MATHEMATICAL MODELLING OF DRYING OF *PAMPUS CHINENSIS*

[1]Riya Anand, [2]Saloni Rathore, [3]B.S.Rawat
[1, 2]Scholar, [3]Associate Professor
[1, 2, 3] Department of Physics, UCALS, Uttaranchal University, Dehradun, India

Abstract**:** This paper is based on the establishment of mathematical modelling of drying of Roopchand (Chinese silvery Pomfret/ *Pampus chinensis*). All the experiments were performed in laboratory of department of physics. At three different constant drying temperatures viz. 50^0C, 60^0C and 70^0C and at constant wind speed, experiments were performed. The migrations of moisture content were measured at an interval of one hour to find the drying moisture ratios. On the basis of different statistical parameters viz. correlation coefficient(R), root mean square (RMS), reduced chi-square, moisture ratio, drying efficiency and mean bias error (MBE) suitable model has been proposed. The estimation of these parameters was based on the different available well established mathematical models. A result shows that the Midilli model could describe the drying behaviour of *Pampus chinensis* and Kucuk model with close approximation.

Index words**: Mathematical modelling, Drying, *Pampus Chinensis*.**

I. INTRODUCTION

Drying is a method used to sustain food by decreasing moisture content to a level so that the microorganisms won't be able to grow and reaction rate decreases. Dehydration (or drying) been used over the world from a very long time to prolong food items and agricultural products. Nowadays, the drying process is one of the popular procedures of preserving food *(*Saguy et al, 1980).

Drying is the process in which heat and mass transfer occurs at the same instant through the moisture removal from the product into the surrounding medium. That leads to decrease in mass and volume of product resulting in minimum costs for storing, packaging and transporting (Vega-Gálvez et al., 2010). It is the common and ancient method of preserving food, providing longer storage, light weight for transporting to different places and small space for storage. In this way, the product's microbial metabolism decreases and chemical changes while storage becomes minimum (Erteken et al, 2004, Sagar et al, 2010).

Pampus chinensis is a sea water fish found in the Atlantic, Indian, and pacific oceans. Fish is an easily spoilt food item and becomes uneatable in few hours at very hot and humid temperatures (Fellows et al, 1992). However, fish is well known to contain high value of nutritional protein which comprises important amino acids and minerals (Chukwu, 2009; Jain and Pathare, 2007; Sarower-E-Mahfuj *et al.,* 2012)

The mathematical modelling is based on the outline of collection of equations describing the system as precise as possible (Celma et al, 2011). A mathematical model also being frequently used to evaluate the variables which involves in the drying process, to predict drying dynamics and to elevate the operating limit and conditions (Karathanos et al, 1999, Chinnan, 1984, Doymaz, 2004, Kashaninejad et al, 2004, Madamba et al., 1996, Palipane et al, 1994, Sharaf-Elden et al., 1980, Syarief et al, 1984, White et al, 1981).

In the present study different constants involve in different selected models has been estimated and suitable model for drying behaviour of *Pampus chinensi* has been proposed.

2. MATERIAL AND METHOD

2.1 Sample preparation and drying conditions

The samples of *Pampus chinensi*, undertaken in this experiment were collected from the local fish market. The selected *Pampus chinensi* fish were first simply cut into shape somewhat like a butterfly and then cleaned properly with water to remove all the blood, dirt, dust and other impurities from its surface and surface water from the sample was soaked using an absorbent paper. After this some amount of salt was rubbed onto sample's surface. The drying experiment was performed in an incubator, which is developed for this purpose only.

The incubator was switched on for about one hour to achieve the desirable stable temperature. Sample was spread onto the tray and placed into the incubator. The changes in weight of sample were monitored throughout the experiment by weighing periodically using an electronic balance. Weighing of fish samples was carried out after every one hour. And the weighing process continued for the other two temperatures.

2.2 Mathematical modelling of drying curves

Twelve different well established models which are used to estimate the suitable drying behaviour of *Pampus chinensi* has been given in Table 1. On the basis of drying curve obtained from the experiment conducted at three constant temperatures and constant wind speed were fitted in different models and estimated statistical parameters.

