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STUDIES ON DRYING OF SORGHUM SEEDS IN A FLUIDIZED BED DRYER

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ABSTRACT

Sorghum grain ranks fifth in cereals global production. Sorghum is used for human nutrition all over the world. Drying of sorghum is necessary to avoid germination and fungal infection. Fluidized bed drying technology is used to dry the grains in the present study. This paper dealing with the drying kinetics of sorghum seeds under the operating parameters such as temperature, flow rate of the drying medium, and solids holdup. The drying rate was found to increase significantly with increase in temperature and marginally with flow rate of the heating medium and to decrease with increase in solids holdup. The drying rate was compared with various simple exponential time decay models and the model parameters were evaluated. The experimental data were also modeled using Fick's diffusion equation. And also found the bed voidage.

INTRODUCTION

Sorghum is used for human nutrition all over the world. It is a major crop for many poor farmers, especially in Africa. There are several types of sorghum, including grain sorghums, grass sorghums (for pasture and hay), sweet sorghums (for syrups), and Broomcorn. Grain sorghum requires less water than corn, so is likely to be grown as a replacement to corn and produce better yields than corn in hotter and drier areas, such as the Southern US, Africa. Sorghum is also considered to be a significant crop for animal feeds. Sorghum fibers are used in wallboard, fences, biodegradable packaging materials, and solvents. Dried stalks are used for cooking fuel, and dye can be extracted from the plant to color leather. A more recent use of sorghum is for ethanol. By-products from ethanol production, such as sorghum-DDGS (distillers dried grains with soluble), are also finding a place in the market. One of the most important factors in maintaining the quality of seed is the moisture content. Too high moisture leads to deterioration in seed quality as a result of the microorganism growth and premature germination [1].

Mature grain sorghum in the field contains about 30% moisture. At moisture levels higher than 25%, the seeds are too soft to withstand the threshing action. The ideal moisture content for harvesting grain sorghum is about 20%. Harvested seeds have to be dried immediately, otherwise, because of internal heating; germination will be reduced when moisture content is high. Seeds are to be dried to a moisture content of 10-12%. Drying is a method of food preservation that works by removing water from the food, which inhibits the growth of microorganisms. [2, 3]

Drying of solids is generally understood to follow two distinct drying zones known as constant rate period and falling rate period which meet at critical moisture content. The critical moisture content varies with operating parameters and with the type of drying equipment. The constant rate period is understood to have maximum drying rate. As considering the falling rate period, the rate of diffusion of moisture to surface of solids becomes the limiting factor for moisture transfer. The extent of drying zones is decided based on the type of material [4]. Fluidized beds are widely used for the drying of granular solids such as grains, fertilizers, chemicals, pharmaceuticals and minerals. This technique offers advantages such as the high heat capacity of the bed, improved rates of heat and mass transfer between the phases and ease in handling and transport of fluidized solids. The drying rate in the fluidized bed is strongly influenced by the characteristics of the material and the conditions of fluidization. [5].

Knowledge of drying kinetics is essential for sizing the dryer as well as for choosing the optimal drying conditions. Numerous mathematical models have been developed to estimate the drying kinetics. These range from analytical models, often built by regression of experimental data. In general, the drying rate in constant rate period in fluidized bed drying is modeled using (a) simple empirical correlation relating drying rate to the influencing parameters or utilizing heat and mass transfer coefficient between solids and gas in fluidized bed (or) (b) Using mass transfer models, assuming the bed to make of bubble phase, emulsion phase, and a dense phase with the exchange of mass and energy between these phases. [6].

