Chapter 5

MATHEMATICAL MODELING

The process of dying is governed by the basic laws of heat and mass transfer. Equations governing mass conservation, energy conservation, heat transfer rate, and mass transfer rate, and diffusion equation were applied.

Basic input requirements for an analytical study of a given dryer geometry include the following:

1. Solid - moisture equilibrium relation
2. Transport coefficients for the diffusion of heat and moisture in the solid.
3. Thermo physical properties of the solid being dried.
4. Drying kinetics

5.1 Assumptions:

1. Material and air are in plug flow.
2. The temperature gradients within grains are neglected for computing the mass diffusion equation. This is because of the high value of thermal diffusivity as compared with mass diffusivity (about 10^6 times greater).
3. The Material to material conduction is neglected.
4. The process of simultaneous heat and mass transfer between solid and air occurs at constant pressure.
5. Both the gas and particle are well mixed at every cross-section. Therefore particle moisture content and temperature are uniform at any time.
6. Water diffuses radially from the interior of the particles to the surface by molecular diffusion.
7. Steady flow.
8. C_p values and latent heat of vaporization are constants.
9. Moisture diffusivity is constant

5.2 GOVERNING EQUATIONS FOR MATHEMATICAL MODELING

The following equations apply to the total bed.

Mass Balance Equation

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

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

Enthalpy Balance Equation

Similarly, the total enthalpy balance between a solid material and air leads to

$$m\frac{\partial H_m}{\partial t} = \rho_a U_{op} A(H_{in} - H_{out})$$

Mass Transfer Rate Equation

The movement of water vapor from solid to surrounding air is governed by mass transport phenomena at the outer surface of the solid and is expressed as

$$-m\frac{\partial X}{\partial t} = h_m A_{gt}(\Delta Y)_m$$

Heat Transfer Rate Equation

The total heat being transferred from air to the solid material, in general, performs two tasks; raising the temperature of the solid material and supplying latent heat for vaporization. This is stated by

$$m\frac{\partial H_m}{\partial t} - mL\frac{\partial X}{\partial t} = hA_{gt}(\Delta T)_m$$

Diffusion equation

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

During falling rate of drying, diffusion of water through the solid for the spherical shape is expressed as

$$\frac{\partial x}{\partial t} = D_{wm}\left[\frac{\partial^2 x}{\partial r^2} + \frac{2}{r}\frac{\partial x}{\partial r}\right]$$

The Set of boundary conditions applicable to the diffusion equation are:

$$\text{At } t = 0, \quad x = X_{Ain} \qquad \text{At } r = 0, \quad \frac{\partial x}{\partial r} = 0;$$

$$\text{At } r = r_0, \quad \rho_m D_{wm}\frac{\partial x}{\partial r} = h_m(Y_E - Y_i)$$

An residence time of the material solid inside the dryer RT is defined as [Geldart, 1986]

$RT = Holdup/G_m$ Where $Holdup = VB(1-\epsilon)\rho_p$

Holdup denotes total mass of the solid inside the dryer at any instant of time and G_m is the mass flow rate of material.

