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Modelling the Dehydration Characteristics of Taro (Colocasia Esculenta) Slices in a Convective Cabinet Dryer

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A B S T R A C T

This study was undertaken to determine the thin layer dehydration characteristics of Taro (Colocasia esculenta) slices in a convective cabinet dryer. The dehydration characteristics of the untreated taro slices were examined at air temperatures of 50, 60 and 70°C, sample thickness of 4 and 8 mm and at air velocity of 1.2 m/s. The effects of air temperature and sample thickness on the dehydration characteristics were determined. The experimental data obtained were fitted to eight thin layer dehydration models which are Newton, Page, Modified page, Henderson and Pabis, Logarithmic, Two terms, Wang and Singh, and the Two term exponential models. The regression was done using Sigma plots 10 statistical software. The accuracies of the models were measured using four statistics namely the coefficient of determination (R2), Reduced Chi-square (χ2), Root mean square error (RMSE), and the Mean bias error (MBE). All the drying models used, except the Modified Page's model, were able to describe the dehydration characteristics of taro slices. However, the Logarithmic model proved to be the most précised for the description of the dehydration of the taro slices in a convective cabinet dryer.

1. Introduction

Taro is known as a crop of tropical and sub-tropical climates and grown mainly for its corms. It is an important staple food cultivated in the south-eastern and south-western parts of Nigeria.

Cocoyam as a tuber crop contains a high percentage of their fresh weight as water, accordingly they exhibit relatively high metabolic activity compared to other plant derived foods such as seeds. This metabolic activity continues after harvest thus making the crop highly perishable. Drying is one of the simplest methods used to improve the shelf life of agricultural products, by reducing their moisture content to a level that will make the micro-organism inactive. Traditionally, agricultural products are dried in the open air and exposed to sunlight which usually takes several days. This is a common practice yet with several draw backs: it is time consuming, prone to contamination with dust, soil, sand particles and insects and being weather dependent. Therefore using hot-air drying, which is more rapid providing uniformity and hygiene and is viable for industrial food drying process (Doymaz and Pala, 2002)

Drying is the oldest and a classical method of food preservation and it is a difficult processing operation mainly due to undesirable change in the qualities of drying product (Maskan, 2000).

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The basic objective of drying agricultural product is the removal of water in the solid up to certain level at which microbial spoilage and deterioration chemical reaction are greatly minimized (Krokida and Marinos- Kouris, 2003)

The reduction in mass and volume improved the efficiency of packaging. In thin layer drying of agricultural materials the entire product is exposed to the drying air that flows through the product to a depth of up 20 cm (Oyerinde et al., 2006). It normally forms the basis of understanding the drying process since every material is unique. These studies are fundamental to developing mathematical and computer simulation models on for the drying of taro. The objective of this study is to determine the thin layer dehydration characteristics of taro (Colocasia esculenta) slices in a convective cabinet dryer.

2. Materials and Method

The taro corms were purchased from a local market in Akure, Ondo State, Nigeria. They were stored at an ambient temperature of 22 to 25oC in an open shade until dehydration processing commenced. Prior to the commencement of each experimental run, the purchased cocoyam corms were washed to get rid of dirts and debris using tap water. It was further hand peeled using a clean stainless kitchen knife and then was cut into the required thickness of either 4 mm or 6 mm using a metered board and a fixed knife so as to minimize error. The taro corms in sliced-form was then weighed using a weighing balance and then placed on the stainless mesh basket (drying basket) of the hot air cabinet dryer.

