Study of Fluidized Bed Drying Method Used For Safe Storage of Rice And Its Analyais

Rakesh Verma*[1] and Bharat Raj Singh[2]

ABSTRACT

Rice is used as a staple food by more than 60 percent of world population. The method used for Cooking of rice for eating purpose is most common and popular. Rice starch is used in making ice cream, custard powder, puddings, gel, distillation of potable alcohol, etc. It is used in confectionery products like bread, snacks, cookies and biscuits. The defatted bran is also used as cattle feed, organic fertilizer (compost), and medicinal purpose and in wax making. Rice is used as animal feed, fuel, mushroom bed, for mulching in horticultural crops and in preparation of paper and compost. Rice yields have been increasing since the 1960s, but since the 1990s, growth in rice production has been slower than population growth. Indeed, it is anticipated that rice production will need to increase by 30% by 2025 in order to sustain those who need it for sustenance. In the present work fluidized bed drying method used for safe storage of rice and analysis of rice conditions and we find that inlet air temperature has the most important effect on the drying rate of material, increasing the inlet air temperature increases the drying rate of the material. Inlet material flow rate has the most important effect on thermal efficiency. Increasing the inlet material flow rate increases the efficiency but decreases the drying rate. At lower flow rate of material, efficiency is low.

***Keywords**: Fluidized bed, Drying of rice, Paddy rice, Drying rate, Rice yield*

1. INTRODUCTION

L Garnavi et al. [2006], developed a mathematical model based on the two-phase theory of fluidization is presented for the continuous fluidized bed dryers. In contrast to the previous models, the uniformity of the bubble size along the height of the bed is not assumed. Therefore, the bubble diameter varies along the bed height. The numerical solution of the model shows that dryer performance is affected by the superficial gas velocity, average residence time, humidity, temperature and diameter of solid particle. The results obtained from variations in the superficial gas velocity imply that the performance of the fluidized bed dryer is largely affected by the drying at the constant rate drying stage [1] .

Ramli and Daud [2007] have modelled plug flow fluidized-bed dryer in which moisture contents in particulate solid and air and their temperatures are considered to be dependent on non-dimensional parameters representing gas-solid flow ratio, specific heat demand, total number of transfer units and specific drying load. The output from the model has been compared with experimental of results for paddy. The model was found to underestimate both the solid

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moisture content and temperatu re near the solid inlet [2].

From the above literature surv ey, it is found that simulation studies on fluidize d bed dryer are being carried out continuously. Howe ver algorithm has been revealed for the numerical sol ution of discretize heat and mass transfer equations wh ich are highly implicit and therefore tedious to solve .

Rice is one of the major stapl e crops in the world. The demand for rice in the India is growing faster than any other major source of calories for especially urban dwellers. Local production and processing usually yields rice of poor quality for storage and consumption. This is due to in adequate knowledge of processing, especially with the control of moisture content. According to Ahmed et al. (2006), moisture content is one of the most imp ortant factors affecting the quality of rough rice duri ng storage and that, it is at a high level at the time of harvest and must be reduced to below 15 % dry basi s with an appropriate drying process.

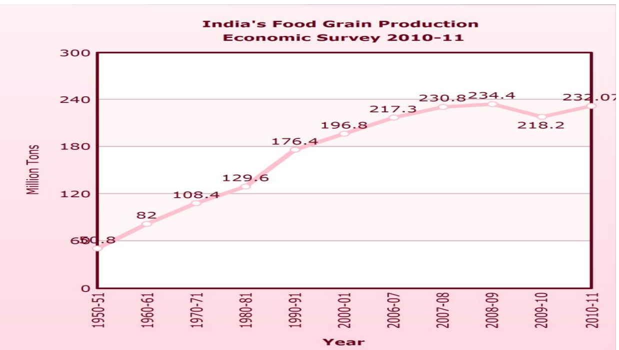

Fig. 1. Production of grain million tons Vs different year [Source: Economic Survey 2010-11]

The above chart shows India's food grain production from 1950-50 till 2010-2011[2]. From 2005-06 to 2008-09, India's fo od grains production has registered a rising trend and touched a record level of 234.47 million tons i n 2008-09 and declined to 218.11 million tons during 2009-10(final estimation).