5.3. Discretization of Bed

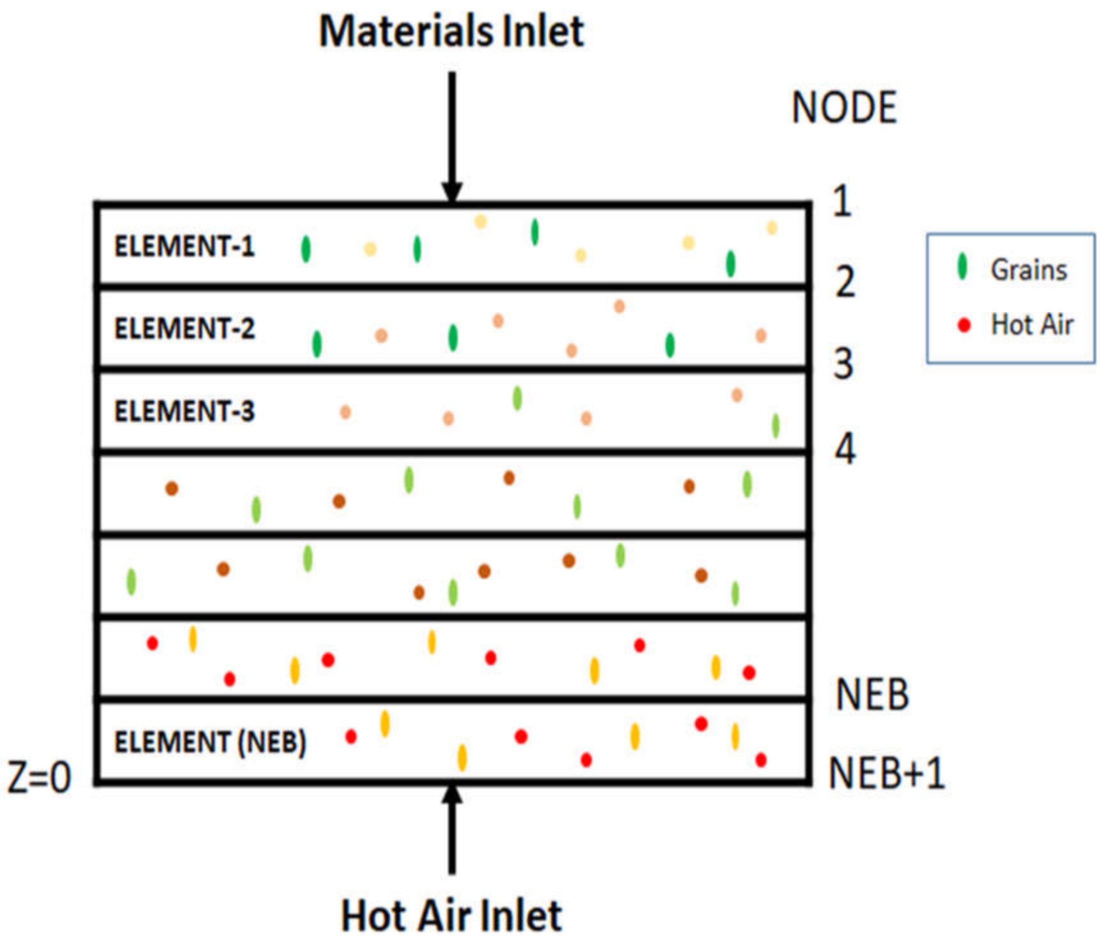

Figure 5.1. Discretization of counter flow deep bed into N elements with (N+1) nodes

