CHAPTER VI

SIMULATION OF DEEP BED DRYING MODEL AND APPLICATION

This chapter is designed to investigate rough rice drying in a fixed bed dryer by using a computer simulation model to study drying air and grain conditions during the drying process.

Deep bed drying refers to heterogeneous drying of grain in a deep layer (more than 20 cm deep) where drying is faster at the inlet end of drying air than at the exhaust end (Noomhorm, 1986). It is assumed to be comprised of a stack of thin grain layers positioned normal to the direction of air flow. The exhaust air condition from a thin-layer are treated as the input air conditions of the above layer (Figure 6.1). The change in humidity of the air as it passes through a given layer of grain can be estimated by writing a mass balance for that layer. Any moisture lost by the grain will be picked up by the air. The change in temperature of the air as it passes through a given layer of grain can be estimated by writing an energy balance for that layer. If it is assumed that there is no heat lost through the sides of the bin, then the heat given up by the air must be equal to the sensible heat required to raise the temperature of the grain plus the latent heat required to evaporate the moisture leaving the grain.

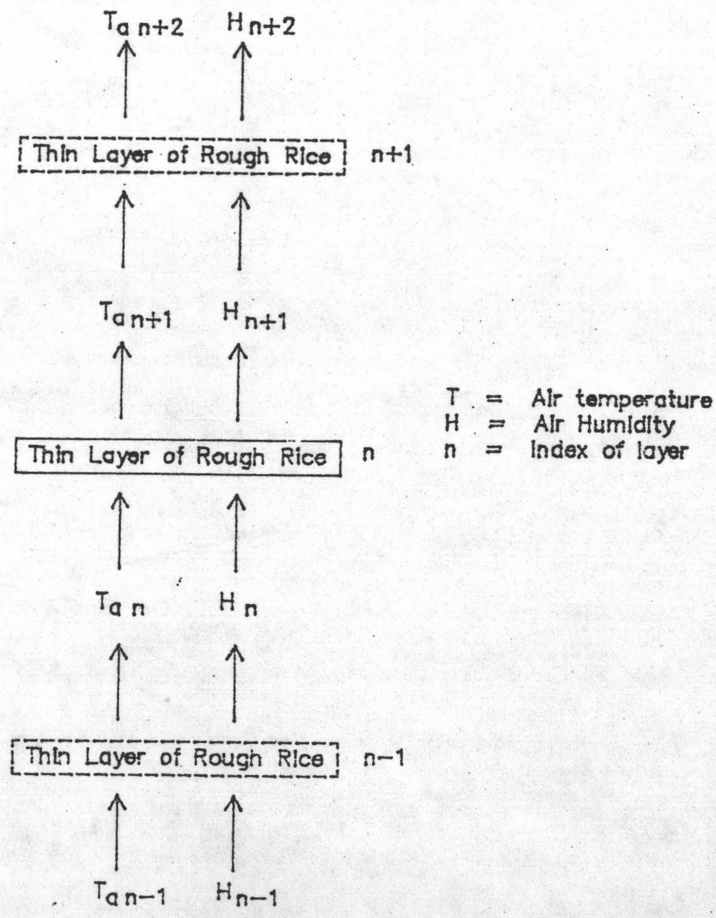

Figure 6.1 Schematic diagram of basic simulation approach.

If the increments of depth and time can be chosen small enough, then the condition of the air will change by only a slight amount as it passes through each layer. By using a mathematical and computer simulation, the moisture and temperature profile in a deep-bed grain drying process can be predicted. The sum of the changes in each layer comprising the grain column gives the overall drying picture of the grain bulk. Thompson (1968) appears to present the most complete empirical deep bed analysis that has been developed for a digital computer solution and requires less computer time. It is decided to apply the concept with this research. Figure 6.2 shows the simulation approach.