Harvested paddy grain (rice) is usually of high moisture content (25-33% dry b asis) [3]. One of the most important factors in main taining the quality of paddy is its moisture content which must be below 15 % dry basis for long terms torage and quality milling. High moisture leads to deterio ration in seed quality as a result of micro-organism growth and respiration. In contrast, too low moisture can lead to unnecessary energy consumption and cracked seeds during drying and milling. Therefore it is necessary to bring the moisture content of paddy to b elow 15 % dry basis for safe storage and processin g.

The fluidized-bed drying is an effective approach for fulfilling the task of dry inggrain and is considered in the present work. Fluidized bed drying (FBD) is one of the drying techniques that provides faster moisture reduction and uniformity of drying. Consequently, this drying technique improves the physical quality in terms of h ead rice yield. However, many researchers were interest ed in paddy FBD with inlet air temperature over 100°C. Despite of the popularity of fluidized bed dr yer for paddy, there are a few reports concerning theor etical drying model using effective diffusivity and deve lopment of mathematical fluidized-bed rough rice dryin g model for predicting evolution of moisture transfer and energy consumption covering wide ranges of drying temperature.

A fluidized bed consists of fl uid solid mixture that exhibits fluid like properties . As such, the upper surface of the bed is relatively horiz ontal, which is analogous to hydrostatic behavior. The b ed can be considered to be an inhomogeneous mixture of fluid and solid that can be represented by a s ingle bulk density.

Fluidized beds are used as a technical process which has the ability to promote high levels of contact between gases and solids. In a fluidized bed a characteristic set of basic properties can be utilized, indispensable to modern process and chemical engineering, these properties include:

- Extremely high surface area contact between fluid and solid per unit bed volume
- High relative velocities between the fluid and the dispersed solid phase
- High levels of intermixing of the particulate phase
- Frequent particle-particle and particle-wall collisions

2. METHODOLOGY

- Literature review in respect to design of dryers, moisture contents in different seeds and food grains.
- Identification and study of requirements for drying of rough rice.
- Find out numerous kinds of heat and mass transfer equations for drying rough rice.
- Collection of all kinds of data related to drying rough rice.
- Prepare a mathematical model for drying rough rice .
- To develop geometry of dryer for storage of paddy (rice) below 15% dry basis moisture content so that throughput becomes high.
- To find the analytical results of drying parameters.

3. MATHEMATICAL MODELING

The differential equation of grain drying model are based on the laws of heat and mass transfer equations. The fluidized bed drying system divided in to the following subsystems blower, heater and drying column. For fluidized bed drying, the most significant component is drying column. Therefore, the thermal balance is derived by applying mass, energy and enthalpy balance to the drying column in of fluidized bed.

The following assumptions are considered for fluidized bed drying process:

(i) The volume shrinkage is negligible during the drying process.

(ii) The temperature gradients with in the particles are negligible.

(iii) The kernel-to-kernel conduction is negligible.

(iv) The process occurs during an isobaric process due to simultaneous heat and mass transfer between the gas and solid.

(v) Material is in plug flow along horizontal direction and air is in plug flow along vertical direction.

(vi) Both the gas and the particles are well-mixed at every cross section. Therefore the particle moisture content and temperature are uniform at any time.

(vii) The particles are isotropic homogeneous spheres of uniform size.

(viii) Water diffuses radially from the interior of the particles to the surface by molecular diffusion.