A locally fabricated hot air cabinet drier was used for the drying experiment. The dryer was constructed from steel sheet as a rectangular dryer of 1 m length, 0.9 m width and 1 m height. The dryer is operated by electric current of 220 volts for hot air drying with a motor power of 0.75 kW. The cabinet drier is made up of three compartments namely: the drying chamber, the plenum chamber and the heating chamber and a centrifugal fan attached to it. An electrical control unit consisting of switches is attached to the external part of the dryer using a wood and angle iron arrangement. The heating chamber has heating element of power rating 3 kW. The drying chamber which is 50 cm by 100 cm by 89 cm in dimension is separated from the drying chamber by a perforated iron sheet which entirely forms the base for the drying chamber. The sample baskets (four in number) are suspended in the drying chamber and are made of stainless steel with the dimensions: 30 cm by 30 cm by 6 cm. The fan is a centrifugal type that is operated by an electric motor of capacity 0.75 kW and a maximum speed of 1400 rev/min. The blades of the fan are such that it sucks fresh air from the surrounding and blows it across the drying element located just above it. The speed of the fan is regulated with an electric voltage regulator

When the heater is switched on and the temperature controller preset to the desired temperature, the blower which has already been switched on will blow air at a pre-determined rate into the heating chamber through the air duct. This air serves as a medium through which the heat reaches the drying chamber. The exhaust escapes through the vent at the top of the dryer.

2.1 *Moisture Content Determination*

The moisture content of the cocoyam corms was determined using the vacuum oven method at 70°C for 24 hours (AOAC, 1990). This experiment was done in triplicates. The average of the three replicates were taken and used as the initial moisture content of the Cocoyam. The moisture content of the cocoyam sample was expressed as:

$$M_o = (W_1 - W_{bd}) / W_{bd} \quad 1$$

on dry basis and ;

$$M_o = (W_1 - W_{bd}) / W_1 \quad 2$$

on wet basis.

where:

M_o = moisture content of the sample,
W_1= Initial weight of the sample (g),
W_{bd} = final weight of the sample (g)

In each drying run of the experiments 25 g of sliced cocoyam was used. At the start of the experiment, the dryer was run idle for about half an hour to reach thermal stability. After which the prepared samples of cocoyam which were uniformly spread within the basket as a single layer was suspended in the drying chamber of the dryer. The drying experiments were carried out at a constant air velocity of 1.2 m/s, air temperature used were 50, 60 and 70°C. These conditions are normally used for air drying of biological materials (Goyal et al., 2007; Nguyen and Price, 2007). The thicknesses used were 4 mm and 8 mm. The sample mass was recorded at 30 minutes intervals using a in mass was recorded for about 1 hour 30 minutes (Sacilic and Unal,2005).

2.2 *Modeling of the drying characteristics*

Moisture ratio was determined in order to compare each set of data. Therefore the dehydration data was converted to moisture ratio using equation 3:

$$MR = (M_t - M_e) / (M_o - M_e) \quad 3$$

which has been used and simplified by many researchers (Togrul and Pehlivan, 2004) to equation 4 :

$$MR = M_t / M_o \quad 4$$

where

MR = moisture ratio,
M_t= moisture content at any time, t,
Mo = initial moisture content.
Me = equilibrium moisture content.

2.3 *Modeling of Drying Process*

In order to predict the drying behavior of cocoyam under different drying conditions, it is necessary to model its drying process. Mass transfer during this period is caused by liquid diffusion or capillary flow. The former is commonly used to describe drying behavior in the falling rate period of fruits and vegetables. The rate of diffusion is governed by moisture concentration gradient as the driving force. Many researchers have adopted empirical and semi empirical thin layer drying models for simplicity and accuracy. The simple type of drying models assumes that rate of exchange in moisture content is proportional to the difference between moisture content and equilibrium moisture content (EMC) of the material. Eight thin layer drying models were adapted to this work (Table 1).

The experimental values for moisture content were converted to moisture ratio (MR) using equation 4 (Togrul and Pehlivan, 2004). The MR were fitted to the thin layer drying models (Table 1). The correlation coefficient (R^2) was the primary criterion for selecting the best model to describe the drying characteristics. In addition to R2, the reduced chi square (χ^2) the mean bias error (MBE) and the root mean square error (RMSE) were used as the evaluation statistics. The statistics were calculated as:

$$R^2 = \frac{\sum_{i=1}^{n}(MR_i - MR_{pre,i})\sum_{i=1}^{n}(MR_i - MR_{exp,i})}{\sqrt{\sum_{i=1}^{n}(MR_i - MR_{pre,i})}\sqrt{\sum_{i=1}^{n}(MR_i - MR_{exp,i})}} \quad 5$$

$$\chi 2 = \frac{\sum_{i=1}^{n}(MR_{exp,i} - MR_{pre,i})^2}{N - n} \quad 6$$

$$RMSE = \left[1/N\sum_{i=1}^{n}(MR_{exp,i} - MR_{pre,i})^2\right]^{1/2} \quad 7$$

