Chapter 9

DESIGN ANALYSIS OF CONTINUOUS COUNTER-CURRENT DEEP BED DRYING OF CORN THROUGH MODELLING AND SIMULATION

9.1. Introduction

The art of drying is as old as civilization. It is the most widely practiced grain preservation method. A large amount of water is evaporated from the grain in the drying process. While drying corn, from 25% to 15% moisture content (w.b.), over 100 kg of water is removed per metric ton, demanding more than 500MJ of energy. Drying requires about 60% of the total energy used in corn production. The results have been generated for drying of corn and are found to be consistent with the expected behaviour. The simulation program developed is fairly general and can be used for any spherical particulate material. The detailed performance prediction results can be used to arrive at an optimum design. Also, optimum performance from an existing dryer design can be obtained by judicious selection of input parameter

9.2. Input parameters taken for counter current grain drying.

Design of dryer geometry:

1. Height of the Dryer (Bed) = 1m
2. Area of cross section of the dryer(cs) = $0.4m^2$

Properties of corn:

Diameter = 0.004m ,$D_{wg} = 5.25*10^{-11}$ m^2/s [ASME, Feb, 1999]

Density = 1350 kg/m^3[ASME, Feb, 1999]

Water diffusivity into air = $31*10^{-6} m^2/s$ [T. L. Norman et al., 2006]

<u>Design set of operating variables</u>:

1. Inlet air Temperature (Tain) = 60ºC[Talbot, 2003]
2. Inlet air Relative Humidity (RHin) = 50%
3. Inlet material flow rate (G_m) = 100 kg/hr
4. Inlet air flow rate (G_a) = 1800 kg/hr
5. Inlet material temperature (T_{min})= 30 ºC
6. Inlet material moisture content(X_{in})= 0.25
7. Ambient air temperature T_{amb} = 30 ºC
8. dX= 0.001 kg/kg d.b.
9. dT=0.1 ºC

<u>Range of variables</u> :

1. Inlet air Temperature (Tain) = 55ºC – 75ºC
2. Inlet air Relative Humidity (RHin) = 40% - 60%
3. Inlet material flow rate(G_m) = 80 kg/hr – 110 kg/hr
4. Inlet air flow rate (G_a) = 1500 kg/hr – 2000 kg/hr

Equilibrium moisture content

A study by[Chen et al., 1989] Along with the modified Henderson equation, the empirical Chung equation (Chung) is frequently employed to predict the moisture content values of grains

The Chung equation has the form [Brooker et al., 1992]

$$X_{eq} = 0.33872 - 0.058970 * ln\,[\,-(T + 30.205) * \ln(P_v\,/\,P_{vs})$$

9.3. Results and Discussion

It is clear from the fig. 9.1 that the moisture content decreases as the grain moves along bed depth whereas the humidity of air increases as air moves towards the top. The sharp decrease in the moisture content in the beginning i.e. near top region of the dryer and the sharp increase in the humidity of air near the top are dependent on each other in accordance with mass balance. Fig.9.2 shows a decrease in temperature of air as it reaches its exit whereas there is an increase in the temperature of material because it reaches the air inlet which is its exit.

