CHAPTER 5

RESULTS AND DISCUSSION

In this work the following parameters : heat capacity, kinetic parameters and thermal conductivity were investigated. The operating conditions had four levels and three variables were carried out to study the effects on the rice hull pyrolysis.

The types of experimental data collected were :

1. weight of water, weight of rice hull or rice hull char, initial and equilibrium temperature ;
2. the bulk density at various time ;
3. the temperature of rice hull bed at furnace wall, and at distances 1.6, 3.2 and 4.8 cm from the wall, as a function of time.

5.1 <u>Heat Capacity</u>

The heat capacity of the rice hulls was measured at initial temperatures of 32, 40, 46 and 56°C with 0.11, 8.49, 16.35, and 24.04% moisture content for rice hulls and for one sample rice hull char. Heat capacity values were calculated using equation (3.1). Figure 5.1 shows that heat capacity depends on the temperature and moisture content and indicates that it increases with increasing temperature and moisture content. The effect of moisture content on the heat capacity values are more predominant than the temperature effect.

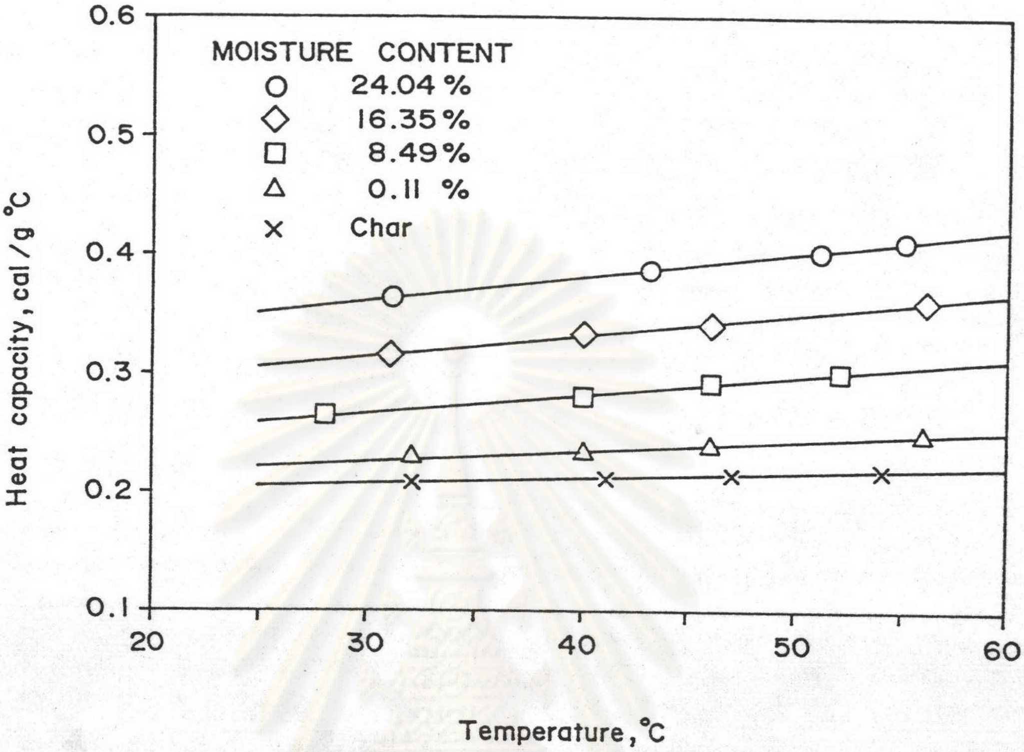

Figure 5.1 Heat Capacity Versus Temperature of Fresh Rice Hulls and Rice Hull Char

When subjecting the heat capacity values to regression analysis, equations relating heat capacity to temperature were established for both rice hull at various moisture contents and rice hull char. The regression equations are presented in Table 5.1. In all equations, T is the temperature in degree Celsius and C_p is the heat capacity in cal/g °C.

