

CHAPTER 1

INTRODUCTION

1.1 Rational/Problem Statement

The energy demand in industries and households is increasing rapidly. The majority of energy comes from fossil fuels such as coal, petroleum and natural gas. The consumption of fossil fuels causes serious environmental problems. Therefore renewable energy is alternative energy source that can be substituted for fossil fuels. Biomass is the most common type of renewable energy. Biomass is organic material from living mechanism such as plants that absorb the sun's energy through photosynthesis. The utilization of biomass is environmental friendly. Because the contents of sulfur and nitrogen in the biomass waste are lower than fossil fuels and carbon dioxide emitted to the atmosphere is taken up by plants for their growth.

Thailand is an agricultural country that produces a huge agricultural output. Agricultural residues such as rice husk, straw, bagasse, palm oil waste, wood waste, etc. are abundant renewable energy resources. In 2009, about 60-90 million tons of agricultural residues were produced. Of these, about 65-70% was unused. The surplus biomass can potentially contribute to 2,000-3,000 MW of electric energy (Prasert and Sajjakulnukit, 2005). Therefore Thailand has a potential for using agricultural residues for energy production.

Biomass utilization as a solid fuel can be used to generate electricity, heat, liquid fuels, or produce modern energy. However, there are many drawbacks from its undesirable properties. In term of physical properties, due to its low bulk density leading to huge storage space requirements, difficulty in handling and high transportation costs. The porous structure is easy to absorb moisture and has high moisture content. This property decreases its heating value and needs pretreatment before utilization. In term of chemical properties, biomass has carbon content lower than fossil fuels such as coal. Some biomass types has a high ash content that may cause problems in combustion devices due to ash fusion inside at higher temperature (Twidell and Weir, 2006; Tester *et al.*, 2005).

Biomass can be converted to energy via thermochemical and biochemical reactions (Worasuwannarak *et al.*, 2006). Gasification is one of the thermochemical processes in the presence of controlled air. It is the conversion process of solid, carbonaceous fuel into combustible gas mixture which contains varying amounts of carbon monoxide, and

hydrogen, normally known as synthesis gas. This gas can be burned directly in a furnace or internal combustion engine or gas turbine for heat or electricity generation. During biomass gasification, tar formation is one of the major problems that must be dealt with because it blocks and fouls the equipment such as the pipes and valves. Tar removal technologies can be divided mainly into two: primary methods, which are treatments inside the gasifier; and secondary methods, which are measures downstream of the gasifier (Mun *et al.*, 2010). To overcome this problem, the two-stage gasification system is introduced that the tar contained in the gas is cracked under high temperature, partially oxidized, and removed subsequently. A two-stage gasifier is named because the pyrolysis process and char gasification are separated into two different independent reactors (Yi and Yonghao, 2010).

A commercial 400 kW electrical two-stage gasification system was constructed in Lopburi province using rice husks as the fuel. It is necessary to perform a further development and study of the optimization conditions to achieve a desired operating of the plant that leads to this study. In this study, parameters related to understanding and design of a two-stage gasification system using rice husk as a fuel will be studied. The outcomes of the study will be used to prepare a detail design of a small scale prototype for construction. Figure 1.1 shows the rice husk used in this study.

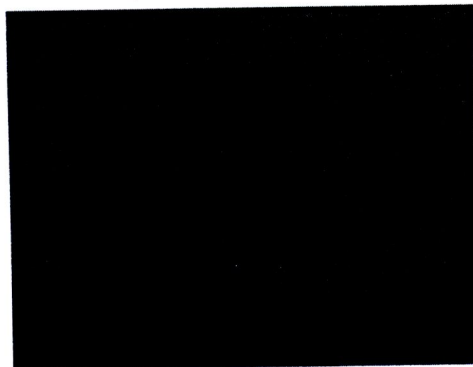


Figure 1.1 Rice Husk

1.2 Literature Review

Many studies have been made on biomass gasification such as the biomass behavior in fluidized bed gasifier, the factors influencing biomass behavior in fluidized bed gasification and the process development for gasification of rice husks which gasification process has high potential to be used and has been widely studied.

1.2.1 Fluidization Behaviour of Rice Husks

Natarajan *et al.* (1997) summarized the quality of fluidization as one of the most important factors that influenced the combustion and gasification efficiencies. Fluidization quality can be controlled by changing superficial velocity. In general, it is difficult to fluidize rice husks due to its cylindrical shape, non-granular and flaky nature. Fluidization behavior of rice husk improves when it is mixed with other solid particles forming a multi-solid system.