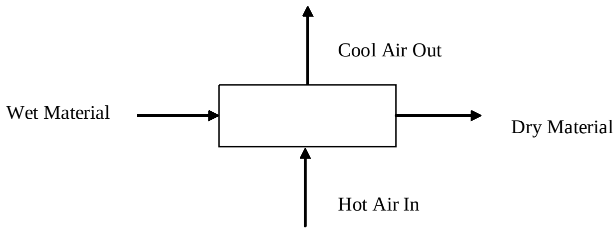

Fig.2. Schematic Diagram of Cross Flow Drying Process

4. GOVERNING EQUATIONS

4.1 Mass Balance Equation

Mass balance of moisture when transferred from solid to air expressed as

$$-m\frac{\partial X}{\partial t} = \rho_a U_{ap} A(y_{out} - y_{in}) \qquad (4.1)$$

4.2 Diffusion Equations

4.2.1 Due to assumptions grain is spherical geometry:

In the case of falling rate drying period diffusion of water through the solid assumes a dominant role and is expressed as

$$M_1 = \frac{\partial X}{\partial t} = D(V_G)\rho_p \left[\frac{\partial^2 X}{\partial r^2} + \frac{2}{r}\frac{\partial X}{\partial r} \right] \quad (4.2)$$

r is sphere radius

4.2.2 Boundary Conditions:

Initial condition: At $t = 0 \quad X = X_{in}$ (4.3)

$$\text{At } r = 0 \quad \frac{\partial X}{\partial r} = 0 \quad (4.4)$$

$$r = r_0, \quad r * \frac{\partial X}{\partial r} = hm * A * (\Delta Y)_m \quad (4.5)$$

Consequently temperature of solids considered to be uniform at any instant of time while determining mass transfer effects.

Mean residence time of the material solid inside the dryer, RT is defined as

$$RT = w_m / W_m \quad (4.6)$$

$$holdup(w_m) = VB * (1 - por) * \rho_p \quad (4.7)$$

where, w_m is the so called hold up and denotes total mass of the solid inside the dryer at any instant of time and W_m is the mass flow rate of material.

4.2.3 Formula used for Computations in Drying:

$$W_m = W_{min} / ((1 + X_{in}) * 3600 \quad (4.8)$$

$$W_a = CsA * \rho_a * Uo * \rho / (1 + Y_{in}) \quad (4.9)$$

$$CsA = LB * WB \quad (4.10)$$

$$W_{ain} = W_a / 3600 \quad (4.11)$$

Flow ratio (FR), $FR = W_a / W_m$ (4.12)

4.2.4 Heat and Mass Transfer Area between Particles and Air:

Aspect ratio (AR), $AR = LB / WB$ (4.13)

Volume of the bed $VB = LB * WB * H$ (4.14)

Volumetric flow rate of air

$$VF = CsA * Uo \quad (4.15)$$

$$Re_p = \rho_a * Uo * \rho_p * D_a / \mu \quad (4.16)$$

$$por = \left[(18 * Re_p + 0.36 * Re_p^2) / Ar \right]^{0.21} \quad (4.17)$$

$$APUV = 6 * (1 - por) / (D_p * \psi) \quad (4.18)$$

$$Area = APUV * VB / NEB \quad (4.19)$$

4.2.5 Air Outlet Humidity:

$$P_{VS_{amb}} = 610.78 * e^{\frac{17.269 + T_{amb}}{237.3 + T_{amb}}} \quad (4.20)$$

$$Pv_{amb} = RH_{amb} * Pvs_{amb} \quad (4.21)$$

$$Y_{amb} = 0.622 * Pv_{amb} / (P_{atm} - Pv_{amb}) \quad (4.22)$$

$$Y_{in} = Y_{amb} \quad (4.23)$$

$$Y_{out} = Y_{in} + (X_{in} - X_{out}) / FR \quad (4.24)$$

4.3 Discretization of Governing Equation

The next step after derivation of fundamental nonlinear partial differential equations is to use proper approach for discretization of these equations. The discretization can be derived in many ways, hence it is chosen one of the most appropriate for the nature of problem. In our problem, we used control volume approach.

