Science Arena Publications
Specialty Journal of Engineering and Applied Science
ISSN: 2520-5943
Available online at www.sciarena.com
2020, Vol, 5 (1):28-37

Modelling the effect of temperature on the dehydration kinetics of Shrimp

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Abstract: Shrimps *(Penaeusnotialis)* are *highly perishable and* predominantly found in the market in form of frozen raw or cooked products. It is susceptible to microbial deterioration and the types of technology adopted for post-harvest handling have effects on their storage characteristic. *Drying as a method of preservation can reduce these losses. This research studied dehydration kinetics of* Shrimp *(Penaeusnotialis) applying convective oven dryer method at 50⁰C, 60⁰C, 70⁰C, 80⁰C, 90⁰C and 100⁰C, and was imputed into Page, Henderson-Parbis, and Lewis models based on linearize Fick's Second law of diffusion. The average effective diffusivity values ranged between* 8.431×10^{-7} *and* 7.653×10^{-6} *m²/sec.* The activation energy value obtained was 890.3 J/mol. *This is an indication that the drying of Shrimp ocurred in the falling rate period. The Page model, closely tailed by the Henderson-Parbis' were noticed to be the best models applicable for predicting the drying behaviour of the* Shrimp *(Penaeusnotialis) by a non-linear regression analysis.*

Keywords: *Shrimp, drying kinetics, thin layer, activation energy, and effective moisture diffusivity.*

INTRODUCTION

Shrimp are aquatic animals living in saltwater and freshwater environments. Seafood's such as shrimps are less stable due to their high moisture content and enriched nutrients for the growth of microorganisms. Shrimps *(Penaeus notialis)* are *highly perishable and* are found in the market in form of frozen raw or cooked products. Improper postharvest handling and storage of shrimps lead to microbial deterioration. They have close resemblance to crayfish, crabs and lobsters. Seafoods such as shrimps are abundantly available in the Niger Delta in Nigeria. Deterioration of shrimps can be curbed or prevented in a number of techniques such as drying, freezing, salting, chilling, canning and frying (Rungtip*et al.,* 2005, Nwanna*et al* 2004). According to Doymaz (2010) described drying as an industrial preservation technique in which moisture content and water activity of biomaterials are reduced by heated air to alleviate microbiological, biochemical and chemical sploilage.. Sun drying is still prevalent in most of the developing countries of the world but is characterised with some problems associated with contamination owing to dust, sand particles and insects. Sun drying is relied on weather, non-uniformity in drying and takes longer period to dry any biomaterial products (Doymaz, 2010). Drying is one of most acceptable techniques used for a long term preservation of biological materials. It is effective for retaining flavour, colour and nutritive value of seafoods (Rungtip*et al.,* 2005, Lourdes *et al.,* 2007). Preservation of shrimps is commonly done through drying (Rungtip*et al.,* 2005, Nwanna*et al.,* 2004).
Shrimp meat have nutritionally and medicinal values. It is highly proteineous but low in fat and oil (Shahidi and Synowienki, 1991 and Ajala and Oyetege 2013). Shrimp (Plate 1) have high moisture content that leads

to rapid deterioration immediately after harvested. Thus, there is need to mechanized shrimps processing techniques and this has drawn the attention of national and international agricultural researchers to devote utmost interest and resources to engineering research. Presently, these processes are poorly achieved because shrimp turned rancid before drying is completed, based on these shortcomings, it is imperative to design and develop appropriate technology for drying shrimp, thereby determining its drying behaviour in order to calculate the amount of energy required to complete drying process, analyse the activation energy and effective moisture diffusivity using Fick's law of diffusion.

Drying of other biomaterials have been reported such as egg plant (Ertekin and Yaldiz, 2004), mud snail meat (Burubai and Bratua, 2015), green pepper and onion (Yaldiz and Ertekin, 2001), Soyabeans (Gely and Santalla, 2000), apple (Wang et al; 2006), and African nutmeg (Burubai and Etekpe, 2014). Many researchers have reported different types of drying techniques to process and preserved shrimps such as; sun-drying and oven-drying (Ajifolokun*et al*., 2019) freeze-drying (Lourdes*et al*., 2007), super-heated air drying (Prachayawarakorn *et al*., 2002), heat pump drying (Zhang*et al*., 2008), solar drying (Akonor *et al*., 2016), jet-emitted bed drying and hot air drying (Niamnuy *et al*., 2007). Solar drier and hot air have been the most common and cheapest processing techniques of preserving shrimps because they require less sophisticated efforts and inputs (Oosterveer, 2006). The study of drying kinetics and best fitted in the experimental drying curve data into three mathematical predicting models of shrimp were investigated.

