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Studies on Fluidized Bed Drying of Millets (Pennisetum Typhoides)

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Abstract – *In the present paper, experiments were conducted to estimate the drying kinetics of millet in a batch fluidized bed by varying the operating conditions such as temperature, velocity of the drying medium and solids holdup. The drying rate was found to increase significantly with increase in temperature and with velocity of the drying medium, while decrease with increase in solids holdup. The duration of constant rate period was found to be insignificant, considering the total duration of the drying and the entire drying period was considered to follow falling rate period. The drying rate was compared with various simple exponential time decay models and the model parameters were evaluated. The Page model was found to match the experimental data very closely with less root mean square error (RMSE). The bed voidage was estimated by changing the flow rate of the drying medium at different temperatures and a graph was plotted. It is found that the bed voidage increases steadily with the increase in velocity of the drying medium at any respective maintained temperature.*

Key Words: *Millets, Fluidized Bed Drying, Solids Holdup, Falling Rate Period, Page Model, Bed Voidage*

1.INTRODUCTION

Drying is one of the oldest and most widely used methods of food preservation. It is an important unit operation in the food processing industry. Drying is one of the crucial steps in food processing and preservation. Drying is the process of moisture removal from the product, or grain. It provides optimum moisture content to the grain for processing. In preserving grain without deterioration, drying is the cheapest among other methods that is chemical application and controlled atmosphere storage [1].

Millet (Pennisetum Typhoides) is one of the oldest grains known to humans and possibly the first cereal grain to be used for domestic purposes. Millet has been used in Africa, India and China, where it was the prevalent grain before rice became the dominant staple. Today millet ranks as the sixth most important grain in the world, sustains one third of the world's population. The crop when harvested is stored in rhombus and prepared in different forms with additions of condiments and seasonings to obtain varieties for the three square meals. These include food in the form of porridge produced from flour called tuwo as lunch, refreshing drink kunu and fura for tea time, dessert dan-wake and palp, ogi, koko or akamu for breakfast and dinner [2].

The traditional open air-sun drying technique commonly employed in the tropics for this crop and other fruits and vegetables has some disadvantages which includes the slow speed of the process, contamination from exposure to environmental conditions and the hard labour requirement. Furthermore, direct exposure to solar radiation results in undesirable colour changes, lowering quality of the dried products significantly. Therefore, the use of solar and hot air dryers, which are far more rapid and which provide uniformity and hygiene for industrial food drying processes become inevitable [3].

A fluidized bed is formed by a quantity of a solid particulate substance (usually present in a holding vessel) which is placed under appropriate conditions to cause the solid/fluid mixture to behave as fluid. This is usually achieved by the introduction of pressurized fluid through the particulate medium. This results in the medium then having many properties and characteristics of normal fluids, such as the ability to free-flow under gravity, or to be pumped using fluid type technologies. The resulting phenomenon is called fluidization [4]. Fluidized beds find increasing applications in drying of agricultural materials, while they are being widely in use, in industries drying of fertilizers, chemicals, pharmaceuticals and minerals. Fluidized beds as compared to other modes of drying offer advantages such as 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 [5].

Drying of solids is generally understood to follow two distinct drying zones known as the constant rate period and falling rate period demarcated with critical moisture content. The critical moisture content is reported to vary with operating parameters and with the type of drying equipment. The constant rate period is understood to have a maximum drying rate, which remains constant until the critical moisture content with the resistance for moisture transfer in the gas phase. The rate of diffusion of moisture to the surface of solids becomes the limiting factor for moisture transfer as far as the falling rate period is concerned [6, 7].

The objective of this present study is to experimentally identify and compare the drying kinetics of millet in fluidized bed with respect to the operating parameters such as the temperature, velocity of the drying medium and the solids hold up, to fit the experimental data obtained to semi empirical models widely used to describe the fluidized bed drying of millet seeds, to calculate the effective drying parameters and to compare the effect of air velocity on bed voidage at different temperatures.

2. Materials and Methods

Millet seeds obtained from local market used as material for fluidized bed drying. The characteristics of the millet seeds are in the Table 1.