The main observations of fluidization characteristics of rice husks reveal that at the onset of fluidization, the husk bed expands and channels are formed in different regions. However, further increase in velocity effect to an aggregative fluidized bed. The remedy can be mixed husk with other solid particles. The mixtures of char, ash and husk shows channeling and poor movement of individual particles at low velocities, but good mixing occur at the bubbling velocity. Thus fluidization of the rice husks seems to be difficult, unless it is mixed with sand and/or char and/or ash to form a multi-solid system (Xu *et al.*, 1985; Sen and Gosh, 1992).

1.2.2 The correlations for estimating U_{mf}

Many correlations for estimating U_{mf} have been studied. Zhiping *et al.* (2007) have studied the minimum fluidization velocity under different pressures that they also summarized the correlations for estimating U_{mf} in their journal. The correlations for estimating U_{mf} :

Ergun equation:
$$1.75 \frac{1}{\phi \epsilon_{mf}^3} Re_{mf}^2 + 150 \frac{1 - \epsilon_{mf}}{\phi^2 \epsilon_{mf}^3} Re_{mf} = Ar \quad (1.1)$$

Where Archimedes number is:

$$Ar = \frac{d_p^3 \rho_f (\rho_s - \rho_f) g}{\mu^2} \quad (1.2)$$

$$\text{Re}_{mf} = \frac{d_p U_{mf} \rho_f}{\mu} \quad (1.3)$$

In a simplified form, the Ergun equation, in terms of Reynolds number and Archimedes number, can be reduced to:

$$\text{Re}_{mf} = \sqrt{C_1^2 + C_2 Ar} - C_1 \quad (1.4)$$

There are many sets of values suggested for the constants C_1 and C_2 based on different databases used for correlations to predict U_{mf} . These are listed in Table 1.1.

Table 1.1 The Different values of C_1 and C_2 (Zhiping *et al.*, 2007)

Researchers	C_1	C_2
Wen & Yu	33.7	0.0408
Richardson	25.7	0.0365
Babu	25.25	0.0651
Grace	27.2	0.0408
Chitester	28.7	0.0494
Saxena	25.28	0.0571
Thonglimp	31.6	0.0425
Zhiping	22.1	0.0354

1.2.3 Effect of Fluidization Velocity on the Fluidized Bed Combustor

Rozainee *et al.* (2008) studied the effect of fluidization velocity on the bed temperature during the combustion of rice husks in a bench-scale fluidized bed combustor. They experimented at different fluidization velocity, $1.5 - 8 U_{mf}$ to investigate the mixing and combustion characteristics of rice husks. From their experiments, the optimum fluidization velocity was approximately $3.3 U_{mf}$ that the mixing of rice husks with the bed was good with a high degree of penetration into the sand bed. The char particles were observed to be broken into smaller fragments due to the attrition with the sand particles, thereby making the carbon in the char easily available for conversion. At high fluidization velocities in the range of $4.5 - 8 U_{mf}$ were undesirable for the combustion of rice husks because these high fluidization velocities prevented the low-density rice husks particles from penetrating the sand bed. Using a fluidization velocity of less than $3 U_{mf}$ resulted in inferior mixing behavior as the bubbling action was less vigorous. The rice husks formed a

thin layer above the sand bed at $2.5 U_{mf}$ which disrupted the overall mixing and combustion behaviours. In the worst condition at $1.5 U_{mf}$, the rice husks formed a thick stagnant layer and burning was restricted to this layer only.

1.2.4 Effect of Temperature in Fluidization

In the gasification process, the lower temperature is determined by the conditions for complete conversion. It mainly depends on the elemental composition of rice husks and the ER. At the ER of 0.2, the temperature limit is about 700°C and it decreases with the increase in ER. When the gasification temperature is lower than this limit, the carbon in the fuel is not burnt, resulting in lower efficiencies. The higher temperature is limited by ash fusion conditions. Ash fusion temperature is about 100°C and depends on the ash composition and the reaction. Above this temperature, silica and potassium oxide in the ash fuses on the surface of the rice husk char particles forming a glass-like barrier that prevent the further reaction of the remaining carbon (Natarajan *et al.*, 1997).