Table 5.1 Summary of Heat Capacity Equations

Eqn.No.	Regression equation	% Moisture content
1	$C_p=0.2005+0.00085xT$	0.11
2	$C_p=0.2177+0.00161xT$	8.49
3	$C_p=0.2619+0.00179xT$	16.35
4	$C_p=0.3032+0.00199xT$	24.04
5	$C_p=0.1937+0.00046xT$	CHAR

Due to non-availability of published literature on heat capacity of rice hulls, the obtained result could not be compared. Some work on the heat capacity of wood has been reported by Beall (1968) at the same temperature and moisture content, the heat capacities of rice hulls in this experiment, 0.2087-0.4151 cal/g °C, were within the range of the results reported by Beall (0.259-0.338 cal/g °C).

5.2 Kinetic Parameters

Due to the complexity of the mechanisms of pyrolysis as stated in section 2.3.1, a simple kinetic model (equation (4.5)) was used to attempt at representing pyrolysis. The important parameters in the kinetic model consist of a pre-exponential factor (A) and an apparent activation energy (E). These kinetic parameters are used to demonstrate the bulk density change during pyrolysis.

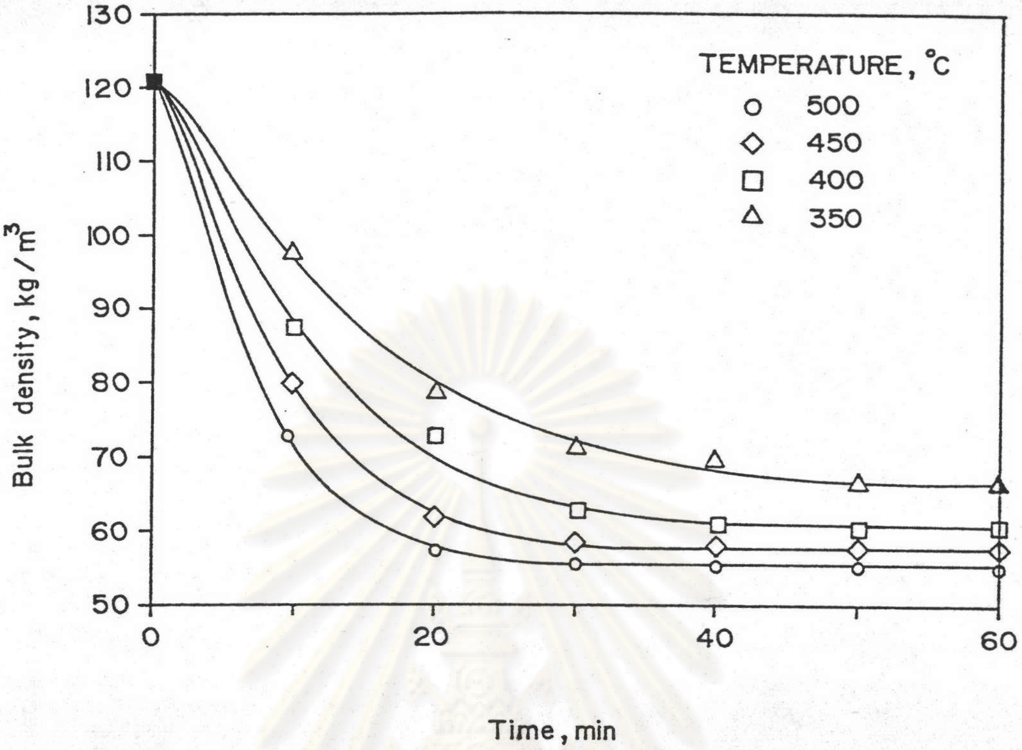

Figure 5.2 Bulk Density Change Curves at 8.49% Moisture Content

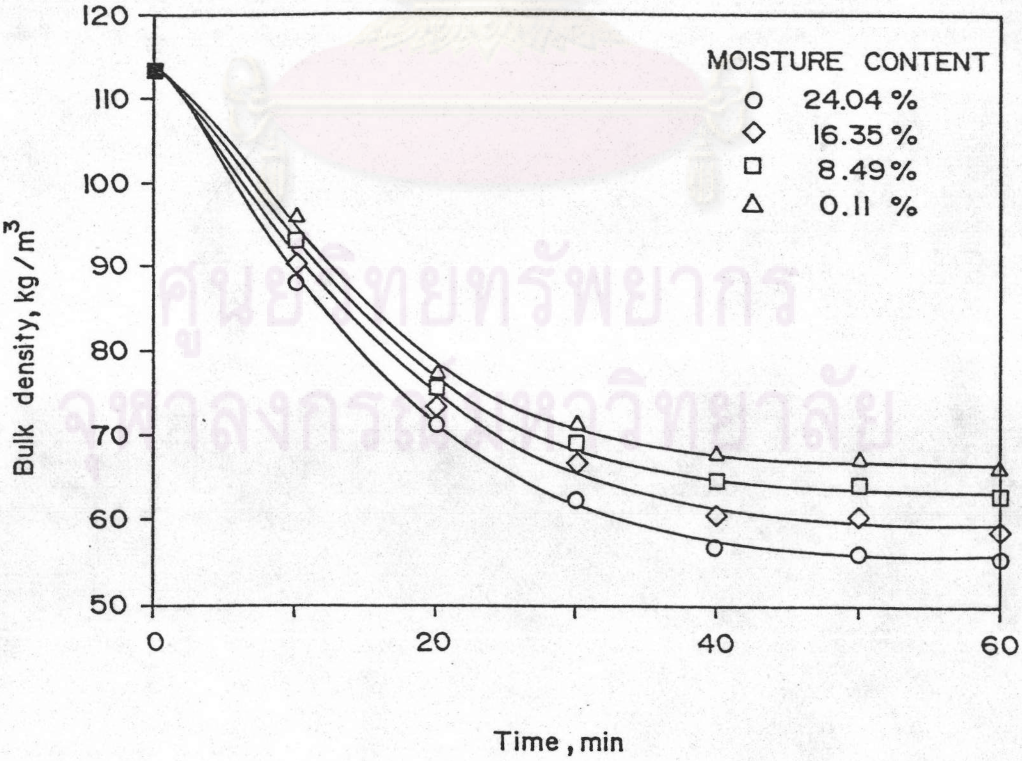

Figure 5.3 Bulk Density Change Curves at 350 °C Temperature

The bulk density change curves in Figures 5.2 and 5.3 present clearly the strong effect of the pyrolysis temperature and moisture content on the pyrolysis rate. The obtained results indicate that at the same moisture content and initial bulk density, the time to complete pyrolysis and the mass of residual char decrease with increasing pyrolysis temperature. The pyrolysis rate occurs rapidly initially and then slows down until the final density is attained.

Due to the fact that the reactions involved in the pyrolysis are complex, the obtained activation energy value and pre-exponential factor value are combinations of several reactions. From the fitting of pyrolysis model on experimental data it was found that the activation energy value of rice hull pyrolysis was 6715 J/mol and the pre-exponential value was 0.45 1/min at 350-500 °C pyrolysis temperature.

5.3 Temperature History during Rice Hull Pyrolysis

During pyrolysis, the temperature inside the rice hull bed can be separated into three zones based on the graph showing the variation of temperature with time as shown in Figure 5.4.

In zone I, the preheated zone, the rice hull is heated by conduction heat transfer from the furnace wall. The temperature inside the rice hull bed is increased until heat flow is balanced by the energy requirements for evaporation of moisture which occurs in zone II. In this zone I little actual drying will usually occur.

