CHAPTER VII

RESULTS AND DISCUSSION

7.1 Thin-layer rough rice drying

7.1-1 Thin-layer rough rice drying model

Experimental data of thin layer drying tests composed of weight of rough rice, elapsed drying time and controlled conditions of drying air. The measured weight of rough rice was transformed to moisture content. Then the moisture content and elapsed drying time are used to find the best thin-layer drying model. A complete summary of the conditions for all of the samples and the data collected from the experiment are contained in Appendix A. Experimental uncertainty estimation of the average moisture content using the apparatus and procedure of this work is shown in Appendix B. Appendix A contains the corresponding code and the experimental values of average moisture content at different time intervals. The code for each test gives the values of all independent variables. The explanation of the code is also included in the appendix A. The following thin-layer drying model was developed using those available experimental data :

$$\overline{M} = (M_i - M_e)\exp(-Kt^N) + M_e \qquad \text{........(7.1)}$$

$$K = \exp(-1.79-0.3711H^{1/2}+0.0153TM_i-0.84T+11.0581TM_i^{-1}) \quad (7.2)$$

$$N = -9.1210+3.855\text{x}10^{-5}H^2-0.3735M_i+3.8746M_i^{1/2} \qquad \text{........(7.3)}$$

The ranges of independent variables used to develop this model

Drying air temperature : 35-60°C

Drying air relative humidity : 30-70 percent

Initial moisture content of rough rice : 20-40 percent, D.B.

The coefficient of determination for this model is 0.953. The equilibrium moisture content from calculation by equation (2.49) were found slightly lower than the actual moisture content of the rough rice samples at the end of the drying tests. (for example at typical condition : T = 50 C, H = 29 %, M_i = 35.87 % D.B.; the average moisture content at the end of the drying test is 10.56 % D.B. while the equilibrium moisture content is 9.67 % D.B.) This indicated that the samples had almost reached equilibrium when they were removed from the dryer at the end of each drying test. Henderson's equation (Henderson, 1952) was utilized to relate the calculated equilibrium moisture content to the absolute temperature, T_a, and relative humidity, H, of the drying air. The following empirical equation was abtained from direct least square fit.

$$M_e = \left\{ \frac{-\ln(1-H/100)}{4.723\times10^{-6} \times T_a} \right\}^{1/2.386} \qquad \text{............(7.4)}$$

The value of the coefficient of determination (R^2) was found to be 0.97.

Typical drying curves for thin layer of rough rice (RD7) at different drying conditions are presented in Figure 7.1 through Figure 7.12.

7-1.2 Effect of drying conditions on thin-layer drying rate

Thin-layer drying rates increased with increasing temperature and with decreasing relative humidity. The effect of temperature and effect of relative humidity on thin layer drying rate for specific experiment are shown in Figure 7.13, 7.14 and Figure 7.15, 7.16

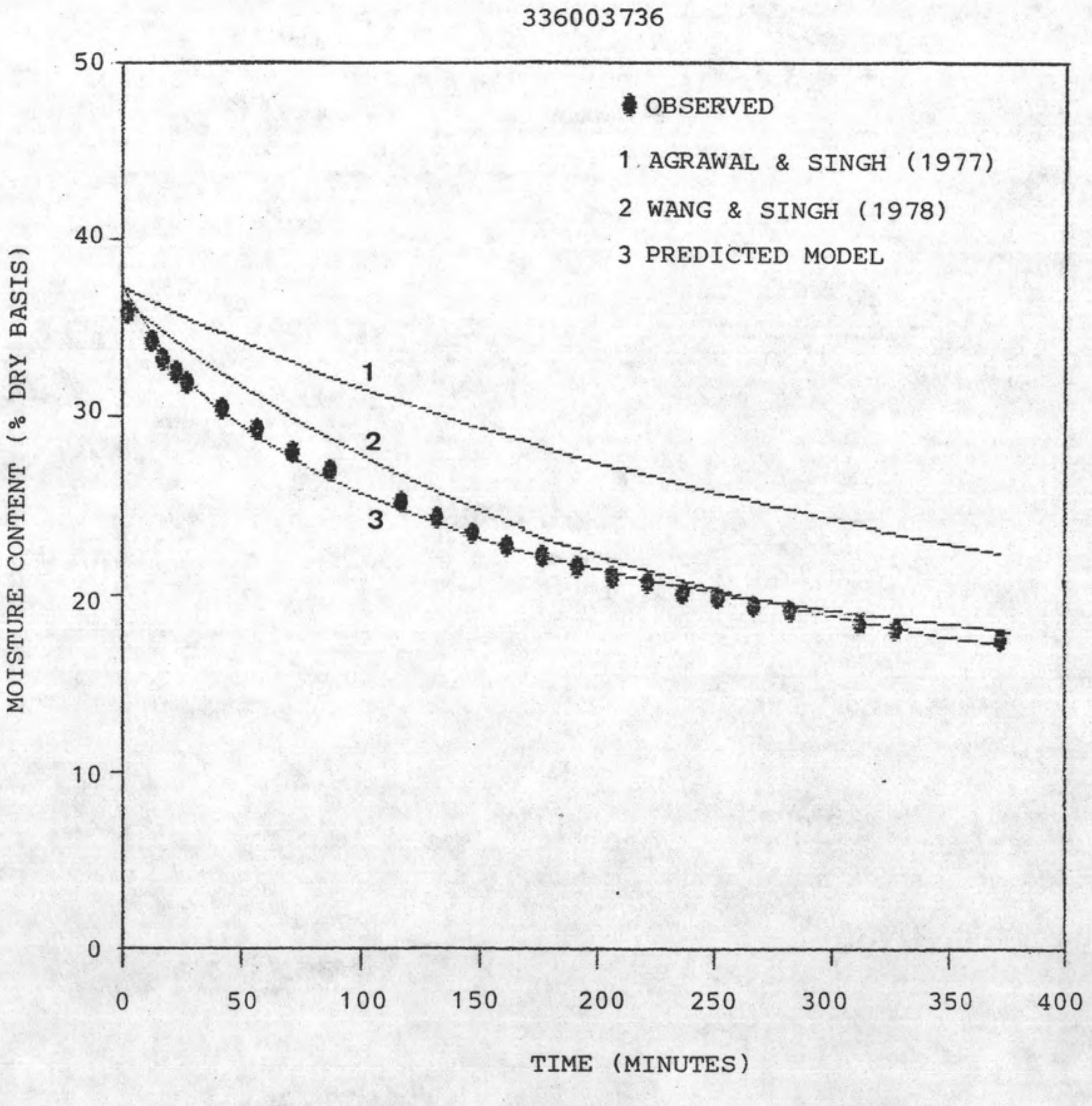

Figure 7.1 Comparison between the observed and predicted moisture contents against time at T = 33 °C, RH = 60 %, M_i = 37.36 % D.B.

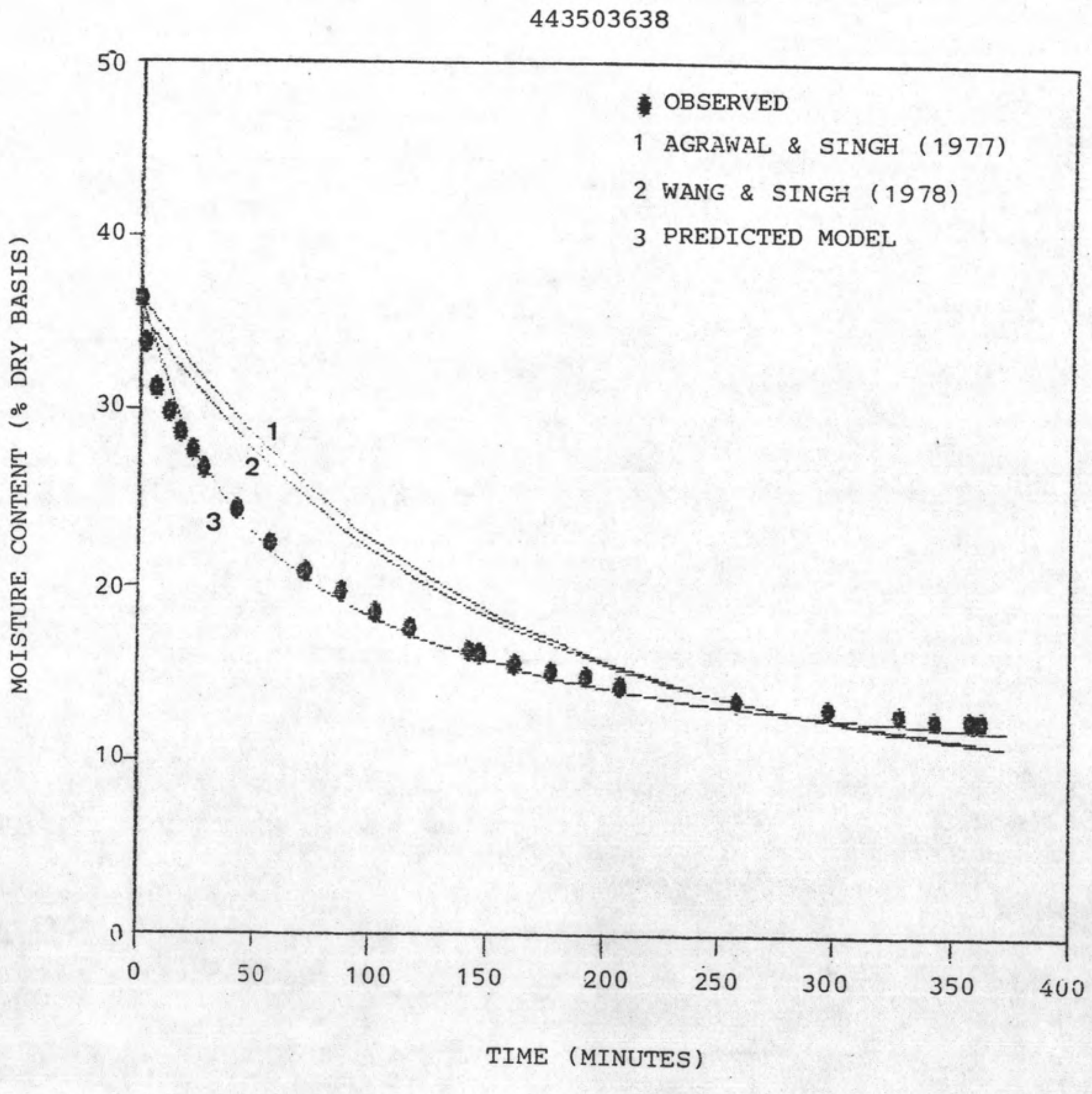

Figure 7.2 Comparison between the observed and predicted moisture contents against time at T = 44 °C, RH = 35 %, M_i = 36.38 % D.B.