Table 1: Mathematical models used for the drying curves of drying *Pampus chinens.*

Model no.	Model name	Model equation	References
1	Lewis	$M_R = \exp(-kt)$	(Lui et al,1997, Callaghen et al,1971)
2	Page	$M_R = \exp(-kt^n)$	(Agarwal et al,1997, Zhanget al,1991)
3	Modified page	$M_R = \exp[(-kt)^n]$	(Overhults et al,1973, White et al,1981)
4	Henderson and Pabis	$M_R = a\exp(-kt)$	(Henderson and Pabis,1961)
5	Yagcioglu et al.	$M_R = a\exp(-kt) + c$	(Yagcioglu et al,1999)
6	Two-term	$M_R = a\exp(-k_0 t) + b\exp(-k_1 t)$	(Henderson,1974, Rahman et al,1998)
7	Two-term exponential	$M_R = a\exp(-kt) + (1-a)\exp(-kat)$	(Sharaf-Elden et al,1980))
8	Wang and Singh	$M_R = 1 + at + bt^2$	(Wang and Singh,1978)
9	Diffusion approach	$M_R = a\exp(-kt) + (1-a)\exp(-kbt)$	(Kassem,1998)
10	Verma et al.	$M_R = a\exp(-kt) + (1-a)\exp(-gt)$	(Verma et al,1985)
11	Modified Henderson and Pabis	$M_R = a\exp(-kt) + b\exp(-gt) + c\exp(-ht)$	(Karathanos,1999)
12	Midili and Kucuk	$M_R = a\exp(-kt^n) + bt$	(Midili et al,2002)

2.2.1. Correlation Coefficient (R)

$$R^2 = \frac{\sum_{i=1}^{N}\left(M_{r_i} - Mr_{pre,i}\right) * \left(Mr_i - Mr_{exp,i}\right)}{\left[\sum_{i=1}^{N}(Mr_i - Mr_{pre,i})^2\right] * \left[\sum_{i=1}^{N}(Mr_i - Mr_{exp,i})^2\right]} \quad (1)$$

2.2.2 Mean Bias Error (MBE)

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(M r_{pre,i} - Mr_{exp,i}) \quad (2)$$

2.2.3 Root Mean Square Error (RMSE)

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(M r_{pre,i} - Mr_{exp,i})^2\right]^{\frac{1}{2}} \quad (3)$$

2.2.4. Reduced chi-square (χ^2)

$$\chi^2 = \frac{\sum_{i=1}^{N} Mr_{exp,i} - Mr_{exp,i})^2}{N-n} \quad (4)$$

2.2. 5. Efficiency (EF)

$$EF = \frac{\sum_{i=1}^{N}\left(MR_{i,exp} - MR_{i,expmean}\right)^2 - \sum_{i=1}^{N}\left(MR_{i,pre} - MR_{i,exp}\right)^2}{\sum_{i=1}^{N}\left(MR_{i,exp} - MR_{i,expmean}\right)^2} \quad (5)$$

2.2.6 Moisture ratio (M_R)

$$Mr = \frac{m - m_{exp}}{m_o - m_{exp}} \quad (6)$$

III. RESULTS AND DISCUSSIONS:

The statistical parameters estimated by using different models have been shown in Table 2, Table 3 and in Table 4. On the basis of the maximum value of R^2 and lowest value of $\chi2$ and RMSE values, suitable drying behaviour of *Pampus chinensis* has been proposed. Among the twelve drying mathematical models, Midilli gives the maximum value of R^2 (0.99938) at 50°C, 0.99970 at 60°C and 0.99815 at 70°C, lowest value of $\chi^{2,}$ (0.001) at 50°C, 5E-05 at 60°C and 0.0005 at 70°C *and* the lowest RMSE value of 0.01 at 50°C, 0.0065 at 60°C and 0.002 at 70°C. The variation of moisture ratio with time at different constant temperatures has been shown in Figure 1. From the figure, one may predicts that drying rate decreases gradually with the increment of drying time. The variation of moisture ratio with time at different constant temperature of drying *Pampus chinensis* fish has been shown in Figure 2, Figure 3 and Figure 4 respectively. These results show that, as usual high air drying temperature decreases drying time and increase the drying rate. Experimental versus predicted moisture ratio in case of Midilli at different temperatures viz. 50^0C, 60^0C and 70^0C of drying *Pampus chinensis* are shown in Figures 5, Figure 6 and Figure 7 respectively.