Where $MR_{exp,i}$ is the experimentally observed moisture ratio, $MR_{pre,i}$ the *i*th predicted moisture ratio, N the number of observation and n the number of constants. (Kingsley *et al.,* (2007)

The experimental dehydration data of cocoyam slices obtained were fitted to the eight thin layer drying models. In order to select the best model the values for the MBE, $\chi 2$ and RMSE were used as the criteria. The Non-linear regression analysis was carried out using Sigma plots 10.0.

2.4 Validation of the established model

The established model was validated by plotting the moisture ratio against time for the experimented and the predicted values of the establish model for a particular experimental run.

3. Results and Discussion

3.1 Moisture content of cocoyam

The initial moisture content was found out to be 70 % (wet basis). This value agreed well with reports from the literature about untreated roots and tubers crops (Oyerinde et al., 2006).

3.2 Effects of temperature on the drying characteristics

Taro slices were dried at 10°C intervals from 50°C to 70°C to investigate the influence of temperature on their drying characteristics. Higher temperature produced a higher drying rate and consequently the drying time is reduced as evident on Figures 1a and 1b. Total drying time was reduced with increasing temperature. This is due to the increase of heat transfer between the air and the cocoyam slices and acceleration of water migration inside them. The results were similar to the earlier observations on the drying of garlic slices (Madamba et al., 1996) and on onion slices (Sarsavadia et al., 1999).

At constant temperature, a decreasing moisture ratio with increasing drying time was observed and also the drying rate decreased continuously with the decrease in moisture ratio and increase in drying time as shown in Figure 2. All other experimental runs showed similar trend. It further shows that most of the drying of taro in thin slices took place in the falling rate period. This means that internal resistance governed the mass transfer. The drying rate of cocoyam slices decreased with increase in temperature. This has been observed by earlier researchers (Ertekin and Yaldiz, 2004).

3.3 Effect of slice thickness on the drying characteristics

During most drying runs, as shown in Figures 3 a, b and c, 4 mm had the shorter drying time. This was not surprising because the diffusion model assumed that diffusion takes place in only one direction from inside to the surface of the slabs. Side way diffusion was negligible. This observation is in agreement with Falade et al. (2007) for yam slices and Nguyen and Price (2007) for banana slabs.

3.4 Evaluation of the models

The best model describing the thin layer dehydration characteristics of taro slices was chosen from Table 1 with R2 above 0.9 and the lowest of the values of RMSE, MBE and χ^2. Generally all the models used for this study can model the drying characteristics of taro slices because their R2 are all in acceptable range except for Modified Page model whose R^2 was more often than not so low. Considering other statistics used (RMSE, MBE and χ^2), Logarithmic model predicted the drying behavior of Taro (Colocasia esculenta) with χ^2 range of 0.000119582 to 0.101106064, MBE within the range of -3.30E-08 to 0.120999 and RMSE of the range 0.010588 to 0.304435. Table 2 shows the performances of the models on each treatment and the values of their coefficients and constants. Olurin et al (2012) got similar result for the drying of blanched field pumpkin (Cucurbita pepo L) slices.

3.5 Validation of the established model

Validation of the established model was made by comparing the observed moisture ratio to the moisture ratio predicted by the established model (Logarithmic model) in any particular run as seen on Figure 4. A good fit can be graphically observed. Ertekin and Yaldiz (2004), Goyal et al. (2007) and Kingsly et al. (2007) obtained similar results in the drying of egg plant, plum and organically produced tomato respectively.