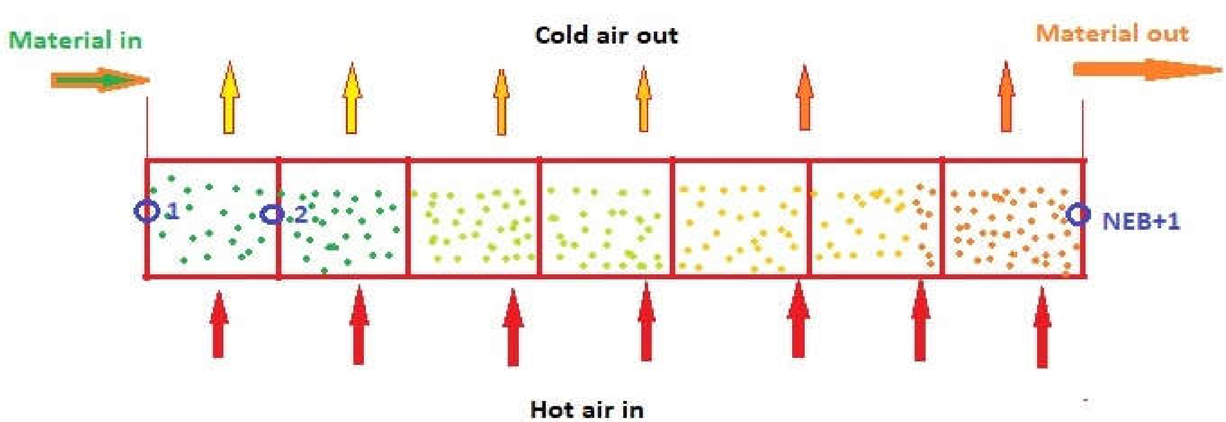

Figure 5.2. Discretization of cross flow fluidized bed dryer along length

Figure 5.1 gives the discretization of the counter flow deep bed dryer. The total bed is divided into NEB number of the element with equal length, and therefore equal volume using (NEB+1) nodes 1st one lying at the entry point of the bed and the last one is at exist as shown in the figure below. Hot air at uniform inlet condition enters through the bottom while material flow in the vertical direction with a controlled constant height depending upon the need. The condition of the inlet air can be varied along the dryer length.

Figure 5.2 gives the discretization of the cross-flow fluidized bed dryer. The total bed length is divided into NEB number of elements with an equal span, and therefore the equal volume, using (NEB+1) number of nodes, the first one lying at the entry point of the bed and the last one at the exit. Hot air at uniform inlet conditions enters through the bottom while the material flows in the horizontal direction with a constant bed height.

The governing equations for a general element along the dryer length are given below:

5.4 Governing equations for each discretized element inside the bed.

Mass balance equation

$$G_m\,(X_i - X_{i+1}) = G_a\,(Y_{i+1} - Y_i) \qquad \text{(Eq.1)}$$

Heat transfer rate equation:

$$G_m\big(H_{m,i+1} - H_{m,i}\big) + G_m\,(X_i - X_{i+1})hfg = h\,(A)(\Delta T)_m \qquad \text{(Eq.2)}$$

Enthalpy balance equation:

$$G_m\,(H_{m,i+1} - H_{m,i}) = G_a\,(H_{a,i} - H_{a,i+1}) \qquad \text{(Eq.3)}$$

Mass Transfer Rate Equation:

$$G_m\,(X_i - X_{i+1}) = h_m\,(A)(\Delta Y)_m \qquad \text{(Eq.4)}$$

For continuous counter flow deep bed drying $(\Delta T)m,\ and\ (\Delta Y)m$ is given below,

$$(\Delta T)m = LMTD = [(T_{a,i} - T_{m,i}) - (T_{a,i+1} - T_{m,i+1})]/[ln\{(T_{a,i} - T_{m,i})/(T_{a,i+1} - T_{m,i+1})\}]$$

$$(\Delta Y)\ m = LMYD = [(Y_i - Y_{eq,i}) - (Y_{i+1} - Y_{eq,i+1})]/\ [ln\{(Y_i - Y_{eq,i})/(Y_{i+1} - Y_{eq,i+1})\}]$$

For continuous cross flow fluidised bed drying $(\Delta T)m,\ and\ (\Delta Y)m$ is given below,

$$(\Delta T)m = LMTD = [(T_{ain} - T_{a,i})/[ln\{(T_{ain} - T_{m,i+1})/(T_a - T_{m,i+1})\}]$$

$$(\Delta Y)\ m = LMYD = [(Y_i - Y_{in})/\ [ln\{(Y_{eq,i} - Y_{in})/(Y_{e,i} - Y_i)\}]$$

Diffusion equation is as follow;

$$\frac{\partial x}{\partial t} = D_{wm}\left[\frac{\partial^2 x}{\partial r^2} + \frac{2}{r}\frac{\partial x}{\partial r}\right] \qquad \text{(Eq.5)}$$

The Set of boundary conditions applicable to the diffusion equation are:

$$\text{At } t = 0,\quad x = X_{Ain} \qquad \text{At } r = 0,\quad \frac{\partial x}{\partial r} = 0;$$

$$\text{At } r = r_0,\quad \rho_m D_{wm}\frac{\partial x}{\partial r} = h_m(Y_E - Y_i) \qquad \text{(Eq.6)}$$