4.4 Discretization of the Bed

Residence time of grain in each bed element (*RTE*),

$$RTE = RT / NEB$$

Length of the bed per element

(LBE), $LBE = LB / NEB$ (4.26)

Mass flow rate of air per element

(W_a, E), $W_aE = W_a / NEB$ (4.27)

Flow ratio per element

(FRE), $FRE = FR / NEB$ (4.28)

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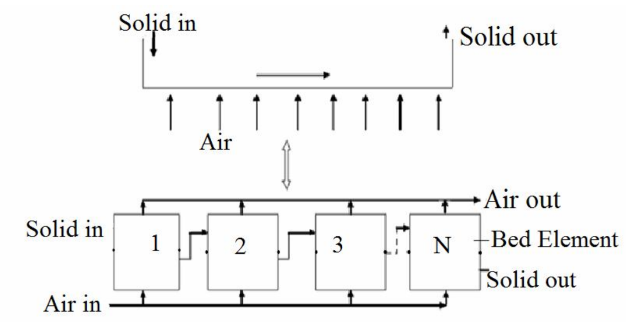

Fig. 3. Discretization of Fluidized Bed Dryer along the length

Mass balance on each element:

$$W_m (X_{in} - X_{out}) = W_a (Y_{out} - Y_{in}) \quad (4.29)$$

Mass transfer rate equation on each element:

$$W_m (X_{in} - X_{out}) = h_m A_{gt} ([\Delta Y)]_m \quad (4.30)$$

4.5 Discretization of the Grain

Radius of the grain (R_0), $R_0 = D_p / 2$ (4.31)

Surface Area of the gain *(Ar ea G)*,

$$AreaG = 4*\pi * R_0^2 \quad (4.32)$$

Volume of grain (VG), $VG = (4/3)*\pi * R_0^3$ (4.33)

$$M_1 = VG*\rho_p \quad (4.34)$$

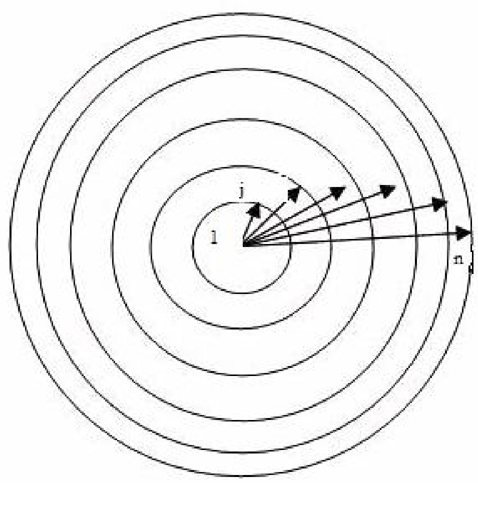

Fig. 4. Discretization of Grain along the Radius

The grain is divided into NEG number of concentric elements with equal volume, an d therefore equal mass, using (NEG+1) nodes, one at th e centre and another at the outer surface and other in between.

This gives VEG=VG/(NEG) (4.35)

$$R_2=R_0/(NEG)^{1/3} \quad (4.36)$$

$$R_i=R_2*(i-1)^{1/3} \quad (4.37)$$

Where i is varies from 3 to NE G.

Radius R_1 is defined as

$$R1=R_2/(N_{R1R2}) \quad (4.38)$$

Where N_{R1R2} is large number used for repre senting the centre of the grain with a nonzero, yet vary small, value to avoid division by zero during numerical computation.

The volume associate with node 1 and node (NEG+1) is equal to (VEG/2); whereas volume associated with all other node is equal to VEG.

4.6 Method for Solution of Gov erning Equations

4.6.1 Discretization :

(i) Number of elements along dryer length equal to NEB

(ii) Number of nodes along dryer is equal to NEB+1

(iii) Element number i extends from node (i to i+1)

(iv) Number of elements along radiu s of the grain equal to NEG.

(v) Number of nodes along grain ra dius is equal to NEG+1.

4.6.2. Selection of dX and dT :

(i) Minimum values of concentr ation differential (dX) and temperature differential (dT) to be used for computations are selected.

4.6.3 Computation for Element 1 :

(i) At node 1, X_1 and T_{m1} are known.

(ii) For hot air in cross flow mode T_{ain} and Y_{in} are known at the inlet to the elem ent 1.