4. Conclusions

This study show that the drying of taro slices in a convective cabinet dryer can be accurately predicted using the Newton, Page ,Henderson and Pabis, logarithmic, Wang &Singh, two term, two term exponential models. Logarithmic model prove to be the model with the best prediction for drying of taro slices in a convective cabinet dryer. The modified page model proved to be the worst model as the coefficient of determination (R^2) was always zero. In other word, it is not applicable to the drying of taro slices in thin layers in a convective cabinet dryer. The drying of taro took place in the falling rate period. Sideway diffusion was negligible as 4 mm dry faster than 8mm in all the experimental runs.

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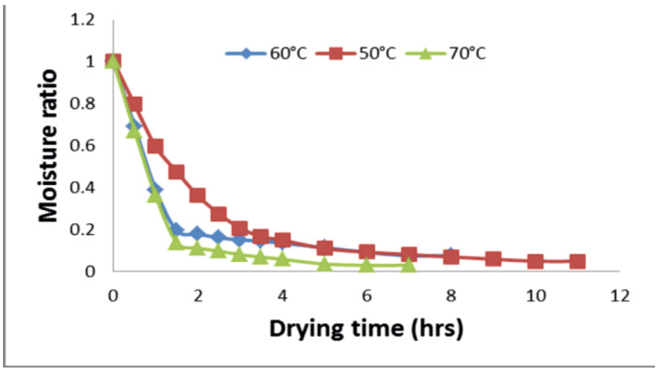