Table 2: Model constants and parameters on the modelling of *Pampus chinensis* drying at 50℃

Model	Model constant	Correlation coefficient (R)	Mean bias error (MBE)	Root mean square Error (RMSE)	Reduced chi-square (X^2)	Efficiency (EF)
Lewis	k=0.096	0.99714	-0.004	0.02141	0.000474	0.9937
Page	k=0.0735,n=1.1056	0.99877	-0.003	0.0141	0.000211	0.9975
Modified page	k=0.3099,n=0.3099	0.99714	-0.004	0.0214	0.000489	0.9937
Henderson and Pabis	a=1.0286, k=0.0987	0.99761	-0.005	0.0196	0.0004	0.995
Yagcloglu et al.	a=1.0636,k=0.0842,c=-0.06	0.99938	-3E-09	0.01	0.0001	0.9988
Two term	a=0.5143, k0=0.0987, b=0.5143, k1=0.0987	0.99761	-0.005	0.0196	0.0004	0.995
Two term exponential	a=1,k=0.096	0.99714	-0.004	0.0214	0.0005	0.9937
Wang and Singh	a=-0.07, B=0.0013	0.99458	-0.007	0.0295	0.0009	0.9902
Diffusion approach	a=-10.81, k=0.1446, b=0.9616	0.99898	-0.003	0.0128	0.0002	0.9979
Verma et al.	a=0.101, k=0.096, g=0.096	0.99714	-0.004	0.0214	0.0005	0.9937
Modified Henderson and Pabis	a=0.3429, k=0.0987, b=0.3429, g=0.0987, c=0.3429, h=0.0987	0.99761	-0.005	0.0196	0.0005	0.995
Midilli and Kucuk	a=0.9969,k=0.0814,n=1.0381, b=-0.00118	0.99938	-3E-05	0.01	0.0001	0.9994

Table 3: Model constants and parameters on the modelling of *Pampus chinensis* drying at 60℃

Model	Model constant	Correlation coefficient (R)	Mean bias error (MBE)	Root mean square Error (RMSE)	Reduced chi square (X^2)	Efficiency (EF)
Lewis	k=0.1199	0.99712	-0.003	0.02	0.0004	0.9946
Page	k=0.1089,n=1.0405	0.99773	-0.004	0.0189	0.0004	0.9954
Modified page	k0.3458 , n=0.3458	0.99746	-0.004	0.0199	0.0004	0.9946
Henderson and Pabis	a=1.0069,k=0.1204	0.99749	-0.004	0.0198	0.0004	0.9948
Yagcloglu et al.	a=1.0482,k=0.1015,c=-0.066	0.99913	-7E-04	0.0112	0.0001	0.9984
Two term	k=0.5034, B=0.5034, k_0=0.1204,K_1=0.1204	0.99749	-0.004	0.0198	0.0005	0.9948
Two term exponential	a=1, k=0.1195,	0.99746	-0.004	0.0199	0.0004	0.9946
Wang and Singh	a=-0.087, b=0.002	0.99106	-0.009	0.0374	0.0015	0.9843
Diffusion approach	a=-0.444, k=0.1921, b=0.7103	0.99789	-0.004	0.0182	0.0004	0.9957
Verma et al.	a=0.0363, k=0.1195, g=0.1195	0.99746	-0.004	0.0199	0.0004	0.9946
Modified Henderson and Pabis	a=0.3356, k=0.1204, h=0.1204, b=0.3356,g=0.1204,c=0.3356	0.99749	-0.004	0.0198	0.0005	0.9948
Midilli and Kucuk	a=1.0098, k=0.1356, b=0.004,n=0.8867	0.99970	0.0004	0.0065	5E-05	0.9995

Table 4: Model constants and parameters on the modelling of *Pampus chinensis* drying at 70℃

Model	Model constant	Correlation coefficient (R)	Mean bias error (MBE)	Root mean square Error (RMSE)	Reduced chi square (X^2)	Efficiency (EF)
Lewis	k=0.1244	0.99117	-0.004	0.037	0.0014	0.9806
Page	k=0.102, n=1.0911	0.99246	-0.006	0.0342	0.0013	0.9848
Modified page	k=0.3527,n=0.3527	0.99117	-0.004	0.037	0.0015	0.9806
Henderson and Pabis	a=1.0094,k=0.1257	0.99124	-0.005	0.0368	0.0017	0.9811
Yagcloglu et al.	a=1.2155,k=0.0792,c=-0.25	0.99684	-0.002	0.0207	0.0005	0.9946
Two term	a=0.5047,k_0=0.1257,b=0.5047 ,k_1=0.1257	0.99124	-0.005	0.0368	0.0017	0.9811
Two term exponential	a=1.4733, k=0.142	0.9833	-0.013	0.035	0.0014	0.9833
Wang and Singh	a=-0.095,b=0.0024	0.99337	-0.007	0.0321	0.0012	0.9879
Diffusion approach	a=-5.705,k=0.1901,b=0.9332	0.99310	-0.006	0.0327	0.0013	0.9861
Verma et al.	a=0.1202,k=0.1244,g=0.1244	0.99117	-0.004	0.037	0.0016	0.9806
Modified Henderson and Pabis	a=0.3365,k=0.1257,h=0.1257, b=0.3365,g=0.1257,c=0.3365	0.99124	-0.005	0.368	0.002	0.9811
Midilli and Kucuk	a=1.0042,k=0.1357,n=0.7528, b=-0.015	0.99815	-0.0002	0.017	0.0004	0.9963