The objective of the present study is to experimentally investigate the drying kinetics of sorghum grains in a fluidized bed dryer with respect to the operating parameters such as the temperature, flow rate of the drying medium, and the solids hold up. Although the effect of operating parameters on the drying rates are well known and the influencing parameters to respond in similar fashion qualitatively, the drying kinetics can vary quantitatively depending on the nature of the material and the drying conditions. It is further attempted to verify the compatibility of experimental drying kinetics with various simple models given in the literature, and with complex models such as Fick’s diffusion equation. A good fluidization behavior in terms of perfect mixing of the bed material was observed visibly. This was substantiated with low fluctuation in the bed pressure drop, which is an indication for smooth fluidization without formation of slugs. The minimum fluidization velocity was not found to vary with the temperature within the range of temperatures covered in the present study. [7]

MATERIALS AND METHODS

Sorghum seeds used in the experiment were collected from local super market. The drying experiments were conducted using a fluidized bed dryer column with the internal diameter of 0.05 m and a height of 0.5 m. The air distributor was 2 mm thick and with 2 mm perforations having 13% free area. A fine wire mesh was spot welded over the distributor plate to arrest the flow of solids from the fluidized bed in to the air chamber. Air from the blower was heated and fed to the fluidization column through the air chamber. Volumetric discharge capacity of air blower is 200 m^3/h. The electrical heater consisted of a multiple heating element each of 2KW rating. A temperature controller, provided to the air chamber, facilitated control of air temperature within+_5^{0}C of the set temperature for the entire operating range of 313k to 333k. Air flow was measured using a calibrated orifice meter. Table 1 shows the physical characters of sorghum grain as well as the experimental conditions covered in the present study.

A known quantity of 0.125 kg sorghum seeds with initial moisture content of 20% (db) was taken in a fluidized bed, and air at the desired rate was introduced into the column. As fluidization continued, the dry bulb and wet bulb temperatures of the inlet and out let of the fluidized bed column were noted for each interval time of 1min. For these temperatures humidity was calculated using psychometric chart. Moisture ratio can be calculated using humidity values.

Initially the minimum bed height at minimum fluidization velocity (H_{mf}) was noted. After maintaining the steady velocity and temperature, initial bed height was increased during the drying process.

TABLE 1: Characteristics of the Material and the Range of Experimental Parameters Covered in the Present Study

Characteristics	**Range of parameters**
Name of the material	Sorghum (Sorghum Bicolor)
Shape of material	Non Spherical
Sphericity	0.901
Size, dp(mm)	3.34
Particle density(kg/m^3)	820
Minimumfluidization velocity,Umf(m/s)	0.647
Temperature of fluidizing air(^{0}C)	40,50,60
Fluidizing air velocity (m/s)	0.85,1.06,1.27
Solids hold up (kg)	0.125,0.15,0.175

After getting steady temperatures in the outgoing air and at the final stage of drying, the increase in bed height ($H-H_{mf}$) was noted. The bed voidage at minimum fluidization velocity was given in the table. From the above equation at particular drying medium velocity and temperature, the bed voidage was calculated.

Drying Kinetics

The moisture ratio is calculated as

$$MR = \frac{M}{M_o} \quad (1)$$

TABLE 2: The Emprical Model Equations

Newtons Model (NM)	MR=exp (-kt)
Page Model (PM)	MR=exp ($-kt^n$)
Henderson and Pabis (HPB)	MR=a exp (-kt)

Drying curves were fitted with three thin-layer drying equations, to select a suitable model for describing the drying process. Non-linear regression analysis was performed. The coefficient of determination (R^2) was one of the main criteria for selecting the best equation. In addition to the coefficient of determination, the goodness of fit was determined by other statistical parameters such as reduced mean square of the deviation (χ^2) and root mean square error (RMSE). For goodness fitting, R^2 value should be higher than χ2 and RMSE values should be lower (Sarasavadia et al.1999)[8]. Fick's diffusion equation for the particles was used for the calculation of effective moisture diffusivity. The effective diffusivity was calculated using the slopes method. The diffusion coefficient was typically calculated by plotting the experimental drying data in terms of ln (MR) versus the drying time (Maskan *et al*. 2002) [9].