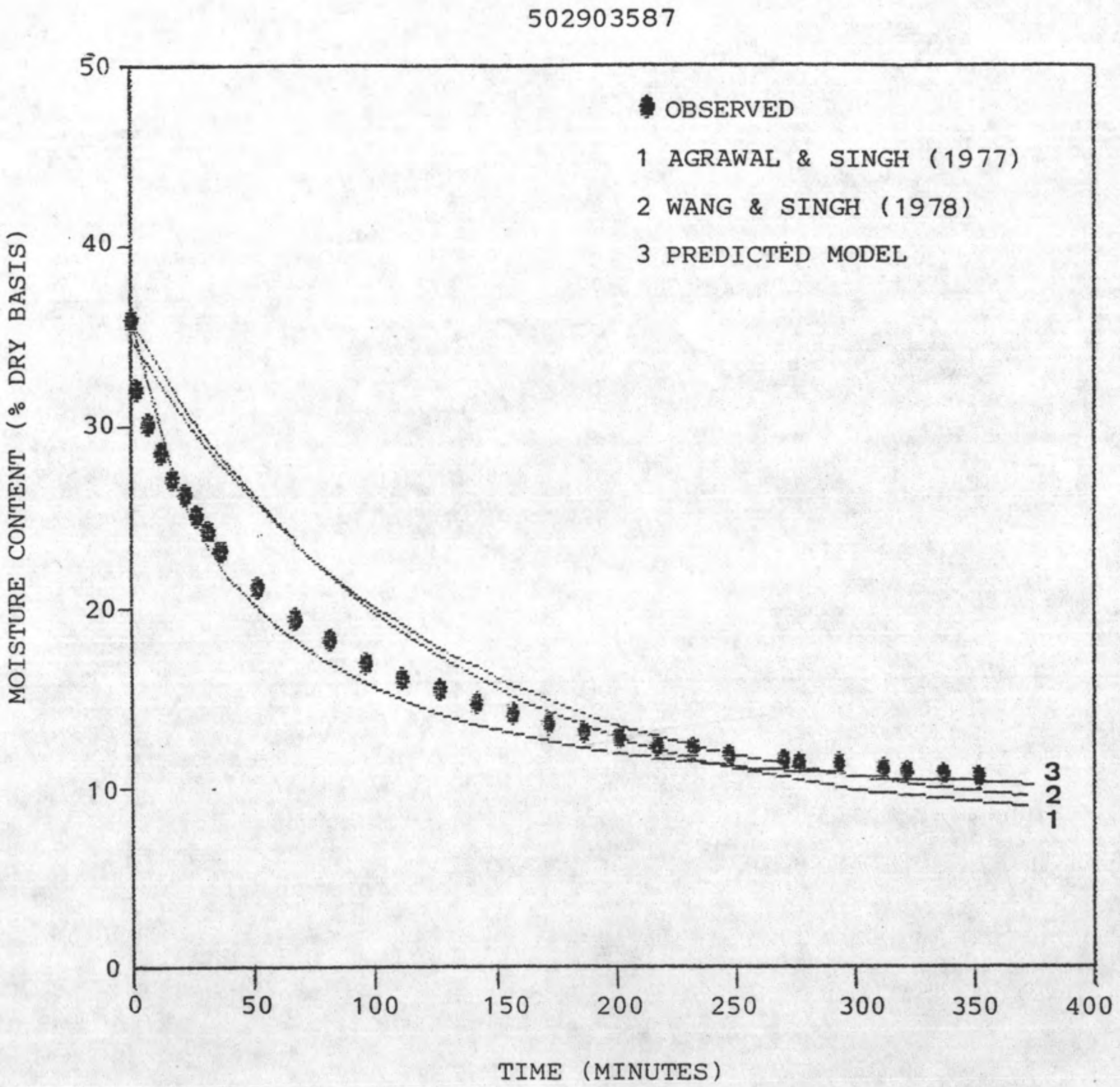

FIGURE 7.3 COMPARISON BETWEEN THE OBSERVED AND PREDICTED MOISTURE CONTENTS AGAINST TIME AT T = 50 °C, RH = 29 %, M_i = 35.87 % D.B.

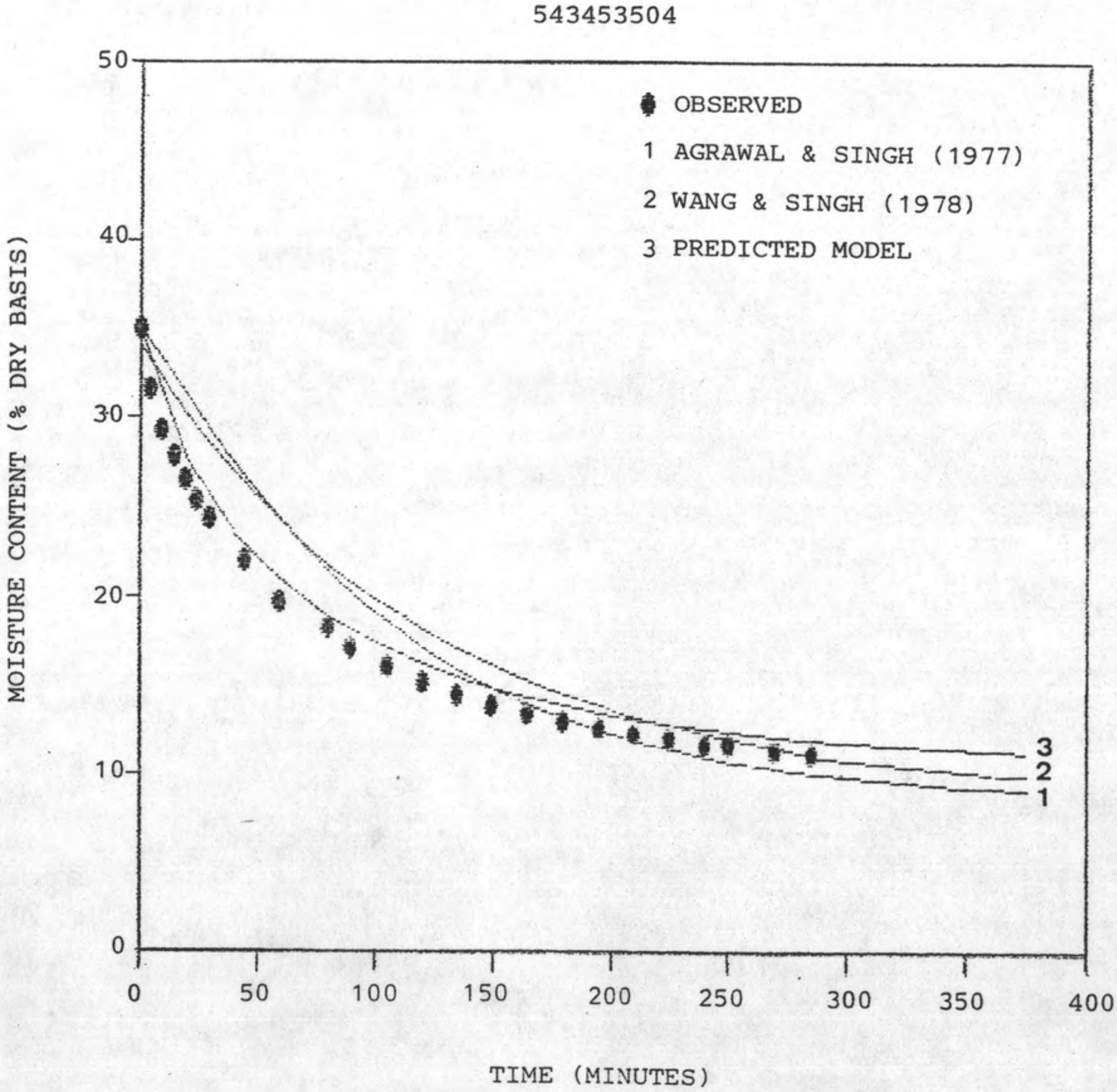

FIGURE 7.4 COMPARISON BETWEEN THE OBSERVED AND PREDICTED MOISTURE CONTENTS AGAINST TIME AT $T \doteq 54^{\circ}C$, $RH = 34.5$ %, $M_i = 35.04$ % D.B.

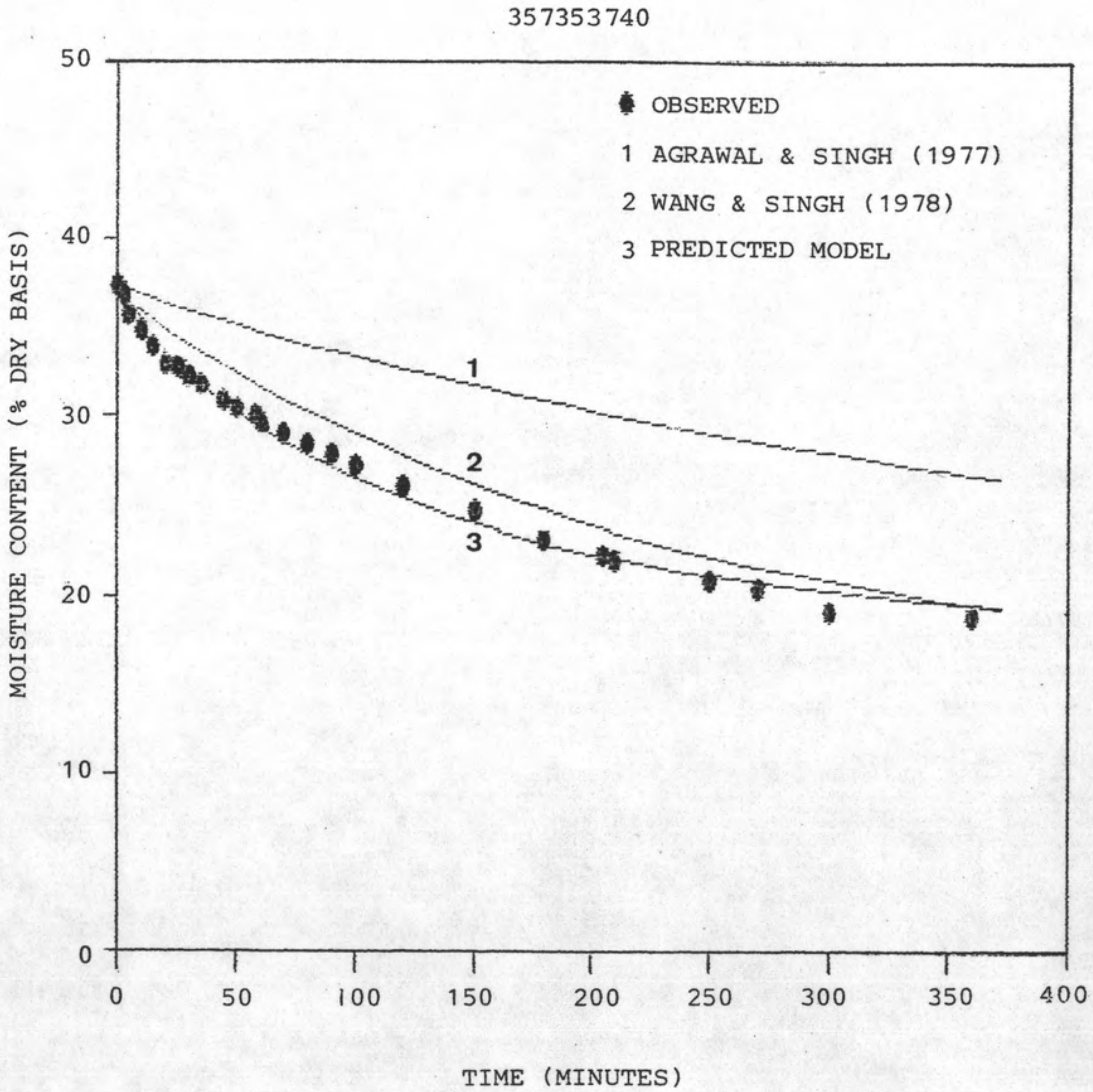

FIGURE 7.5 COMPARISON BETWEEN THE OBSERVED AND PREDICTED MOISTURE CONTENTS AGAINST TIME AT T = 35 °C, RH = 73.5 %, M_i = 37.40 % D.B.

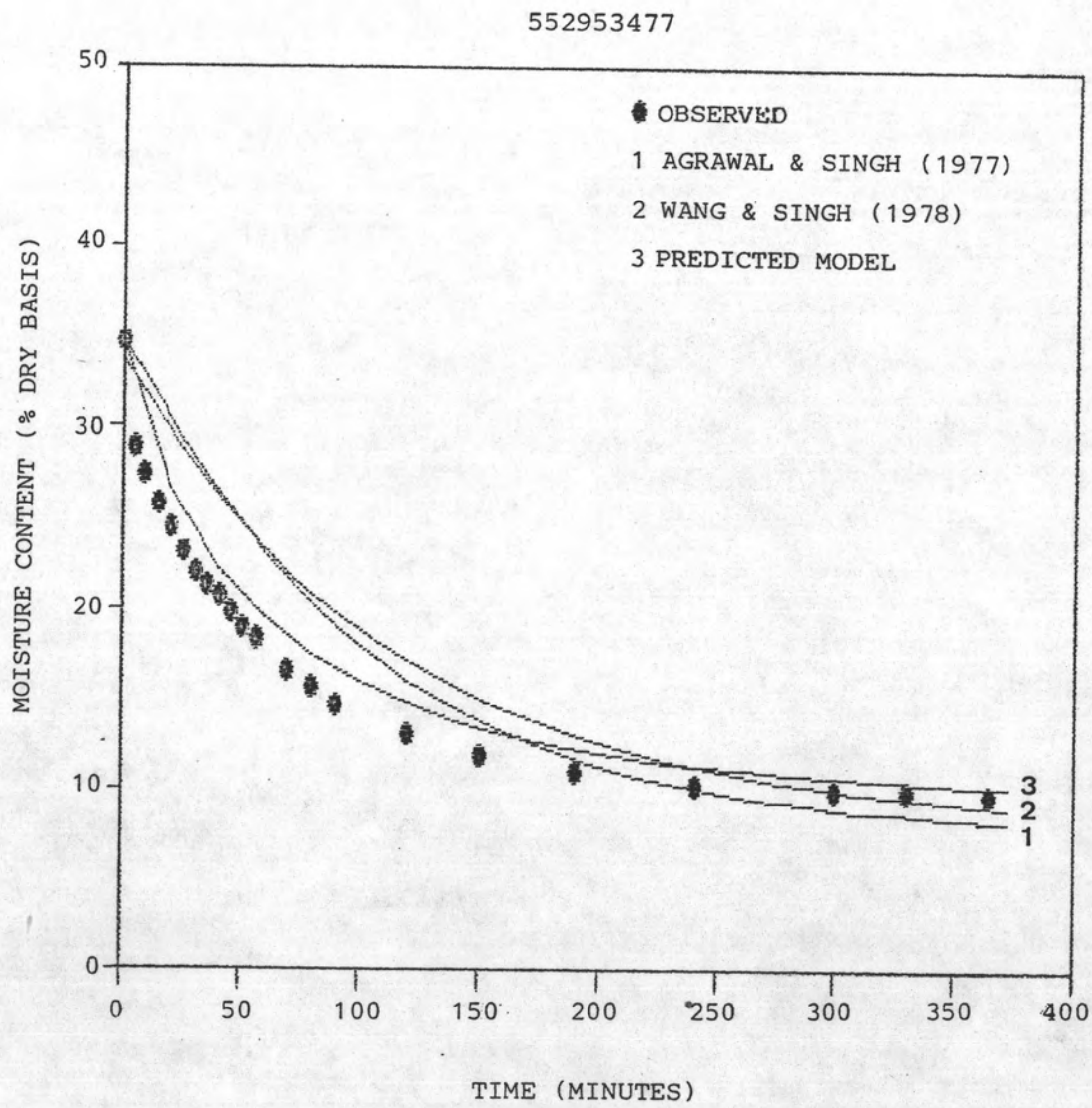

FIGURE 7.6 COMPARISON BETWEEN THE OBSERVED AND PREDICTED MOISTURE CONTENTS AGAINST TIME AT T = 55 °C, RH = 29.5 %, M_i = 34.77 % D.C.