Plate 1: Shrimp *(Penaeusnotialis)*

Materials and Method

Freshly harvested shrimp *(Penaeusnotialis)*was bought from Ondewari town market Southern Ijaw local government area of Bayelsa state, Nigeria. The shrimp *(Penaeusnotialis)* was taken to the food processing laboratory in Niger Delta University, Bayelsa State Department of Agricultural and Environmental Engineering in order to study their drying kinetics. The shrimpwas measured with vanier caliper with equal thickness of 0.013 m and was weighed with top digital balance. Initial weight was taken as 38.6 g and was oven dried using (WTC binder oven Model WTCB 1718). The samples of equal weight and thickness were measured and oven dried at varying temperatures from 50^0C-100^0C with an increment of 10^0C. The initial moisture content of the samples was then determined by the oven method as recommended by ASAE standard (S368 41 2000). The samples were studied and experimental data and predicted data were calculated accordingly from the beginning of the drying experiment to when its equilibrium moisture content took place. The method of drying employed in this research was oven drying method. This method was also applied by Jittanit, (2011) for pumpkin seeds and grape seeds (Robert *et al*., 2008). The drying test was replicated thrice at each temperature levels and averages were recorded.

Thin Layer Models

Thin layer models were used to betel the dehydration of kinetics from different types of permeable materials. The thin layer drying models are mainly depicted the drying of agricultural products fall mostly into three classes namely theoretical, semi-theoretical and empirical. The theoretical takes in consideration only intern resistance movement of moisture stasis while semi-theoretical and empirical models put into consideration extern movement resistance to moisture stasis between the agricultural biomaterial and the aura.

Fick's Second Law of Moisture Diffusion

Fick's second law of moisture diffusion was used in this technical research in a permeable media and was adapted in the method of drying as reported by (Crank, 1975)

$$\frac{\delta m}{\delta t} = D\frac{\partial 2m}{\partial t2} \tag{1}$$

where m is moisture content (kg water/kg solid); t = time (s); D = diffusion coefficient for moisture in solids (m^2/s).

Moisture Ratio

The initial weight of the Shrimp *(Penaeusnotialis)*was measured to be 38.6gram and the moisture content of the sample was determined with the cited to the bone-dried according to AOAC (2000) using the equation (2)

$$\text{MR} = \frac{m_i - m_e}{m_0 - m_e} \text{x } 100\% \text{ (wetbasis)} \tag{2}$$

where MR = dimensionless moisture ratio, M_i = instantaneous moisture content (g water/g solid) m_e = equilibrium moisture content (g water/ g solid), m_0 = Initial moisture content (g water/ g solid). Nevertheless, due to incessant undulating of relative humidity of the dehydration air in dryer, equation can be written as equation (3).

$$\text{MR} = \frac{m_i}{m_0} \tag{3}$$

Moisture Content

The initial weight of the Shrimp *(Penaeusnotialis)*was measured to be 38.6 g and after drying the experimental data was taken. The moisture content of Shrimp *(Penaeusnotialis)*was calculated using equation (4) as reported by AOAC (2011)

$$\text{MC} = \frac{w_i - w_d}{w_i} \text{x } 100\% \tag{4}$$

where MC is the moisture content, w_i is the initial wight of the sample before drying and w_d = is the mass of the sample at time t.