(iii) The computational task lies in determining X_2 and T_{m2} values at node 2 and T_{aout} and Y_{out} for the element. The distribution of m oisture inside the grain (values of x_1, x_2, x_3…..x_n) determines X at any instant of time (at any locati on along dryer length)

(iv) This task is executed in an iterative manner by satisfying the five governing equations in sequential manner.

5. RESULTS AND DISCUSSION

5.1 *Desired Considerations for Rice after Drying*

The following considerations have been chosen from literature [11] for rough rice when dried for long period storage.

1. Average moisture content for storage = below 15% (kg/kg; d b)
2. Maximum temperature = 43 ^{0}C

5.2 Input Parameters Used for Computation

5.2.1 Dryer Geometry :

1. Length of the bed (L) = 2.4 m
2. Width of the bed (WB) = 0.3 m
3. Height of the bed (HB) = 0. 1m
4. Distributor plate thickness (DPT) = 0.003m
5. Diameter of hole (DH) = 0.002m
6. Number of holes (NH) = 5730

5.2.2 Constants Used in Rough Rice :

1. Diameter (D_p)[11] = 44mm
2. Density (ρ_p)[11] = 1200kg/m^3
3. Diffusivity of water in air (D_{wa}) [14] = 31*10^{-6}m^2/s
4. Diffusivity of water in grain (D_{wg}) [14] = 3.59*10^{-11}m^2/s
5. Constants used in Chung equation

   E = 0.29393

   F = 0.046015

   C = 35.703

5.2.3 Range of Operating Variables :

1. Ambient temperature (Tamb) = 20 - 40^{0}C
2. Relative humidity = 30 -70%
3. Air inlet temperature (Tain) = 40^{0}C - 50^{0}C
4. Inlet moisture content of material (XAin) = 18 - 30 % (kg/kg; d.b)
5. Inlet material flow rate (Wm) = 25 (kg/hr) - 50(kgh)

5.2.4 Standard Data Set Used for Result Interpretation :

1 Inlet moisture content of the material (XAin) = 25% (kg/kg;dry basis)
($X_{critical}$ = 31.63 % (kg/kg;d.b) DBT = 43^{0}C,RH = 50%,WBT=25.5^{0}C
2. Inlet material temperature (Tm in) = 30^{0}C
3. Inlet air temperature (Tain) = 43^{0}C
4. Inlet material flow rate (Wmin) = 50 kg/hr
5. Ambient air temperature (Tamb) = 30^{0}C
6. Relative humidity of inlet air (RH) = 50%
7. Moisture change differential (dX) = 0.001 (kg/kg;d.b)
8. Temperature change differential (dT) = 0.01 ^{0}C
9. Operating velocity factor (Uopf) = 0.05

5.2 Results

Figure 5.1 shows the plot between Average moisture content Vs number of element along the bed at different number of element inside the grain (NEG). From This graph we selected number of element along the bed and inside the grain. As shown in Fig. 5.1 there are not too much deviation of outlet moisture content with number of elements of the bed (NEB) after NEB=25 and also plots at NEG=15 and NEG=20 are overlap each other, after NEG=15 there is no change in outlet moisture content of the material. Therefore we fixed NEB=25 and NEG =15 for discritizing differential equation and get accurate results.

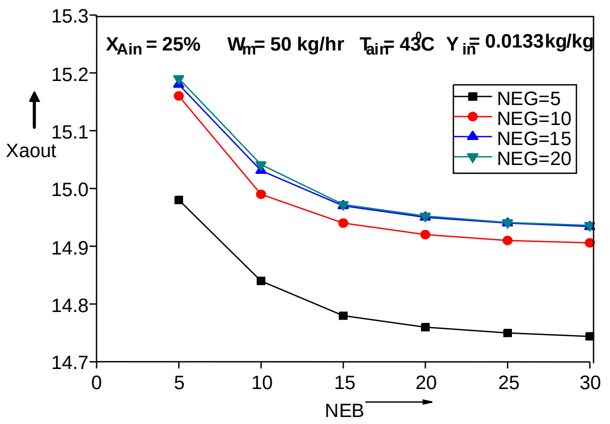

Fig. 5. Outlet moisture content Vs Number of elements along the bed at different number of elements inside the Grain

