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Drying of Pearl Millet Using Fluidised Bed Dryer: Experiments and Modelling

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Abstract: Pearl millet is a highly nutritious cereal rich in essential compounds like phytic acid, niacin and minerals like phosphorous, zinc, iron etc., To prevent microbial growth and store it for longer time, it needs to be dried. The experiments are carried out in laboratory scale fluidised bed dryer and modelling work is done. The experimental data are made to fit with fifteen thin layer models and the model with best fit was chosen based on the statistical analysis values of R^2, RMSE and SSE. The best fit models are Page model, Modified Henderson and pabis model, Midilli model and Modified Page model II with maximum R^2 values and minimum RMSE, SSE. By using fick's diffusion equation the effective diffusivity values are determined and they vary between 5.19 x 10^{-11} and 2.69 x 10^{-10} m^2/minute. The activation energy ranges between 12.05 and 46.61 kJ/kmol. The heat and mass transfer co-efficient for a single particle of Pearl millet is also calculated,
Key words: Pearl millet, fluidised bed dryer, statistical analysis, thin layer models.

1. Introduction

Pearl millet is known by its scientific name of Pennisetum glaucum. It is one of the most commonly grown millet in the Indian subcontinent. It is rich in essential compounds like phytic acid, niacin and an excellent source of protein, fibre. It has very high starch content and rich in minerals like phosphorus, zinc. It has about 378 calories per 100 gm. It has various health benefits like reducing the risk of cancer, beneficial for diabetes, helps in weight reduction etc., It needs to be dried in order to prevent the microbial attack and store it for a longer time.

In agro-based industries, drying is an important process because it reduces the water activity, thus preserve foods by avoiding microbial growth and deteriorative chemical reactions. Fluidised bed dryer is commonly used for drying particulate materials like grain and fruits due to a better heat and mass transfer, shorter drying time, better quality of the products obtained, and shorter reconstitution time. It has been considered as an economical drying method in comparison with other drying techniques.

Fluidised bed drying has been used for drying various agricultural products like canola [8,17], finge millet [10,22], green peas [7], potatoes [13], shelled corn [15], pepper corn [16], coconut [18], sweet potatoes [19] etc., and with other products like ammonium chloride [22], lignite [4], bovine intestine [11], baker's yeast [12] , coated sodium per carbonate particles [1] etc.,

The main objective of this study is to dry the pearl millet in pilot scale fluidised bed dryer and to determine the best fit model among widely used fifteen thin layer models based on statistical analysis. In addition to this, effective moisture diffusivity and activation energy is determined. Further heat and mass transfer co-efficient are also calculated.

2. Materials and Methodology

2.1. Raw Material

Pearl millet was used as the material for drying and their properties are listed in table 1.

Table 1: Characteristics of Pearl millet

Parameters	Characteristic value
Scientific name	Pennisetum glaucum
Shape	Conical
Mean particle diameter in mm	1.907
Bulk density in kg/m^3	626.34
Pure component density in kg/m^3	960
Gas hold up	0.4125
Minimum fluidisation velocity in m/s	0.483
Terminal settling velocity in m/s	4.080
Fluidisation regime	Bubbling regime

2.2. Experimental Set Up and Procedure

The set up consist of a Glass column, the conical portion of which was filled with Pearl millet. The material was supported on the screen mesh held between two flanges. Air from the Blower was heated in the heater box and passed through the column. Orifice with differential manometer was provided to measure the air flow rate. The flow rate can be adjusted by needle valve provided for air supply to the column. Sensors were given at different positions to measure the temperature at different points. Fig.1 and 2 shows the experimental set up and schematic representation.

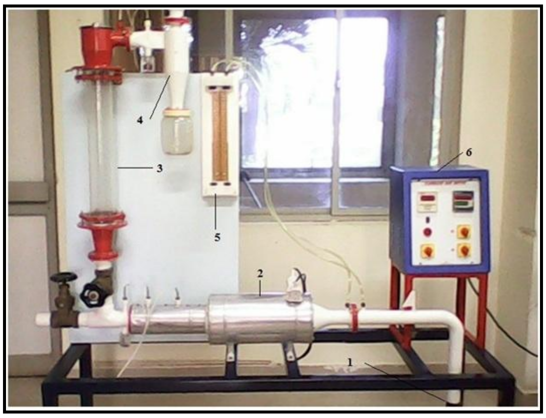


Fig. 1 Experimental set up of fluidised bed dryer 1-Blower, 2- Preheater, 3- Drying chamber, 4- Cyclone separator, 5- Water manometer, 6- Temperature indicator