Calculation on Effective Moisture Diffusivity

In calculating the effective moisture diffusivity (Deff) the application Fick's second law equation of diffusion was used. However, constant moisture diffusivity infinite slab geometry and a uniform initial moisture distribution was taken into consideration in equation (5).

$$MR = \left(\frac{8}{\pi^2}\right) \sum_{n=0}^{\infty} \frac{1}{2n+1} \exp^{\left(\frac{-(2n+1)\pi^2}{4L^2}\right) Deff^t} \tag{5}$$

Where Deff is the effective diffusivity (m^2/s) and L is the sample thickness in (m) measured to be 0.013m and t is the drying time. Equation (5) was deduced to produce equation (6)

$$MR = 0.8104 \exp\left(-\frac{\pi^2}{4l^2} Deff^t\right) \quad (6)$$

In other to Linear the equation (6) natural logarithm of both sides is taken thereby transforming it to produce equation (7) (BurubaiandEtekpe, 2014)

$$In(MR) = In\ (0.8104) \exp\left(-\frac{\pi^2}{4l^2} Deff^t\right) \quad (7)$$

Hence, equation (7) produces equation (8)

$$In(MR) = In\ (0.8104) - \frac{9.872}{0.001024} Deff^t \quad (8)$$

Therefore, plotting In(MR) versus drying time (t), which resulted a slope, whereby, the effective moisture diffusivity was obtained.
Further deducing of equation (8) will produce equation (9) and equation (10)

$$Slope = -146036Deff \quad (9)$$

$$Deff = \frac{Slope}{0.001024.} \qquad Deff = \frac{Slope}{-146036} \quad (10)$$

Activation Energy
Arrhenius equation was used to calculate the activation energy as shown in equation (11)

$$Deff = D_o esp\left[-\frac{Ea}{R\ (T+273.15)}\right] \quad (11)$$

whereD_0 is the pre-exponential factor of the Arrhenius model in m^2/s, Ea is the activation energy in kj/mol, R is the universal gas constant kj/mol k and T is the absolute air temperature.
Taking natural logarithm of both sides simplified to produce equation (12)

$$InDeff = InD_0\left[-\frac{Ea}{8.3145\ (T+273.15)}\right] \quad (12)$$

The activation energy was calculated by plotting natural logarithm In(Deff) against inverse of the absolute temperature $\left(\frac{1}{T}\right)$
Non- linear regression equation was used to determine each constant of selected statistical model in order to obtain the best model for experimental data that described the drying curves. The best suitable and most appropriate of the selected model was examined from reduced chi-square (X^2), root mean square error (RMSE), coefficient of determination (R^2) and mean bias error (MBE). The higher the values of R^2 (proximity to one), the lower the values of (X^2) and the RMSE (proximity to zero) ascertained definitely the goodness of fit (McMinn, 2006). These evaluation criteria methods can be determined as

$$X^2 = \sum_{i=1}^{n} \frac{(MR_{pre} - MR_{exp})^2}{N-K} \quad (13)$$

$$MBE = \frac{1}{N}\sum_{i=0}^{n}(MR_{Pred} - MR_{exp}) \quad (14)$$

$$RMSE = \frac{1}{N}\sum_{i=0}^{n}(MR_{Pred} - MR_{exp})^{1/2} \quad (15)$$

Lewis model

MR =exp(-kt) (Kingly et al., 2007) (16)

Taking natural logarithm of both sides deduced equation (17)

In(MR) = -kt (17)

A plot of In(MR) against time T and the constant k is evaluated

Henderson- Parbis Model

MR = aexp(-kt) (Chinnman, 1984) (18)

Taking natural logarithm of both sides deduced equation (19)

In(MR) = Ina- kt (19)

A graph of In(MR) against time T and the constant 'k' and coefficient 'a' is obtained from the graph.

Page Model

MR =exp(-kt^n) (Karathonos and Belessiotics, 2003) (20)

Taking natural logarithm of both sides deduced equation (21)

$$\log(-\ln(MR)) = n\log t + \log k \quad (21)$$

A plot of $\log(-\ln(MR))$ against logt and constant K and coefficient is deduced from the graph

Results and Discussions

The moisture ratio of the sample was determined from the drying data (moisture ratio) collected plotted against time as shown in Figure1