Fig. 1a: Effects of drying temperature on the drying of 4 mm thickness

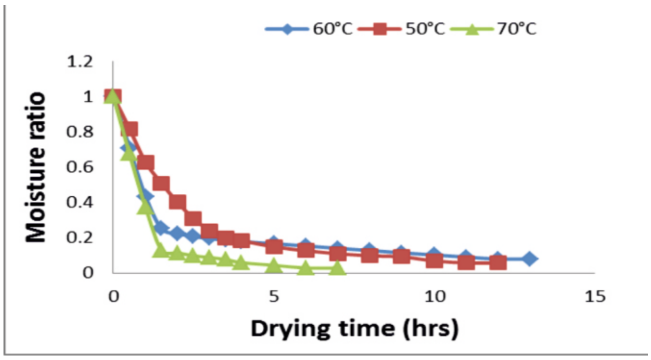

Fig.1b: Effects of drying temperature on the drying of 8 mm thickness

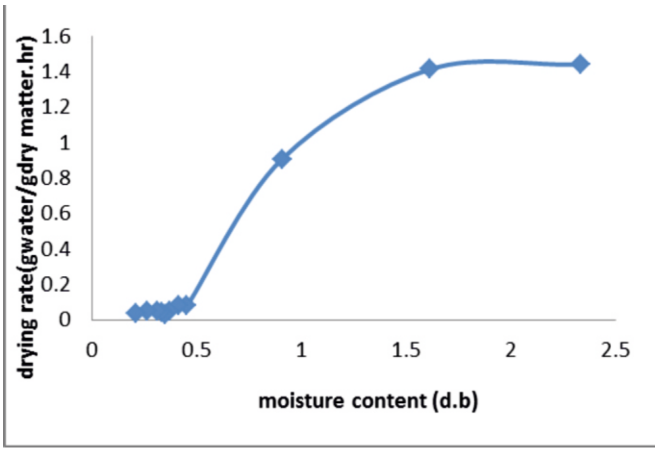

Fig 2 : Dehydration of 4 mm thickness at a constant temperature of 60°C

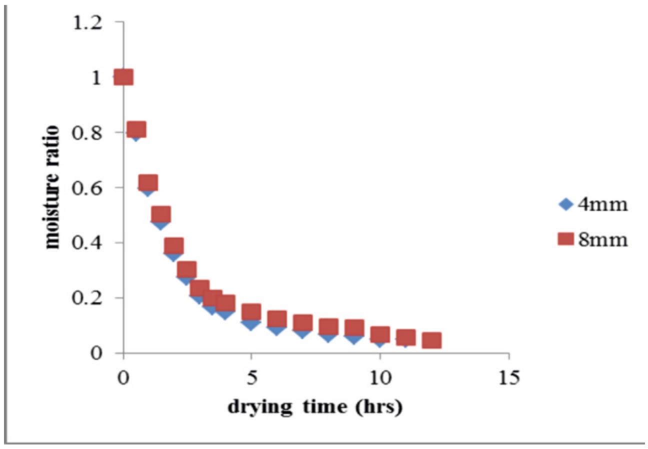

Fig. 3a: Dehydration of taro slices at 50°C

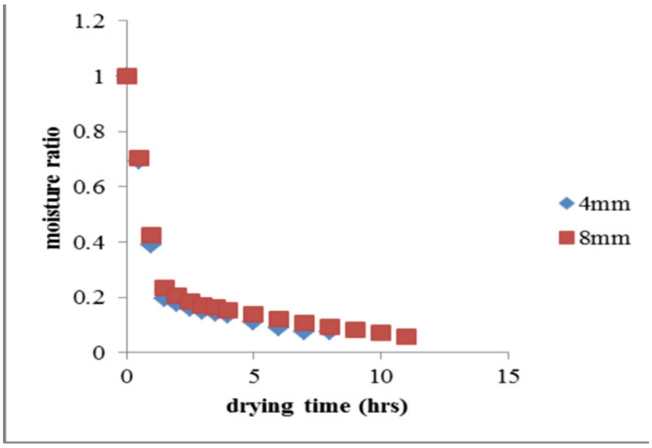

Fig.3b: Dehydration of taro slices at 60°C

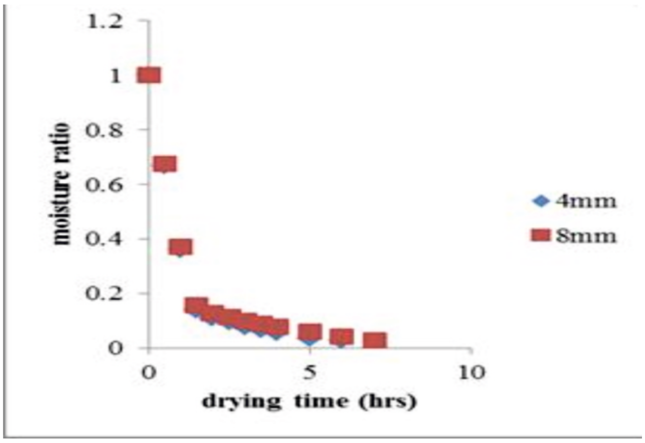

Fig.3c: Dehydration of taro slices at 70°C

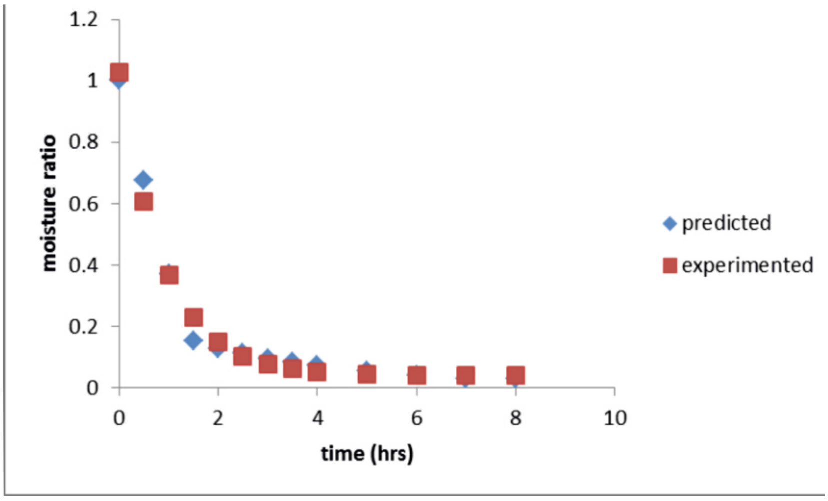

Fig 4: Validation of the established model

Table1: Some selected thin layer drying models.