Table -1: Characteristics of Millet Seeds

Name of Material	Millets
Shape of Material	Spherical
Size dp(mm)	2.478
Particle density, kg/m^3	1111
Minimum fluidization velocity, m/s	0.673
Bed voidage at minimum fluidization velocity	0.3024

2.1 Fluidized Bed Dryer

The fluidized bed used for the drying of millet seeds, shown in above Figure 1, consisting a cylindrical fluidized bed column of 5cm internal diameter and height of 50cm. The gas distributor was 2mm thick with 2mm 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 blower with volumetric discharge capacity of 200m^3/h was used. Air velocity from the Compressor was measured using a Rota meter, before being heated and fed to the fluidization column, through the air chamber. The electrical heater consisted of a multiple drying element each of 2KW rating. The wet bulb and dry bulb temperatures were measured using thermometers. The schematic diagram and photograph of the experimental set up was shown in Figure 1.

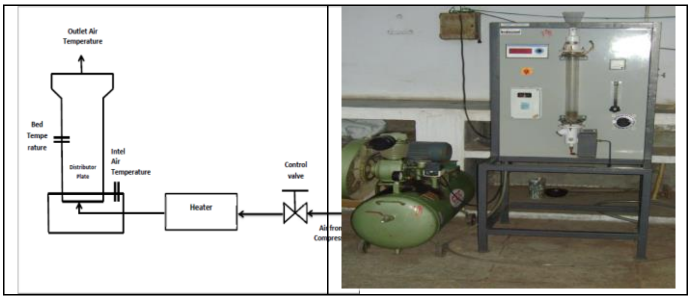

Figure-1: Schematic diagram and photograph of the experimental set up

2.2 Experimental Procedure

Air at desired temperature and velocity was allowed to flow through the fluidization column. A known quantity of the millet with known initial moisture content was introduced in to the column after ensuring the steady temperature and air velocity. The fluidization gas velocity was decided based on the minimum fluidization velocity of the millet. Fluidization velocities of approximately 1.5 to 2 times the minimum fluidization velocity were chosen for the experiments. The air to the fluidization column come from the air compressor and the air velocity is maintained by using a Rota meter. The temperature in the column was maintained by using the electrical heater. Drying of millet seeds is taking place in fluidized bed, so at every one minute wet bulb and dry bulb temperatures of inlet and outgoing air were noted down. This procedure is continued till steady state reading in temperatures is attained. The experiments were repeatedly conducted for different temperatures, velocities and different weights.

3.0 Results and Discussions

3.1 The Effect of Drying Medium Temperature on Drying Kinetics

The Figure-2 shows the effect of drying medium temperature on drying kinetics. It can be known that at lower temperature the drying rate is slow whereas at higher temperature it is faster. An increase in temperature of the drying 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 leading to a higher drying rate. The increased transport properties of the fluids with increase in temperatures is well known and the experimental data are in concurrence with the basic concepts of mass transfer.

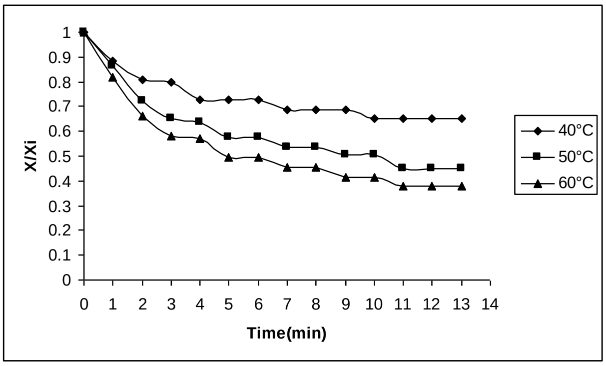

Figure-2: Effect of temperature of the drying medium
(0.150 kg of millet seeds, 30gm of water, 1.06m/s air velocity)

3.2 Effect of Air Velocity on Drying Kinetics in Fluidized Bed Dryer

In general an increase in velocity of the drying medium reduces the external resistance for mass transfer, aiding a higher transfer rate. Since the intra particle moisture diffusion controls drying rate during falling rate period, the decrease in external resistance for mass transfer is not expected to increase the rate of drying significantly. However an increase in the velocity of the drying medium results in dispersion of diffused moisture from solids in a larger volume of inlet air, which results in higher bed temperature. The higher bed temperature increases the moisture diffusion rate, resulting in an increased drying rate. This was evidenced by continuous recording of the bed temperature which indicated a higher bed temperature at higher air velocities.