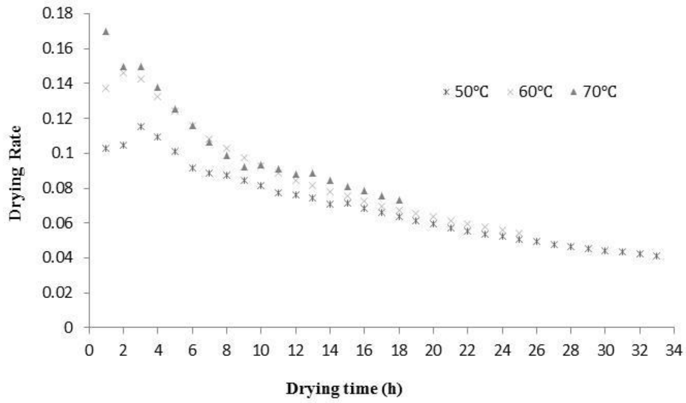

Figure 1: Variation of drying rate with time at different temperature of *Pampus chinensis*.

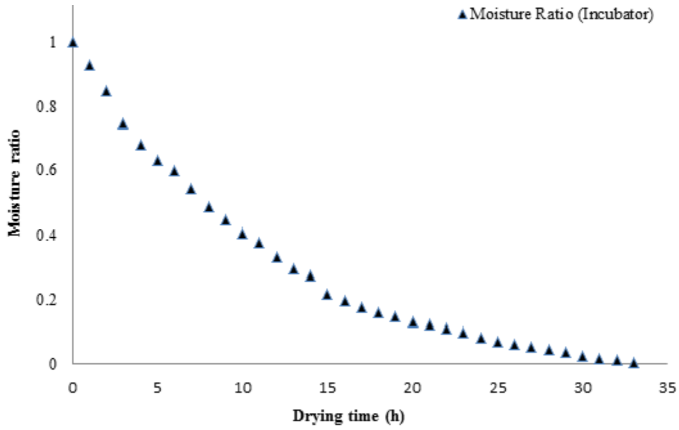

Figure 2: Variation of Moisture Ratio and drying time at 50℃.