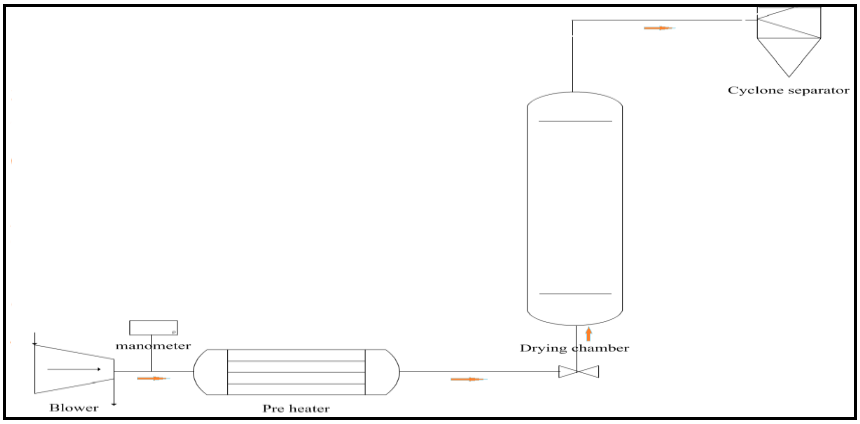


Fig. 2 Schematic representation of Fluidised bed dryer

Sample of about 150g of Pearl millet with the initial moisture content of 17% was loaded into the column. The set point was fixed as 40^0C for temperature and 2.1 m/s for velocity. At regular time interval of 10 minutes sample was collected. 2g of sample was weighed, packed and dried in the hot air oven at 105^0C for 24 hours to determine the moisture content. The experimental run for various conditions is listed in table 2.

Table 2: Experimental conditions with run no.

Run no	Temperature in ^{0}C	velocity in m/s
1	40	2.1
2	40	3
3	40	3.4
4	50	2.1
5	50	3
6	50	3.4
7	60	2.1
8	60	3
9	60	3.4

2.3. Fluidisation Behaviour

Prediction of minimum fluidisation velocity was important because the velocity should be maintained above this. Ergun equation was widely used for the determination of minimum fluidisation velocity [12] and it is given by

$$\frac{1.75\rho u_{mf}^2(1-\varepsilon)}{\phi d_p\varepsilon^3}+\frac{150\mu u_{mf}(1-\varepsilon)^2}{\phi^2 d_p^2\varepsilon^3}-\square\rho g(1-\varepsilon)=0 \qquad (1)$$

The terminal settling velocity is calculated using Haider and Levespiel correlation

$$u_t^* = u_t\left[\frac{\rho^2}{\mu(\rho_p-\rho)g}\right]^{1/3} \qquad (2)$$

Where u_t^* is given by

$$u_t^* = \left[\frac{18}{(d_p^*)^2}+\frac{2.335-1.744\phi}{(d_p^*)^{0.5}}\right]^{-1} \qquad (3)$$

The experimental minimum fluidisation velocity lies between the theoretical minimum fluidisation velocity and terminal settling velocity so that the particle will be under fluidisation condition. Prediction of fluidisation behaviour is important and it was done by using Walli's model based on the value of Walli's factor (V_e).The expression was given by

$$\frac{1.79}{n}\left(\frac{gd_p}{u_t^2}\right)^{0.5}\left(\frac{\rho_p-\rho_f}{\rho_p}\right)^{0.5}\left(\frac{\varepsilon_{st}^{1-n}}{(1-\varepsilon_{st})^{0.5}}\right)-1=V_e \qquad (4)$$

The fluidisation regime for corresponding values of Walli's factor was

$V_e > 0$ Homogenous regime
$V_e < 0$ Bubbling regime

2.4. Mathematical Modelling of Pearl Millet

The experimental data obtained were fitted with fifteen models to determine the model which successfully explain and predict the drying behaviour of pearl millet. These models use the term moisture ratio and it is represented as

$$MR = \frac{X_t - X_e}{X_i - X_e} \quad (5)$$

The models and their equations are listed in table 3. The modelling work was done by non-linear regression analysis using MATLAB software. The co-efficient of determination (R^2) was one of the main criteria in choosing the best fit model. In addition to this, the goodness of fit is evaluated by Root mean square error (RMSE) and Sum of squares error (SSE). For best fit model the value of R^2 should be higher and value of RMSE, SSE should be lower.