Drying air at temperature, T°C and absolute humidity, W_o kg water per kg dry air is passed through a thin layer of rough rice at moisture content, $\overline{M}$ percent moisture and temperature, T_g °C for a drying time interval, Δt. During this interval $\Delta\overline{M}$ percent moisture is evaporated from the rough rice into the air increasing its absolute humidity to $W_o + \Delta W$ kg water per kg dry air. During drying the temperature of the drying air is decreased, ΔT°C in proportion to the temperature increase of the rough rice, ΔT_g °C and the evaporative cooling accompanying the moisture evaporation. The amount of drying performed would be calculated by a thin-layer drying equation with constants dependent on the drying air temperature, relative humidity and initial moisture content of rough rice. Complete heat balances were used to calculate the final air temperature and grain temperature consistent with the evaporative cooling accompanying the moisture evaporation and with the initial temperature of the drying air and the

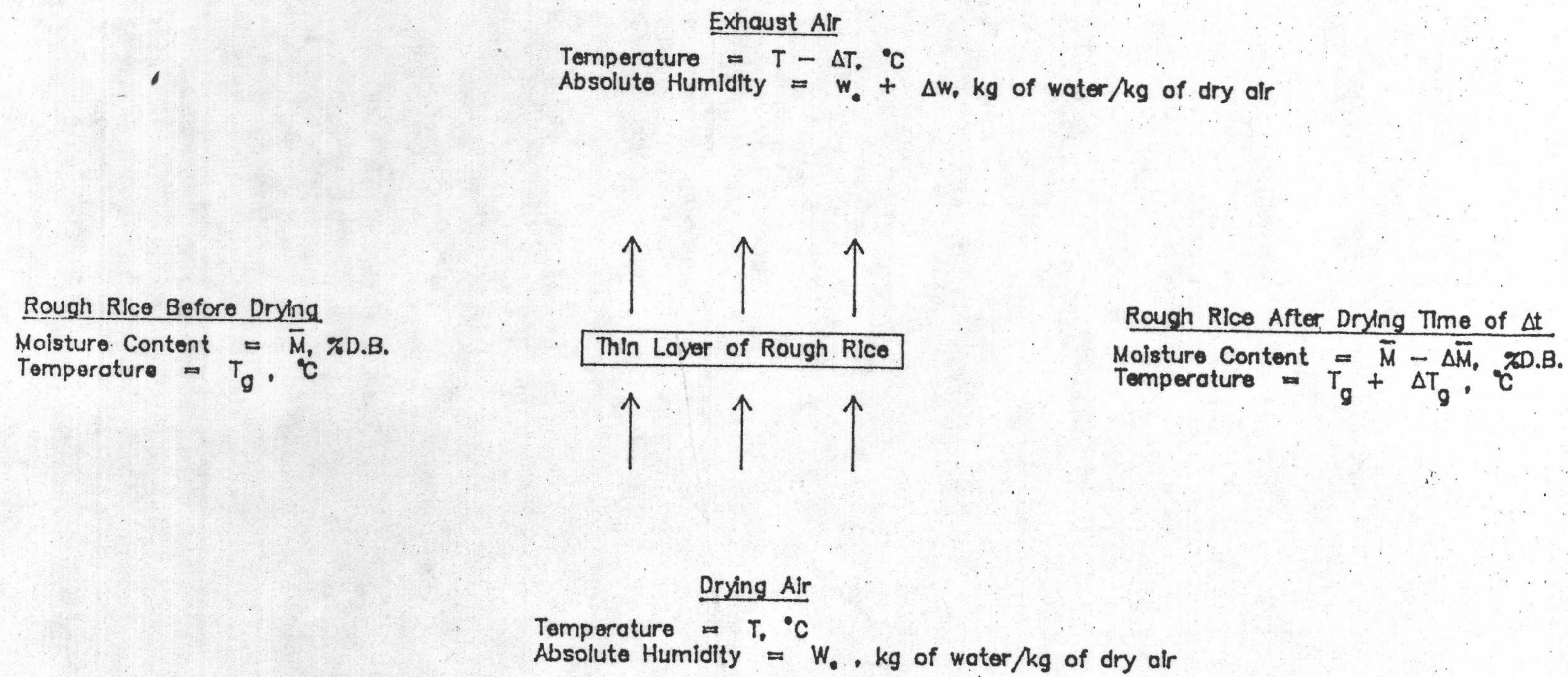

Figure 6.2 Schematic diagram of deep bed simulation approach

grain. The other assumptions made in the development of rough rice drying models are : (1) The volume shrinkage is negligible during the drying process; (2) The air is moving uniformly through a bin so that leaves all points on the surface at the same time; (3) The system is thermally insulated and is impervious to moisture gain or loss; (4) The heat capacities of moist air and of grain are constant during short time periods.