5.5 Discretization of Particle

Figure 5.3 shows the discretization of the grain. The spherical grain kernel is divided into NEG number of concentric elements with equal volume, and therefore the equal mass of dry grain, using (NEG+1) number of nodes. If node 1 is placed at the center of the grain, the water diffusion conductance between the pair of nodes 1 and 2 will become zero. If it is placed very near to the centre, the above conductance will still be much smaller in comparison to its value for pair of nodes 2 and 3. Both of these arrangements will lead to erroneous results by keeping the moisture content at node 1 least affected with the passage of time during numerical computation. In order to combat this numerical imbalance, the node 1 is placed at half of the radius where node 2 is located. This arrangement makes the water diffusion conductance between pair of nodes 1 and 2 to be of the same order of magnitude as that for pair of nodes 2 and 3. Thus numerical errors in final results get very much reduced. The last node lies at the outermost surface of the grain.

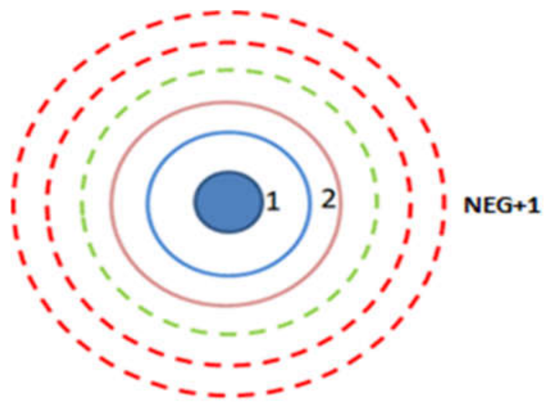

Figure 5.3. Discretization of grain along the radius.

5.6 Generation of Diffusion Equations Using Implicit Method

While discretizing the diffusion equation, the mass balance method, similar to the standard energy balance technique, is used over a finite control volume of spherical shape. Using fully implicit formulation, in which the future unknown nodal values of mass concentration in grain kernel are considered to prevail throughout for each time span Δt, right from the beginning of its entry into a dryer element to its exit from the same, the formula for steady mass transfer in the radial direction is applied over the period. The moisture balance equation for a general node is developed by equating the net moisture going out of it due to diffusion mass exchange with the neighboring nodes, during the time span of its stay inside an element, to the decrease in its moisture content over the same time period.

Let M represent the dry mass of each full element of the grain. This is the mass associated with grain volume with the radius of node 2. Since node 1 has a radius that is half of the radius at node 2, the spherical volume at node 1 is (1/8) of the volume at node 2. Therefore, the grain mass between the centre and the node 1 is (M/8) and that between node 1 and node 2 becomes equal to (7M/8).

Half of the mass between two consecutive nodes is associated with nodes on either side of it. Thus, node 3 to node NEG, each one has mass M associated with it; whereas, node (NEG+1) has only a mass of (M/2) attributed to it. The grain mass of (M/8) between centre to node 1 has is fully attached with node 1. A mass of (7M/8) is enclosed between node 1 and node 2 and both the nodes share half of it. Accordingly, node 1 has a total mass of (4.5M/8) and node 2 has a total mass of (7.5M/8).

Assuming Δt as residence time of grain for each element along dryer length and we get the following algebraic equations for diffusion of water inside the grain for different nodes.