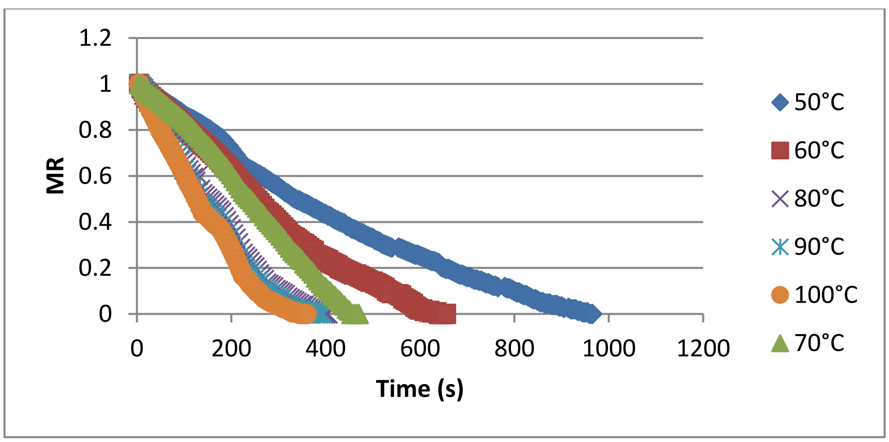

Figure 1: Moisture ratio for Shrimp *(Penaeusnotialis)* at different temperature

The result obtained from Figure 1 revealed that the higher the temperature, the shorter the time of drying. It was observed that drying of Shrimp *(Penaeus notialis)* falls mainly under the falling rate period. This indicated that, the drying rate of Shrimp *(Penaeus notialis))* was basically controlled by internal diffusion.

The obtained result is similar to other scientists on drying of different biomaterials and food products (Doymaz, 2004; Kilic, 2009; Burubai and Etekpe, 2014).

Fitting of Drying Curves

The statistical parameters are useful in analysing experimental results. The statistical parameters considered in this work are coefficient of determination (R^2), mean square error (MSE) reduced chi-square (X^2) mean bias error (MBE) as shown in Table 1 below.

Table 1: Statistical results of the model for Shrimp *(Penaeusnotialis)*

Model	Temp	Constant &	R^2	MBE	MSE	X^2
		Coefficient				
Page	50	k=0.000022,	0.9975	-0.0015	0.024333	0.000597
		a= 1.5684				
	60	k=0.0000134,	0.9716	-0.00005	0.00079	0.00000063
		a=1.7194				
	70	k=00000039	0.9334	-0.00373	0.04842	0.002373
		n=1.7586				
	80	k=0.0000021	0.9704	-0.00383	0.043721	0.001941
		n=1.6825				
	90	k=0.0001	0.9793	-0.00182	0.031456	0.001067
		n=1.6374				
	100	k=0.000	0.9678	-0.00447	0.0442	0.001994
		n=1.6705				
Henderson	50	k=0.0018	0.7141	0.00221	0.350345	0.123723
		a=1.555				
	60	k=0.0028	0.7687	0.0555	0.815085	0.670573
		a=1.8327				
	70	k=0.0013	0.5133	0.0062	0.080167	0.006504
		a=1.3214				
	80	k=0.0026	0.6566	0.0238	0.27177	0.075013
		a=1.4258				
	90	k=0.0046	0.7935	0.0682	0.741332	0.559049
		a=1.6188				
	100	k=0.0043	0.7223	0.0477	0.471813	0.227245
		a=1.5284				
Lewis	50	k=0.0018	0.7141	0.0133	0.211933	0.045095
	60	k=0.0028	0.7687	0.0291	0.427982	0.18402
	70	k=0.0013	0.5133	0.0062	0.08002	0.006441
	80	k=0.0026	0.6566	0.0152	0.172898	0.030125
	90	k=0.0046	0.7935	0.0404	0.439089	0.194447
	100	k=0.0043	0.7223	0.02897	0.286846	0.083129

The R^2 values according to the models were recorded in the range of 0.9334-0.9975 for page model, 0.5133-0.5133 for Henderson model and 0.5133-0.0.5133 for Lewis model. The MSE values ranging from 0.00079-0.04842 for page, 0.080167-0.815085 for Henderson, and 0.08002-0.439089 for Lewis model. It shows that page has the lowest MSE value and the reduced Chi-square value (X^2) closer to 0 which ranging from 0.0000063-0.002373 while Henderson model ranging from 0.006504-0.0670573, 0.030125-0.194447 for Lewis model. Therefore page model been the lowest MSE and (X^2)-value closest to zero is considered to be the best model predicting the drying behaviour of Shrimp. Thus, a relationship between measured and predicted moisture ratios is as shown in Fig 2 and since the moisture ratio values are banded or clustered along the straight line of the graph, it is an indication of good fitness of the page model in relating the drying characteristics of Shrimp.