The relation between bed voidage and minimum fluidization velocity is,

$$m = \frac{H - H_{mf}}{H_{mf}} = \frac{1 - \varepsilon_{mf}}{1 - \varepsilon} - 1 = \frac{\varepsilon - \varepsilon_{mf}}{1 - \varepsilon} \qquad (2)$$

TABLE 3:Evaluated Drying Kinetics Parameters at Various Operating Conditions

Temperature (K)	Weight (kg)	Velocity (m/s)	Page model			
			k	n	RMSE	χ^2
313	0.125	1.06	0.0876	0.88	0.0153	0.00184
313	0.15	0.85	0.032	1.18	0.0235	0.00395
323	0.125	1.27	0.191	0.601	0.0269	0.00069
323	0.175	1.06	0.291	0.683	0.035	0.00146
333	0.175	1.27	0.1947	0.72	0.0246	0.00065
333	0.15	0.85	0.148	0.80	0.0223	0.00054
			H&P model			
313	0.125	1.06	k	a	RMSE	χ^2
313	0.15	0.85	0.053	0.91	0.0508	0.00258
323	0.125	1.27	0.036	0.95	0.094	0.00973
323	0.175	1.06	0.057	0.84	0.064	0.00409
333	0.175	1.27	0.099	0.77	0.0883	0.0078
333	0.15	0.85	0.088	0.85	0.0571	0.00359
			Newton's model			
313	0.125	1.06	k	RMSE	χ^2	
313	0.15	0.85	0.055	0.0404	0.00163	
323	0.125	1.27	0.042	0.0463	0.00214	
323	0.175	1.06	0.078	0.084	0.00705	
333	0.175	1.27	0.135	0.1036	0.00107	
333	0.15	0.85	0.103	0.0697	0.00534	

TABLE 4: Evaluated Effective diffusivity Coefficient at Various Operating Conditions

Parameters			Effective Diffusion coefficient
T(K)	W(kg)	U(m/s)	$D_{eff} \times 10^{10}(m^2/s)$
313	0.125	1.06	3.01
313	0.15	0.85	2.35
323	0.125	1.27	2.85
323	0.175	1.06	4.53
333	0.175	1.27	5.5
333	0.15	0.85	4.04

RESULTS AND DISCUSSION

Experimental data showing the effect of temperature, flow rate of the heating medium and solids holdup are shown as plots of MR versus time, in Figures 1 to 3. Figures 1 to 3 shows the drying rate decreasing, from the starting (t = 0) until the end of drying, indicating the absence of Constant drying rate period or presence of constant rate period for an insignificant period of time compared to the total drying time.

The rate of drying is higher at the early stage of drying while the moisture content was high and reduces as the moisture content decreases. Figure1 shows the effect of temperature of the heating medium at two different solids holdup. An increase in temperature of the heating medium increases the drying rate and it can be attributed to the higher bed temperature of particles in the bed, which increases the intra particle moisture diffusion to the surface of the solid resulting in a higher drying rate. Similar trend was observed at different higher solid hold up but rates were reduced (figure 2).

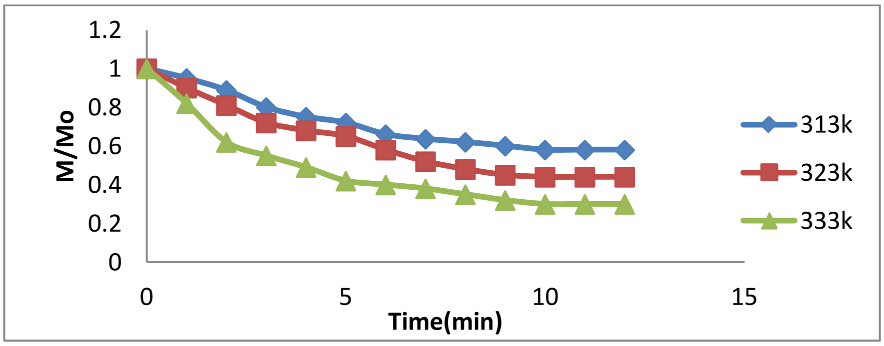

Figure:1 Effect of temperature of the heating medium (U: 0.85 m/s, W: 0.125 kg)