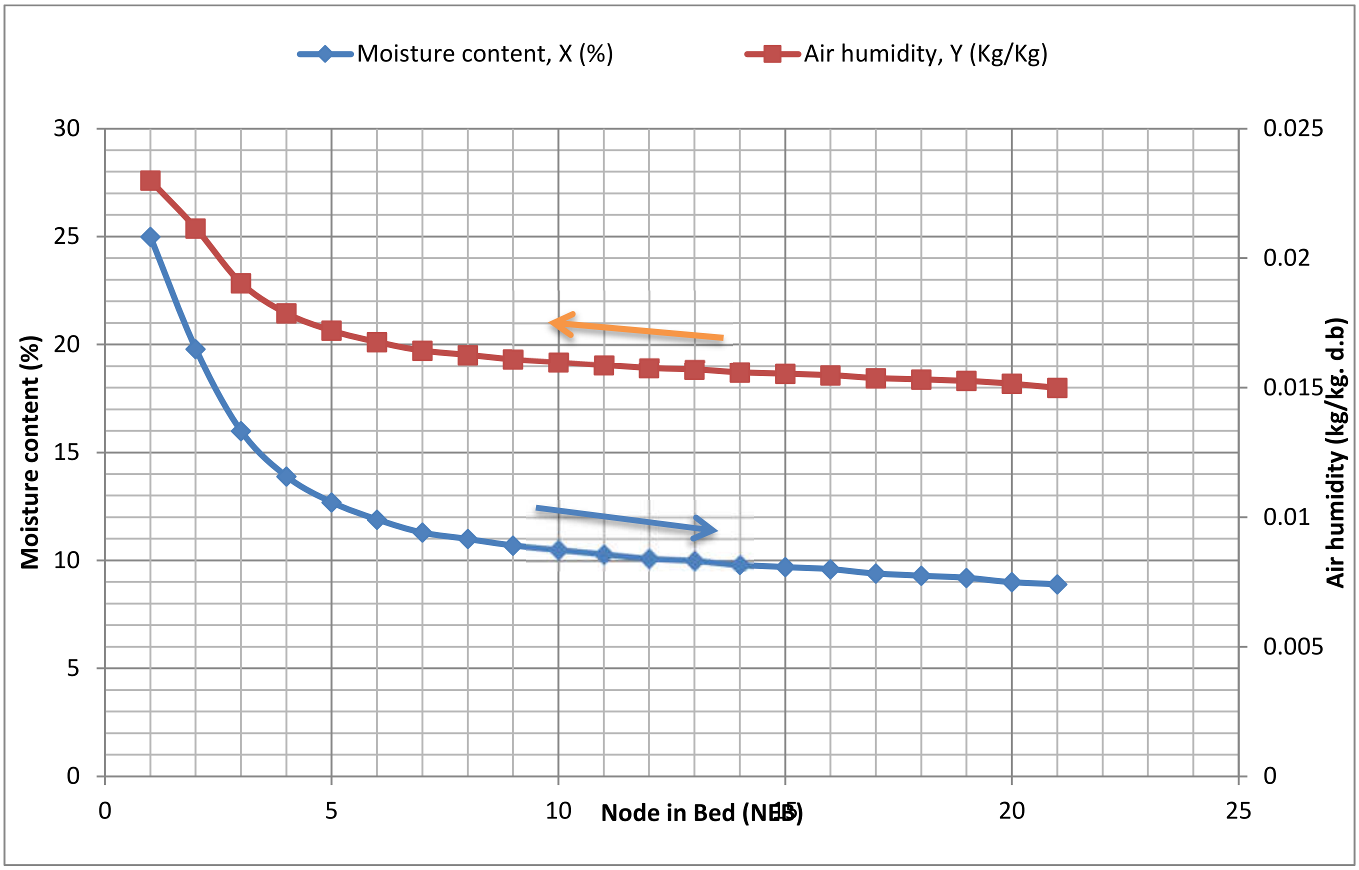

Figure 9.1. Variation of Moisture content of grain, X and humidity of air, Y along bed

Fig.9.3. shows the profile of moisture within the grain when it pass through different nodes of bed. When grain is at the first node, each node within the grain has same moisture content which is 25%. When the grain moves further along bed depth, the moisture comes out at the surface and gets evaporated thereby decreasing the moisture content throughout the grain. Thus, the grain moisture profile shows decrease in moisture content as grain moves down in the dryer. It is also seen that there is a sharp decrease in the moisture content while moving from first to the second node within the grain as compared to the drop in moisture in the succeeding nodes in grain.

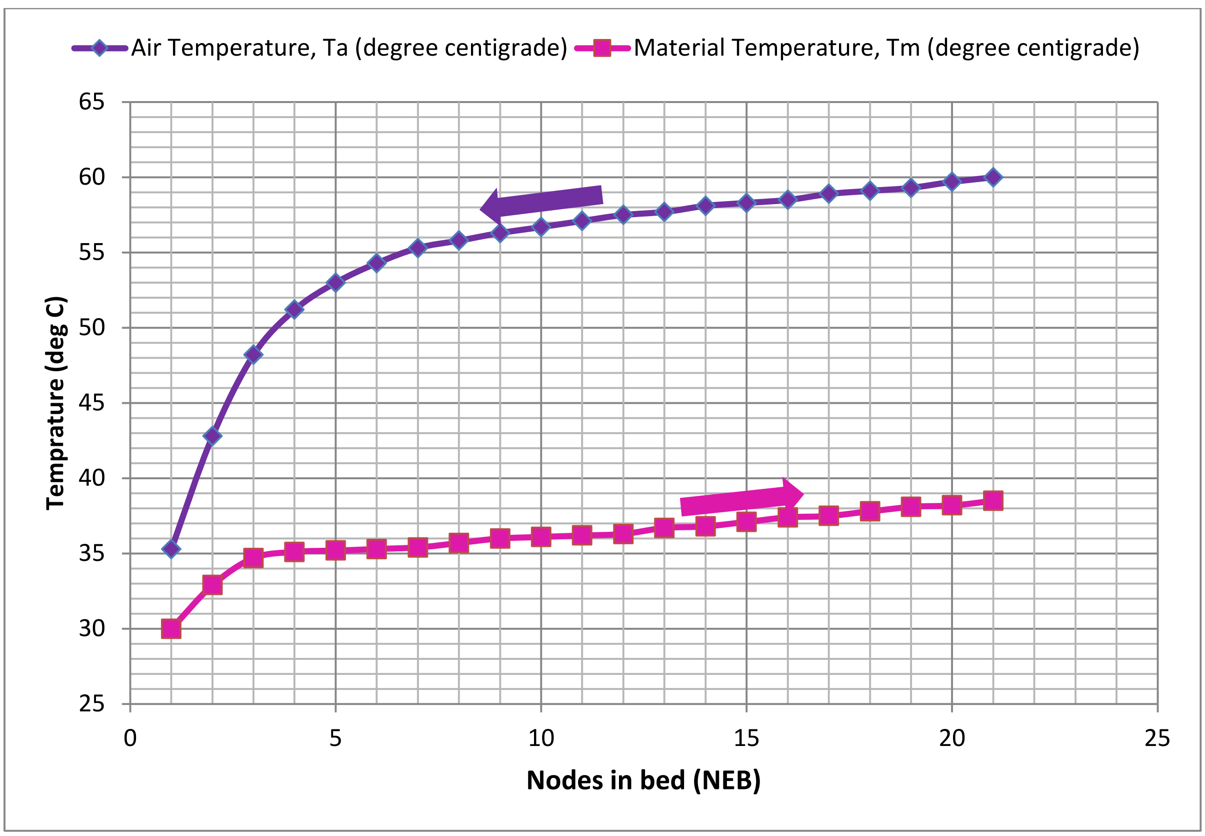

Figure 9.2. Variation of air temperature, T_a and material temperature, T_m along bed

