# CHAPTER VI

# DISCUSSION

## 6.1 Discussion of the Physical and Chemical Properties of Rice Hull

The percentage of hull in paddy varied widely from 20 to 25 %. Rice hulls were difficult to handle because of their silica-cellulose structural arrangement, with imparted peculiarities different from those of any other plant offal. No other plant offal even approached the amount of silica founded in rice hulls. The structure of silica-cellulose was results in the object that does not burn or even liberate heat in a manner resembling that of any other organic substance. This offered an inherent resistance to burning.

The physical and chemical properties of rice hull were easy to visualize wide differences in widely separated with different varieties and climatology. The analysis of rice hulls were variable by type, variety and milling equipments. The physical properties of rice hull from this experiment was shown in Table 5.1 were a little different from the value of literatures showing in Table 5.1. The significant difference was the calorific value. In this experiment, it was about 3,410 kcal/kg. From the previous works, the calorific value was 3,115 kcal/kg [19], 3,790-4,000 kcal/kg [20] and 3,370 kcal/kg [21]. The variation of them may cause by

1. types of paddy
2. places of cultivation
3. post harvested storing time
4. milling processes
5. rice hull handling.

Therefore, the physical peculiarities of rice hulls made them difficult to store in outdoor piles. They were easily drifted by the wind, and when rainsoaked and decomposing, Dry storage in a warehouse is expensive because of the low density of the hulls. However, the size and shape of the hulls also permit fluidity and case of bulk handling using normal conveying equipment. At the same time, their lightness imposed problems in volume handling. For example, conveying equipment that was able to accommodate 50 tons of paddy was able to handling only ten tons of rice hulls in the same period. They also caused excessive wear on handling machinery because of their high silica content.

## 6.2 Discussion of the Minimum Fluidization

Two experiments were performed to find the minimum fluidized-bed velocity of air used for combustion of rice hull. The results were 23 cm/sec at bed height 10 cm and 24.5 cm/sec at bed height 15 cm. Therefore, the average minimum air flow rate to the column was about 18.2 kg/hr. The value of literatures found that the minimum fluidized-bed velocity was 32.5 cm/sec [29] and 22.5 cm/sec [30]. These values were different. The differences may cause from physical properties of rice hull and rice hull using during the experiment. But in fact, it was significant in this point because the operating conditions were still over the minimum fluidization of rice hull. It was only a guideline to specify the operating conditions of this experiment.

## 6.3 Discussion of the Fluidized-Bed Combustor

Fluidized-bed combustion is an existing technology used for extracting energy from rice hull at high efficiency levels. It is very useful for the combustion the flame retarding and self-extinguishing materials at ordinary temperatures. Due to the presence of several stages of combustion process combustion depends upon the temperature and the residence time of rice hull in the combustion zone. When rice hull was fed to the column and heated in the absence of air to about 320 °C, spontaneous decomposition took place, with a generation of heat. The mechanism may be started due to the removal of moisture and volatile matter from the surface of the rice hull. Then the existing combustible matter left was only carbon. The combustion would start at the surface of the solid structure of rice hull and move to the center.

In the fluidized-bed, rice hull was well contacted with oxygen and the ash which was the result of combustion was removed from the surface. Then, oxygen was reacted with the new surface of combustible structure. The reactions are believed to be

$$C + O_2 \longrightarrow CO_2$$

$$C + CO_2 \longrightarrow 2CO$$

$$CO + 1/2\ O_2 \longrightarrow CO_2$$

But, in the process of rice hull combustion, the reactions could be classified as heterogeneous reactions, represented by the following equation of

$$A_{(fluid)} + bB_{(solid)} \text{ ------> } Product_{(fluid)}$$

For rice hull combustion gas A diffuses through the air film around the fuel B, diffuses to the surface of fuel B and reacts on the surface.

Fluidized-bed technology has recently received considerable interest for coal conversion and many of its characteristics appear to be suitable for small scale conversion of low-grade fuels, such as rice hull. In this experiment, the fluidized-bed combustor consisted of the equipments show in section 3.1. Its design and construction were well suited for the study. The air was well distributed through the metal packed-bed shown in Figure 3.1 to reduce the fluctuation in density of bed and reduce channelling and slugging. Air under pressure was forced through the porous floor at a velocity which lifted and suspended the particles in the combustion chamber. The suspended rice hull from a turbulent chuming mass. The understanding of the combustion of rice hull was a recent development and kinetics of the process have not yet been understood completely. The main advantages of fluidized-bed combustors were uniform temperature conditions, compact size, better control and high heat and mass transfer rates.

In this experiment, when the material and energy balance were calculated. From Table 5.4, it was found that the amount of oxygen in flue gas was reduced linearly when the temperature increased. The reducing of oxygen as shown in Figure 5.3 was tended to meet the limitation of maximum combustion of fuel which the amount of oxygen in flue gas was unable to reduce again.

In this experiment, the combustion efficiencies were high when compared to the previous experiment. From Table 5.4 and Figure 5.4, the combustion efficiencies were increased from about 90 to 95 %, while the temperature of the fluidized-bed combustor increased. From literature, it was found that combustion efficiency of rice hull was about 56 to 84 % [30] with the same system, but the distributor was flat. The efficiencies in this experiment were too high because the combustion efficiency was defined as a ratio of heat released from rice hull to the combustion heat of rice hull. There was a few carbon left from the system as fly ash from cyclone outlet which was the cause of too high in efficiency. From Figure 5.5, the excess oxygen was plotted against hot gas from combustor prior to the cyclone. The percentage of hot gas was depended on the excess air. When the excess air was increased, the percentage of hot gas from combustor was too. At the same air feed rate, the high temperature caused the combustion efficiency higher. From Figure 5.5, the combustion at 700 °C was better than at 400 °C and it had a lower excess air too.