Table 3: Thin layer drying models used for the modelling of Pearl millet

No.	Model	Equation
1	Lewis or Exponential model	$MR = \exp(-kt)$
2	Page model	$MR = \exp(-kt^n)$
3	Henderson and Pabis model	$MR = a\exp(-kt)$
4	Modified Page model I	$MR = \exp(-(kt)^n)$
5	Wang and Singh model	$MR = 1 + at + bt^2$
6	Logarithmic model	$MR = a.\exp(-kt + c)$
7	Two term model	$MR = a.\exp(-k_0 t) + b.\exp(-k_1 t)$
8	Two term exponential model	$MR = a.\exp(-kt) + (1-a)\exp(-kat)$
9	Diffusion approach model	$MR = a.\exp(-kt) + (1-a)\exp(-kbt)$
10	Verma et al model	$MR = a.\exp(-kt) + (1-a)\exp(-gt)$
11	Modified Henderson and Pabis model	$MR = a.\exp(-kt) + b.\exp(-gt) + c.\exp(-ht)$
12	Midilli model	$MR = a.\exp(-kt^n) + bt$
13	Modified Page model II	$MR = \exp\left(-k\left(\frac{t}{L^2}\right)^n\right)$
14	Thomson model	$t = a.\ln(MR) + b.\ln(MR)^2$
15	Simplified Fick's diffusion equation	$MR = a.\exp\left[-c\left(\frac{t}{L^2}\right)\right]$

2.5. Effective Moisture Diffusivity and Activation Energy

Fick's diffusion equation was widely used for the determination of effective moisture diffusivity and is given by

$$MR = \frac{6}{\pi^2}\exp\left(\frac{-\pi^2 D_{eff} t}{r^2}\right) \quad (6)$$

The effective moisture diffusivity was obtained by plotting graph between ln(MR) and time.

The Activation energy can be computed using Arrhenius type equation and is given by

$$D_{eff} = D_0 \exp\left(\frac{-E_a}{RT}\right) \quad (7)$$

2.6. Heat and Mass Transfer Co-Efficient

The heat and mass transfer co-efficient are required for ideal dryer design. The heat and mass transfer co-efficient in a bed for a single particle is given by the correlations [24]

$$Nu = 2 + 1.8 Re_p^{1/2} Pr^{1/3} \quad (8)$$

$$Sh = 2 + 1.8 Re_p^{1/2} Sc^{1/3} \quad (9)$$

3. Results and Discussion

3.1. Effect af Operating Conditions on Drying Time

Pearl millet with the mean particle diameter 1.907 mm was used for drying and their particle size distribution is shown in Fig.3. Fig.4 shows the effect of temperature and velocity on drying time. It depicts that the drying time decreases with the increase in inlet air temperature and velocity. The falling rate period alone was alone observed in the rate of drying curve as shown in Fig.5. It was the typical characteristic of agricultural products as reported earlier and it symbolise that internal mass diffusion governs the process.