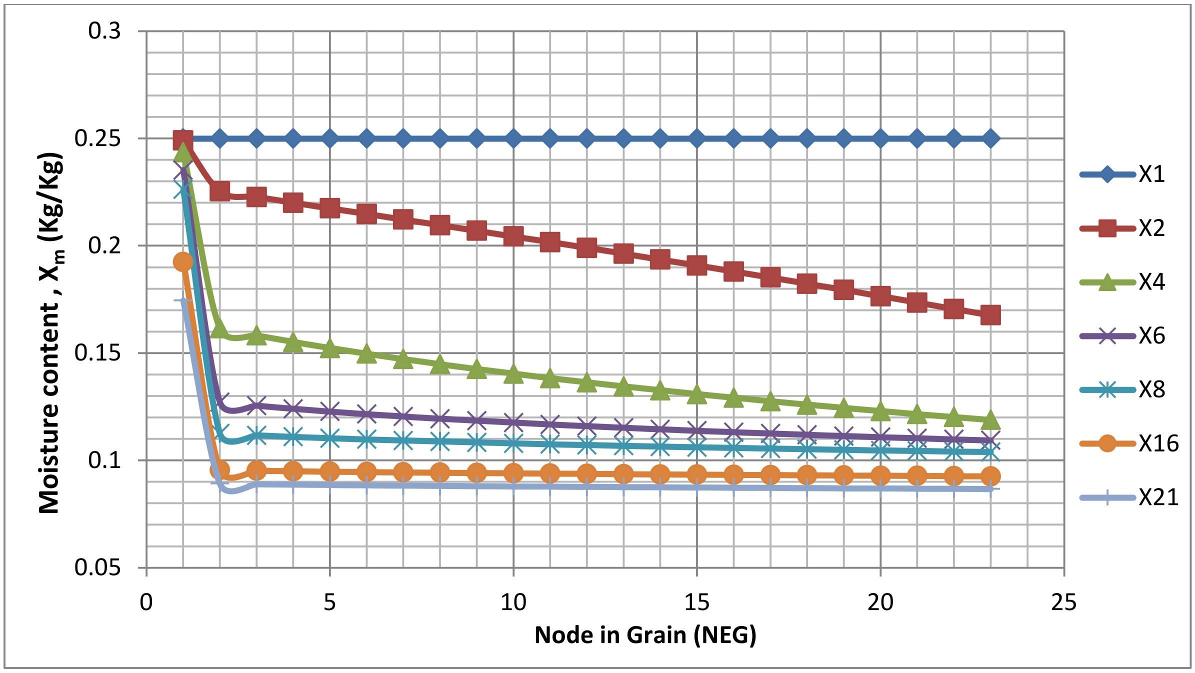

Figure 9.3. Variation of moisture content within grain, X_m at various nodes in bed

Temperature of material at outlet as well as the temperature of air at the outlet increases with the increase in mass flow rate of air as shown in fig.9.4. When the mass flow rate of air increases, there is an increase in the enthalpy of air or rather the heat content of air will increase. Also, for other conditions remaining same, the heat utilized by material will increase but is not more than the increase in the heat content of air. Thus some extra amount of heat content remains in the air as a result of which air temperature increases. Material temperature increases because the heat utilized by the material is increased which causes increase in temperature of material at the outlet.

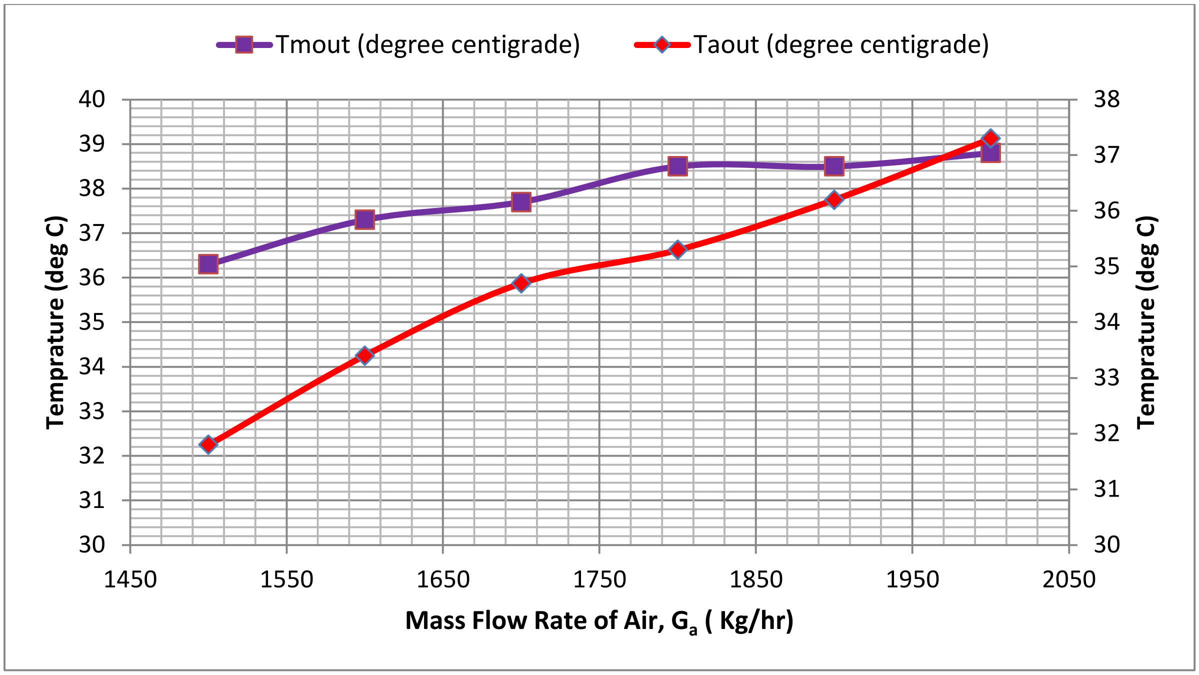

Figure 9.4. Variation of T_{mout} and T_{aout} with the mass flow rate of air, G_a