Overall water diffusivity C_{jm1} and C_{jp1} as given below.

$$C_{jm1} = \frac{4\pi r_j \, r_{j-1} D_{wg} \rho_p}{r_j - r_{j-1}}$$

$$C_{jp1} = \frac{4\pi r_j \, r_{j+1} D_{wg} \rho_p}{r_{j+1} - r_j}$$

For node 1:

$$\frac{4.5M}{8\Delta t}\left(x_1^p - x_1\right) = C_{jp1}(x_1 - x_2) \quad \text{(Eq.7)}$$

Node2:

$$\frac{7.5M}{8\Delta t}\left(x_2^p - x_2\right) = C_{jp1}(x_2 - x_3) - C_{jm1}(x_1 - x_2) \quad \text{(Eq.8)}$$

Node j: where j =3 to NEG

$$\frac{M}{\Delta t}\left(x_j^p - x_j\right) = \mathrm{C_{jp1}}\left(\mathrm{x_j} - \mathrm{x_{j+1}}\right) - \mathrm{C_{jm1}}(\mathrm{x_{j-1}} - \mathrm{x_j}) \quad \text{(Eq.9)}$$

Node NEG+1:

$$\frac{M}{2\Delta t}\left(x_{NEG+1}^p - x_{NEG+1}\right) = h_m A(\Delta Y)_m - C_{NEG}(x_{NEG} - x_{NEG+1}) \quad \text{(Eq.10)}$$

Solving the above simultaneous equations using the Tri-Diagonal Matrix Algorithm (TDMA), we get moisture content values at the different nodes of the grain. And Evaluation of $(\Delta Y)_m$ the above equation requires knowledge of the equilibrium moisture content of canola in terms of temperature and relative humidity.

5.7. Formulae used in intermediate computations for drying

Gm=Wm/(3600*(1+Xin)) (11)

Ga= CS*Usup*ρa (12)

CS = LB*WB (13)

FR = Ga / Gm (14)

$\rho_a = 353.049/(T_{ain} + 273.15)$ (15)

$g = 9.81\ m/s^2$ (16)

$Ar = \rho_a Dp^3 (\rho_p - \rho_a) g / \mu_a^2$ (17)

Heat and Mass transfer Area between Particles and Air

Aspect ratio (AR), AR=LB/WB (18)

Volume of the bed, VB=LB*WB*HB (19)

Volumetric flow rate of air VF=CS*Usup (20)

Area per unit volume APUV=6*(1-por)/(Dp*ψ) (21)

Area=APUV*VB/NEB (22)

Reynolds number $Re_p = \rho_a * U_{sup} * D_p / \mu_a$

Void fraction ϵ or porosity (por) comes from [Geldart, 1986]

$$\epsilon = \left[\frac{(18\ Re_p + 0.36\ Re_p^2)}{Ar}\right]^{0.21}$$

Air Outlet Humidity [Lawrence, 2005]

$Pvs = 610.78 * e^{(17.269*T)/(237.3+T)}$ (23)

Pv =RH/Pvs (24)

$Y = 0.622*Pv/(P_{atm} - Pv)$ (25)

Computation of Enthalpy components [Brooker et al., 1992**]**

Following relations are used

$H_{min} = (Cp_m + X_{in}\, Cp_w) T_{min} - X_{in}(\Delta H_{sin})$ (26)

$$\mathrm{H_{mout}} = (\mathrm{Cp_m} + \mathrm{X_{out}}\, Cp_w)\mathrm{T}_{mout} - \mathrm{X_{in}}(\Delta \mathrm{H_{sout}}) \quad (27)$$

$$\mathrm{H_{ain}} = \mathrm{Cp_a} * \mathrm{T}_{ain} + \mathrm{Y_{in}}[\mathrm{Cp_w} * \mathrm{Tdp_{in}} + \mathrm{hfg} + \mathrm{Cp_v} * (\mathrm{T_{ain}} - \mathrm{Tdp_{in}}) \quad (28)$$

$$\mathrm{H_{aout}} = \mathrm{Cp_a} * \mathrm{T}_{aout} + \mathrm{Y_{out}}[\mathrm{Cp_w} * \mathrm{Tdp_{out}} + \mathrm{hfg} + \mathrm{Cp_v} * (\mathrm{T_{aout}} - \mathrm{Tdp}_{out}) \quad (29)$$

For Material, [Brooker et al., 1992**]**

$$Cp_m = C1 + C2 * M \quad (30)$$

where C1 and C2 are constants, and its varies from material to material, and its value is provided in table 5. In the appendix section.