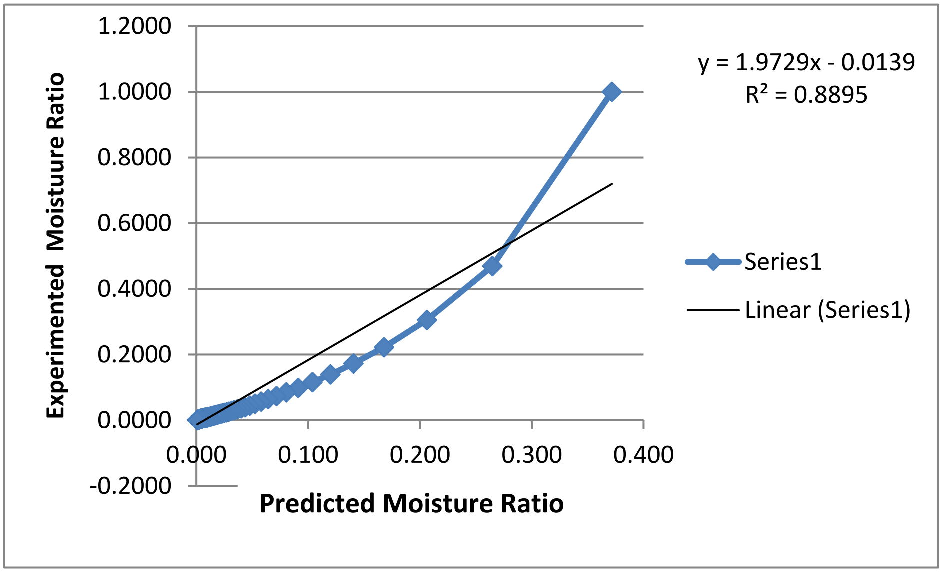

Figure 2. Relationship between experimental and Predicted moisture ratio

Effective Moisture Diffusivity

There was strong positive relationship between moisture diffusivity and drying temperature and the kinetics could be as a result of higher temperatures affecting the activity of water molecules, causing higher moisture diffusivity. Similar results were reported by Sacilik (2007), Jittanik (2011), Doymaz (2004) and Robert*et al.* (2008). For Oryctes rhinoceros larvae, the same approach was used in determining the effective moisture diffusivity. Figure 3 showed the effective moisture diffusivity varied from 8.431×10^{-7} to $7.653 \times 10^{-6} m^2/sec$ for respective temperature ranges from 50^0C, 60^0C, 70^0C, 80^0C, 90^0C and 100^0C. According to Table 2 of the Shrimp showed that the effective moisture diffusivity increases with an increase in temperature. The obtained results is similar to Burubai and Bratua (2015) and Sacilik (2017)