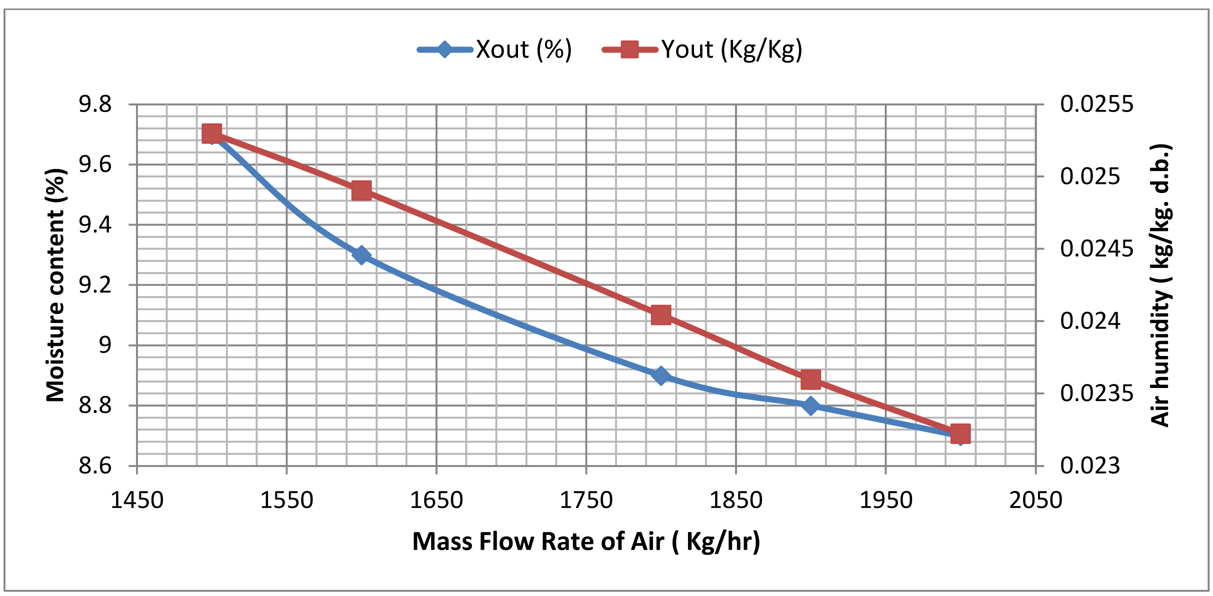

Figure 9.5.Variation of X_{out} and Y_{out} with the mass flow rate of air, G_a

Fig.9.5. show decrease in both the moisture content of material as well as the humidity of air with the increase in mass flow rate of air,