Where, M is the moisture content in wet basis, i.e. $M = X * 100/(X + 1)$

$$K = Cs * Tm \quad (31)$$

The equation for the latent heat of vaporization of material (Hfgm) is given below,

$$Hfgm = (2502.2 - 2.39 * T_m) * [1 + A \exp(-B * M)]$$

Where A and B are constants and their values are given in table 2. in the appendix section,

The equation for the latent heat of vaporization of air (Hfga) is given below;

For $237.16 < T_m < 338.72$

$$Hfga = (2.503 * 10^6 - 2.383 * 10^3 * T_m)/1000 \quad (32)$$

For $338.72 < T_m < 533.16$

$$Hfga = (7.33 * 10^{12} - 1.6 * 10^7 * T_m^2)^{0.5}/1000 \quad (33)$$

$$\Delta Hs = Hfgm - Hfga \quad (34)$$

Hence enthalpy of the material (Hm) is calculated as,

$$Hm = K - X^* \Delta Hs \qquad (35)$$

For Air [Lawrence, 2005**],**

The dew point temperature of the air can be estimated by the equation [16]

$$\boldsymbol{T_d} = \frac{b\left[ln\left(\frac{RH}{100}\right)+\frac{aT}{b+T}\right]}{a-ln\left(\frac{RH}{100}\right)-\frac{aT}{b+T}} \qquad (36)$$

Where:
a=17.625, *b*=243.04 *T* is in ºC, *Td* is in ºC, *RH* is in %

Sutherland's equation [Reid] is used to correlate viscosity ($\boldsymbol{\mu}$) and thermal conductivity ($\boldsymbol{K}$) with temperature [Reid et al., 1987]

$$\mu_{air} = \frac{1.4592\, T^{3/2}}{109.10+T} \qquad \left[\frac{N.s}{m^2}\right] \qquad (37)$$

$$K_{air} = \frac{2.3340*10^{-3}\, T^{3/2}}{164.54+T} \qquad \left[\frac{W}{m.K}\right] \qquad (38)$$

Specific heat follows a quadratic relationship [Reid et al., 1987]

$$\boldsymbol{Cpa = 1030.5 - 0.19975\, T + 3.9734 * 10^{-4}\, T^2} \quad \left[\frac{J}{kg.K}\right] \qquad (39)$$

Calculation of Mass Transfer Coefficient for Deep bed dryer (hm) [Upadhyay et al., 1975]

For Reynolds number, **0.01< Re < 10;**

$$\epsilon\, J_d = 1.075\, Re_{Dp}^{-0.826} \qquad (40)$$

Where

$$J_d = \frac{hm}{\rho_a * Usup} * Sc^{2/3} \quad (41)$$

$$Re_{Dp} = \frac{\rho_a * Dp * Usup}{\mu * (1-\epsilon)} \quad (42)$$

Simplifying;

$$\frac{hm}{(\rho_a * Usup)} * Sc^{2/3} = \frac{1}{\epsilon} 1.075 \, Re_{Dp}^{-0.826} \quad (43)$$

For higher Reynolds number**, Re > 10;**

$$\epsilon \, J_d = 0.455 \, Re_{Dp}^{-0.40} \quad (44)$$

Simplifying;

$$\frac{hm}{(\rho_a * Usup)} * Sc^{2/3} = \frac{1}{\epsilon} 0.455 \, Re_{Dp}^{-0.40} \quad (45)$$

Calculation of Heat Transfer Coefficient (h) for Deep bed dryer [Whitaker, 1972**]**

For $20 < Re_{Dp} < 10^4$, Whitaker suggested;

$$\frac{h \, Dp}{k} = \frac{1-\epsilon}{\epsilon} \left[0.5 \, Re_{Dp}^{1/2} + 0.2 \, Re_{Dp}^{2/3}\right] Pr^{1/3} \quad (46)$$