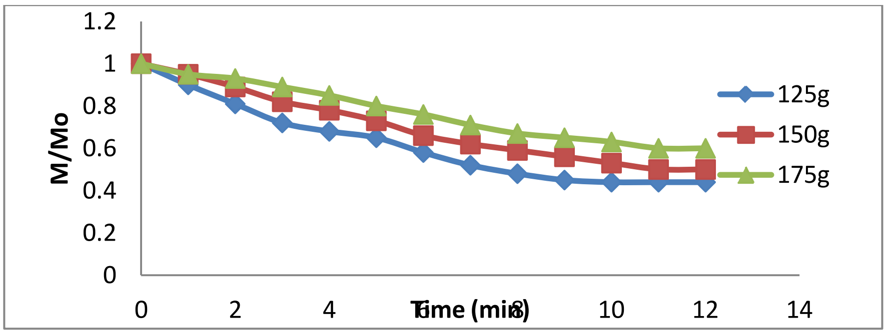

Figure: 2 Effect of solids holdup (U: 1.06m/s, T: 313 k)

Figure 3 show a marginal increase in drying rate with air flow rate and it may be attributed to a reduction in external mass transfer resistance during early stages of drying while the drying rate and the moisture content are high. Looking at the drying curve, as the rate of drying reduces from start until the end of drying period one would expect the entire operation to be an internal mass transfer controlled and would expect a negligible effect of air flow rate on the drying rate. Repeat experiments were conducted to eliminate the effect of experimental error on assessing the effect of air flow rate on the drying rate and the conclusion of a marginal effect on drying rate was based on the consistent observation on two sets of a experiments conducted with two different solids hold ups.

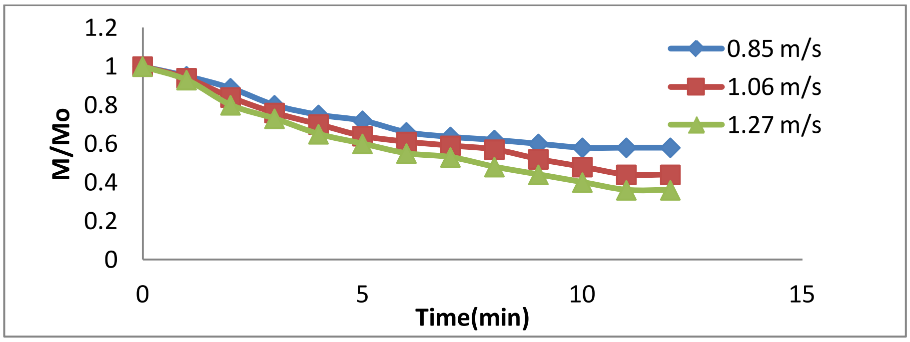

Figure : 3 Effect of flow rate of heating medium(W: 0.15 kg, T: 323 k)

The experimental drying rates were fitted with various model equations, by minimizing the root mean square error (RMSE) between the experimental drying rate and the model equation.

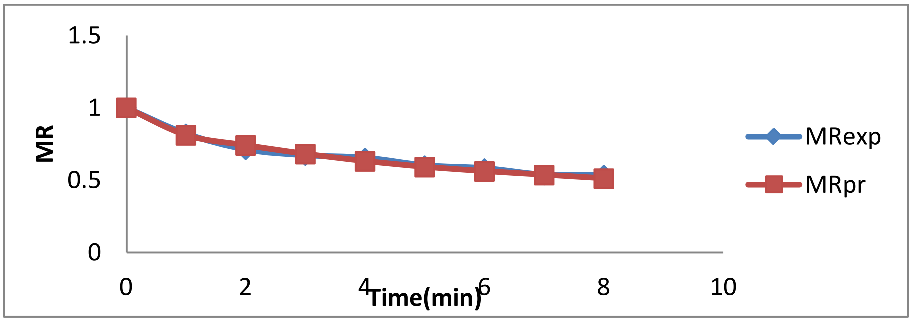

Figure : 4 Comparison of drying kinetics with page model data (W: 0.175kg, U: 1.27 m/s, T: 323k)