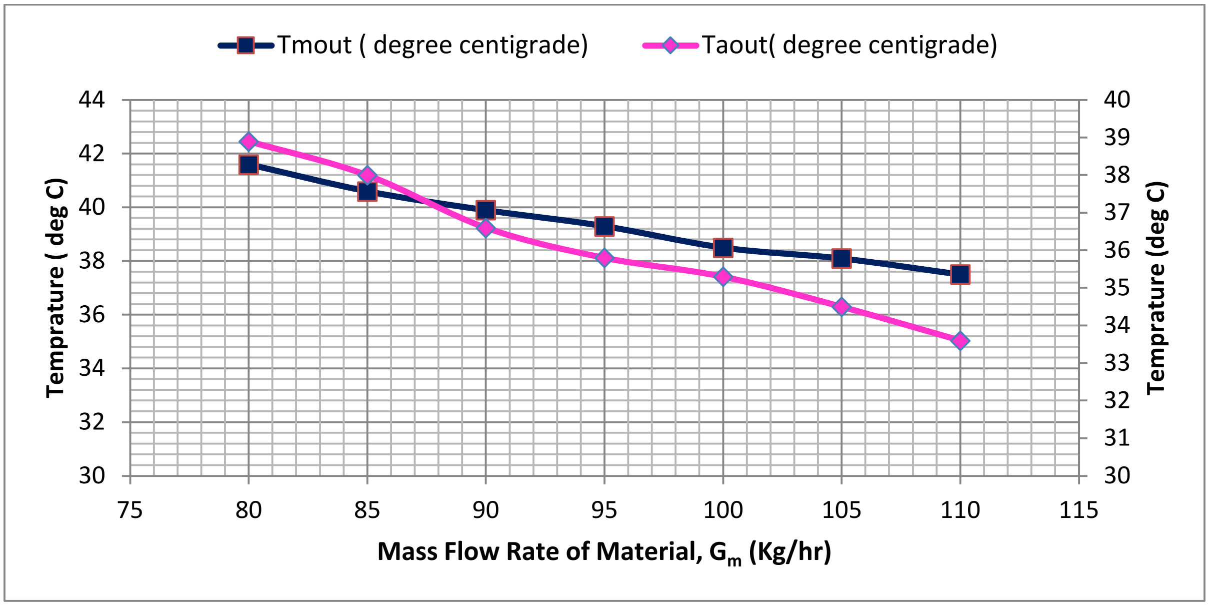

Figure 9.6. Variation of T_{mout} and T_{aout} with material mass flow rate, G_m

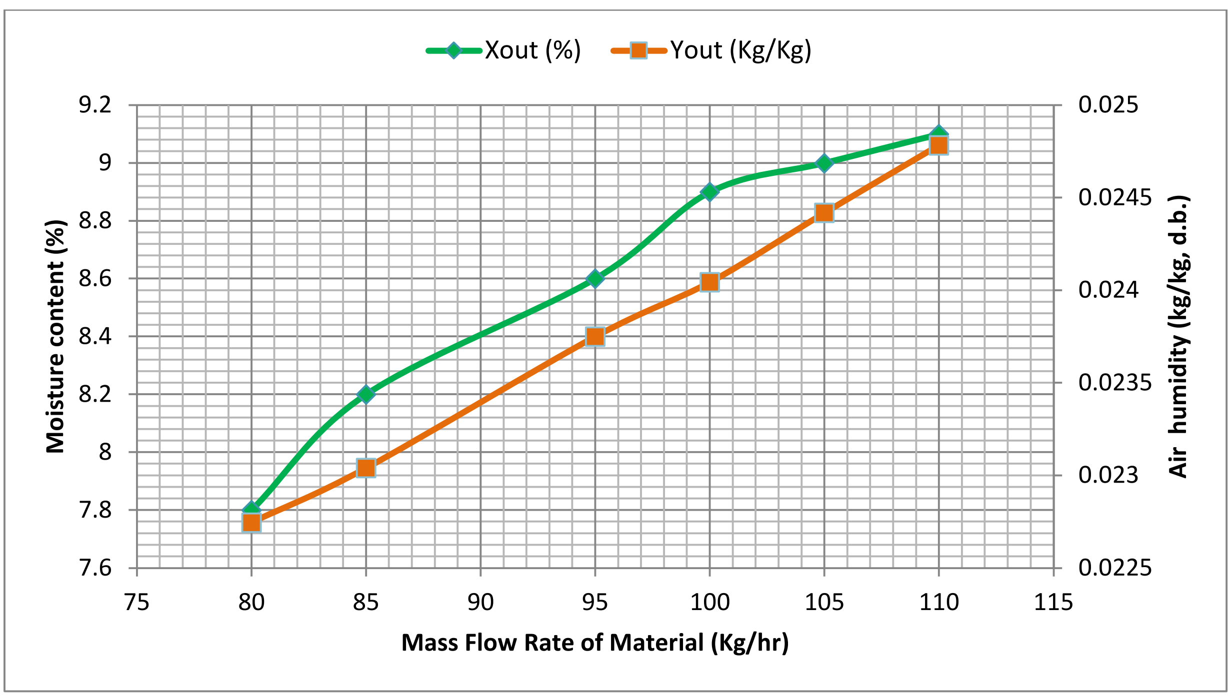

Figure 9.7. Variation of X_{out} and Y_{out} with the material mass flow rate, G_m

As per fig.9.6. on increasing the material mass flow rate, the amount of enthalpy required by material to remove its moisture is increased but the enthalpy provided by air is same as there is no change in the conditions of air. As a result of lesser heat content available in air or rather larger heat content required by material which is not available in air, there is a fall in temperature of air and material with increased material mass flow rate.

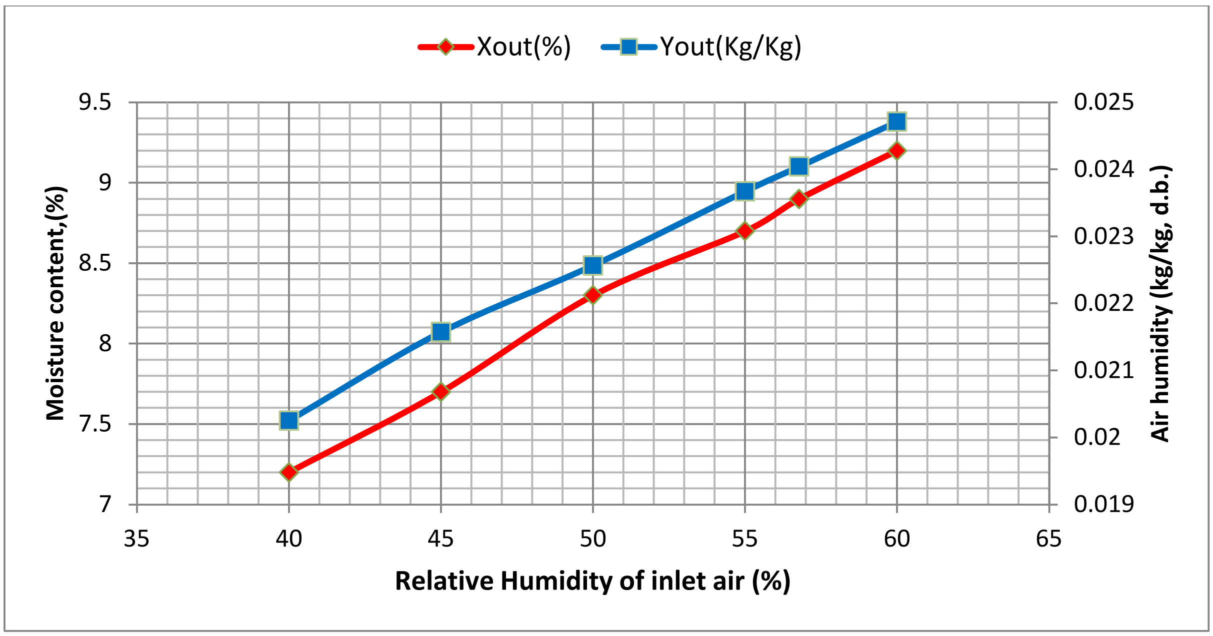

Figure 9.8. Variation of X_{out} and Y_{out} with the inlet air Relative Humidity

As a result of the explanation given in above case, there occurs lesser drying i.e higher X_{out}. This also causes increase in Y_{out}. Also, this happens because of the lesser residence time of material because of increase in material mass flow rate as shown in fig.9.7.