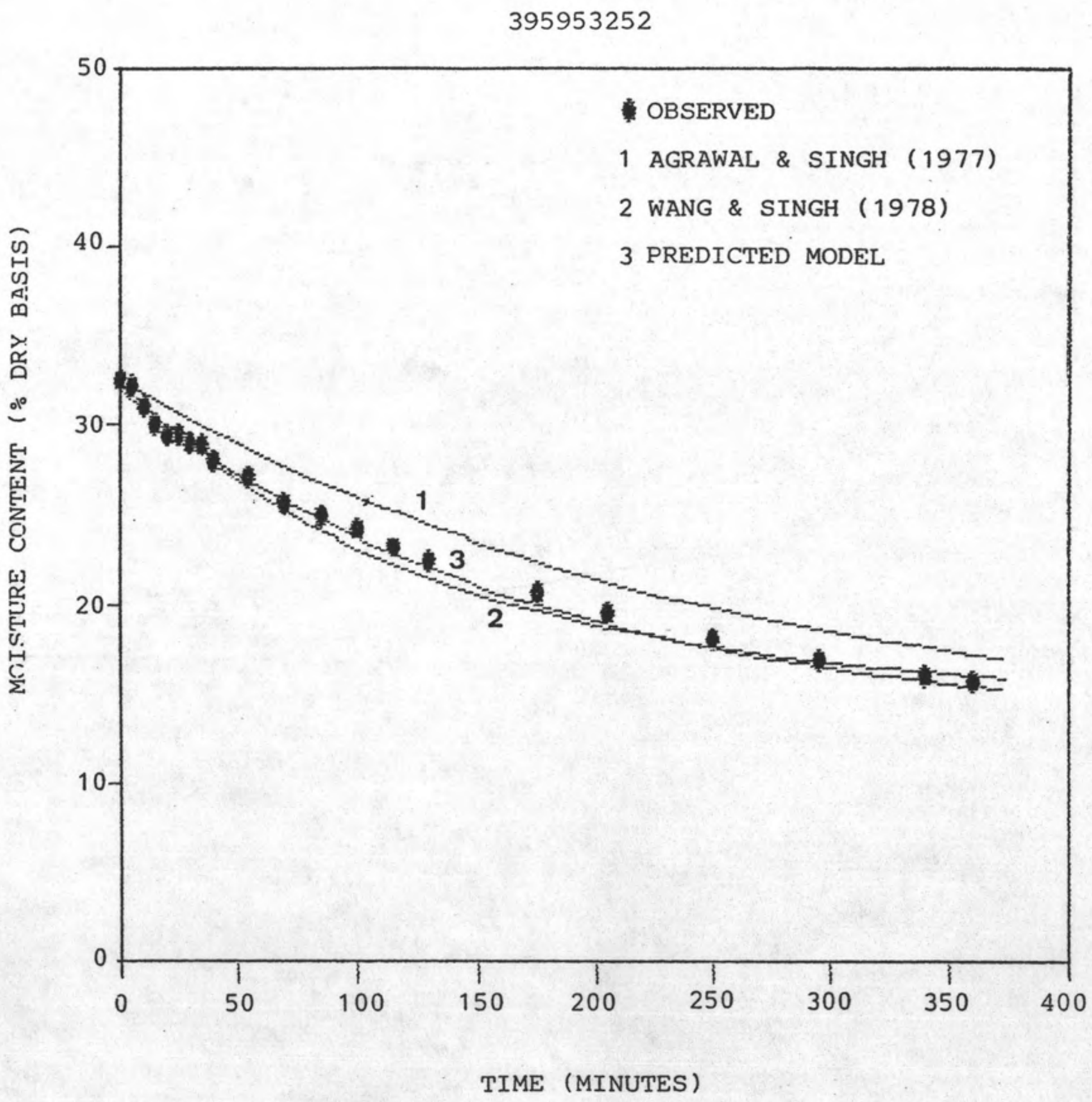

FIGURE 7.7 COMPARISON BETWEEN THE OBSERVED AND PREDICTED MOISTURE CONTENTS AGAINST TIME AT T = 39 °C, RH = 59.5 %. M_i = 32.52 % D.C.

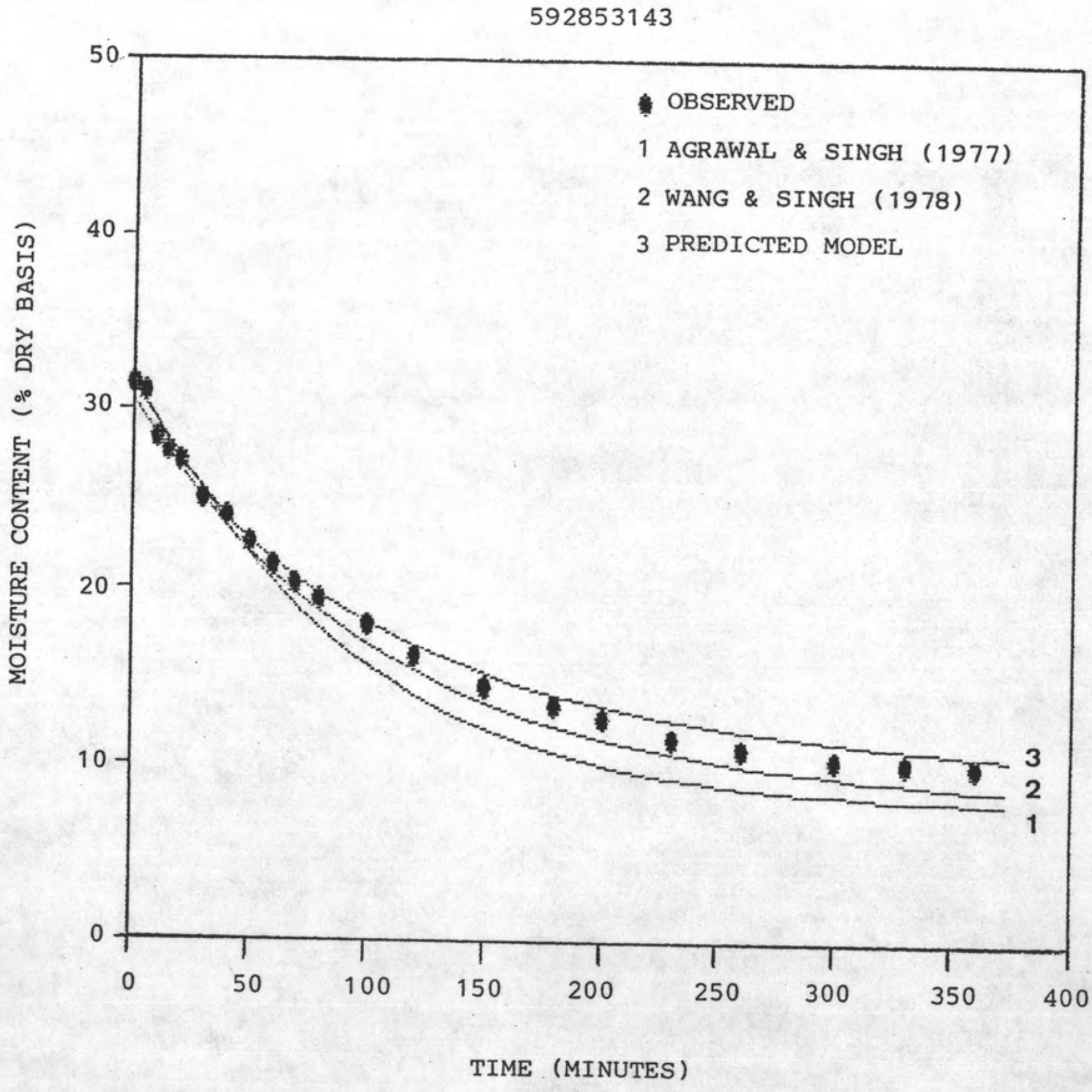

FIGURE 7.8 COMPARISON BETWEEN THE OBSERVED AND PREDICTED MOISTURE CONTENTS AGAINST TIME AT T = 59 °C. RH = 28.5 %, M_i = 31.43 % D.B.

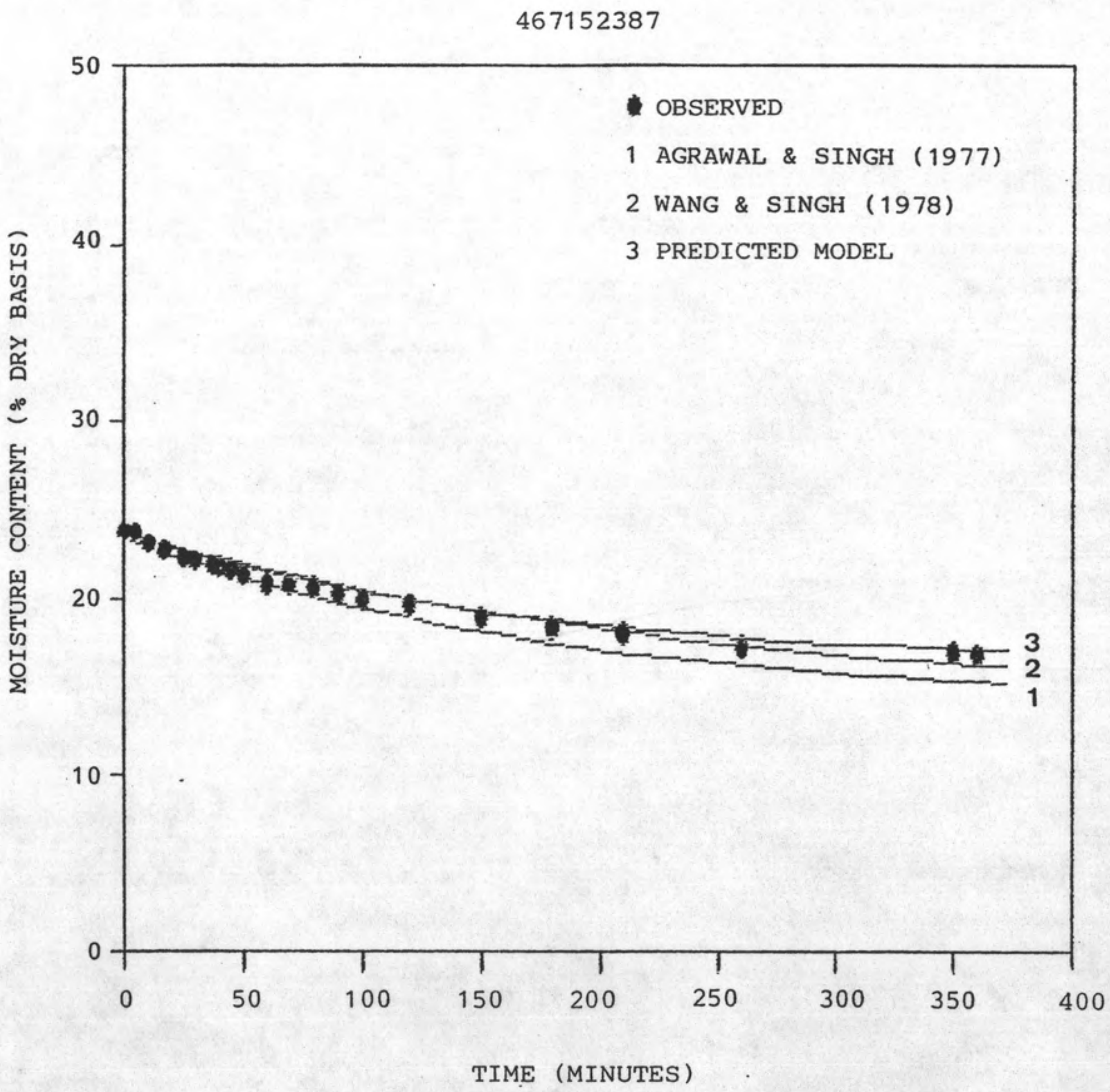

FIGURE 7.9 COMPARISON BETWEEN THE OBSERVED AND PREDICTED MOISTURE CONTENTS AGAINST TIME AT T = 46 °C, RH = 71.5 %, M_i = 23.87 % D.B.