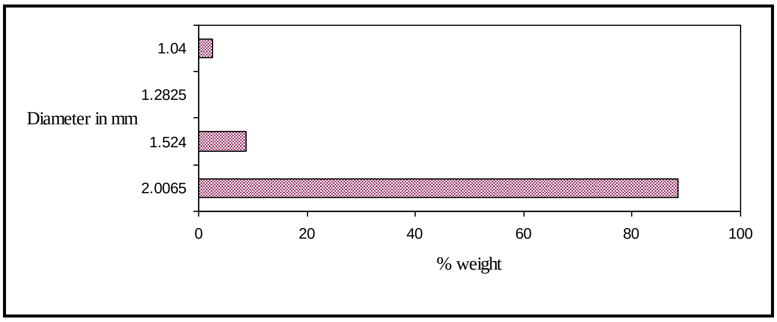


Fig. 3 Particle size distribution

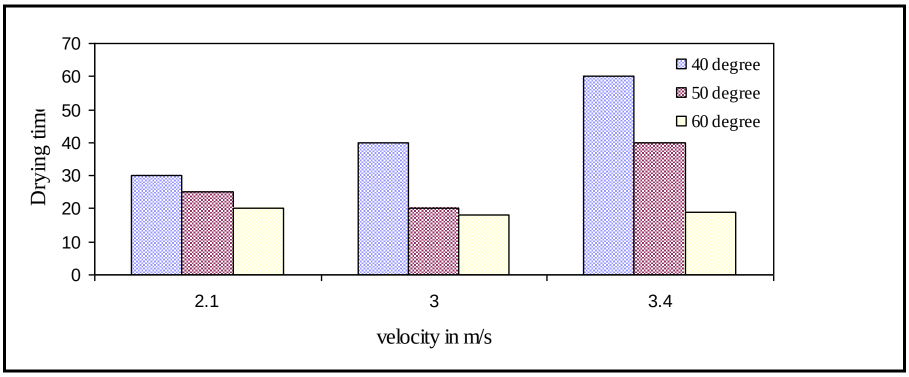


Fig. 4 Effect of Temperature and velocity on drying time

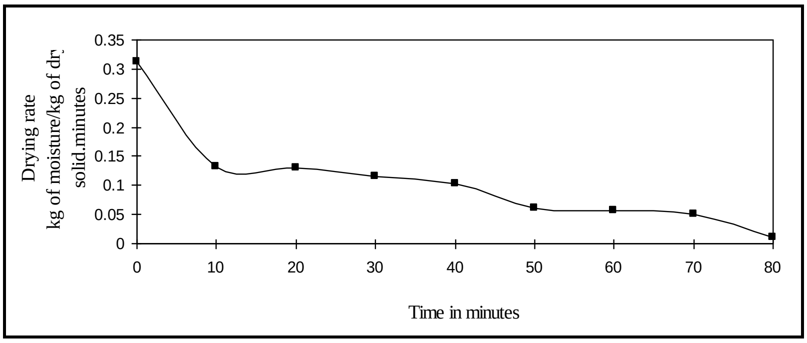


Fig.5 Rate of drying curve

3.2 Modelling of Drying Kinetics

Modelling work for pearl millet was done using least square algorithm in MATLAB for various temperatures and velocities. Statistical results are summarised in table 4 for fifteen thin layer drying models for various conditions. The statistical results indicates that Page model, Modified Henderson and Pabis model, Midilli model and Modified Page model II contains maximum values of R^2 and minimum values of RMSE, SSE. So these models fit with the experimental data and successfully describe drying kinetics of pearl millet. The model constants for the best fit models are listed in table 5. Fig.6 shows the coincidence of experimental and predicted values by best fit models.

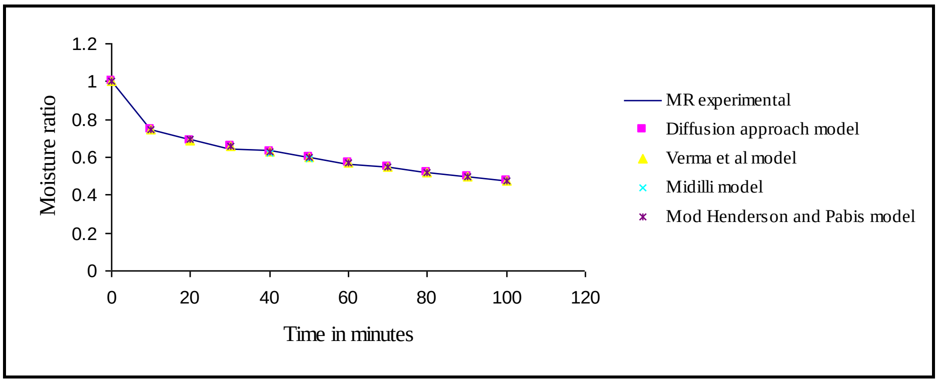


Fig. 6 Experimental and Predicted results for Best fit models

Table 4: Statistical analysis results for fifteen models for various operating conditions

Model no	T in ^{0}C	v in m/s								
		2.1			3			3.4		
		R^2	RMSE	SSE	R^2	RMSE	SSE	R^2	RMSE	SSE
1	40	0.3079	0.0793	0.0629	0.7336	0.0454	0.0206	0.8582	0.0481	0.0232
	50	0.8262	0.0417	0.0174	0.8880	0.0375	0.0141	0.7929	0.0609	0.0371
	60	0.4486	0.0822	0.0675	0.8674	0.0593	0.0351	0.9484	0.0434	0.0188
2	40	0.9507	0.0162	0.0024	0.9802	0.0130	0.0015	0.9906	0.0131	0.0015
	50	0.9939	0.0082	0.0006	0.9877	0.0131	0.0015	0.9905	0.0137	0.0017
	60	0.9925	0.0101	0.0009	0.9824	0.0227	0.0047	0.9916	0.0185	0.0031
3	40	0.4815	0.0526	0.0249	0.8860	0.0313	0.0088	0.9385	0.0334	0.0101
	50	0.9237	0.0291	0.0076	0.9447	0.0278	0.0069	0.9065	0.0432	0.0168
	60	0.7701	0.0559	0.0282	0.9260	0.0467	0.0196	0.9695	0.0352	0.0111
4	40	0.6820	0.0155	0.0024	0.9442	0.0126	0.0016	0.9778	0.0132	0.0017
	50	0.9915	0.0078	0.0006	0.9806	0.0125	0.0016	0.9829	0.0132	0.0017
	60	0.9772	0.0096	0.0009	0.9747	0.0216	0.0047	0.9810	0.0176	0.0031