1.2.5 Effect of Equivalence Ratio in Fluidization

The equivalence ratio (ER) is one of the most important operational variables in biomass gasification with air. It is defined as the air-to-fuel weight ratio used divided by the air-to-fuel weight ratio of stoichiometric combustion. In biomass gasification it varies from 0.20 to 0.40. When the raw gas is going to be burnt in downstream furnaces, without previous cooling, the gasifier can be operated at the minimum ER (about 0.20) because tars are not then a problem and the gas should have the maximum possible heating value.

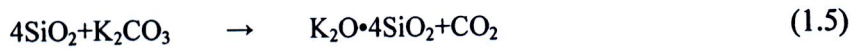
When tars cannot be present in large amounts, the ER to be used depends on the temperatures of the gasifier bed and freeboard. When the gasifier operates at high temperatures (900°C) and with dolomite in the bed, there is some tar cracking in it and the tar yield is low. A low value of ER is about 0.25. If the gasifier operates at temperatures lower than 850°C , the tar yield is high; the ER has then to be increased until about 0.30-0.40 to compensate for such an effect. Values for ER lower than 0.18 are not practical because much tar is produced (process close then to pyrolysis). Values for ER higher than 0.45 produce a useless gas.

On increasing ER, the gas yield increases and the tar yield decreases but the heating value of the gas also decreases (Narvaez *et al.*, 1996).

1.2.6 Effect of Alkali Species and Alkali Contents in Ash

Armesto *et al.* (2002) studied the feasibility of burning rice husks in an atmospheric bubbling fluidized bed and the characterization of the ash formed during the combustion process. The characteristic of rice husk ash was analyzed. Table 1.2 shows the main components of the rice husk ash. The main components are 87.7% of silicon (SiO_2), 5.4% of potassium (K_2O) and 3.7% of phosphorous (P_2O_5) respectively.

In the presence of elements such as alkali metals which are Na and K, and phosphorous in the fuel effects on the properties of the ash such as melting temperatures. The low melting temperatures of the rice husk ashes may cause bed agglomeration in fluidized bed, slagging on furnace and fouling of heat transfer surfaces. Agglomeration occurs when part of the fuel ash melts which causes adhesion of bed particles. Normally, quartz sand is used as bed material. Sand consists mainly of SiO_2 which the melting point around 1450°C . The oxide form of Na and K or salts can react with Si compounds of the bed material according to:



to form eutectic mixture with melting point of 764°C . Fouling and slagging occur when the constituents of ash formed react with flue gases and deposit on surfaces or furnace walls. Gaseous phase deposited is called fouling. The liquid phase deposited is called slagging.

Table 1.2 Rice husk ash analysis (Armesto *et al.*, 2002)

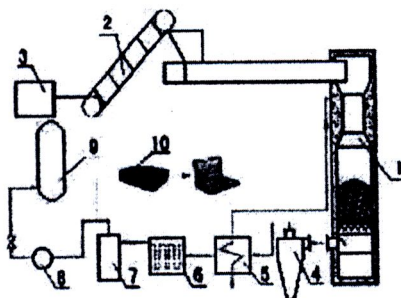
Components	%
SiO_2	87.7
K_2O	5.4
P_2O_5	3.7
CaO	1.3
MgO	0.8
Na_2O	0.2
Fe_2O_3	0.1
Cr	560 ppm
Zn	603 ppm

Khan *et al.* (2009) summarized that the characteristic properties of biomass. In the part of ash, the authors described that high K and Si content typically gives low ash melting temperatures while Mg and Ca increase ash melting temperatures.

In conclusion, to avoid the problem of fouling and slagging, ash analysis has to analyze that the component of ash used to determine the operation temperature in fluidized bed gasification.

1.2.7 The Design of the Two-Stage Gasification Process

Yi *et al.* (1997) studied the performance characteristic of rice straw gasification in a two-stage gasifier by using the two-stage gasifier developed by Shang Jiao Tong University. The experimental devices are shown in Figure 1.2, including feeding device, two-stage gasifier, gas cleaning devices, measurement, data acquisition system, and other components. The gasifier consists of three parts: the pyrolysis unit, throat for oxidation and char-bed for gasification.