The equilibrium conditions of the air and grain after an interval of time of passing air through the grain bed is established by the following equations of energy balance between grain and air.

Heat lost (or gained) by air + heat lost (or gained) by rough rice + heat used in evaporation (or reclaimed in condensation) = 0

enthalpies at T_o per kg of dry air (dry air + water vapor in air + grain)	=	enthalpies at T_e per kg of dry air (dry air + water vapor in air + grain)

$$C_aT_o + W_o(2502.3+C_vT_o) + CT_{go} = C_aT_e + W_o(2502.3+C_vT_e) + CT_e$$

where the subscript o refers to original and e to equilibrium value of air temperature, T, grain temperature, T_g, and absolute humidity, W, and C_a is the specific heat of dry air, kJ/kg°C, C_v is the specific heat of water vapor , kJ/kg°C and C is the specific heat of the rough rice multiplied by the grain to air ratio. The ratio is found by dividing the weight of rough rice in a layer by the weight of air passing through that layer in the time increment Δt.

The first two terms on each side of the equation represent the initial and equilibrium heat content of the air, and the third terms are the initial and equilibrium heat content of the rough rice. Solving this equation for the unknown equilibrium temperature :

$$T_e = ((C_a + C_v W_o)T_o + CT_{go})/(C_a + C_v W_o + C) \quad ......(6.1)$$

Each time a thin-layer is considered, new values of T_e and W_o are used. This means that new values of M_e and RH are recomputed. Another factor involved in the computations is that M_i does not change for any location in the bed. Therefore, each thin layer drying curve used passes through the same moisture content at zero time. For each curve (or for each set of values for T_e and W_o), a different time is needed to dry a thin-layer to a given moisture content.

As each thin-layer is considered, it is necessary to calculate an equivalent time. Equivalent time is the time that would have been needed to dry the layer to its present moisture with air at T_e and W_o, plus the time increment Δt :

$$t = \exp[(\ln(-\ln \overline{MR}) - \ln K)/N] + \Delta t \quad ....(6.2)$$

The final moisture ratio of the thin layer at time o (at the end of the time increment) is :

$$\overline{MR}_f = \exp(-Kt^N) \qquad \text{........(6.3)}$$

After the final average moisture in the layer is found, the following equation is used to determine the average absolute humidity of the air leaving the layer over the time Δt :

$$W_f = W_o + \Delta W \qquad \text{........(6.4)}$$

and

$$\Delta W = (\overline{M}-\overline{M}_f)R \qquad \text{........(6.5)}$$

where R is the mass of the grain per mass of air furnished during Δt.

The average exhaust air temperature, T_f, of the air leaving the layer over the time Δt is found by another heat balance that considers the evaporation of the water removed in Δt :

<u>enthalpies of air flow into layer per Kg dry air at T_e</u> (dry air + water vapor in air + grain) = <u>enthalpies of air exhausted from layer per Kg dry air at T_f</u> (dry air + water vapor in air + grain + water removed from grain + latent heat in excess of that of free water)

$$C_aT_e + W_o(2502.3+C_vT_e) + CT_{ge} + C_w\Delta WT_{ge} = C_aT_f + W_f(2502.3+C_vT_f) + CT_f + \Delta L\Delta W$$

where $T_e = T_{ge}$ from equation (6.1)

The first two terms on each side of the equation are the initial and final heat content of the air; the third term is the initial and final heat content of the rough rice. The fourth term on the left side of the equation is the heat content of the water that was evaporated, and the last term in the equation is the heat of vaporization required to evaporate moisture from the rice above that required to evaporate the same amount of free water. Solving this equation for the unknown final air temperature :

$$T_f = \frac{(C_a + C_v W_o)T_e - \Delta W(2502.3 + \Delta L - C_w T_{ge}) + CT_{ge}}{C_a + W_f C_v + C} \quad \text{......(6.6)}$$