3.3 Effect of Solid holdup on Drying Kinetics

An increase in the solids hold up is found to decrease the drying rate and it can again be attributed to the lower effective bed temperature at higher solids holdup. An increase in solids holdup increases the surface area of contact between the drying medium and solids proportionally.

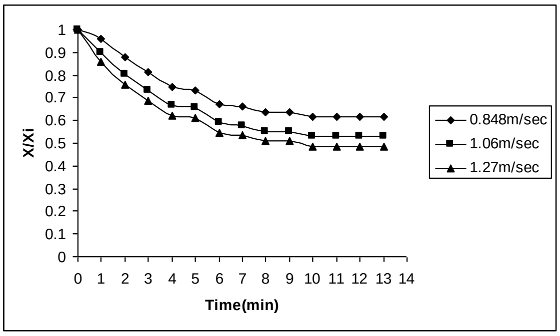

Figure 3: Effect of Air Velocity of the drying medium
(0.150kg of millet seeds, 35gm of water, 60°C temperature)

With the external conditions remaining unaltered, the higher area of contact between the phases enhances the transfer rate and hence a larger quantity of moisture diffuses from the solids resulting in a lower bed temperature. The larger contact area increases the drying rate while the lower bed temperature reduces the drying rate. Both the competing process results in lowering of drying rate with increase in solids holdup. The lower bed temperature is evidenced from the continuous recording of the bed temperature during drying.

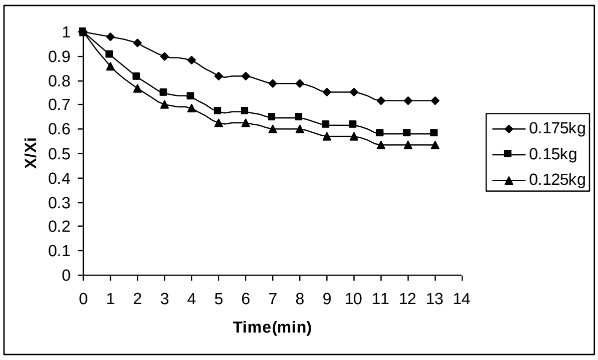

Figure 4: Effect of Weight of the Solids
(1.27m/s air velocity, 35gm water, 50°C temperature)

3.4 Modeling of Drying Kinetics in Fluidized Bed Drying

The simple exponential time decay models, popularly known as Newton model, Page model, Henderson and Pabis models are used for fluidized bed drying. Page model has produced good fits with less RMSE than others to describe drying of millet seeds in Fluidized bed drying. This model can be shown as follows.

$$\mathbf{MR=exp\,(-kt^n)}$$

Where **MR** is the moisture ratio defined as

$$\mathbf{MR=(X-X_e)/(X_i-X_e)}$$

This model assumes that the duration of constant rate period was found to be insignificant, considering the total duration of drying and experimental data also follows the same.

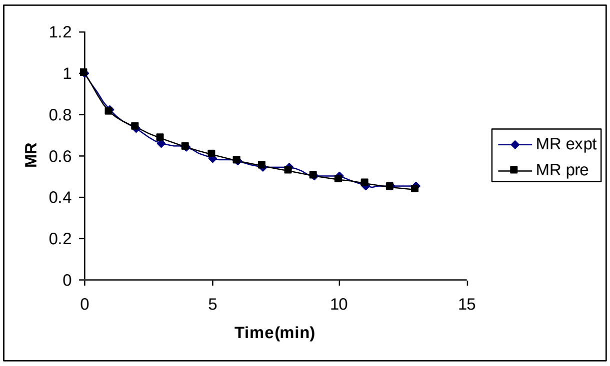

Figure 5: Comparison of Page model with experimental drying kinetics
(0.150 kg millets, 1.27 m/s air velocity, 30gm water, 50°C)