5	40	0.6408	0.0438	0.0173	0.9232	0.0257	0.0059	0.9481	0.0307	0.0085
	50	0.9674	0.0190	0.0033	0.9759	0.0183	0.0030	0.9333	0.0364	0.0120
	60	0.8240	0.0489	0.0216	0.9660	0.0317	0.0090	0.9857	0.0241	0.0052
6	40	0.9753	0.0122	0.0012	0.9625	0.0190	0.0029	0.9749	0.0226	0.0041
	50	0.9870	0.0127	0.0013	0.9849	0.0154	0.0019	0.9722	0.0250	0.0050
	60	0.9632	0.0238	0.0045	0.9800	0.0257	0.0053	0.9916	0.0195	0.0031
7	40	0.9753	0.0130	0.0012	0.9760	0.0163	0.0019	0.9927	0.0130	0.0012
	50	0.9910	0.0113	0.0009	0.9854	0.0162	0.0018	0.9895	0.0164	0.0019
	60	0.9910	0.0126	0.0011	0.9808	0.0270	0.0051	0.9917	0.0208	0.0030
8	40	0.7200	0.0704	0.0446	0.8616	0.0345	0.0107	0.9401	0.0330	0.0098
	50	0.9259	0.0287	0.0074	0.9569	0.0245	0.0054	0.9008	0.0445	0.0178
	60	0.6641	0.0676	0.0411	0.9414	0.0415	0.0155	0.9840	0.0254	0.0058
9	40	0.9753	0.0122	0.0012	0.9760	0.0152	0.0019	0.9927	0.0122	0.0012
	50	0.9909	0.0107	0.0009	0.9850	0.0154	0.0019	0.9895	0.0153	0.0019
	60	0.9910	0.0118	0.0011	0.9805	0.0254	0.0052	0.9909	0.0204	0.0033
10	40	0.9753	0.0122	0.0012	0.9760	0.0152	0.0019	0.9927	0.0122	0.0012
	50	0.9909	0.0107	0.0009	0.9850	0.0154	0.0019	0.9895	0.0153	0.0019
	60	0.9910	0.0118	0.0011	0.9805	0.0254	0.0052	0.9909	0.0204	0.0033
11	40	0.9761	0.0152	0.0011	0.9839	0.0158	0.0012	0.9928	0.0154	0.0012
	50	0.9971	0.0076	0.0003	0.9909	0.0151	0.0011	0.9927	0.0162	0.0013
	60	0.9925	0.0135	0.0009	0.9907	0.0222	0.0025	0.9954	0.0184	0.0017
12	40	0.9698	0.0144	0.0015	0.9805	0.0147	0.0015	0.9926	0.0132	0.0012
	50	0.9945	0.0089	0.0006	0.9884	0.0144	0.0015	0.9907	0.0154	0.0017
	60	0.9926	0.0114	0.0009	0.9844	0.0243	0.0041	0.9928	0.0193	0.0026
13	40	0.9507	0.0172	0.0024	0.9802	0.0138	0.0015	0.9906	0.0139	0.0015
	50	0.9939	0.0087	0.0006	0.9877	0.0139	0.0015	0.9891	0.0156	0.0020
	60	0.9748	0.0197	0.0031	0.9824	0.0241	0.0047	0.9916	0.0196	0.0031
14	40	0.4600	25.6900	0.5940	0.8433	13.8400	0.1723	0.9093	10.5300	0.9973
	50	0.8856	11.8300	0.1259	0.9166	10.1000	0.9170	0.8700	12.6000	0.1430
	60	0.7257	18.3100	0.3017	0.8902	11.5900	0.1208	0.9491	7.8880	0.5599
15	40	0.4815	0.0558	0.0249	0.8860	0.0332	0.0088	0.9385	0.0354	0.0101
	50	0.9237	0.0309	0.0076	0.9447	0.0295	0.0069	0.9065	0.0458	0.0168
	60	0.7701	0.0593	0.0282	0.9260	0.0495	0.0196	0.9695	0.0373	0.0111

Table 5: Best fit model constants for various conditions

T in ^{0}C	**v in m/s**	**Page model constants**	
		k	**n**
40	2.1	-0.1299	0.1599
	3	-0.0374	0.4837
	3.4	-0.0378	0.5800
50	2.1	-0.0316	0.5505
	3	-0.0251	0.6260
	3.4	-0.0545	0.5180