It is possible that the above equations will yield W_f and T_f values that result in relative humidities of above 100 percent. Such a state point is infeasible so it is necessary to simulate condensation of the excess water from the air into the rough rice. The following heat balance is used, wherein T_f', W_f' and T_{gf}' represent state conditions after condensation :

$$C_a T_f + W_f(2502.3 + C_v T_f) + CT_{gf} = C_a T_f' + W_f'(2502.3 + C_v T_f') + CT_{gf}' + (W_f' - W_f)C_{wf} T_{gf} \quad \text{........(6.7)}$$

where $T_{gf}' = T_f'$

Also, after condensation has been simulated, the relative humidity associated with T_f and H_f must be 100 percent. The equations cannot be solved easily by direct methods; therefore, they are solved by a method of finding the zero of unknown functions developed by Thompson and Pert (1966).

The final moisture content when condensation is simulated is :

$$M_f = M_f' - (W_f - W_f')/R \qquad \ldots\ldots\ldots(6.8)$$

Thus, by using all equations above, it is possible to compute the air condition T_f and W_f of the air leaving one layer and entering the layer immediately above. Also, the rough rice moisture in a layer at the end of each time increment can be found and used as the initial grain moisture for the following time increment.

A deep bed drying simulation in this dissertation was developed in FORTRAN language and run in the main frame computer at Computer Service Center, Chulalongkorn University. The computer listing is given in Appendix I. The simplified flow chart is presented in Figure 6.3. Computer output data for a particular drying test is also shown in Appendix J. Comparison of experimental and predicted moisture removal rate is further described in the chapter 7.