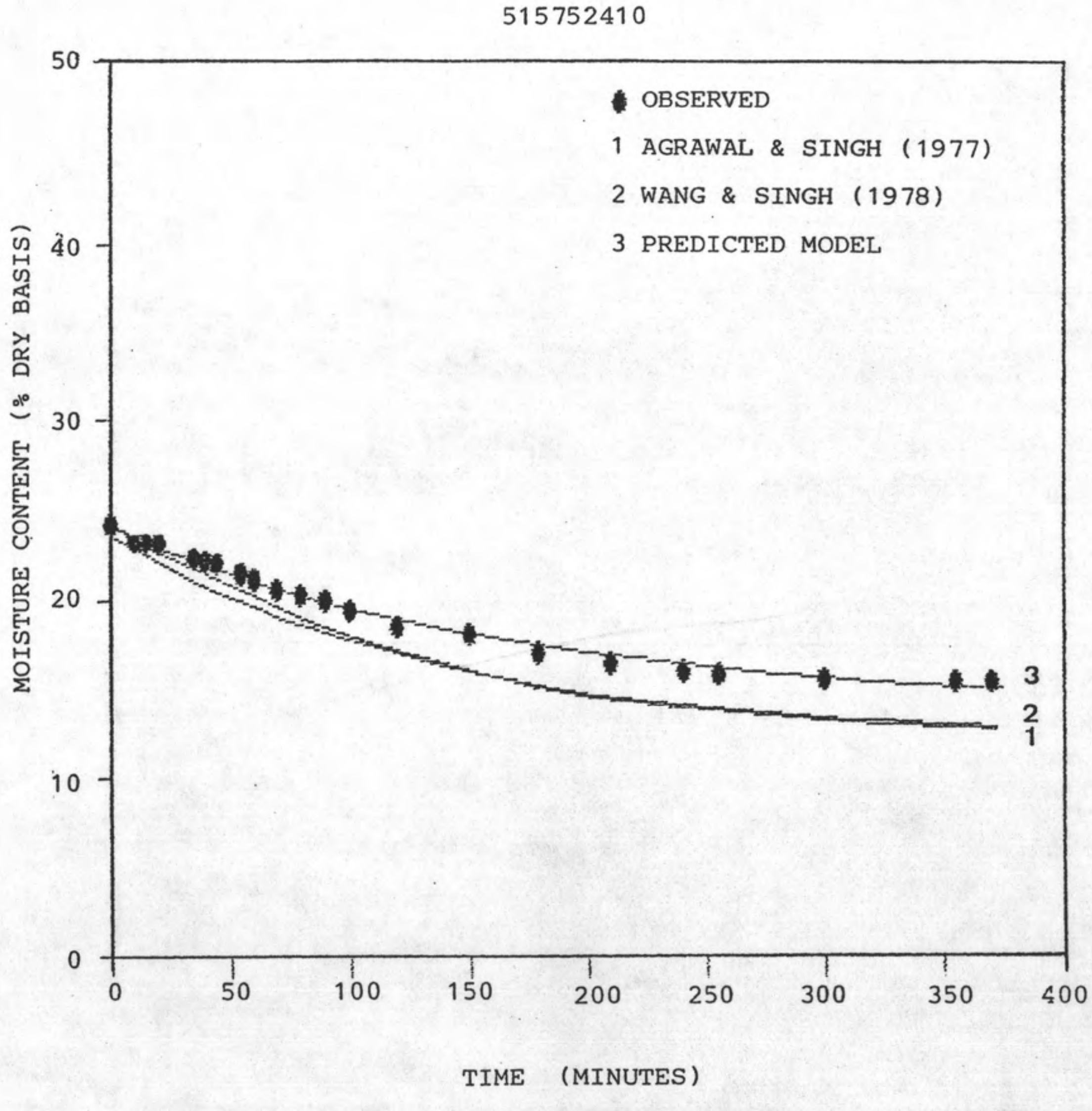

FIGURE 7.10 COMPARISON BETWEEN THE OBSERVED AND PREDICTED MOISTURE CONTENTS AGAINST TIME AT T = 51°C. RH = 57.5 %, M_i = 24.10 % D.B.

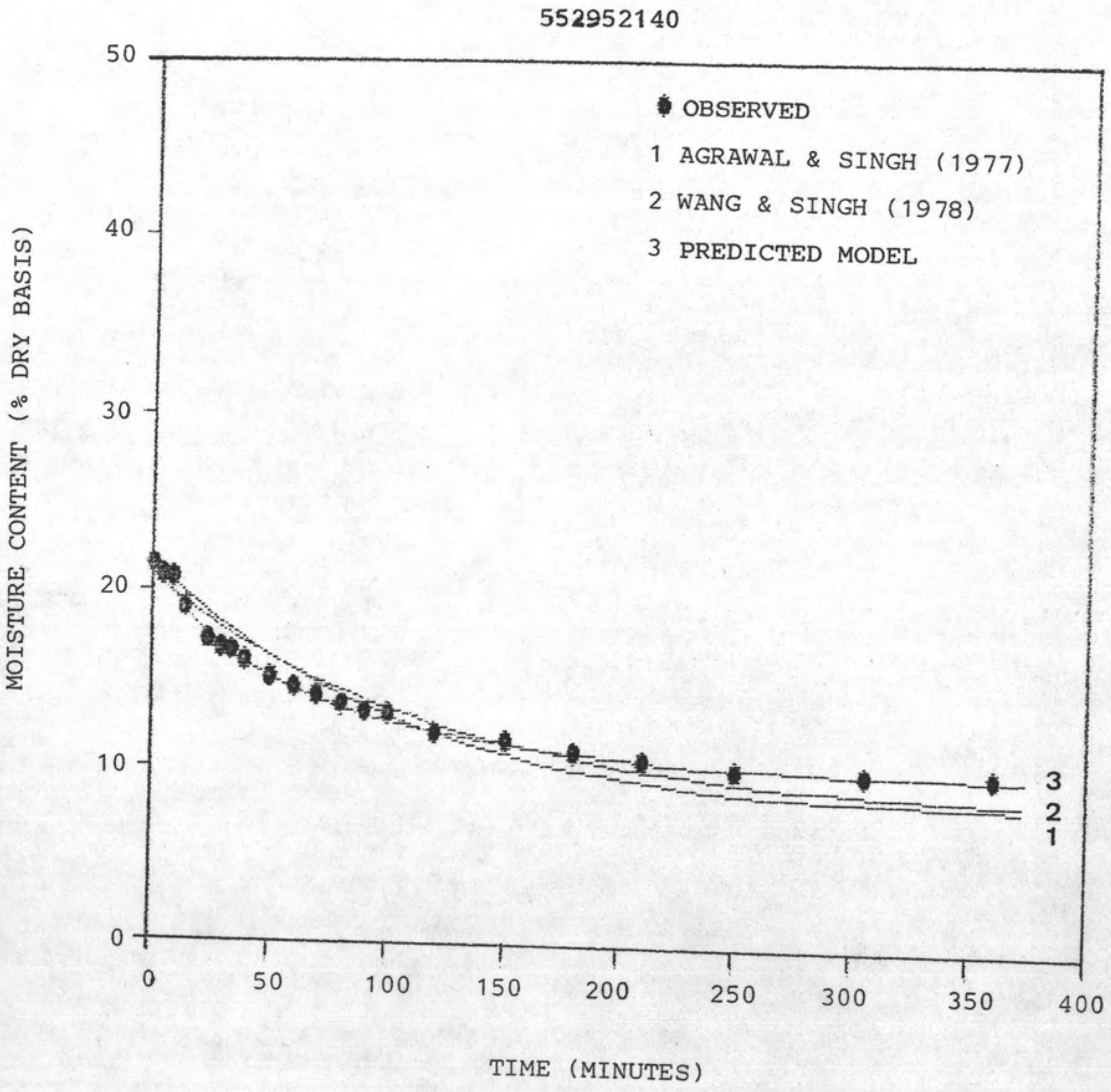

FIGURE 7.11 COMPARISON BETWEEN THE OBSERVED AND PREDICTED MOISTURE CONTENTS AGAINST TIME AT T = 55 °C. RH = 29.5 %. M_i = 21.40 % D.B.

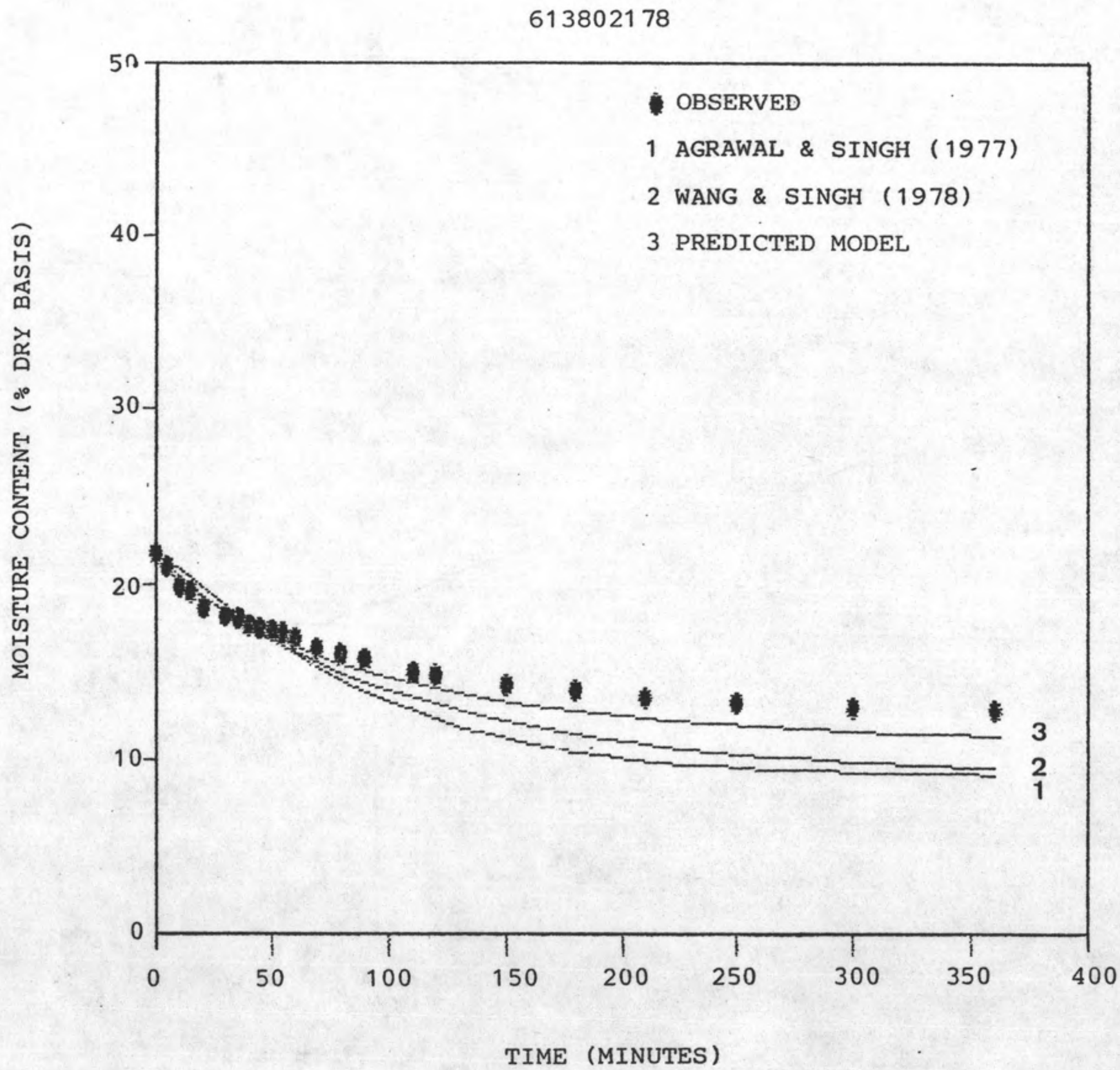

FIGURE 7.12 COMPARISON BETWEEN THE OBSERVED AND PREDICTED MOISTURE CONTENTS AGAINST TIME AT T = 61 °C. RH = 38 %. M_i = 21.78 % D.B.

respectively. High initial moisture content tends to be higher drying rate. This effect is also shown in Figure 7.17 and 7.18.