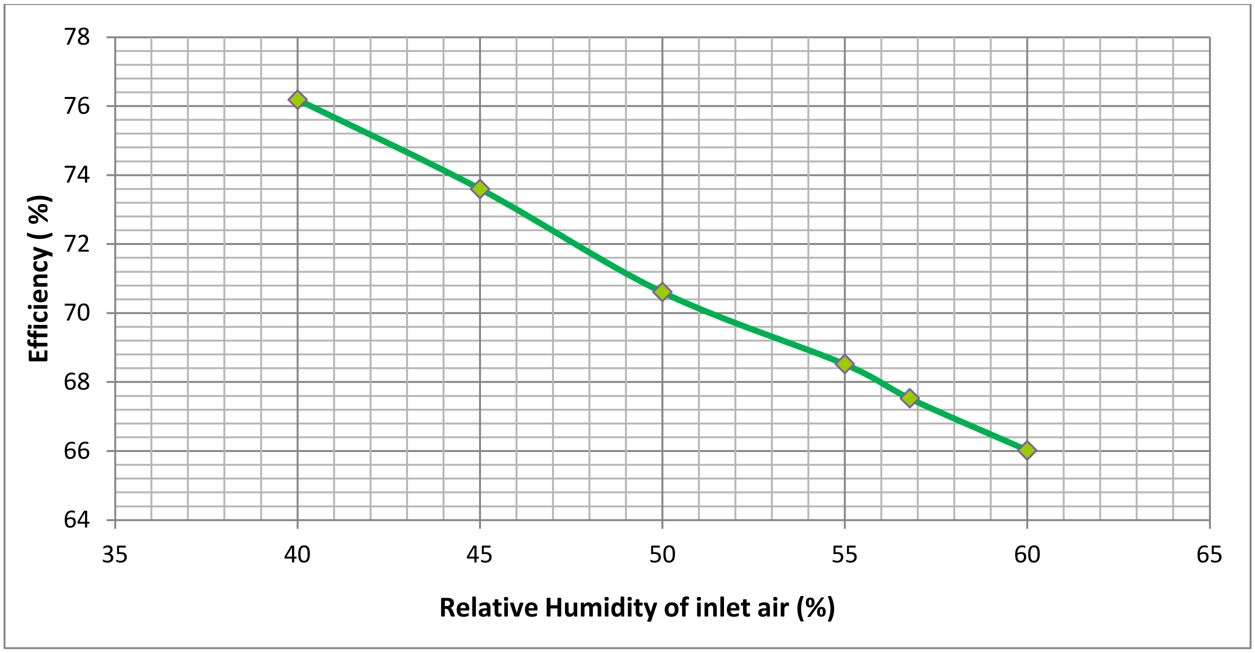

Figure 9.9. Variation of Efficiency of the dryer with the inlet air Relative Humidity

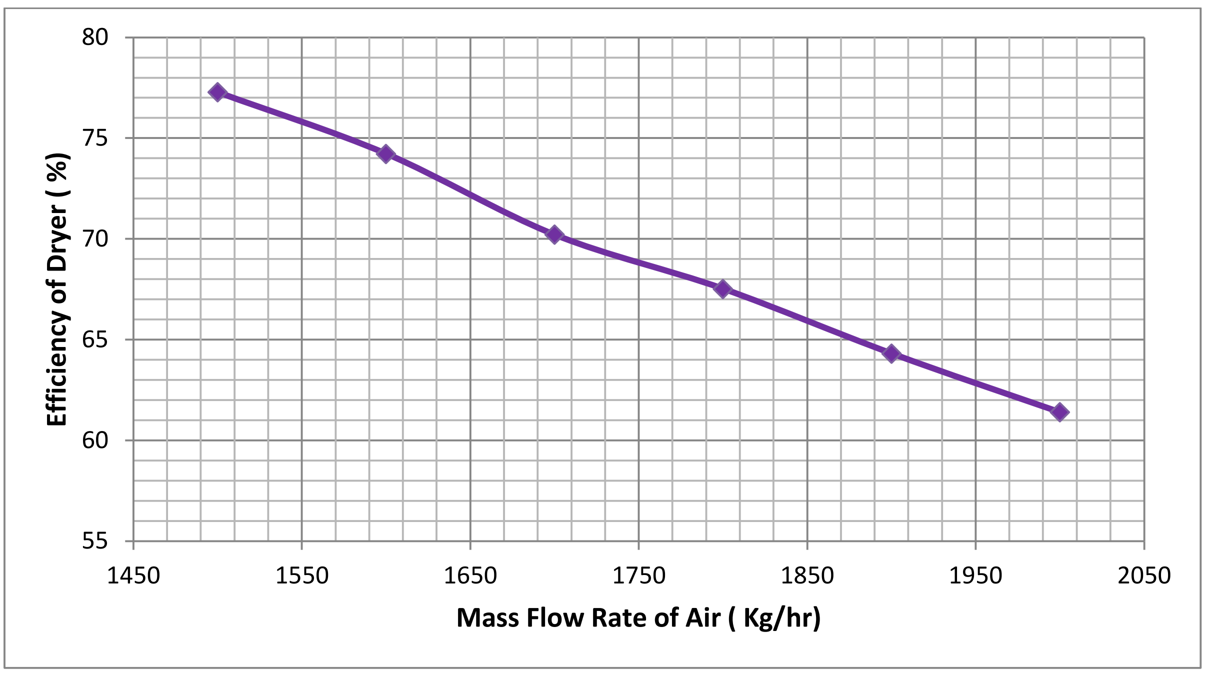

Figure 9.10. Variation of Efficiency of the dryer with the mass flow rate of air, G_a

