2006) Solomon(2007) and (Maskan, 2002).

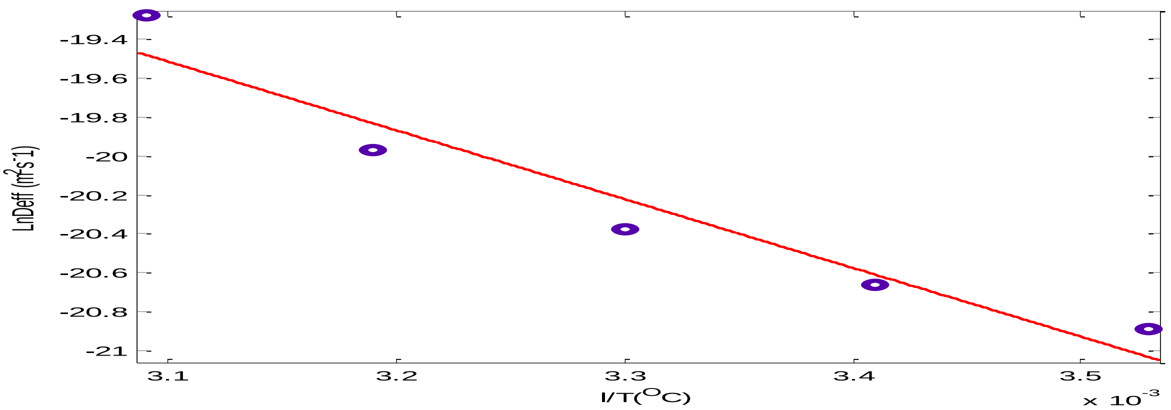

Figure 4.Effect of soaking temperature on the effective diffusivity of untreated ukam fibers

4. CONCLUSIONS

Peleg's equation successfully represented the liquid water absorption behavior of untreated ukam fibers during the soaking process at different temperatures and could be used to estimate the moisture content at given soaking time and temperature within the experimental condition studied. The Peleg's constants K_1were a function of temperature and decreased with increase in soaking temperature while $K_2$was not for untreated ukam fiber. The effective diffusivity of untreated ukam fiber increased with increase in temperature in respect to the Arrhenius type relationship which the activation energy can be calculated. This work revealed that it is possible to model the liquid water absorption characteristics of untreated ukam fiber which assists to optimize soaking conditions.

NOMENCLATURE

D0= Diffusion constant,(m^2 s^{-1}) *L*=Length of sample, (mm)
Deff= Effective diffusivity,(m^2 s^{-1}) *K*=Soaking constant, (s^{-1})
EA=Activation energy,(kJ mol^{-1})K_1=Peleg rate constant, (h $\%^{-1}$) % MC db)
GM=Geometric mean diameter, r (mm) K_2=Peleg capacity constant, ($\%^{-1}$) % MC db)
H=Height of sample (mm) M_o=Initial moisture content, (% db)
Me=Equilibrium moisture content, (% db) *t*= Soaking time, (min)
Mt=Moisture content at a known time, (% db) *T*=Absolute temperature, (K)
R=Sample radius, (m) *W*=Width of sample, (mm) ϕ=Sphericity, (%)
R=Universal gas constant,(8.314 kJ mol^{-1} K^{-1}) R^2=Coefficient of determination

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