7-2 Deep bed rough rice drying

In the previous section a most suitable thin-layer drying model has been presented. The resulting model can be used to predict the drying behavior of a particular grain dryer. The deep bed drying experiments were conducted with rough rice (RD7) to verify prediction. An apparatus in this experiment was explained in details in the chapter 4. Five experiments were conducted using various inlet air conditions and various initial moisture content of rough rice (see chapter 4). Air temperature were determined at points in the bed air inlet and 0.05 m, 0.1 m, 0.15 m, 0.2 m, 0.25 m from the air inlet. The moisture content of rough rice in each layer were checked at the end of drying time. All experimental data from the dryer were compared with the simulated results and conclusions will be presented. Model 2.16 which produced $R^2 = 0.953$ was used to be the thin layer equation in deep bed drying simulation. (In the experiment 2,the computer time = 7.67 sec was used for the simulation and difference between the observed and predicted moisture content at the end of drying time for first,third and sixth layer were 1.8 %,1.7 % and 2 % respectively while model 2.15 gave $R^2 = 0.948$, used computer time 7.48 sec and produced the difference of moisture content 2 %,2.4 % and 3.4 % for first,third and sixth layer respectively). A large number of graphs can be drawn from the output obtained from the simulation. But because of space limitation, only typical results will be shown.

The typical results of the deep bed drying are presented graphically in Figure 7.19 through 7.24. Figure 7.19 and 7.20 are the average moisture content vs time plot of the experimental conditions 1 and 2 respectively. The moisture content of rough rice at the bottom layers of these experiments dropped quickly as expected from the drying rate of a thin layer of rough rice and approached the equilibrium values (10.88 and 14.94). In the experiment 1 during