60	2.1	-0.1027	0.3367
	3	-0.0472	0.6019
	3.4	-0.0332	0.7261

T in ^{0}C	**v in m/s**	**Modified Henderson and Pabis model constants**					
		a	b	c	g	h	k
40	2.1	0.7706	0.0441	0.1853	1.9260	0.0842	0.0000
	3	0.4681	0.4542	0.0777	-0.0015	0.9814	0.0095
	3.4	0.8741	11.1700	-11.0500	0.6766	1.6500	0.0043
50	2.1	0.0657	0.8946	0.0397	0.0056	-0.0145	0.5409
	3	0.0490	0.7762	0.1747	0.0083	-0.0057	0.8253
	3.4	0.0894	0.7915	0.1191	0.0082	0.8838	-0.0085
60	2.1	0.7291	0.1451	0.1255	0.0533	1.5710	0.0017
	3	0.0973	0.0013	0.9000	-0.0453	0.0085	0.6858
	3.4	0.0220	0.9126	0.0651	0.0118	0.5735	-0.0174

T in ^{0}C	**v in m/s**	**Midilli model constants**			
		a	**b**	**k**	**n**
40	2.1	1.0000	0.0017	0.0732	0.4138
	3	0.9994	-0.0004	0.0432	0.4147
	3.4	0.9997	-0.0015	0.0592	0.3743
50	2.1	0.9989	0.0008	0.0256	0.6510
	3	0.9975	0.0011	0.0191	0.7548
	3.4	0.9995	-0.0004	0.0610	0.4665
60	2.1	1.0000	0.0002	0.0968	0.3626
	3	0.9970	0.0014	0.0325	0.7589
	3.4	0.9937	0.0012	0.0232	0.8663

T in ^{0}C	**v in m/s**	**Modified Page model II constants**		
		k	**l**	n
40	2.1	0.1567	1.7970	0.1599
	3	0.3704	10.7100	0.4834
	3.4	0.6090	10.9800	0.5800
50	2.1	0.0225	0.7333	0.5502
	3	0.1038	3.1070	0.6260
	3.4	0.0459	0.7263	0.4837
60	2.1	0.0332	0.0457	0.2434
	3	0.0540	1.1200	0.6023
	3.4	0.0682	-1.6410	0.7257

3.3. Effective Moisture Diffusivity

Temperature and velocity have significant effect on effective diffusivity i.e Effective moisture diffusivity increases with increase in temperature and velocity of air. The values obtained were within the range as previously reported for food materials and are tabulated in table 6.1.The values of activation energy (E_a) and the pre-exponential factor (D_0) values for various velocities are tabulated in table 6.2.

Table 6.1: Effective diffusivity at various temperatures and velocities

T/v	**2.1**	**3**	**3.4**
40	1.53E-10	5.19E-11	9.15E-11
50	1.10E-10	1.25E-10	1.59E-10
60	1.16E-10	2.07E-10	2.69E-10

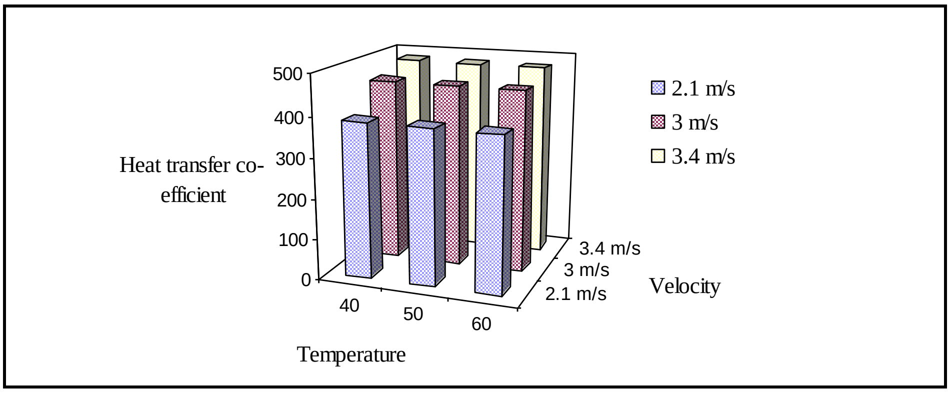
Effective diffusivity in m^2/minute, Temperature in ^{0}C and velocity in m/s

Table 6.2: Activation energy at different velocities

velocity	E_a in J/kmol	D_0 in m^2/s
2.1	12059.457	1.40E-12
3	60213.3136	0.612565
3.4	46619.9236	5.51E-03

3.4. Transfer Co-Efficient

The heat and mass transfer co-efficient of a single particle in air is determined and the Fig.7 shows that the heat transfer co-efficient increases with increase in inlet air velocity and the mass transfer co-efficient increases with increase in inlet air temperature and velocity.