In this experiment, one of the propose was to produce hot air for directly use in drying system, so the efficiency of hot gases production was very important indicator. The efficiency of hot air production was defined as the percentage of energy output of moist flue gas to the combustion heat of rice hull. It was shown that the hot gases production efficiencies were 36 to 45 % (Table 5.4). It depended on the distance between the combustor and cyclone and the point using this amount of heat. The loss may be caused from the expansion in cyclone and surface heat loss of the system.

From Appendix C, when the air feed rate increased the amount of residue from the bottom of the cyclone increased because of the small size of rice hull which did not completely combust was carried over. It was indicated by the increasing heating value of the residues.

The flue gas compositions at any conditions were determined by gas chromatography. Many samples of one condition were checked against the compositions of flue gas in case of complete combustion. The results from the chromatograms showed high fluctuations because it was dependent upon the combustion phenomena in the column and the period of feed.

## 6.4 Discussion of the Fluidized-Bed Dryer

The fluidized-bed dryer column for this experiment was designed and constructed as a horizontal multi-chamber continuous fluidized-bed dryer and the experimental set of equipments is presented in section 3.2. The distributor was designed to have small holes to create the pressure drop across itself and reduce channeling and slugging of the bed. The contact between hot air and paddy was nearly uniform throughout the entire bed.

The advantages of the horizontal multi-chamber continuous dryer were to increase the time of drying, to be able to operate at low temperature and to be able to operate the process continuously.

During continuous operation the fluidized-bed dryer the initial moisture content of parboiled-rice which was about 52-58 % (dry basis) was reduced to 18-28 %.

During the drying experiment, parboiled paddy was left to be dried on the surface before it was transfered to the fluidized-bed dryer. Therefore, the moisture of parboiled paddy left to be dried in the fluidized-bed dryer was the moisture inside the grain. Because of the inner materials of parboiled paddy were composed of small cells that hardly allow water to permeate through their cell walls, if severe drying conditions were imposed, resulting in a completely dry zone or hard shell around the drying grain, then inner resistances may dominate. On the other hand, the material that shrinks rapidly during drying is seldom inner-resistance dominant. In parboiled paddy, the limitation step was the diffusion process in which water migrated from the center of the grain to its surface, and then evaporated by hot air.

In this experiment, the test run on drying parboiled paddy was carried out to study the performance of drying. All data were collected as shown in Appendix H. The material and energy balances were calculated and shown in Table 5.7. In this part, it was only to study the thermal efficiency when the temperature of the inlet air increased and the effect of bed height which indicated, in the form of increase of residence time, the tendency shown in Figure 5.6 that as the residence time of parboiled paddy in the dryer increased, the drying efficiency increased also. Figure 5.7 showed that the efficiency curve increased rapidly with temperature and then decreased when temperature exceeded 140 °C. This phenomena was probably due to limitation and resistance of the parboiled paddy grain. In this step the diffusion rate of moisture at the center of the grain may be slower because of the grain cell resistant. From the results shown in Table 5.7, the drying efficiency was quite low, approximate about 16-22 %, because the contact time between the parboiled paddy and hot air, in the way of cross flow, was shot, so that most of the heat was lost with hot air output from the dryer which was approximate more than 90 %.

## 6.5 Discussion of the Combined System

The combined system consisted of two sets of equipments as presented in sections 3.1 and 3.2. In the study on this part of the experiment the combustor was operated at one condition, while the air inlet temperature and the bed height of parboiled paddy in the fluidized-bed dryer were varied. The operation was difficult and it took a lot of time before it reached the steady state condition. In this part of the experiment, it was separated into two parts; the first stage drying and the tempering stage. In the first stage operation the combustor was operated at a controlled temperature and the air feed rate to the combustion chamber at 30 $Nm^3$/hr. The dryer was operated at controlled inlet air temperatures of 120, 130, 140 and 150 °C respectively. At each temperature, the height of bed was varied to 3, 3.5, 4 and

4.5 cm respectively. The data of all conditions were taken as shown in Appendix K. The material and energy balances were calculated and shown in Tables 5.8 and 5.9. The results of each condition were shown in Table 5.10 for the first stage drying. When the drying efficiency and the overall efficiency were considered with air inlet temperature in Figures 5.8 and 5.9, they increased when the temperature increased at the same resident time. Similarly, in Figures 5.10 and 5.11, increase in residence time increased drying efficiency and overall efficiency when the temperature was kept constant, but the rate of increase of efficiency was reduced. The reduced efficiency may be the result of the diffusion control of moisture moving from the center of the parboiled paddy grain to the surface.

The hot gas input to the drying system was not enough to supply for drying the parboiled paddy, so the auxiliary heater was used to supplement and control the inlet air temperature. In this experiment, the combustor was too small and was unable to support heat consumption in the dryer, since it was able to supply only about 50-55 % of the heat required by the dryer.

The drying rate was about 6,500 g/hr of parboiled paddy and if parboiled paddy consisted of 25 % of rice hull (dry basis), it would yield rice hull about 34 % less than the amount of rice hull consumed in this condition.

In the tempering stage the combustor was still in the same operating condition and the dryer was operated in the same condition of air inlet temperature at 140 °C and the height of bed was of 4 cm, so the residence time was kept constant to see the effect of conditions from the first stage drying. It was found that the efficiency of drying was reduced when the temperature of the first stage drying increased.

From Figures 5.14 and 5.15, it is shown that the overall efficiency and drying efficiency were reduced when the residencetime of the first stage drying increased. It was because the driving force of moisture transfer was low.

The milling yields of the drying products were shown in Table 5.14. It was found that the parboiled rice yields were of higher quality than the paddy yield.