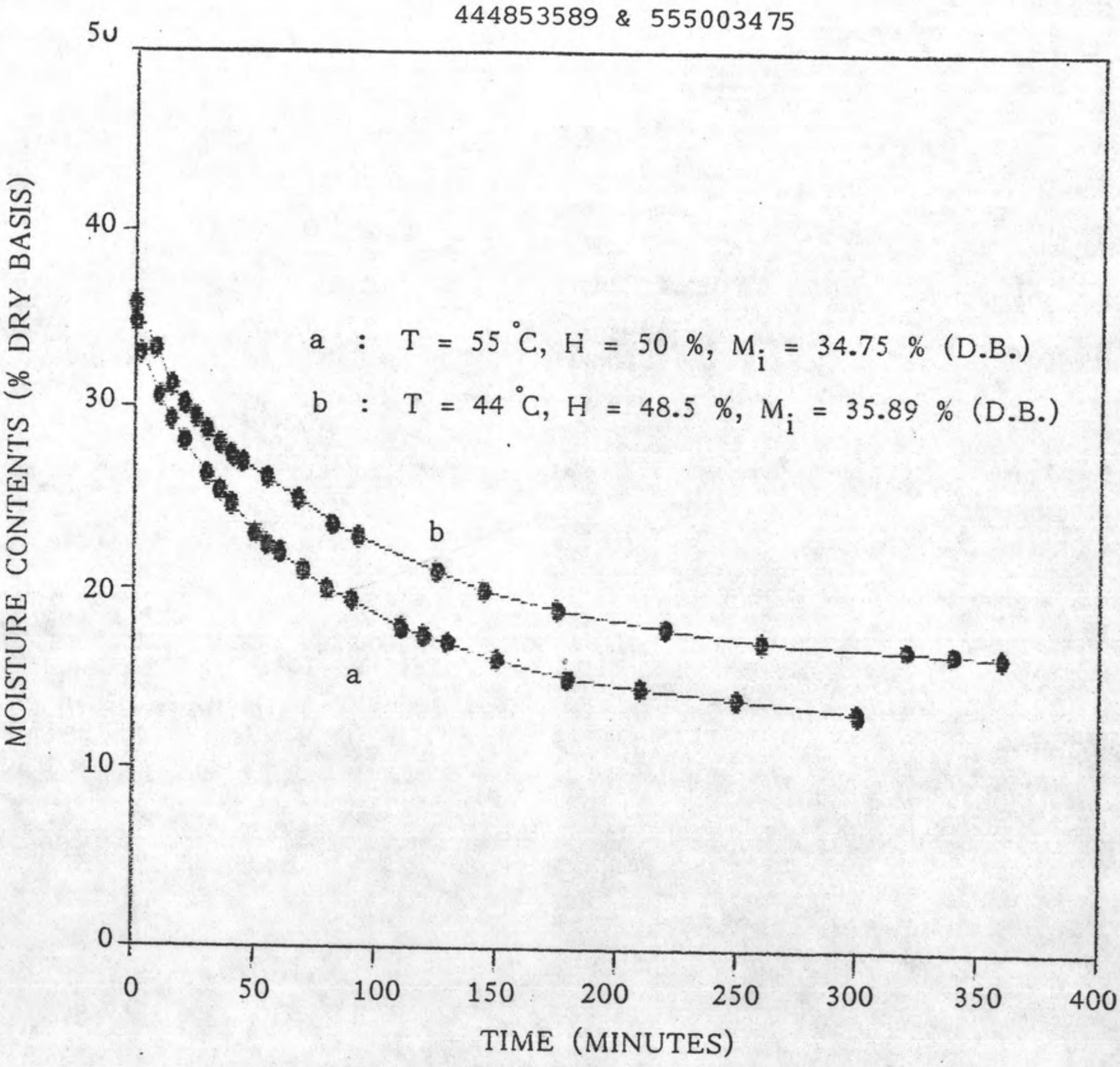

Figure 7.13 Effect of drying air temperature on thin-layer rough rice drying

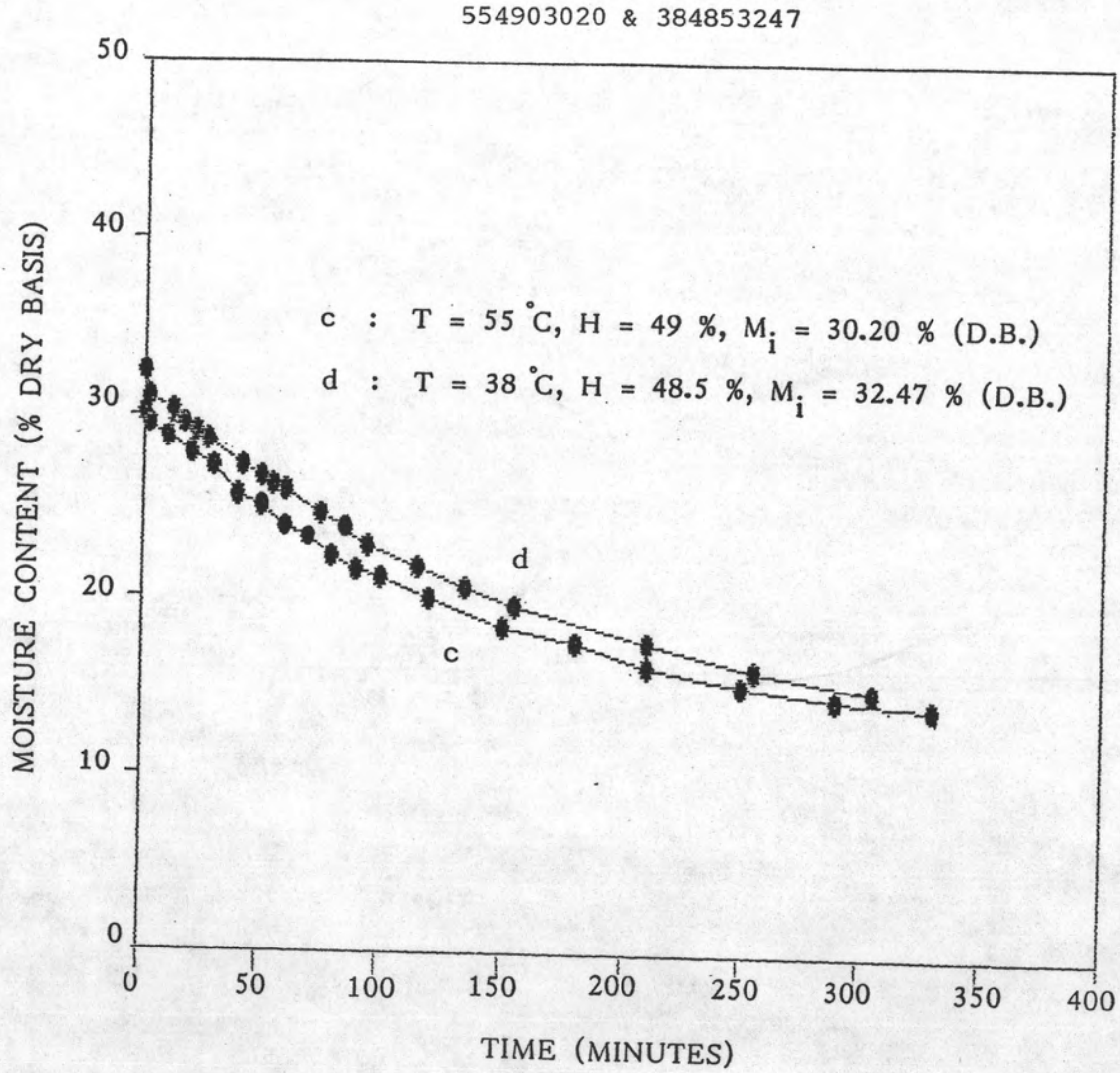

Figure 7.14 Effect of drying air temperature on thin-layer rough rice drying

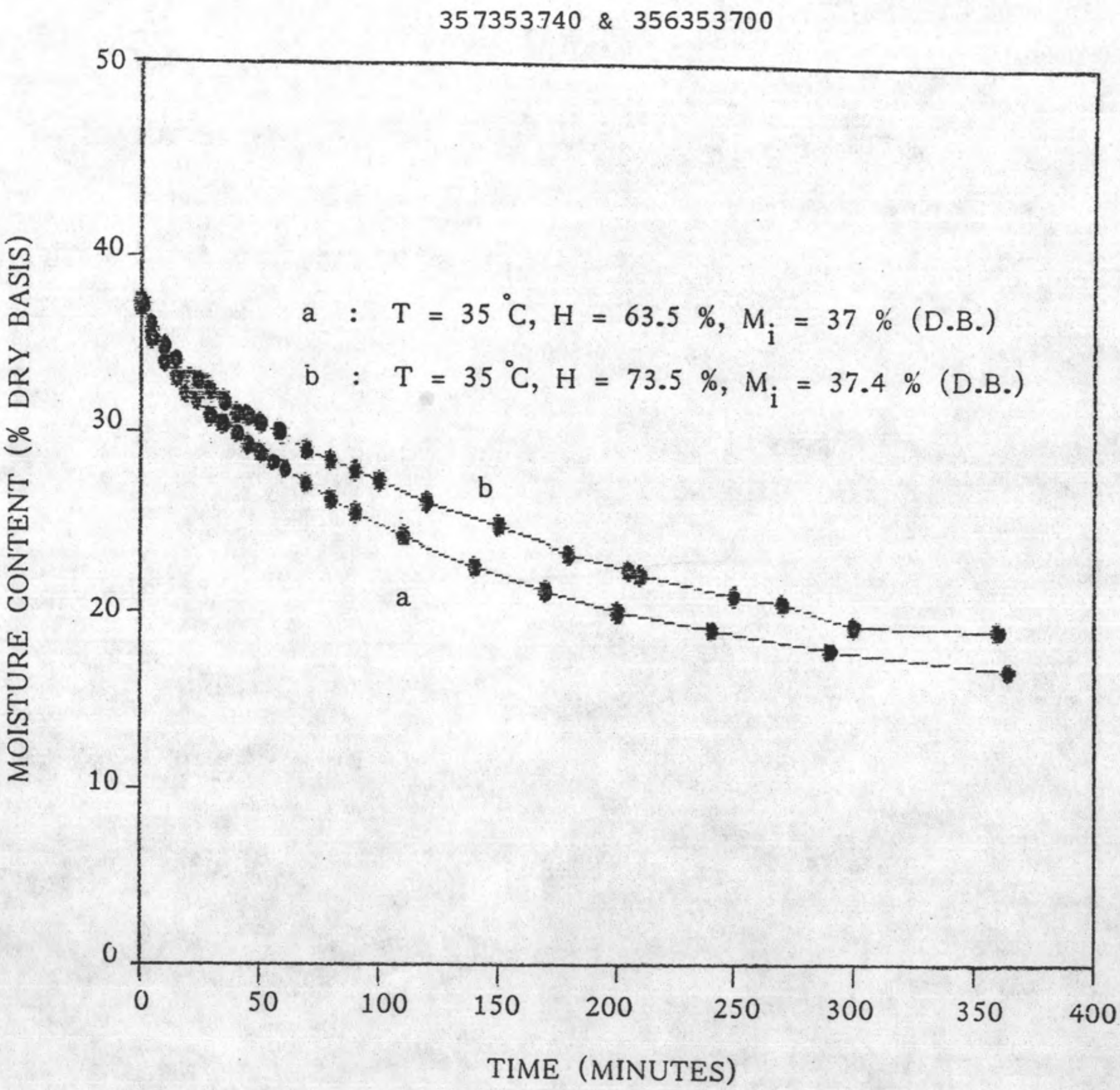

Figure 7.15 Effect of relative humidity of air on thin-layer rough rice drying

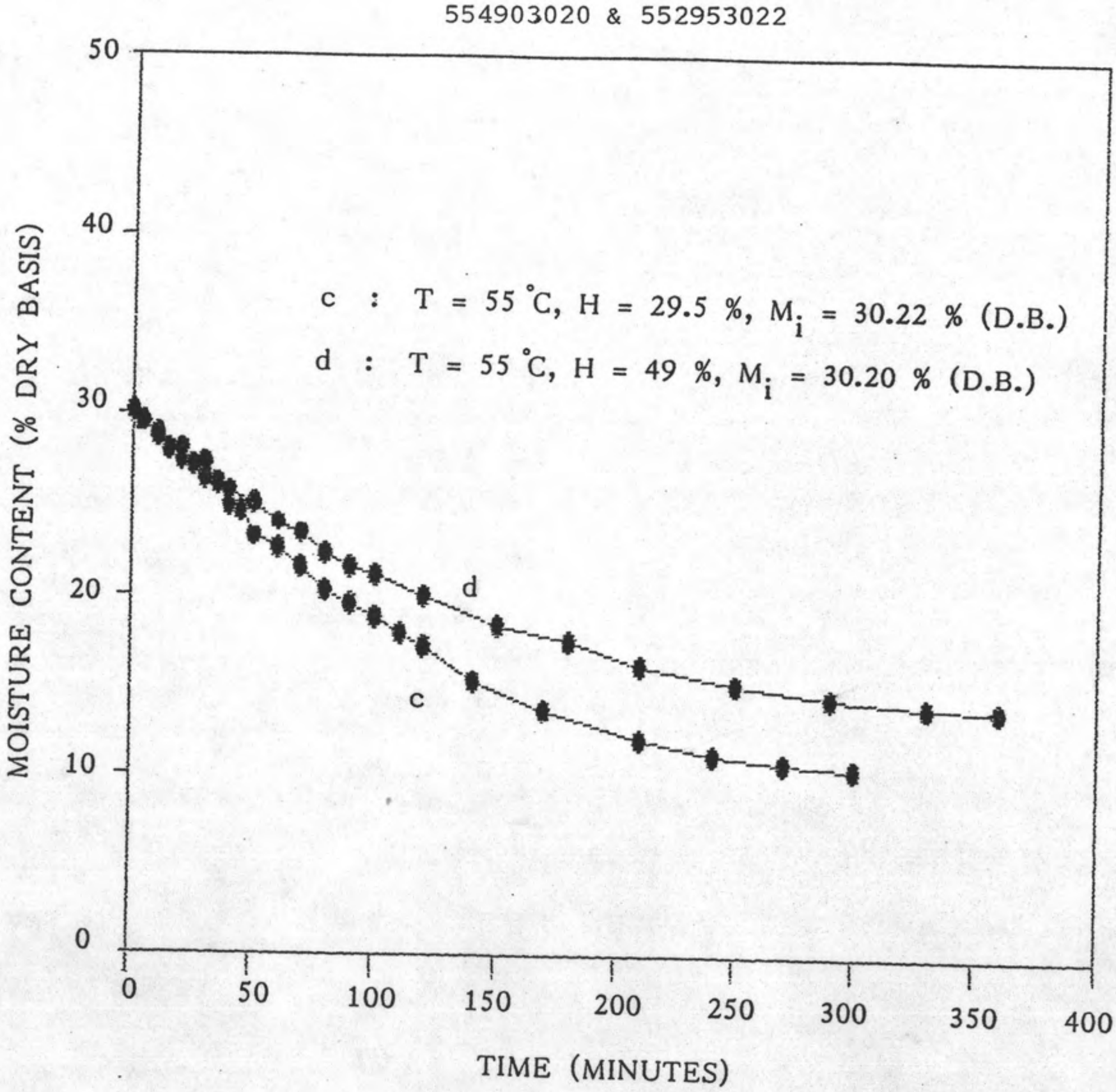

Figure 7.16 Effect of relative humidity of air on thin-layer rough rice drying

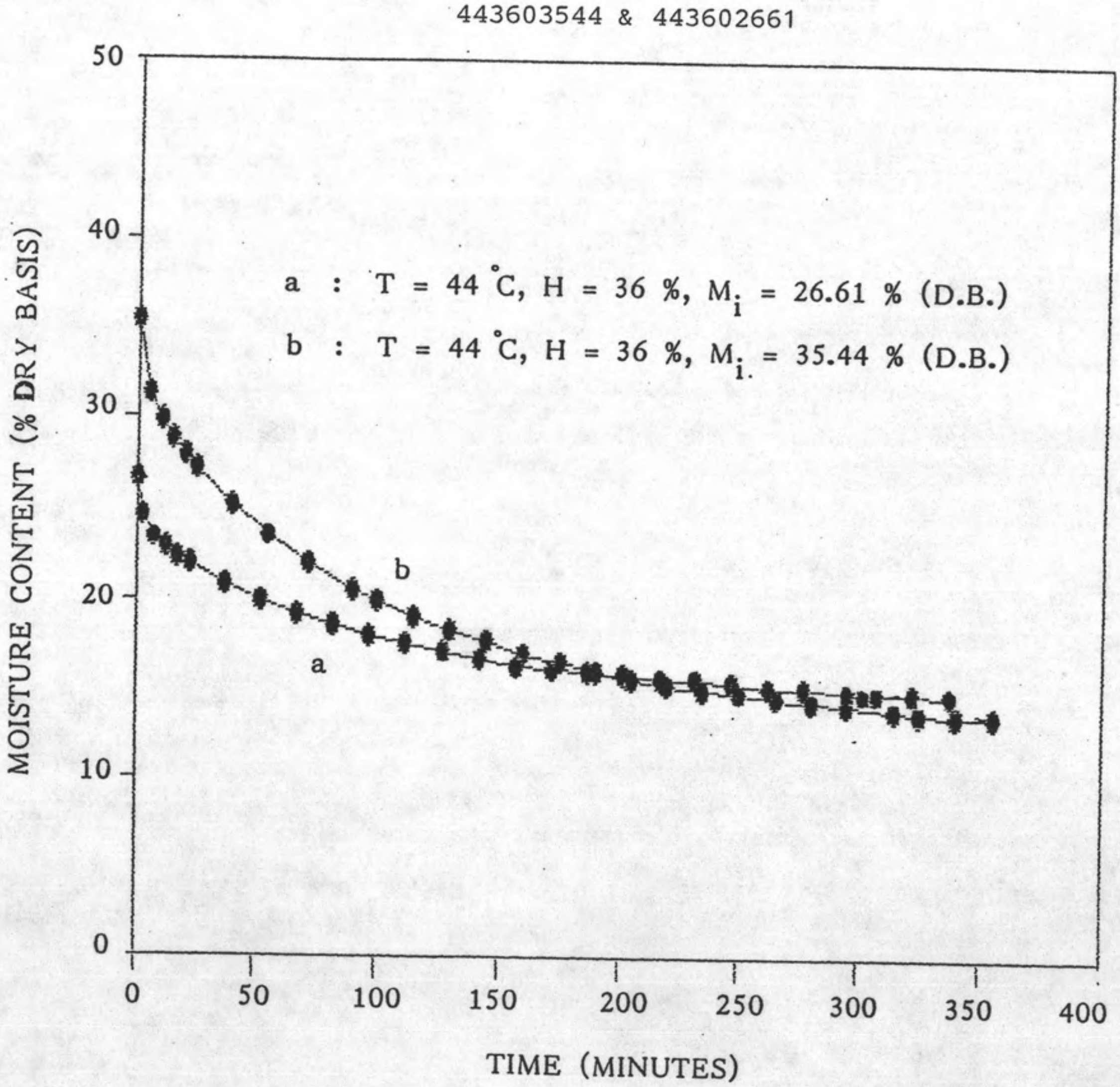

Figure 7.17 Effect of initial moisture content of rough rice on thin-layer rough rice drying

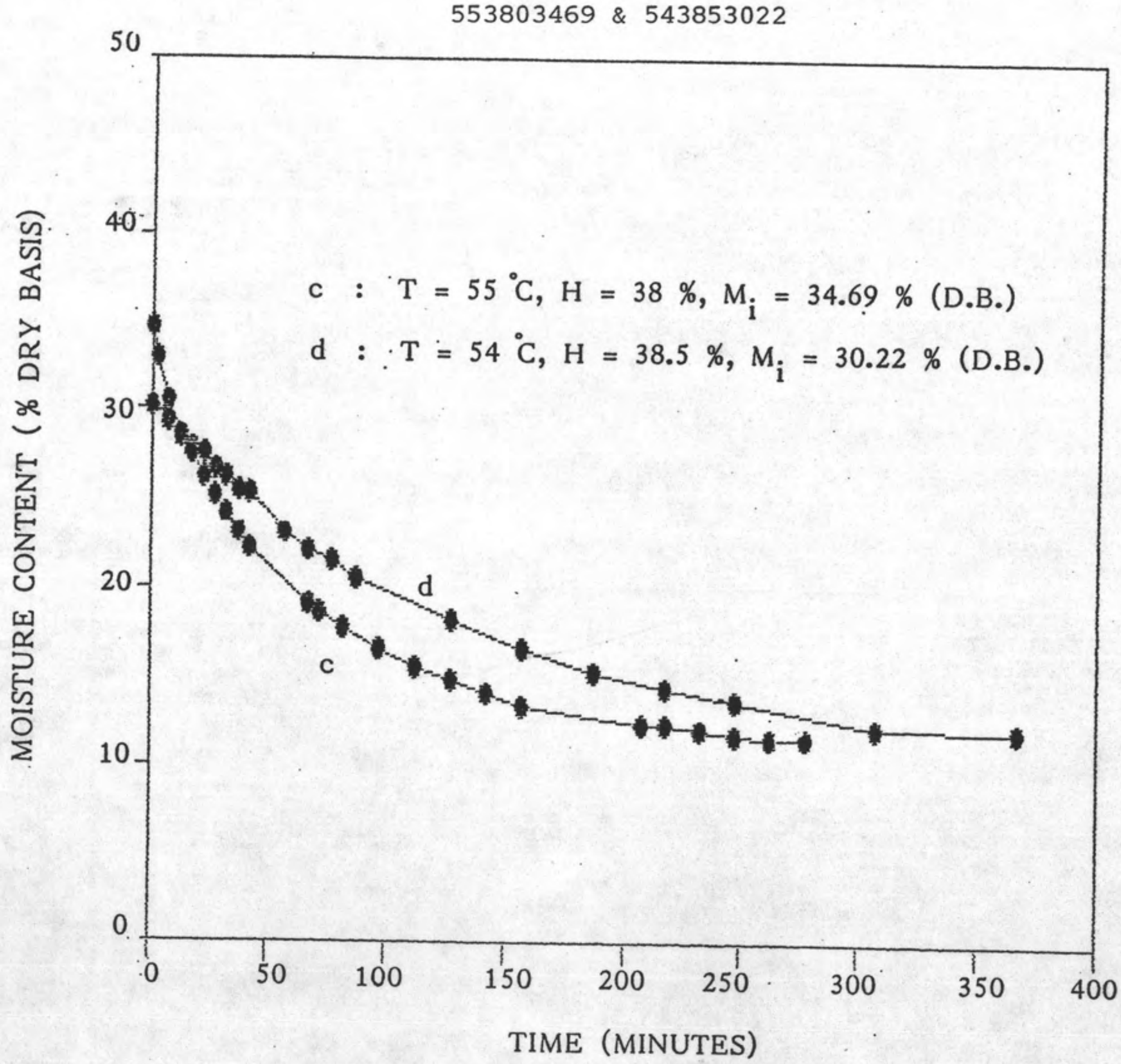

Figure 7.18 Effect of initial moisture content of rough rice on thin-layer rough rice drying

the first half hour of drying,the moisture content at the level 0.275 m from the bottom remained approximately at the initial values and started to be dried approximately fourty minutes later. Similarly, in the experiment 2 at the same level the drying will be started in one hour later. The moisture content at each level in the experiment 1 decreased faster than in the experiment 2. In the experiments, the samples were allowed to warm at room temperature to avoid condensation during drying, so moisture absorption of the grain at any part of the bed is not observed. Predicted values of moisture content for first, third and sixth layer at the end of drying times were found to be lower than the observed values.