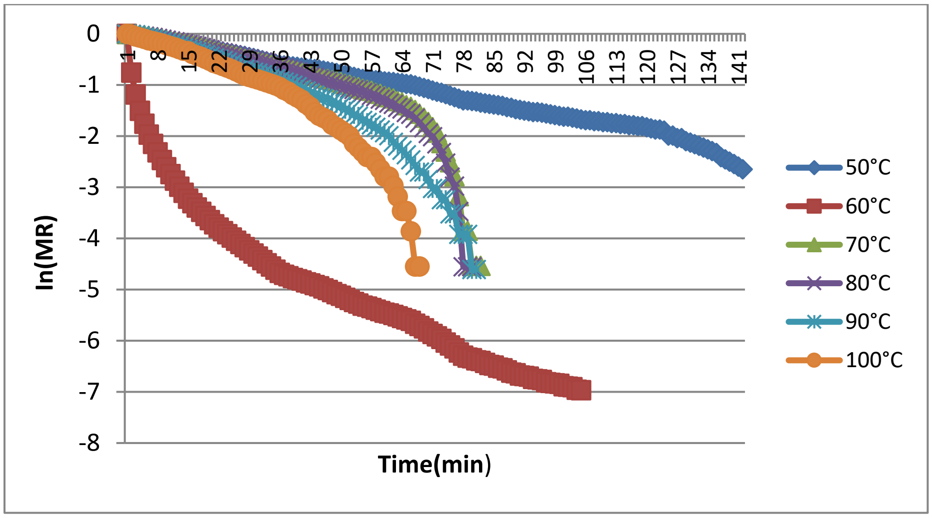

Figure 3: Estimation of Moisture Diffusivity Coefficient of Shrimp *(Penaeusnotialis)*

Table 2: Moisture diffusivity values of Shrimp *(Penaeusnotialis)*

Temp (⁰C	Average effective diffusivity (m^2/s)
50	$7.653x10^{-6}m^2/sec$
60	$1.816\ x10^{-6}m^2/sec$
70	$8.431\ x10^{-7}m^2/sec$
80	$1.686\ x10^{-6}m^2/sec$
90	$2.205\ x10^{-6}m^2/sec$
100	$2.789\ x10^{-6}m^2/sec$

Activation Energy

Activation energy is the energy that is responsible for the initiation of mass transfer from a wet biomaterial during drying. The temperature dependence of moisture diffusivity is reported to obey Arrhenius Law, and the activation energy was calculated from the In Deff Versus temperature curve as shown in Figure 4 by using equation (12).The energy of activation for Shrimp *(Penaeusnotialis)*and the R^2 value were recorded as, 890.3J/mol and 0.5848 respectively. The result obtained in this work for activation energy of Shrimpunder the range of values12.7-110 KJ/mol for biomaterials as reported by Zogzas*et al.* (1996).

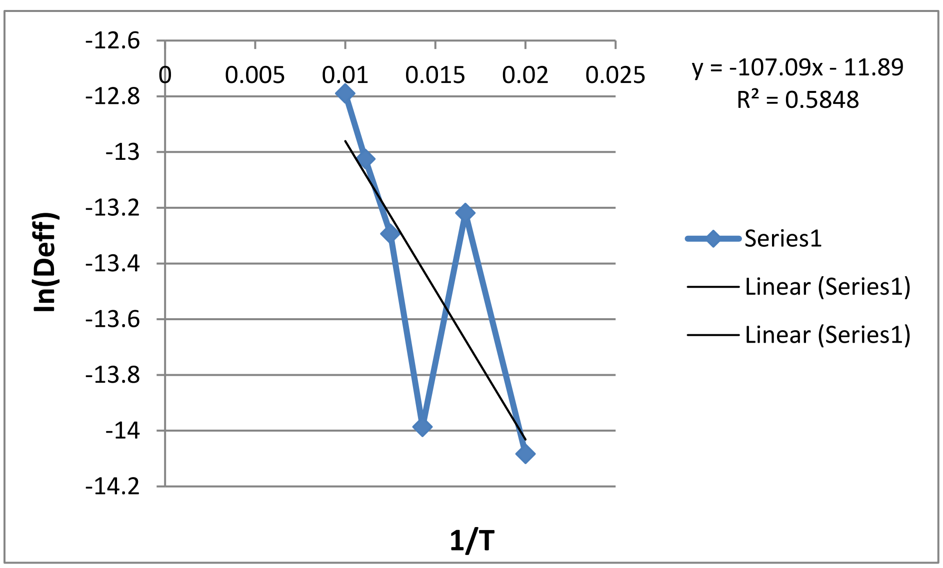

Figure 4: Activation Energy of of Shrimp *(Penaeus notialis)*

Conclusion

The drying kinetics of Shrimp *(Penaeusnotialis)*was investigated and it was evident that the drying process falls under the falling rate period like other biological materials. Out of the three thin layer models that were investigated, the best predicting model for Shrimp *(Penaeusnotialis)* are page model and Henderson model having undergo mathematical analysis of the drying parameters. The *effective diffusivity values ranged between* $8.431x10^{-7}$ *and* $7.653x10^{-6}$ m^2/sec. The activation energy value obtained was 890.3 J/mol.

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