Calculation of Mass Transfer Coefficient for fluidized bed dryer (hm) [Arun S. Mujumdar, 2014]

For $0.1 < Re_p < 15$

$$Sh = 0.374 * Re_p^{1.8} \quad (47)$$

For $15 < Re_p < 500$

$Sh = 2{,}01 * \mathrm{Re}_p^{0.5}$ (48)

$hm = Sh^{*} Dwa^{*} \rho_a / D_p$

where , $\mathrm{Re_p} = \rho_a * \mathrm{U}_{sup} * D_p / \mu_a$

Calculation of Heat Transfer Coefficient (h) for fluidised bed dryer [Arun S. Mujumdar, 2014]

For

$0.1 < \mathrm{Re}_p < 80$

$Nu = 0.03 * \mathrm{Re}_p^{1.3}$ (49)

$80 < \mathrm{Re}_p < 500$

$Nu = 0.316 * \mathrm{Re}_p^{0.8}$ (50)

$h = Nu^{*} K_a / D_p$ (51)

5.8. Pressure Drop in Packed Bed (Deep bed) [Rohsenow et al., 1998]

Ergun provided a semi-empirical equation that could be used to a variety of flow circumstances. Pressure loss is assumed to be induced by simultaneous kinetic and viscous energy losses in this method. The pressure decrease is caused by four elements in Ergun's formulation. They are (1) fluid flow rate, (2) fluid characteristics (such as viscosity and density), (3) packing closeness (such as porosity) and orientation, and (4) solid particle size, shape, and surface. For pressure drop across a packed bed of mono sized particles, Ergun came up with the following equation:

The **Ergun equation** that is commonly employed is given below:

$f_p = \frac{150}{\mathrm{Re_p}} + 1.75$ (52)

Here, the friction factor f_p for the packed bed, and the Reynolds number $\mathrm{Re_p}$They are defined as follows.

$f_p = \frac{\Delta P \times D_p}{L \times \rho a \times U_{sup}^2} + \left(\frac{\epsilon^2}{1-\epsilon}\right)$ (53)

where Re_p is defined as: $$Re_p = \frac{D_{p\times}\rho a \times U_{sup}^2}{(1-\epsilon)\times\mu} \quad (54)$$

D_p: Equivalent spherical diameter of the particle defined by

$$D_p = 6 \times \frac{volume\ of\ the\ particle}{surface\ area\ of\ the\ particle} \quad (55)$$

Where:

ΔP : Pressure Drop

U_{sup} : superficial velocity

ρa : Density of air

L : Length of the dryer

ϵ : Void fraction of the bed

μ : Dynamic viscosity of the fluid

Pressure Drop in fluidized bed [Geldart, 1986]

Pressure before distributor plate (PBDP) i,e, by the blower, is nothing but the sum of atmospheric pressure (P_{atm} =101.325 Kpa), pressure drop in distributor plate(ΔPDP) and pressure drop in the bed (△ PBD)

$$PBDP = P_{atn} + \Delta PDP + \Delta PBD \quad (56)$$

Pressure before bed (PBB),$PBB = P_{atm} + \Delta PBD$ (57)

Velocity before bed, $UBB = Uop * \left[\frac{PBDP}{PBB}\right]^{1/\gamma}$ (58)

Temperature before bed, $TBBED = (T_{ain} + 273.16) * \left[\frac{PBB}{PBDP}\right]^{(\gamma-1)/\gamma}$ (59)

Velocity after bed, $UAB = \frac{(PBB*UBB)}{(TBED+273.16)} * \frac{(T_{BED}+273.16)}{P_{atm}}$ (60)

Where $T_{BED} = \frac{(T_{ain}+T_{min})}{2}$ (61)

Pressure Drop in Bed

DHD is the Hole Diameter of the Distributor's plate

Area of a hole in the air distributor, Ahole $= \frac{\pi}{4} * (DHD)^2$ (62)

The total area of holes in the distributor, AholeT $=$ No. of holes * Ahole (63)