Model	Name	Reference
MR= exp(-kt)	Newton	Liu andBakkerArkema(1997)
MR=exp(-kt^n)	Page	Zhang and Litchfield (1991)
MR=a exp(-(kt)^n)	Modified Page	Overhults *et al*;(1973)
MR=a exp (-kt)	Handerson and Pabis	Kingsley *et al.*,(2007)
MR=a exp(-kt)+c	Logarithmic	Yaldiz *et al;(2001)*
MR=a exp(-k_0t)+b exp(-k_1t)	Two term	Rahman *et al*.,(1998)
MR=1+at+bt^2	Wangh and Sing	Wang and Singh (1978)
MR=a exp (-kt)+(1-a)exp(-kat)	Two term exponential	Sharaf-Eldeen *et al*.,(1980)

Temperature/ Thickness	MODEL	ADJ R^2 Final	COEFFICIENTS	χ^2	MBE	RMSE	Rank
70°C 4mm	Newton	0.9825	k=1.0063	0.001654382(4)	-0.00182(5)	0.038587(5)	5
	Page	0.9825	k=0.9959,n=1.096	0.000635896(1)	-0.01183(6)	0.023923(1)	2
	Modified page	0.0000	k=4.18E-08,n=-004	0.154727985(8)	-0.10225(8)	0.373169(8)	8
	Henderson & Pabis	0.9845	k=1.0248,a=1.0195	0.001536518(3)	0.000924(2)	0.037187(3)	2
	Logarithmic	0.9812	k=1.1255,a=0.9979,c=0.0304	0.00153391(2)	6.87E-07(1)	0.037155(2)	1
	Wang& Singh	0.7642	a=-0.4803,b=0.0519	0.011632001(7)	0.018494(7)	0.096466(7)	7
	Two term	0.9827	k_0=-0.0781,a=0.0205,b=1.007,k_1=1.1066	0.001728653(5)	0.000951(3)	0.037188(4)	4
	Two term exponential	0.9811	k=1.2205,a=0.6172	0.00186119(6)	-0.00177(4)	0.038587(5)	6
70°C / 8mm	Newton	0.9768	k=0.9471	0.001900197(6)	-0.01801(6)	0.041881(6)	6
	Page	0.9746	k=0.9524, n=0.9691	0.001898799(5)	-0.01764(5)	0.041866(5)	5
	Modified page	0.0000	k=2.75E-08, n=-0.0355	0.118693357(8)	-0.07864(7)	0.331003(8)	8
	Henderson & Pabis	0.9746	k=0.9578,a=1.0114	0.001884278(3)	-0.01731(4)	0.041705(4)	4
	Logarithmic	0.9841	k=1.11,a=0.9805,c=0.0463	0.001091552(1)	7.06E-08(1)	0.031743(3)	1
	Wang& Singh	0.7586	a=-0.2601,b=0.0162	0.02717885(7)	0.039486(8)	0.151649(7)	7
	Two term	0.9821	k_0=0.1347,a=0.4321,b=0.5895,k_1=0.8483	0.001186058(2)	-3E-05(2)	0.031679(1)	2
	Two term exponential	0.9771	k=1.6436,a=0.3504	0.001890646(4)	-0.01328(3)	0.039997(3)	3
60^0C/ 4mm	Newton	0.9337	k=0.8053	0.002742894(5)	-0.02051(1)	0.050143(5)	4
	Page	0.9517	k=0.8923,n=0.6936	0.101849145(8)	0.114323(7)	0.305551(8)	8
	Modified page	0.0000	k=2.56E-009,n=-0.0254	0.002742084(4)	0.020389(5)	0.050136(4)	5
	Henderson & Pabis	0.9282	k=0.7860,a=0.9793	0.001339746(1)	3.79E-09(2)	0.035044(2)	1
	Logarithmic	0.9818	k=1.0260,a=0.9283,c=0.0960	0.101106064(7)	0.120999(8)	0.304435(7)	7
	wang&singh	0.6673	a=-4050,b=0.0388	0.021632701(6)	0.032668(6)	0.134266(6)	6
	Two term	0.9805	k_0=0.0517,a=0.1270,b=.08997, k_1=1.1899	0.001443198(2)	-5.3E-05(2)	0.034679(1)	1
	Two term exponential	0.9458	k=1.6436,a=0.3504	0.002457447(3)	-0.01332(4)	0.045253(3)	