1. two stage gasifier 2. transport 3. hopper 4. cyclone dust collector 5. air pre-heater
6. bag filter 7. dehumidify 8. induced draft fan 9. gas tank 10. gas analyzer

Figure 1.2 Schematic layout of the experiment devices (Yi *et al.*, 1997)

Henriksen *et al.* (2006) built a small-scale demonstration plant for fully automatic operation for at least 1000 hours at the capacity of 75 kW thermal. The gasifier called “Viking” is a traditional two-stage gasifier which means that the pyrolysis and char gasification takes place in separate reactors as shown in Figure 1.3. The plant consists of seven parts: feeding system, pyrolysis unit, char gasifier, grate, gas system, baghouse filter, engine and control.

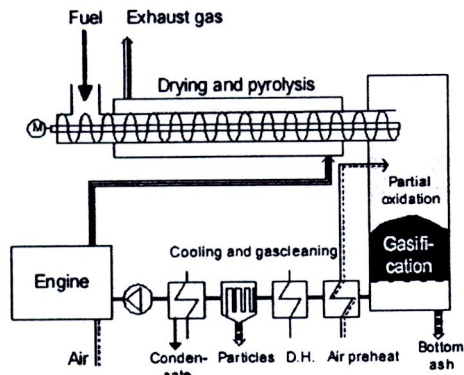


Figure 1.3 The Viking gasifier (Henriksen *et al.*, 2006)

Bentzen *et al.* modified the two-stage gasification process in order to upscale plants. The upscaleable concept, which offers both low tar and high efficiency, can be designed as fluidized bed. The developed concept was based on separate pyrolysis and gasification units as shown in Figure 1.4. The volatile gases from the pyrolysis (containing tar) are partially oxidised in a separate chamber and the tar content is dramatically reduced. Both pyrolysis and gasification chamber are bubbling fluidized bed, fluidized with steam. For moist fuels, the gasifier can be integrated with a steam drying process, where the produced steam is used in the pyrolysis/gasification chamber.

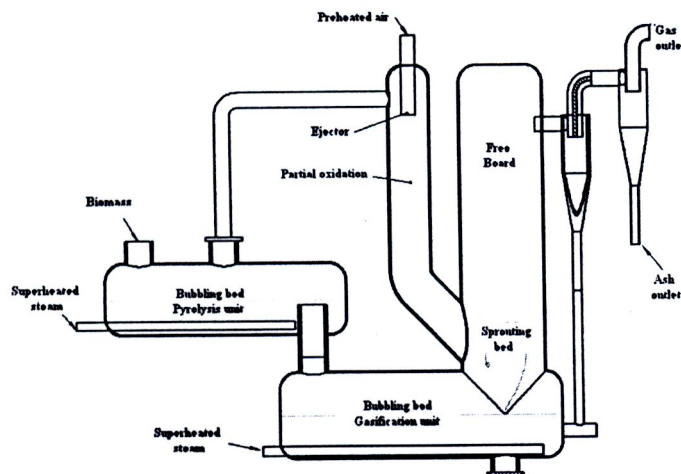


Figure 1.4 Schematic layout of a two-stage gasification of fluidized bed (Bentzen *et al.*)

From these experiments about a two-stage gasifier, it can be summarized that a two-stage gasification system consists of five main components: feeding unit, pyrolysis unit, char gasifier, air preheating unit and gas cleaning unit.

1.3 Objectives

1. To study the related parameters essential for the design of a lab-scale (50 kW thermal) two-stage gasification system.
2. To design a lab-scale (50 kW thermal) two-stage gasification system.

1.4 Scope of Research Work

Rice husks were used as material in this work. The chemical properties of rice husks which are ultimate, proximate, ash and calorific value was analyzed. The minimum fluidization velocity was experimented. In order to design a two-stage gasification system of rice husks, their chemical properties and minimum fluidization velocity experiment were also necessary. A lab-scale two-stage gasification system was designed to facilitate varying essential the parameters such as ER ratio and superficial velocity. A two-stage gasification system that was designed consists of feeding device, bubbling fluidized bed pyrolysis, downdraft gasifier, air supplied system, gas cooling and cleaning devices. This system will be used to test effects of parameters on gas quality in the future.

The detail research work scope cover;

1.4.1 Raw biomass analysis

- A. Proximate analysis
- B. Ultimate analysis
- C. Calorific value
- D. Ash analysis

1.4.2 Minimum fluidization velocity experiment

1.4.3 Study the related parameters

1.4.4 Design of a two-stage gasification system