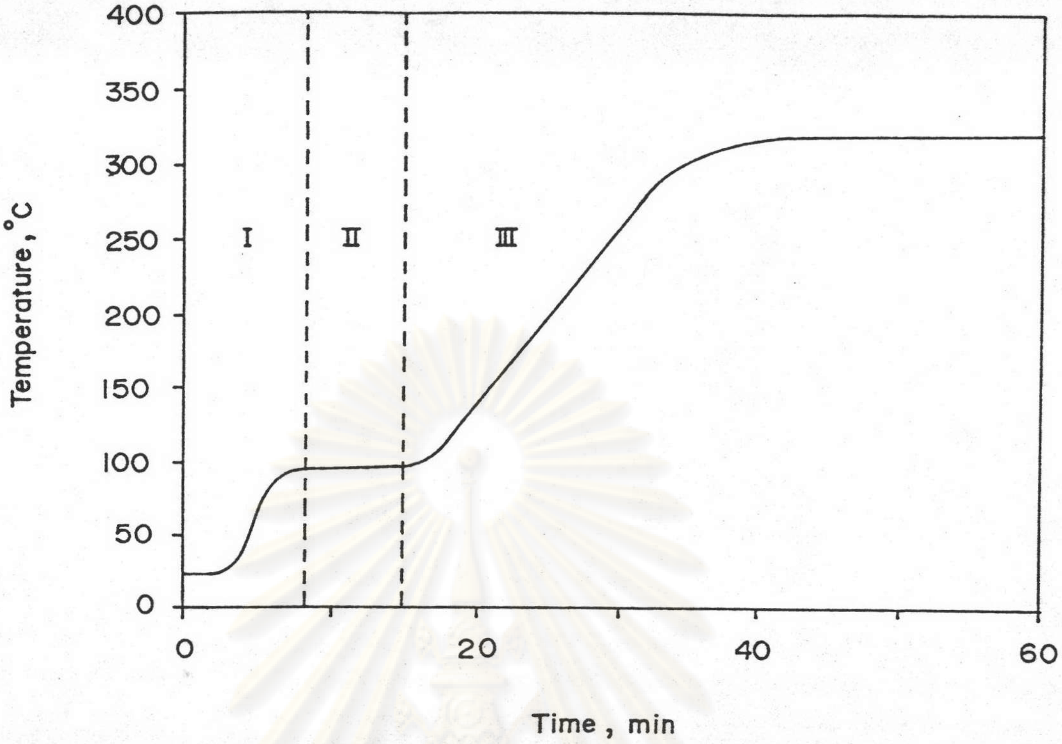

Figure 5.4 Temperature History in the Center of Rice Hull Bed

Zone II, drying starts at about 90-94 °C, the temperature cannot rise above this until the surface and unbound moisture have been driven off. Obviously a fair amount of energy is required to vaporize the moisture.

Pyrolysis then occurs in zone III, the rice hull is pyrolysed to gases, tars and chars. The decreased energy requirement of pyrolysis (see Figure 4.2) in zone III results in increased temperature. The effects of variables on the temperature history are discussed as follows :

5.3.1 Moisture Content

Figure 5.5 shows the temperature profiles obtained during pyrolysis of a 113.50 kg/m^3 bulk density sample with 8.49% moisture content up to a temperature of 350°C. These profiles may be compared to those shown in Figure 5.6, recorded during an experiment under similar conditions, except with a rice hull moisture content of 16.35%. In the latter case the drying time is increased, due to greater moisture content which results in increased total time of pyrolysis as the pyrolysis period is shifted.

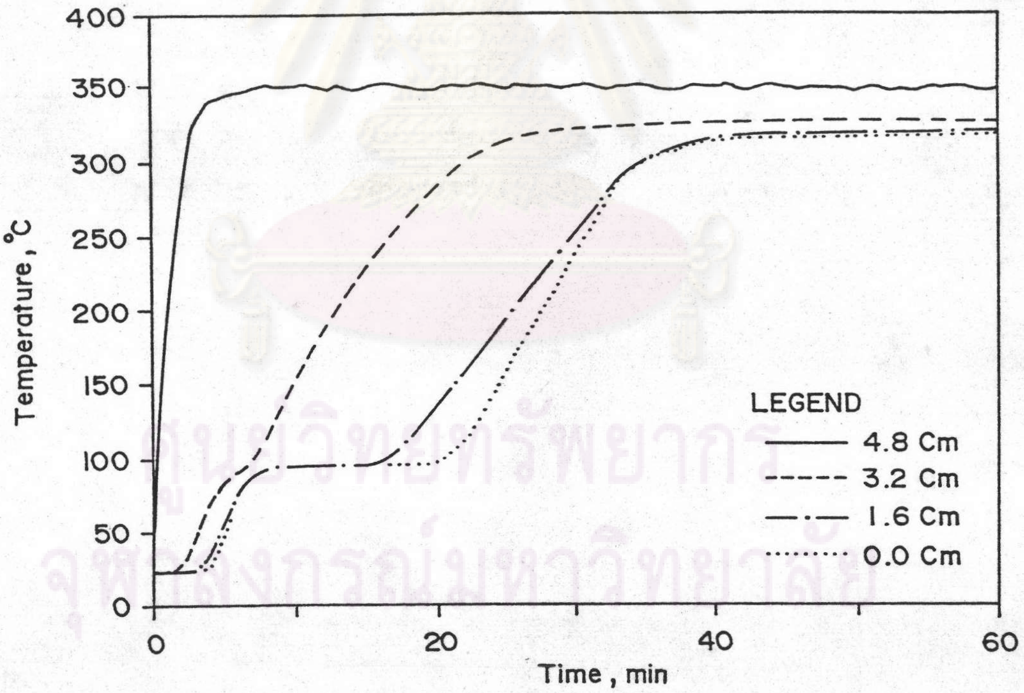

Figure 5.5 Temperature Profiles at 350°C Temperature with 113.5 kg/m^3 Bulk Density for Moisture Content of 8.49%