Typical drying air temperature-time profiles at various heights of the experiments are presented in Figure 7.21 and 7.22. It also can be seen from the figures that air temperature in the grain bed rose quickly during the first two hours of drying. After this time they continued to rise and approached the inlet air temperature. Observed temperatures of air between layers were found to be lower than the predicted values. Figure 7.23 and 7.24 are also shown the moisture content-time profiles from the simulation in the difference forms.

The difference between the observed and predicted values might be caused by a variation of drying air temperature. Drying air conditions were fixed for specific drying interval in the deep bed drying model, in the experiment it could not be kept constant at specific conditions. The analytical description also assumed a perfectly insulated container. When the drying air temperature

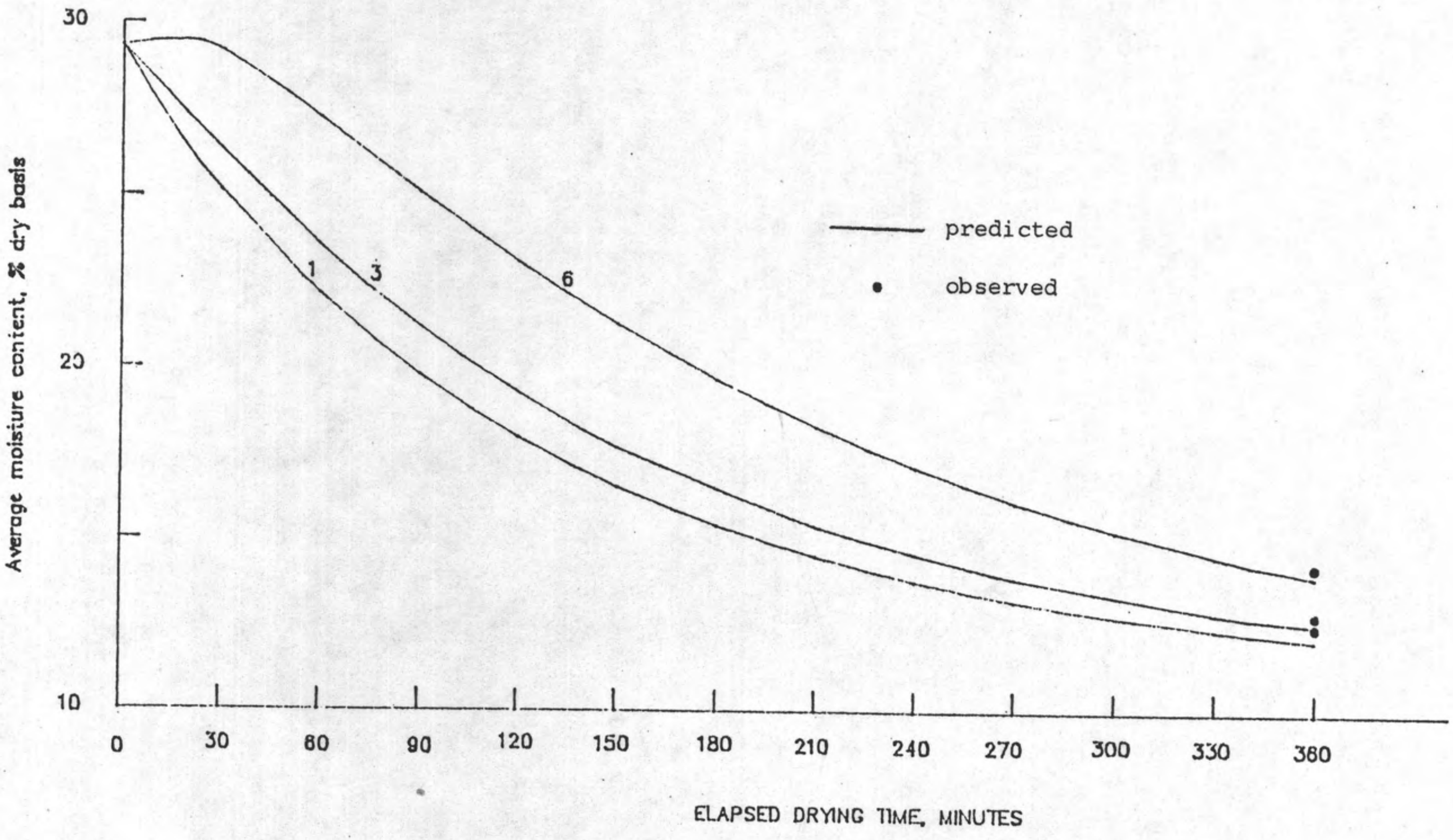

Figure 7.19 Plot of average moisture content against time, at various depths, in a deep bed of rough rice being dried with heated air (experiment 1)

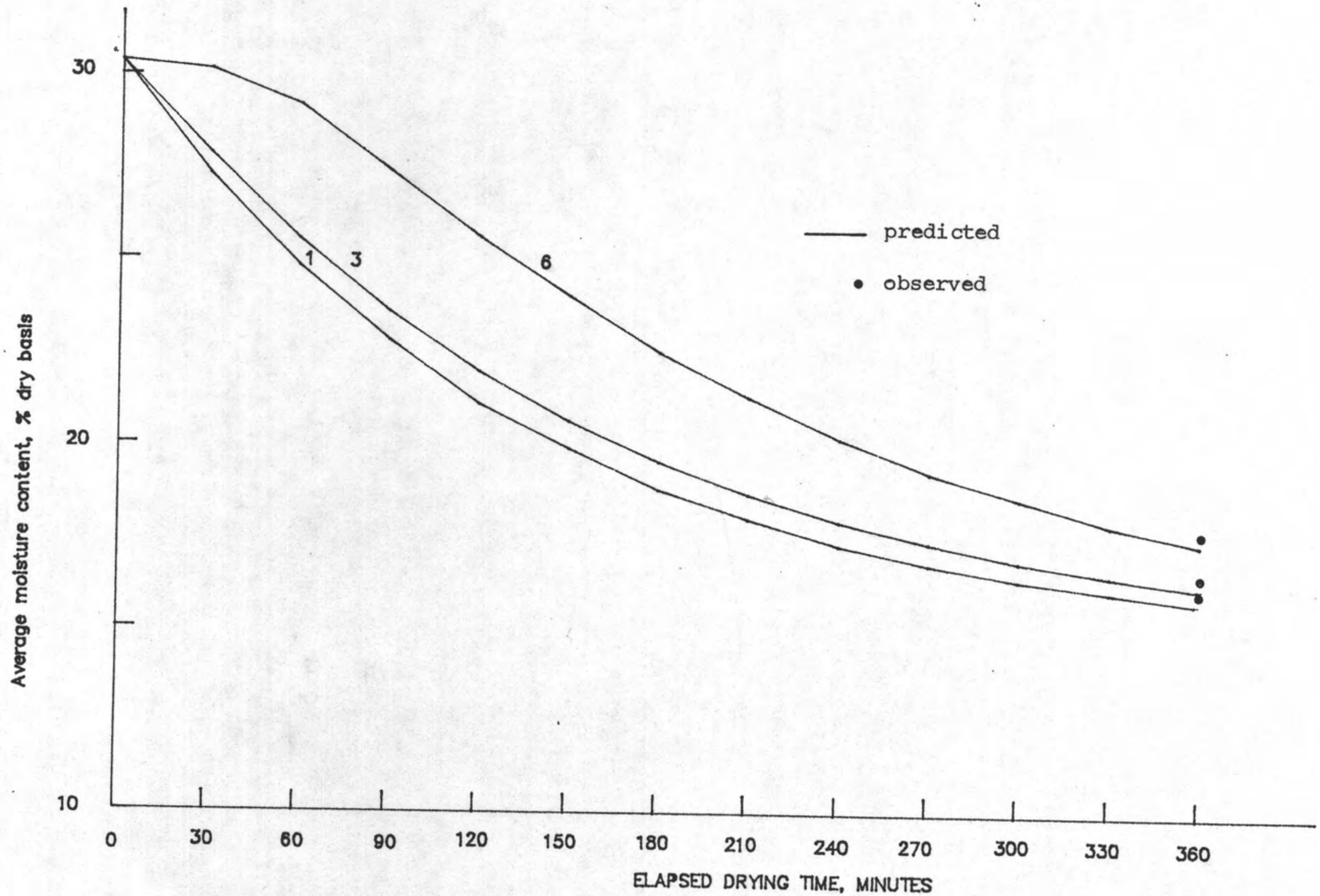

Figure 7. 20 Plot of average moisture content against time, at various depths, in a deep bed of rough rice being dried with heated air (experiment 2)

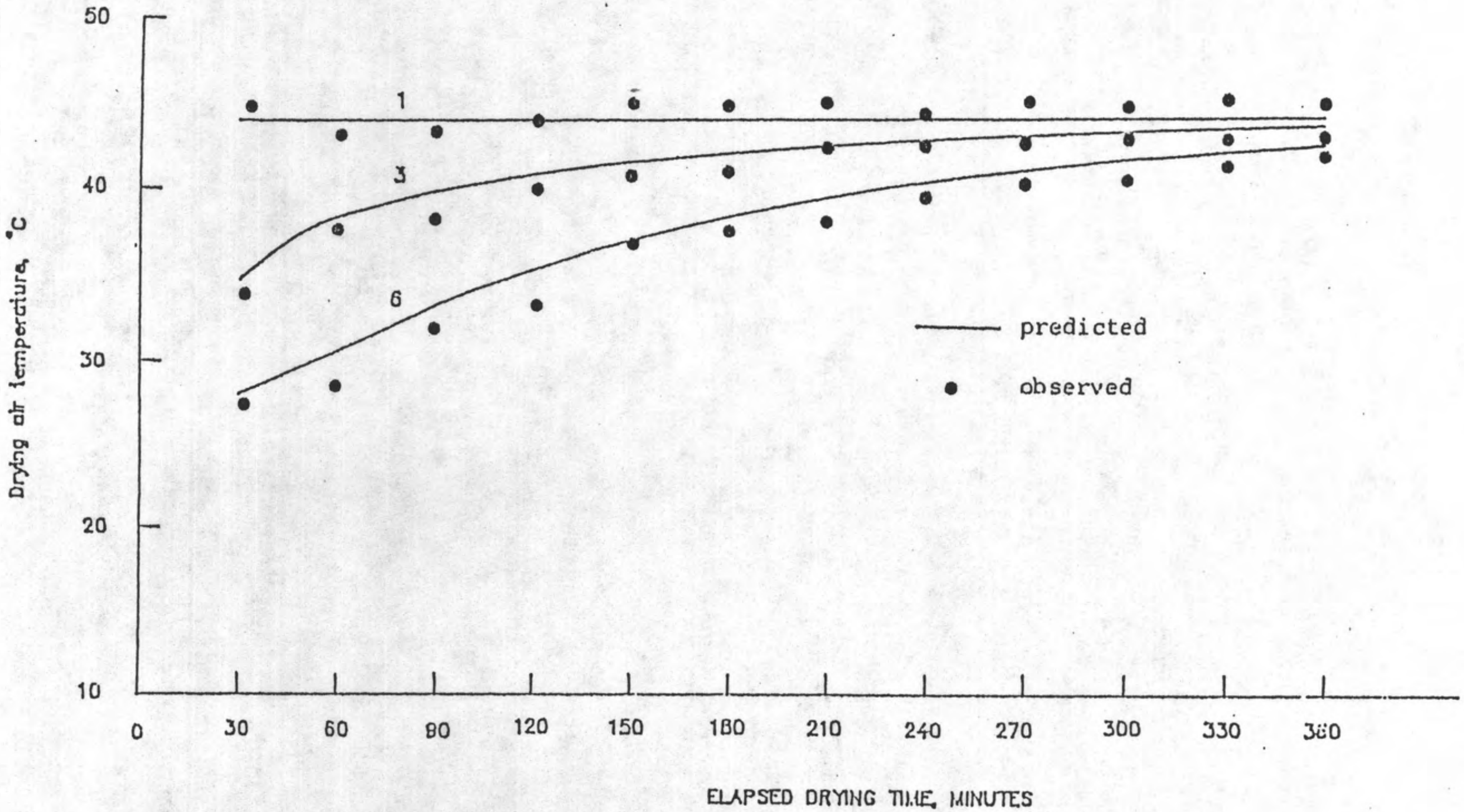

Figure 7.21 Plot of drying air temperature against time, at various depths, in a deep bed of rough rice being dried with heated air (experiment 1)