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Thus discretization information are fixed by using the Figure 5.1 as under:

1. Number of elements of the bed (NEB) = 25
2. Number of elements of the grain (NEG) = 15

XAin = 25% Wm = 50 kg/hr
Tain = 43°C Yin= 0.0133kg/kg

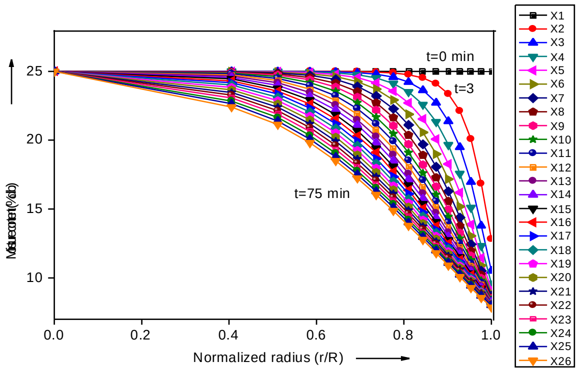

Fig.6. Moisture content profiles within Rice kernel

The initial moisture content of rough rice was 25% dry basis the moisture content at the internal layers of rice kernels did not decrease significantly during drying period but at the outer layer of rice kernels decrease very quickly. The moisture content of the centre (r/R=0) in a rice kernel almost remained the initial moisture content after drying of 75 min while the moisture content at the surface (r/R=1) dropped to 7.9%d.b show above in Fig.6 Consequently, the moisture content gradients were created within the rice kernels during the drying period. High moisture gradient is occurred at surface of grain.

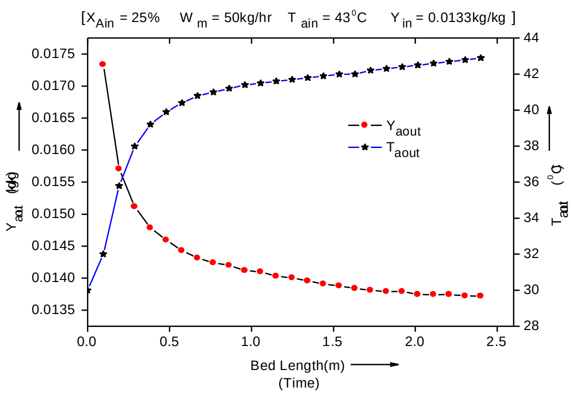

Fig.7. Average Outlet Moisture Content and temperature of Grain Vs Length of the Dryer (Time)

Figure 7 shows that average outlet moisture content in the grain drop continuously along the length of the dryer (or with time) at decreasing rate. On observing the plot, it is seen that drying rate and temperature of grain is faster initially then decrease with length (or time).Because there is no moisture gradient in grain initially. So that driving potential for the mass transfer is more therefore drying rate faster and it decreases with time. Driving potential for mass transfer is reduces faster with reduction in moisture content and it is increase with rise in temperature of the grain as shown in above Fig. 6. Grain temperature increases continuously along the length of the dryer at decreasing rate due to the above reason. Final moisture and temperature of grain are on the expected line for long term storage.

6. CONCLUSIONS

In this study a software is used to solve above mathematical model for storage of grain below 15% d.b and geometry of dryer taken for high flow of grain in dryer. From the various parametric changes, following conclusions have been drawn:

(i) The inlet air temperature has the most important effect on the drying rate of material and by increasing the inlet air temperature; it increases the drying rate of the material.

(ii) Inlet material flow rate has the most important effect on thermal efficiency. While inlet material flow rate increases, the efficiency of the drying rate increases and at lower flow rate of material, efficiency goes down.

(iii) High moisture grain drying needs tempering for going to safe moisture content .

Thus on the basis of above results and output received from mathematical model, it is concluded that suitable design can be created for optimal utilisation of fluidized bed dryer.

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