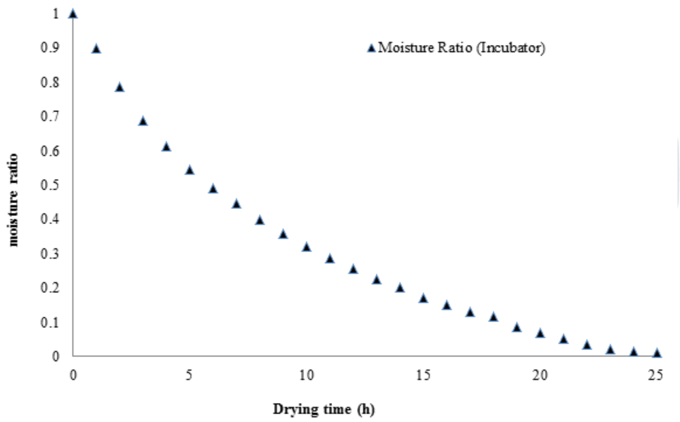

Figure 3: Variation of Moisture Ratio and drying time at 60℃

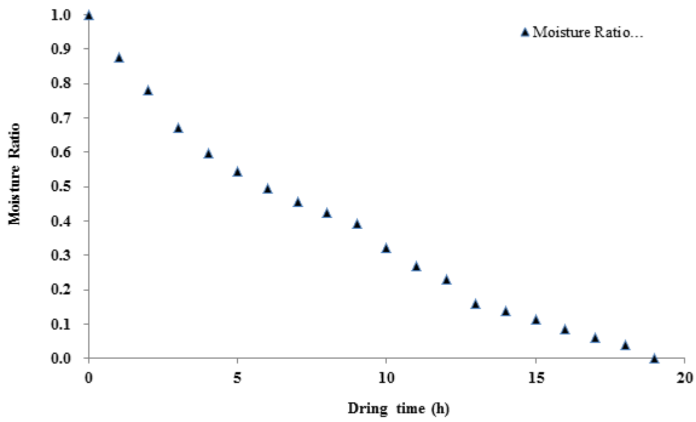

Figure 4: Variation of Moisture Ratio and drying time at 70℃

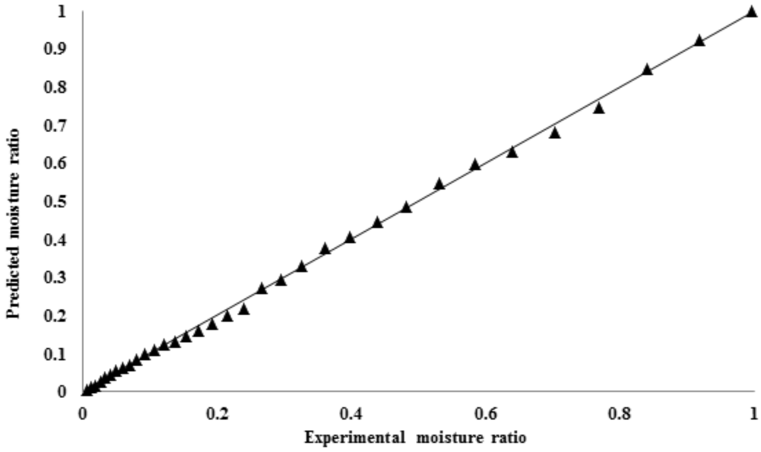

Figure 5: Experimental versus Predicted moisture ratio in case of Midilli **at 50℃ of drying Pampus *chinensis***

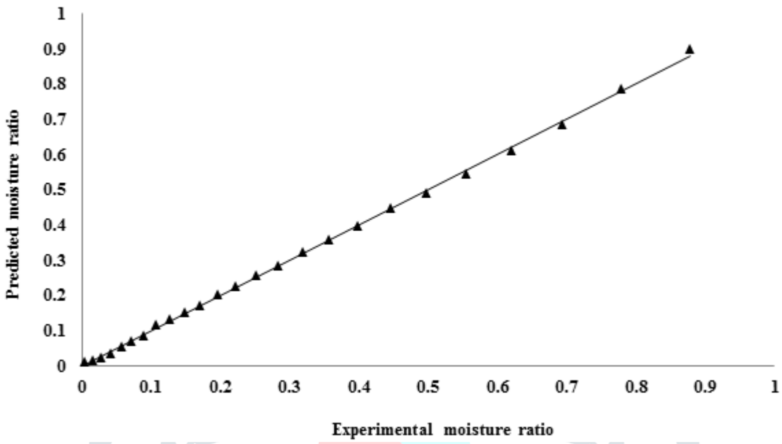

Figure 6: Experimental versus Predicted moisture ratio in case of Midilli **at 60℃ of drying Pampus *chinensis***

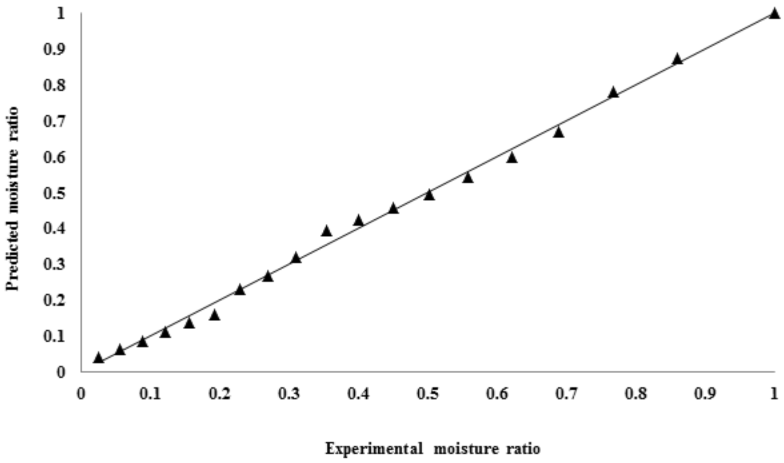

Figure 7: Experimental versus Predicted moisture ratio in case of Midilli **at 70℃ of drying *Pampus chinensis***

IV. CONCLUSION

In this research paper, thin layer drying of fish *Pampus chinensis* was examined and discussed at different drying temperatures of $50℃, 60℃$ *and* $70℃$. It was concluded that the drying of fish was described by the decreasing drying period. Both the drying rates and moisture ratio of the fish decreased with time. Twelve selected drying models among which the Midilli et al. model was the appropriate fit describing the fish drying for all the temperatures. The results justify that the Midilli et al. Model was ideal for predicting the drying curve of *Pampus chinensis*. Further, Midilli was validated by differentiating predicted moisture ratio against experimental moisture ratio.

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