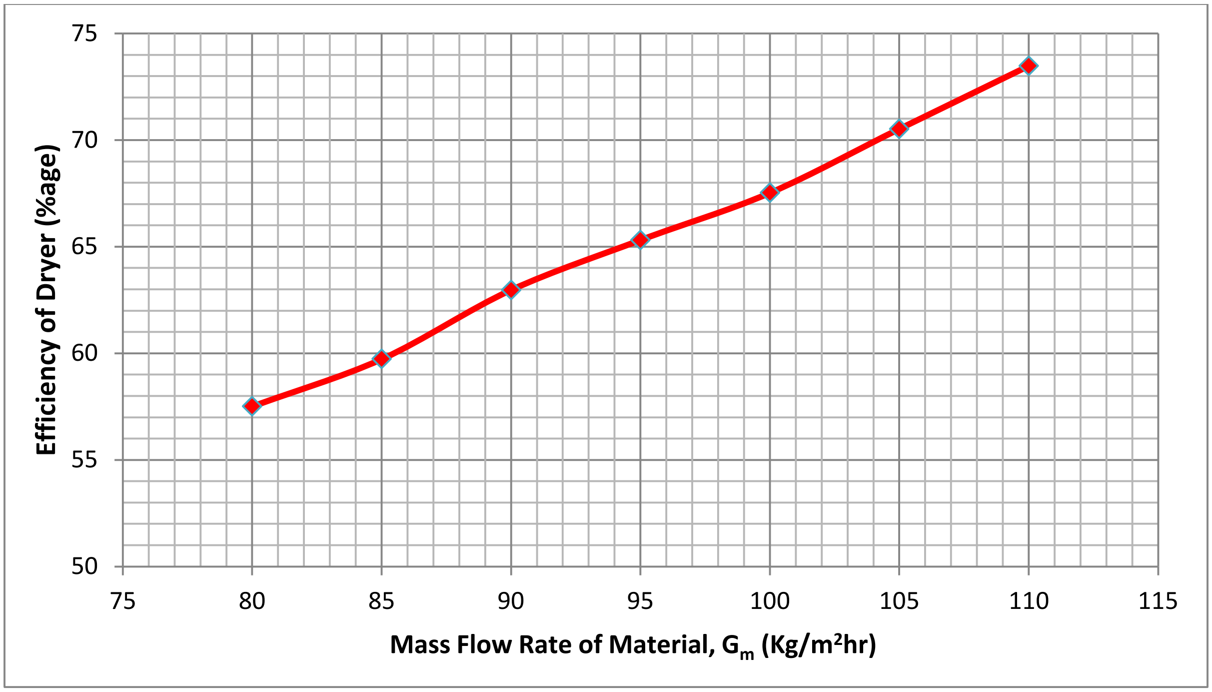

Figure 9.11. Variation of Efficiency with the mass flow rate of material, G_m

Fig9.8 shows when inlet air relative humidity increases, this implies that the mass transfer potential is reduced as Y_{in} has increased. This causes lesser drying of the material leading to higher value of X_{out} along with increase in Y_{out}.

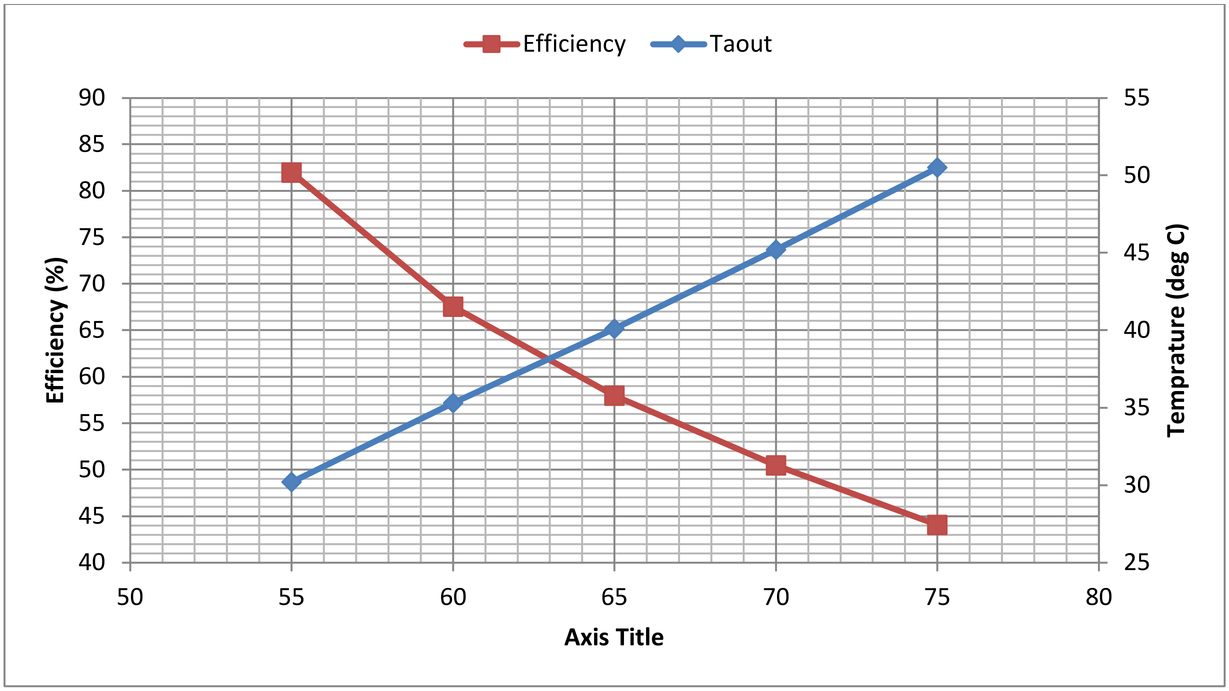

Figure 9.12. Variation of Efficiency of dryer and Taout with T_{ain}

Considering the formula for efficiency of dryer, the Total Heat Supplied (THS) by the air is increased as Y_{in} increases by increasing Relative Humidity but , because of higher value of X_{out}, i.e lesser drying, the Heat Utillized (HU) by the material is reduced. This causes reduction in the ratio of HU/THS thereby reducing the efficiency of the dryer. which reflects in fig.9.9.