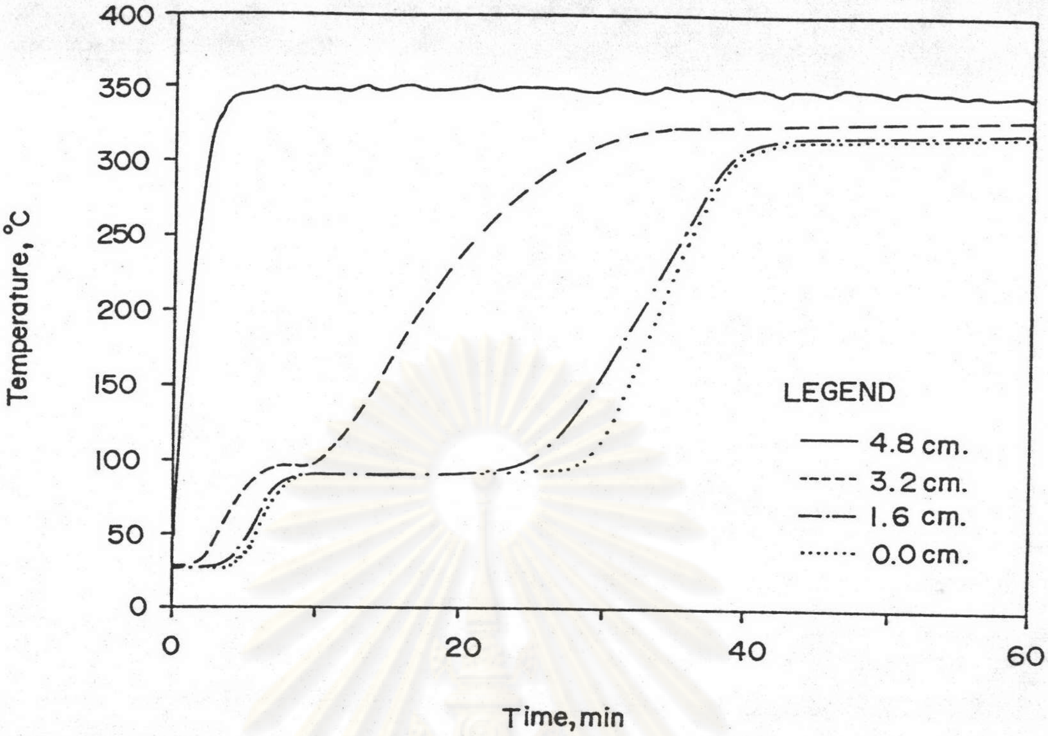

Figure 5.6 Temperature Profiles at 350 °C Temperature with 113.5 kg/m^3 Bulk Density for Moisture Content of 16.35%

From Figures 5.5 and 5.6, it is observed that drying occurs in the same temperature range (90-94 °C) and this occurs also for other temperature profiles (see Appendix B) which indicates that the moisture in rice hull evaporates at this temperature range.

5.3.2 Temperature and Bulk Density

From Figures 5.7 and 5.8 it is shown that the change in pyrolysis temperature and bulk density have an effect on the drying time as well as moisture content. The obtained results