3.5 Finding RMSE

Experimental drying rates were compared with various model predictions and the model parameters were estimated by minimizing the root mean square error (RMSE) between the experimental drying rate and the model prediction.

$$RMSE = [1/N\,(\sum^{N} (x_{pre,i} - x_{exp,i})^2)]^{0.5} \times 100$$

Table-2: Evaluated drying kinetics parameters at various operating conditions

Temp (°C)	W (kg)	U (m/sec)	Page Model			H&P Model			Newton Model	
			k	n	RMSE	k	a	RMSE	k	RMSE
40	0.175	0.848	0.08	0.77	2.78	0.03	0.98	3.30	0.04	3.3
50	0.175	0.848	0.12	0.65	2.41	0.04	0.90	4.06	0.05	5.3
60	0.175	0.848	0.14	0.65	2.44	0.05	0.89	4.28	0.06	5.6
50	0.15	0.848	0.17	0.51	1.88	0.04	0.86	4.95	0.06	7.3
50	0.15	1.27	0.21	0.54	1.41	0.05	0.84	5.24	0.07	7.7
50	0.125	1.27	0.08	0.69	2.64	0.03	0.92	3.82	0.04	4.9

Table 2 compares the model parameters along with RMSE values for Page model, Newton model and Henderson and Pebis model. It can be seen from the table that the Page model is found to match experimental data very closely with less RMSE error. The k values are increased by with the increase in temperature.

3.6 Bed Voidage

The relation between bed height, minimum bed height, bed voidage and bed voidage at minimum fluidization velocity can be written as;

$$m = \frac{H - H_{mf}}{H_{mf}} = \frac{1-\varepsilon_{mf}}{1-\varepsilon} - 1 = \frac{\varepsilon - \varepsilon_{mf}}{1-\varepsilon}$$

where 'm' is the bed expansion ratio.

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. 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.

3.7 Comparison of bed voidage with air velocity at different temperatures

The Figure 6 was plotted between bed voidage and air velocity at different temperatures maintained. It was observed that bed voidage increases with the increase in air velocity at any particular temperature maintained.

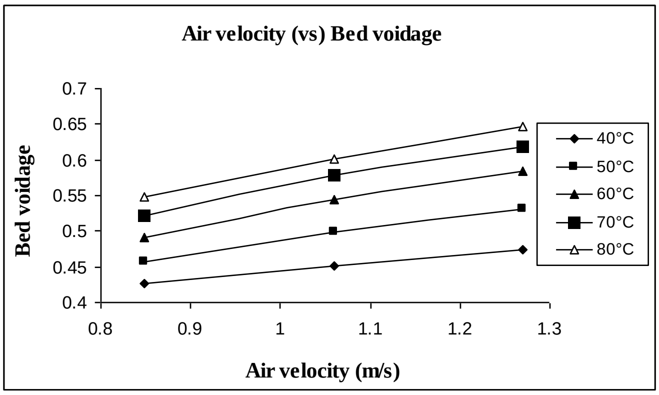

Figure 6 Comparison of bed voidage with air velocity at different temperatures

4. CONCLUSIONS

In the present work, experimental investigations were made in a fluidized bed dryer of having 5 cm ID and 50 cm height cylindrical fluidized bed column. The various operating conditions like air velocity (1.27, 1.06 and 0.848m/s), temperature (40, 50, 60°C) and Solid holdup (0.125kg, 0.150kg and 0.175kg) were maintained. The drying kinetics in the fluidized bed was found at the fluidization conditions.

The drying rate was found to increase significantly with increase in temperature and velocity of the drying medium, while decrease with increase in solids holdup. The duration of constant rate period was found to be insignificant, considering the total duration of drying. The kinetics of drying was tested with simple exponential decay models, like Newton Model, Page Model, and Henderson and Pabis Model. The model parameters are estimated by minimizing the root mean sum of square of error (RMSE) between the experimental drying rate and the model prediction. Page model was found suitable for the experimental data very closely with less root mean sum of square of error (RMSE) between the model prediction and experimental data. Newton model and Henderson and Pabis Model was found not suitable for drying kinetics of millet as those model predictions vary with the experimental data. Furthur the voidage increases steadily with the increase in air velocity at any particular maintained temperature.

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