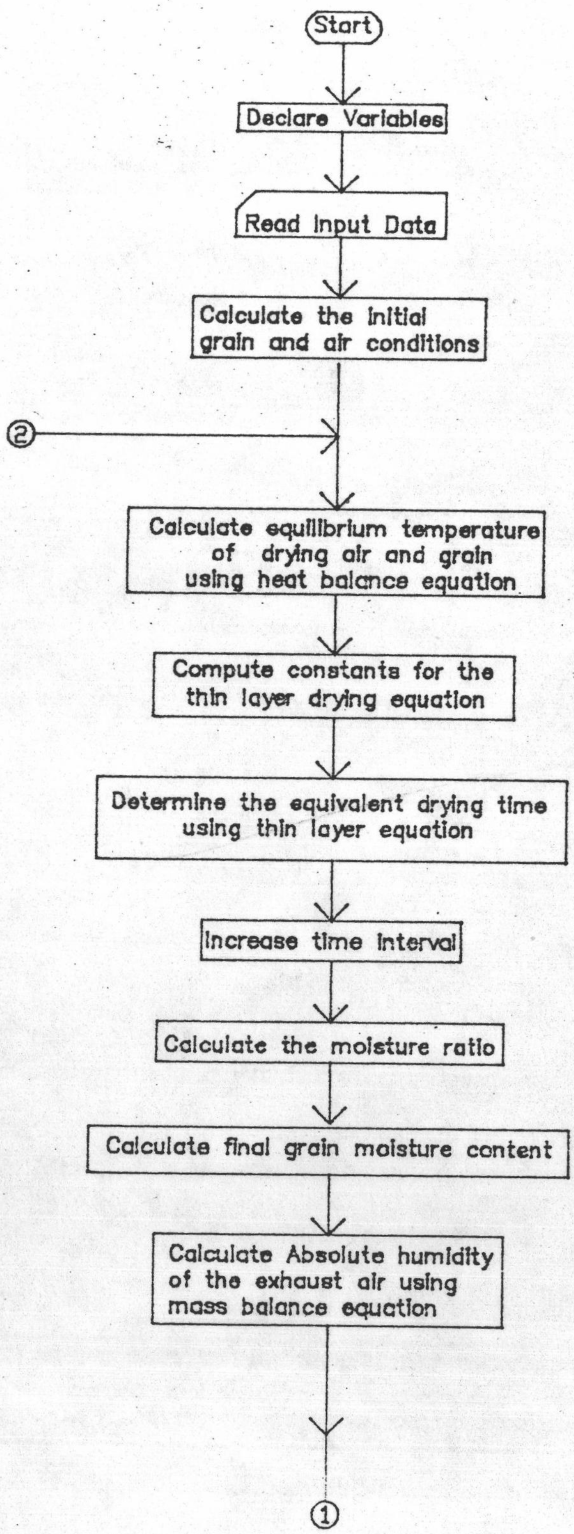

Figure 6.3 Flow chart of deep bed simulation program

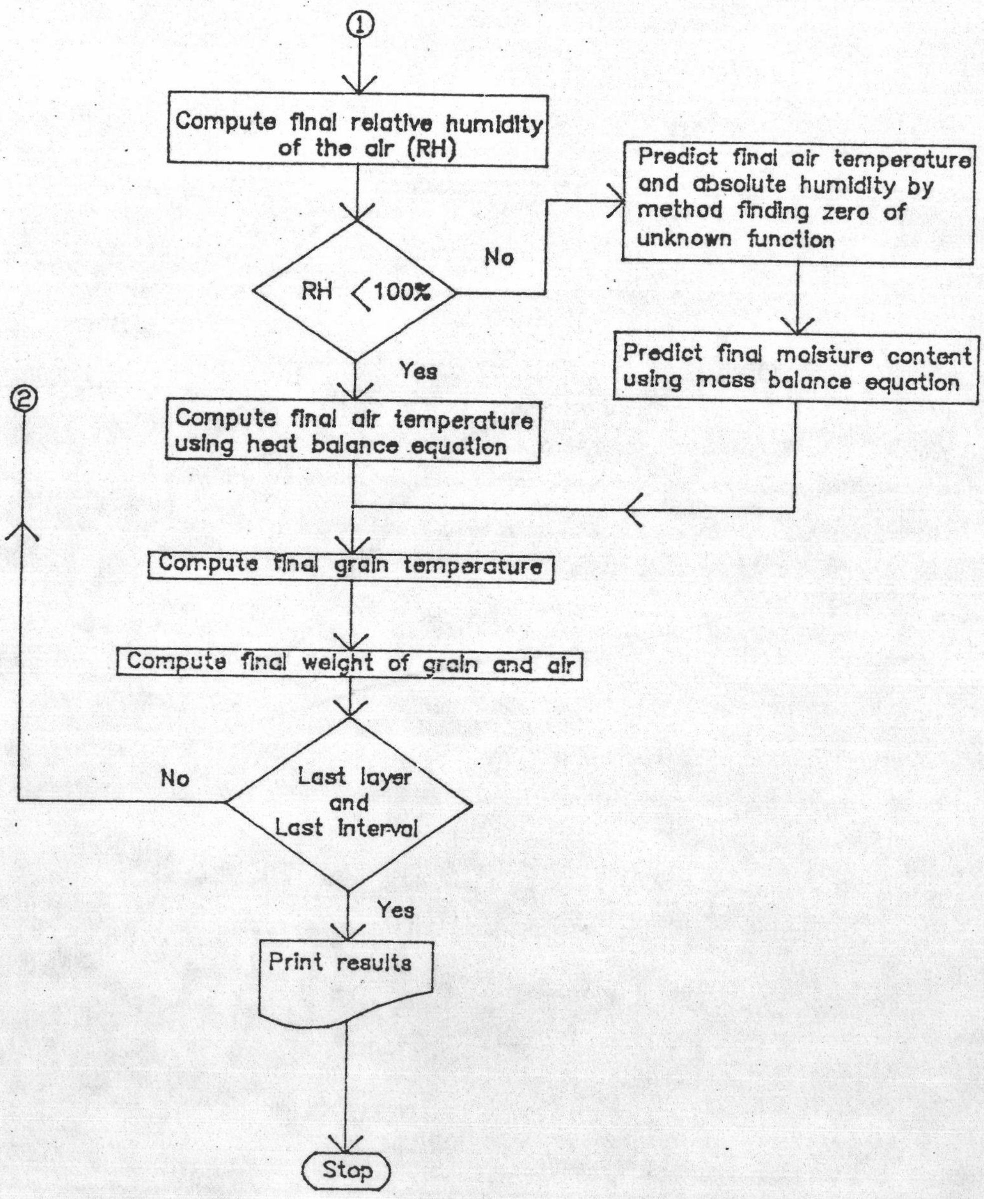

Figure 6.3 Flow chart of deep bed simulation program (continued)