Area of hole factor, AholeF $=$ AholeT $/(LB^*WB)$ (64)

Velocity in the hole, Uhole = Uop / AholeF (65)

Reynolds number of the hole , Rehole $= (\text{Uhole}\ ^*DHD)/(\mu_a * \rho_a)$ (66)

Pressure drop due to contraction loss $\Delta\text{PDC} = \left[\frac{0.5*(1-AholeF)*\text{Uhole}^2}{2}\right] * \rho_a/1000$ (67)

Pressure drop due to expansion loss, $\Delta PDE = \left[\frac{(\text{Uhole} - Uop)}{2}\right] * \rho_a/1000$ (68)

Pressure drop along distributor length, $\Delta\text{PDL} = \left[\frac{(FF^*DPT^*Uhole^2)}{(2*DPHD)}\right] * \rho_a/1000$ (69)

Friction factor, $FF = 0.3164/\text{Re}\ hole^{0.25}$ (70)

Pressure drop in distributor plate $\Delta PDP = \Delta PDC + \Delta PDE + \Delta PDL$ (71)

Pressure drop in the bed $\Delta\text{PBD} = HB * (1 - por) * (\rho_p - \rho_a) * g/1000$ (72)

Air Operating Velocity in fluidized bed dryer is calculated as, Uop [Geldart, 1986]

$\rho_a = 353.49/(T_{ain} + 273.15)$ (73)

$g = 9.81$ (74)

$Ar = \rho_a * D_p^3 * (\rho_p - \rho_a) * g/\mu_a^2$ (75)

$\text{Re}\ mf = (1135.7 + 0.0408 * Ar)^{0.5} - 33.7$ (76)

$Umf = \text{Re}\ mf^*\mu_a/(\rho_a * D_p)$ (77)

$Uop = (1 + Uopf) * Umf$ (78)

5.9. Equilibrium moisture content [Brooker et al., 1992]

Along with the modified Henderson equation, the empirical Chung equation (Chung) is frequently employed to predict the moisture content values of grains.

The Chung-Pfost equation has the form,

$$\mathbf{X_{eq}} = \mathbf{E} - \mathbf{F} \times \mathbf{ln}\left(-(\mathbf{T} + \mathbf{C}) \times \mathbf{ln}\left(\frac{\mathbf{P_v}}{\mathbf{P_{vs}}}\right)\right) \quad (79)$$

Here X_{eq} is the equilibrium moisture content (decimal d.b), and T is the temperature (°C); C, E, and F are product constants. The values for the major grains are tabulated in Table.1 in Appendix A.

Critical Moisture Content

Critical moisture content can be calculated using a suitable equilibrium equation by taking Pv = 0.99Pvs, and it is given by, here we have taken Chung equation as an example.

$$X_{Cr} = E - F * \ln\left[-(T + C) * \ln(0.999)\right] \quad (80)$$

if $X_{\text{in}} > X_{Cr}$ Constant rate period prevails.

if $X_{\text{in}} < X_{Cr}$ Falling rate period prevails.

5.10. Drying Efficiency

The efficiency of the drying operation is an important factor in the assessment and selection of the optimum dryer for a particular task. Some parameter that affects the drying efficiency is as follow:

- Environment, ambient air conditions.
- The design and operation of the dryer.

The drying efficiency, defined as:

$$\text{Drying Efficiency} = \frac{\textit{Heat utilized for moisture removal}}{\textit{heat available for moisture removal}}$$

$\eta = (HU/THS)*100$ (81)

Latent heat utilized, $HU = G_m(X_{in} - X_{out})\ HFG$ (82)

Total heat supplied, $THS = G_a(\,Cp_a + Y_{in}Cp_w)(T_{ain} - T_{amb})$ (83)

Power consumed by the blower can be expressed as

$$P = \left(\text{CS} * \text{Usup} * \text{Pressure drop}\right)/\acute{\eta} \quad (84)$$

Where, $\dot{\eta}$ is the efficiency of the blower.