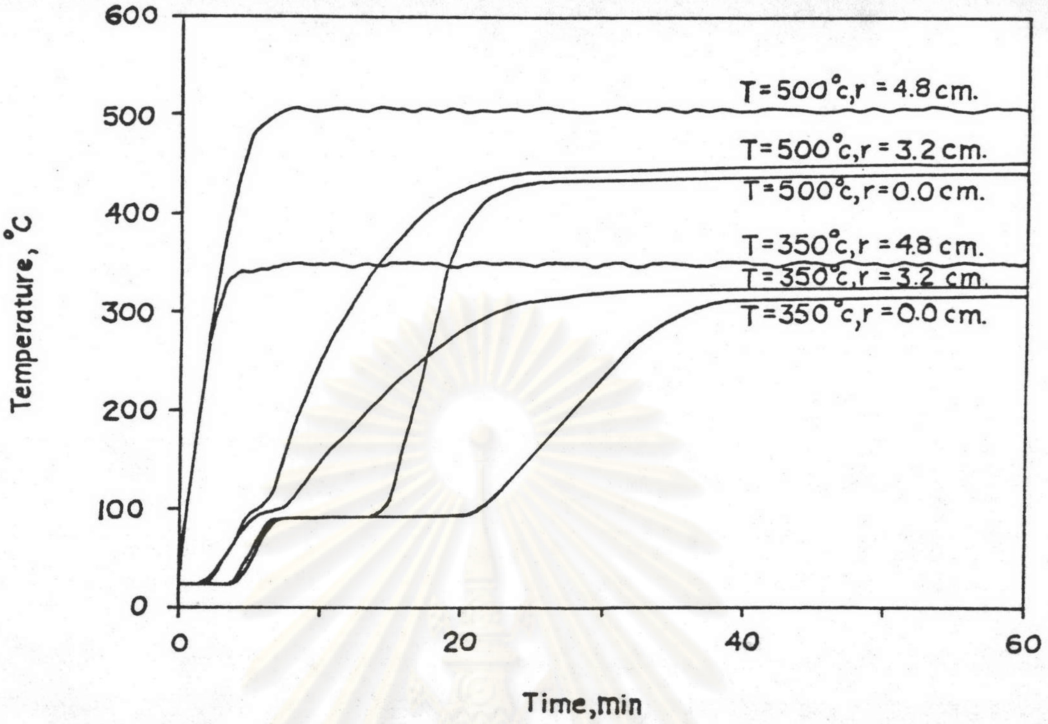

Figure 5.7 Comparison of Temperature Profiles for Experiments with High (T=500 °C) and Low (T=350 °C) Temperature

indicate that drying time decreases with increasing pyrolysis temperature and increases with increasing bulk density.

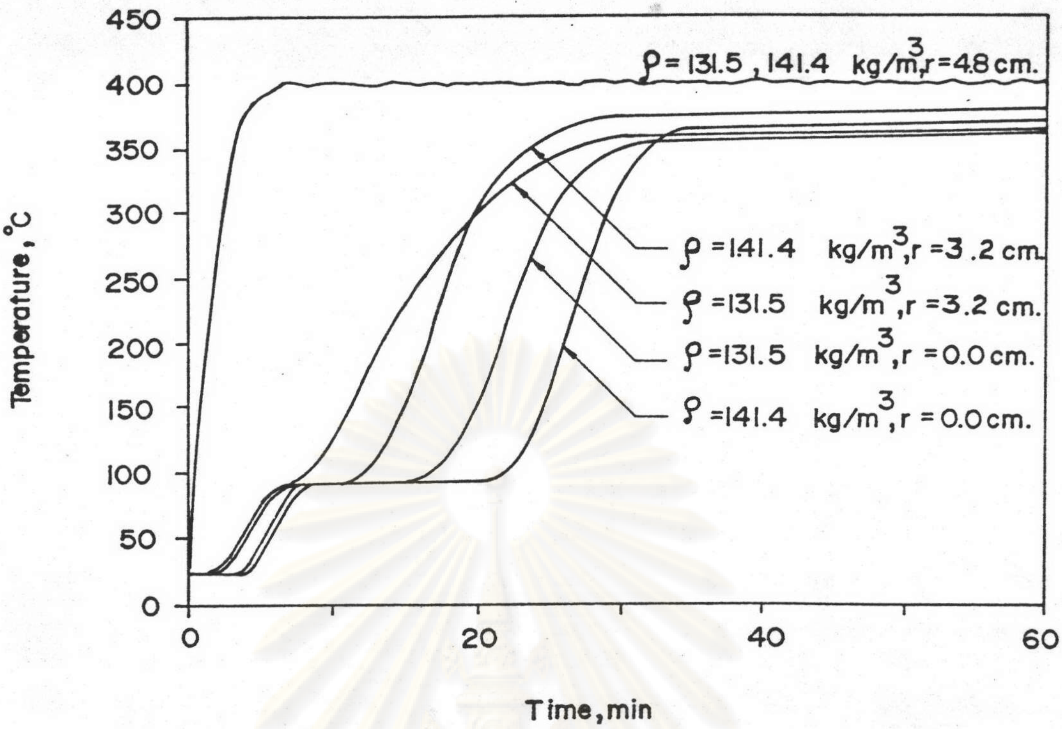

Figure 5.8 Comparison of Temperature Profiles for Experiments with High (ρ=141.4 kg/m^3) and Low (ρ=113.5 kg/m^3) Bulk Density