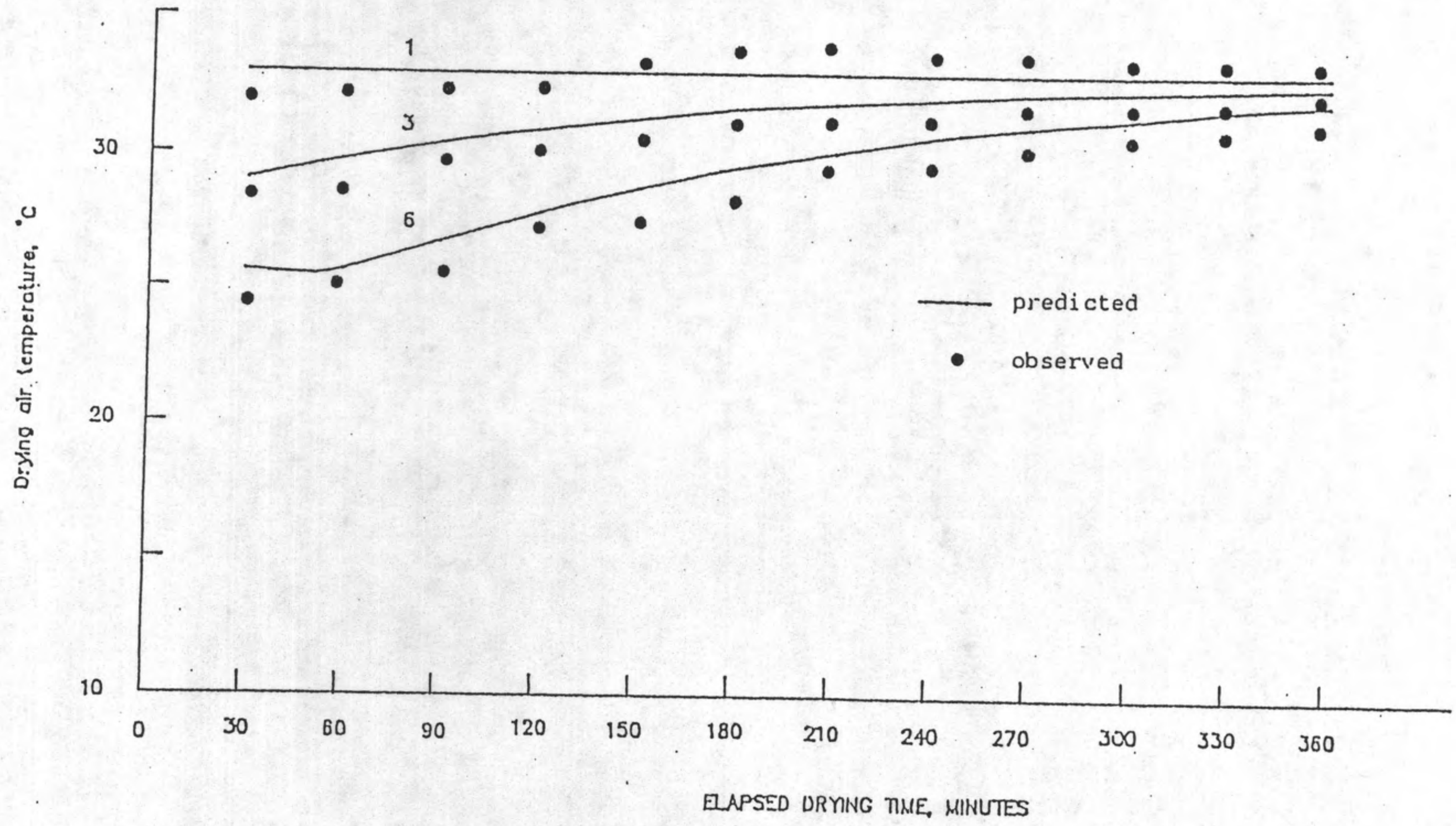

Figure 7.22 Plot of drying air temperature against time, at various depths, in a deep bed of rough rice being dried with heated air (experiment 2)

dropped, the potential of drying was reduced so the high predicted temperature in the rough rice layers appears to agree with the higher drying rate. However the shape of the air temperature and moisture content profile of both predicted and observed had good agreement.

The additional general observations may be made from the experiments. An increase in the drying air temperature increases the drying rate of a grain bed; Using high inlet drying air temperature, the bottom layers of a fixed grain bed will be overdried; If the initial moisture content of grain is low, the drying zone passes more quickly through a grain bed; The depth of the drying zone decreases with a decrease in air temperature, a decrease in air flow rate, and an increase in initial moisture content.

The use of simulation to provide a better understanding of the drying process, in addition, can be used to determine the effect of a change in certain of test variables on the drying efficiency, or to minimize the operating costs. It would be time-consuming, expensive to obtain these data from experiments. Simulation furnishes this information rapidly and at little cost. Clearly, suitably constructed models can be used to help with the design of new driers and to promote the more efficient use of existing driers.

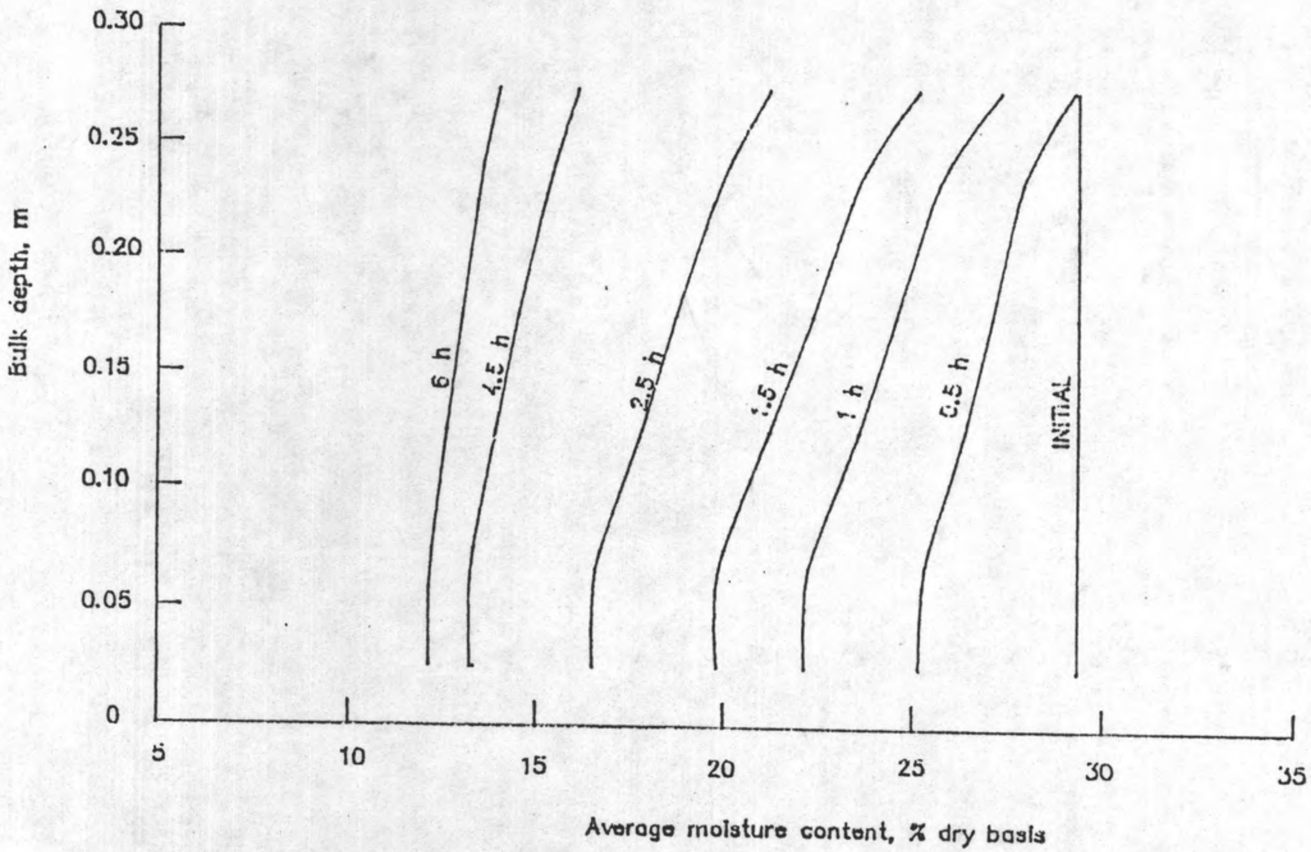

Figure 7.23 Plot of bulk depth against average moisture content, at various drying times, in a deep bed of rough rice being dried with heated air (experiment 1)

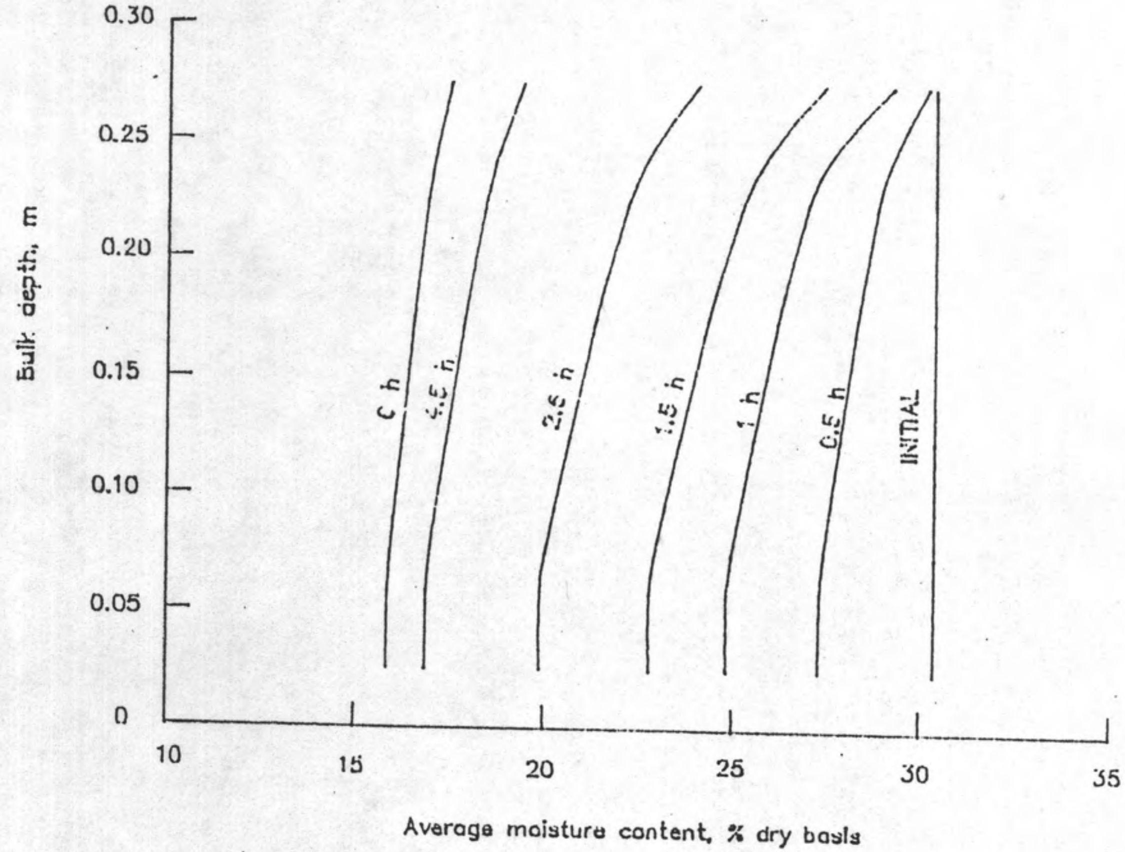

Figure 7.24 Plot of bulk depth against average moisture content, at various drying times, in a deep bed of rough rice being dried with heated air (experiment 2)