Temperature/ Thickness	MODEL	ADJ R^2 Final	COEFFICIENTS	χ^2	MBE	RMSE	Rank
60^0C/ 8mm	Newton	0.9056	k=0.7097	0.004399259(6)	-0.03389(5)	0.0064221(6)	6
	Henderson & Page	0.9513	k=0.8550n=0.5835	0.002676079(3)	-0.01114(3)	0.050088(3)	3
	Modified page	0.0000	k=5.409E-11,n=-0.0234	0.096535693(8)	-0.06323(8)	0.300836(8)	8
	Henderson & Pabis	0.9015	k=0.6698,a=0.9558	0.004349791(5)	-0.03431(6)	0.063859(5)	5
Logarithmic		0.9804	k=1.0039,a=0.9173,c=0.0983	0.00119579(2)	-3.3E-08(1)	0.033482(2)	1
	Wang& Singh	0.4580	a=-4050,b=0.0388	0.037998251(7)	0.054544(7)	0.182342(7)	7
	Two term	0.9841	k_0=0.0561,a=0.2020,b=0.4866,k_1=1.2865	0.001240553(2)	3.29E-05(2)	0.032399(1)	1
	Two term exponential	0.8409	k=1.5565,a=0.3011	0.00422226(4)	-0.02264(4)	0.059772(4)	4
50^0C/ 4mm	Newton	0.9888	k=0.4912	0.00094938(6)	-0.014(5)	0.029834(6)	6
	Page	0.9903	k=0.5298,n=0.9025	0.000769092(4)	-0.01013(4)	0.026852(4)	4
	Modified page	0.0000	k=1.12570*10^008,n=0.0215	0.117675878(8)	-0.06013(8)	0.332146(8)	8
	Henderson & Pabis	0.9881	k=0.4875,0.9934	0.0000945167(5)	-0.01428(6)	0.029767(5)	5
	Logarithmic	0.984	k=0.5720,a=0.96848,c=0.0512	0.000119582(1)	4.84E-08(1)	0.010588(2)	1
	Wang&Singh	0.8552	a=-2897,b=0.0198	0.012278683(7)	0.028238(7)	0.103659(7)	7
	Two term	0.9986	$k_0$0095,a=0.047,b=0.9686,k_1=0.5683	0.000127788(2)	5.51E-07(2)	0.010574(1)	2
	Two term exponential	0.9925	k=0.8052,a=0.4344	0.000635809(3)	-0.00859(3)	0.023587(3)	3
50^0C/ 8mm	Newton	0.9772	k=0.4380	0.001831923(1)	-0.0181(5)	0.041523(1)	2
	Page	0.9850	k=0.5107,n=0.8215	0.001126151(5)	-0.00959(2)	0.032556(5)	5
	Modified page	0.0000	k=1.16E-11,n=-0.0136	0.1114359(8)	-0.05748(8)	0.323853(8)	8
	Henderson & Pabis	0.9763	k=0.262,a=0.9779	0.001785697(6)	-0.0188(6)	0.040996(6)	6
	Logarithmic	0.9960	k=0.5398,a=0.9436,c=0.0707	0.000240561(2)	1.19E-08(1)	0.015047(2)	1
	Wang&Singh	0.8235	a=-0.2601,b=0.0162	0.01416286(7)	0.031015(7)	0.111788(7)	7
	Two term	0.9969	k_0=0.6036,a=0.1297,b=0.8900 ,k_1=0.5886	0.001065561(3)	-0.01068(3)	0.030663(3)	3
Two term	exponential	0.9867	k=0.8761,a=0.3571	0.001065561(3)	-0.01068(3)	0.030663(4)	4