5.4 Thermal Conductivity

Under pyrolysis, thermal conductivity is the major parameter which represents the ability of a material to transfer heat. In this study the thermal conductivity of rice hulls was obtained by fitting the pyrolysis model with the experimental curves for the temperature changes inside the rice hull bed. By using a deepest descent algorithm and a minimized least squares (ϵ) as the optimization criteria, the thermal conductivity value during pyrolysis was expressed as follows : $k = 3.1\text{x}10^{-3} + 4.5\text{x}10^{-3} (\rho - 0.15) + 1.9\text{x}10^{-6}(T - 20)$ with $\sigma = 0.19$ where σ is the standard deviation equal to $\sqrt{\epsilon^2/n}$ (n = number of experimental points). In this relationship, ρ is the bulk density in g/cc and T is the temperature in degree Celsius.

For this relationship the simplified model predicts well the temperature profile in the rice hull bed as shown in Figure 5.9.

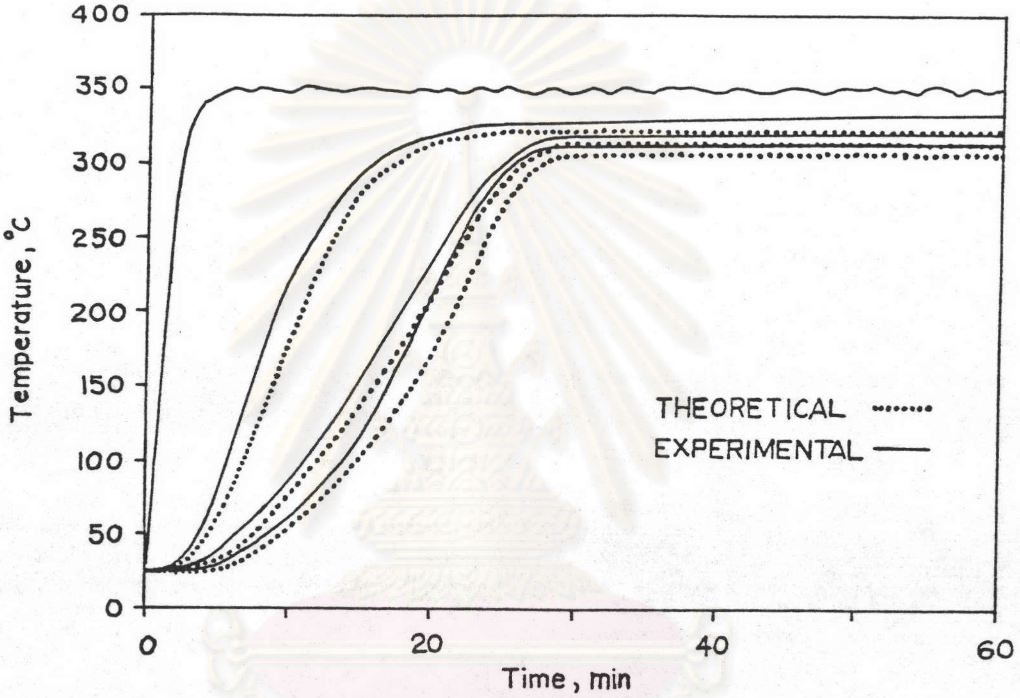

Figure 5.9 Comparison of Temperature Profiles for Theoretical and Experimental Results at 113.5 kg/m^3 Bulk Density with 0.11% Moisture Content

The relationship obtained indicates that thermal conductivity value during pyrolysis cannot be treated as a constant value. The changes in temperature, shape and chemical composition of rice hulls during pyrolysis cause a thermal conductivity variation with time.