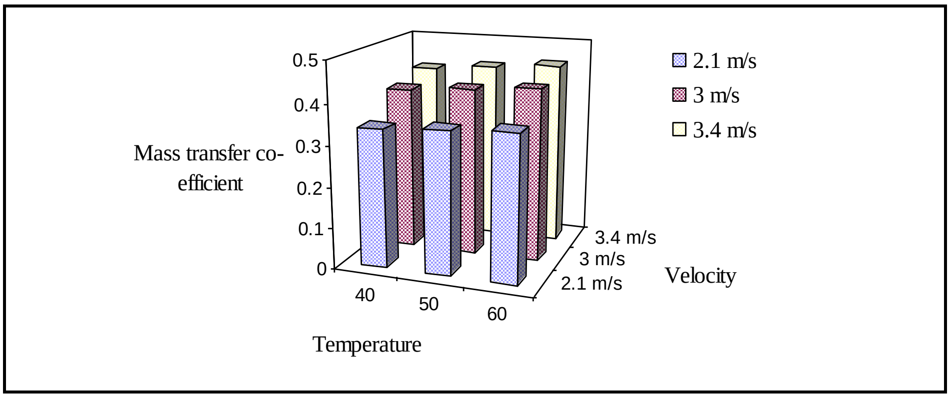


Fig. 7 Effect of Temperature and velocity on Heat and mass transfer co-efficients

4. Conclusion:

The drying time of pearl millet decreases with increase in inlet air temperature, and velocity. The falling rate period alone was present in the rate of drying curve which indicates internal mass diffusion governs the process. Among fifteen widely used thin layer models, Page model, Modified Henderson and Pabis model, Midilli model and Modified Page model II were found to successfully describes the drying kinetics with maximum R^2 and minimum RMSE,SSE values.

The effective moisture diffusivity varies between 5.19 x 10^{-11} and 2.69 x 10^{-10} m^2/minutre. The activation energy ranges between 12.05 and 46.61 kJ/kmol. The heat transfer co-efficient increases with increase in inlet air velocity and the mass transfer co-efficient increases with increase in inlet air temperature and velocity.

Nomenclature

a,b,c,k_0,k_1,k,n,g,h,L	Constants of the drying models
D_{eff}	Effective moisture diffusivity (m^2/minute)
d_p	Particle diameter (m)
D_o	Pre-exponential factor (m^2/minute)
E_a	Activation energy (kJ/mol)
g	Acceleration due to gravity(m/s^2)
H	Heat transfer co-efficient of a single sphere in gas (W/m^2K)
K_d	Mass transfer co-efficient of a single sphere in gas (m/s)
MR	Moisture Ratio
n	Richard zaki co-efficient
Nu	Nusselt number
Pr	Prandtl number
r	Radius of particle (m)
R	Universal gas constant (8.314kJ/kmol.K)
Re	Reynolds number
Sc	Schimdt number
Sh	Sherwood number
T	Temperature (K)
t	Time (minutes)
U_{mf}	Minimum fluidisation velocity (m/s)
U_t	Terminal settling velocity (m/s)
X_t	Moisture content at time t (kg of moisture/kg of dry solid)
X_i	Initial moisture content (kg of moisture/kg of dry solid)
X_e	Equilibrium moisture content (kg of moisture/kg of dry solid)

Symbols

ρ	Density of gas (kg/m^3)
ε	Gas phase hold up
ϕ	Sphericity
μ	Viscosity of gas (kg/m.s)
□ρ	Density difference between particle and gas
ΔX	Difference in moisture content
Δt	Difference in time

References

1. Hematian S & Hormozi F, Drying kinetics of coated sodium percarbonate particles in a conical fluidized bed dryer, Powder Technology 269 (2015) 30–37.
2. Darvishi H, Khoshtaghaza M H & Minaei S, Effects of fluidized bed drying on the quality of soybean kernels, Journal of the Saudi Society of Agricultural Science (2014).
3. Khamforoush M, Mirfatah S M & Hatami T, Application of three types of dryers namely tunnel, fluidized bed, and fluidized bed with microwave for drying of celery, corn, and sour cherry: experiments and Modelling, Ije Transactions b: applications vol. 27, no. 5, (2014) 667.