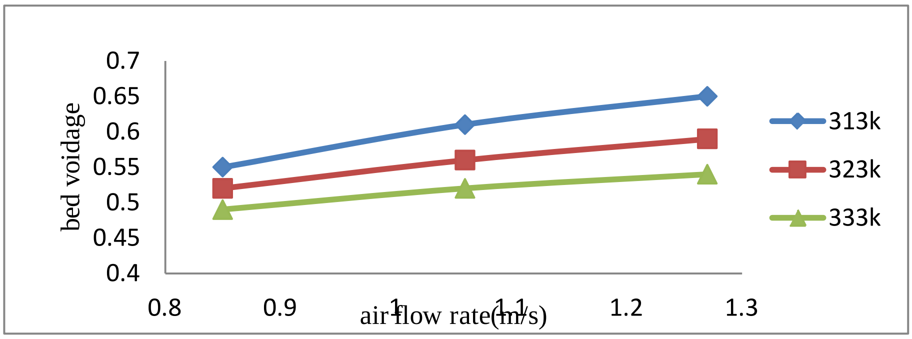

Figure :5 Comparison of bed voidage with air velocity at different temperatures

The evaluated model parameters along with the RMSE values are listed in Table 3. It can be seen from Table 3 that among all the models, the most simple among all, the Page model is found to match experimental data very closely (figure 4), with the RMSE error less than 3.6%. The standard deviation between the experimental data and the model prediction using the page model parameters is less than 4.5×10^{-5}. Although three parameters are used in approximate diffusion model. The model parameters can be utilized to estimate the drying time as well as for designing and scale up of the drying process. The experimental data were also modeled using more fundamental Fick's diffusion equation and the effective diffusivity coefficient was estimated to be within 2.3 to 5.5 $\times10^{-10} m^2/s$. Figure 5 shows the comparison of bed voidage with air velocity at different temperatures. It was observed that bed voidage increases with the increase in air velocity at any particular temperature maintained.

CONCLUSIONS

The drying characteristics of sorghum have been assessed in a fluidized bed dryer with respect to the various operating variables. The drying rate was found to increase significantly with increase in temperature and marginally with flow rate of the heating medium, and to decrease with increase in solids holdup. The duration of the constant rate period was found to be insignificant, considering the total duration of drying and the entire drying period was considered to follow falling rate period. The kinetics of drying was tested with various simple exponential decay models and the Page model was found to match the experimental drying rate closely with the RMSE value less than 3.6%. The effective diffusivity coefficient and bed voidage also found. The estimated effective diffusion coefficient is compared with the literature reported effective diffusion coefficient for other grains and found to be within the same order of magnitude.

NOTATION

a = empirical drying constant exponent in Henderson and Pabis Model

D_{eff} = Effective Diffusion Coefficient, m^2/s

H = bed height, m

H_{mf} = minimum bed height, m

M = moisture content(% dry basis) at any time, kg moisture/kg dry solid

Mo = initial moisture content(% dry basis), kg moisture/kg dry solid

m = bed expansion ratio

MR = moisture ratio

n = empirical drying constant exponent in Page Model

k = drying constant, min^{-1}

T = Temperature, K

t= time, min

U = Fluidization Velocity, m/s

U_{mf} = Minimum Fluidization Velocity, m/s

W = Weight of solid in the fluidized bed, kg

ε = bed voidage

ε_{mf} = bed voidage at minimum fluidization velocity

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