Total Heat Supplied (THS) by air is more than the increase in Heat Utilized (HU) by the material. This causes reduction in the efficiency of the dryer as shown in fig.9.10.

Since there is a rise in the Heat Utilized by the material, whereas the Total Heat Supplied by the air does not change, there is a rise in the efficiency of the dryer as per fig.9.11.

As per fig.9.12. With the increase in T_{ain}, total heat supplied by air increases. Also, heat utilized by material increases. But the increase in HU is less than the increase in THS thereby reducing the efficiency of the dryer and rise in $T_{aout.}$

This data can be used in the performance prediction of the grain dryer with the given geometry

9.4. Validation of programme

Experimental data are used to verify the result of the current computer program's output (fig.13). The program's correctness is justified by the close proximity of the two outcomes in the range of 6%.

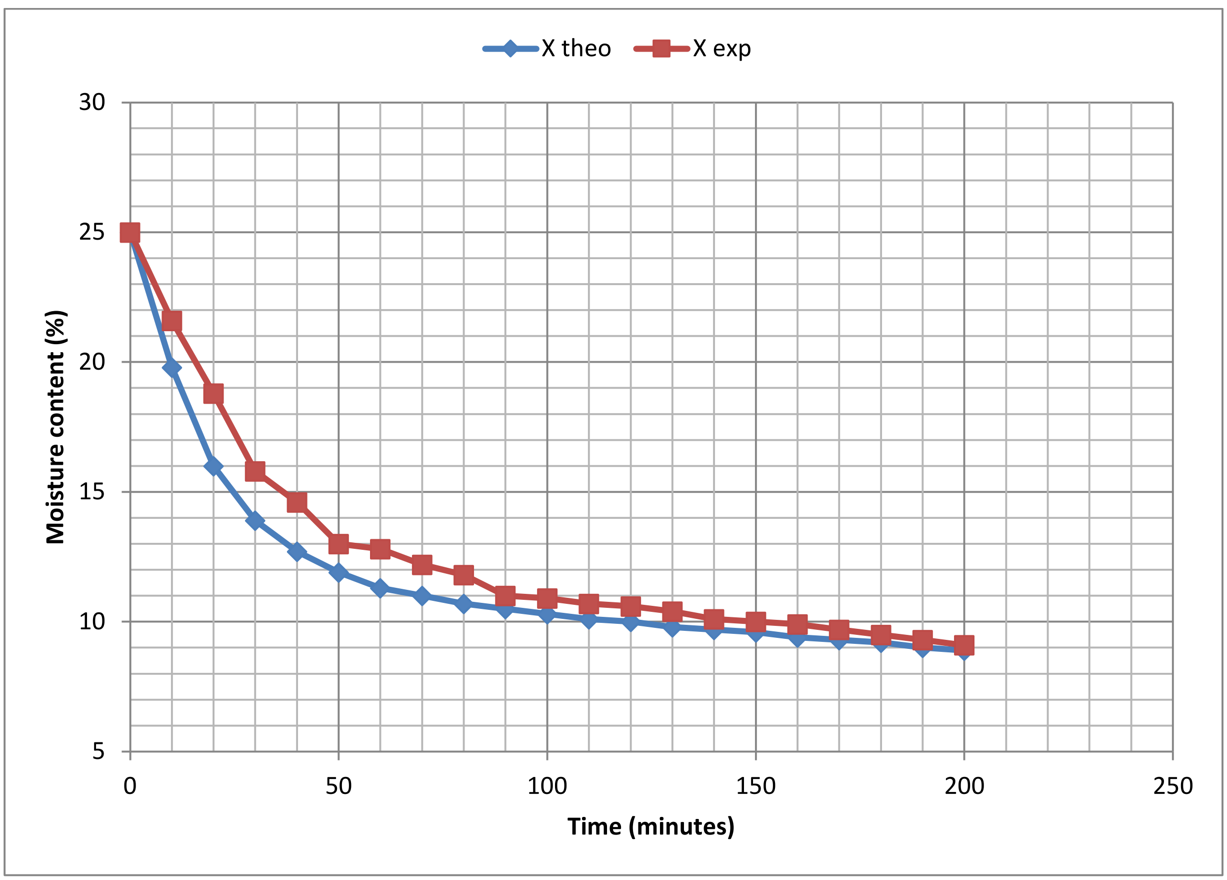

Figure 9.13. Variation of moisture content with Time at T_{ain} 60 deg C and G_a=1800kg/hr.

9.5. Conclusions

The created simulation formulation and computer programme for counter current packed bed drying of corn particles are well fitted for analysing the drying phenomenon. The periodic change of Intra-kernel moisture dispersion provides valuable information for determining optimal design and performance factors. The rating analysis may be employed for enhanced quality and higher efficiency at a suitable level of mass flow for a given shape of the dryer. The model devised is quite broad in nature and may be used to examine the drying processes of any particle. It is easy extensible to include particle analysis. An optimum design of the dryer can be arrived using a given set of input parameters. Also, optimum performance from an existing dryer geometry can be obtained by judicious selection of input parameters.