4. Park J H, Ha Lee C, Park Y C, Shun D, Dal-Hee Bae & Park J, Drying efficiency of indonesian lignite in a batch-circulating fluidized bed dryer, Drying technology, 32 (2014) 268.
5. Srinivas G, Pydi settee Y, Heat and mass transfer studies in a batch fluidized bed dryerusing geldart group D particles, Heat mass transfer (2014).
6. Amiri Chayjan R, Salari K Abedi Q & Sabziparvar A A, Modelling moisture diffusivity, activation energy and specific energy consumption of squash seeds in a semi fluidized and fluidized bed drying, Journal of food science & technology 50(4) (2013) 667.
7. Honarvar B, Experimental and theoretical investigation of drying of green peas in a fluidized bed dryer of inert particles assisted by infrared heat source, Iran. Journal of chemical engineering vol. 32, no. 1 (2013).
8. Malekjani N, Jafari S M, Rahmati M H, Zadeh E E & Mirzaee H, Evaluation of Thin-Layer Drying Models and Artificial Neural Networks for Describing Drying Kinetics of Pearl millet Seed in a Heat Pump Assisted Fluidized Bed Dryer, Journal of Food Engineering 9(4) (2013) 375.
9. Mihindukulasuriya S D F & Jayasuriya H P W, Mathematical modelling of drying characteristics of chilli in hot air oven and fluidized bed dryers, Agric Eng Int: CIGR Journal Vol. 15, No.1 (2013) 154.
10. Shingare S P & Thorat B N, Effect of Drying Temperature and Pretreatment on Protein Content and Color Changes during Fluidized Bed Drying of Pearl millets (Pearl millet, Eleusine coracana) Sprouts, Drying Technology, 31(2013) 507.
11. Senadeeraa W, Alves-Filhob O & Eikevikb T, Influence of drying conditions on the moisture diffusion and fluidization quality during multi-stage fluidized bed drying of bovine intestine for pet food, Food and Bioproducts Processing 9 1 (2013) 549.
12. Akbaria H , Karimia K, Magnus Lundin,Taherzadeh M J,Optimization of baker's yeast drying in industrial continuous fluidized bed dryer, Food and Bioproducts Processing 90 (2012) 52.
13. Balasaheb S , Sharma G P , Sonawane S P & Verma R C, Kinetics of potato drying using fluidized bed dryer, journal of food science & technology 49(5) (2012) 608.
14. Amiri Chayjan R, Amiri Parian J & Esna-Ashari M ,Modelling of moisture diffusivity, activation energy and specific energy consumption of high moisture corn in a fixed and fluidized bed convective dryer, Spanish journal of agricultural research 9(1) (2011) 28.
15. Momenzadeha L, Zomorodiana A & Mowlab D, Experimental and theoretical investigation of shelled corn drying in a microwave-assisted fluidized bed dryer using Artificial Neural Network, Food and Bioproducts Processing 8 9 (2011) 15.
16. Promvonge P , Boonloi A, Pimsarn M & Thianpong C, Drying characteristics of peppercorns in a rectangular fluidized-bed with triangular wavy walls, International Communications in Heat and Mass Transfer 38 (2011) 1239.
17. Gazor H & Mohsenimanesh A, Modelling the Drying Kinetics of Pearl millet in Fluidised Bed Dryer, Czech J. Food Sci. Vol. 28 (2010) 531.
18. Madhiyanon T, Phila A , Soponronnarit S, Models of fluidized bed drying for thin-layer chopped coconut, Applied thermal engineering 29 (2009) 2849.
19. [19] Hatamipour M S, Hadji Kazemi H, Nooralivand A & Nozarpoor A, Drying characteristics of six varieties of sweet potatoes in different dryers, food and bioproducts processing, trans icheme, part c (2007).
20. Tasirin S M , Kamarudin S K, Jaafar K & Lee K F, The drying kinetics of bird's chillies in a fluidized bed dryer, Lee Journal of Food Engineering 79 (2007) 695.
21. Kumaresan R & Virudhagiri R, Simultaneous heat and mass transfer studies in drying ammonium chloride in a batch fluidised bed dryer, Indian journal of chemical technology vol 13 (2006) 440.
22. Sivashanmugam P & Sundaram S, Residence time distribution studies in annular circulating fluidised bed drier, Powder Technology 107 (2000) 256
23. Treybal R E, Mass Transfer Operations third Edition, McGraw-Hill International editions, (1955).
24. Kunii D & Levenspiel O, Fluidisation Engineering second edition, Butterworth-Heinemann series in Chemical Engineering (1991).

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