

Study of Incineration of Acacia Wood Chips for Biomass Power Plant of the Royal Thai Navy in Sattahip, Chonburi Province, Thailand

Thanapong Suriyea, Teeratas Pornyungyuen, and Koonlaya Kanokjaruvijit

Abstract—This research is aimed to find optimal values of parameters of acacia wood chips combustion in a bubbling fluidized bed for electrification within the area of the Royal Thai Navy in Sattahip, Chonburi province, Thailand. The size of wood chips falls in the range of 25 mm in diameter. The bed temperature is set within the range of $800\pm 10^\circ\text{C}$ with the air flow rate of 2.1-3.1 m/min corresponding to the air-fuel ratio between 0.71 and 1.03. The resulting thermal efficiency is approximately 95% with a thermal output of 474.76 kWth, which produced the electricity 0.131 kW-hr.

Keywords—Acacia Wood Chips, Biomass, Combustion, Fluidized Bed.

I. INTRODUCTION

BIO MASS is one of the most attractive sources for renewable energy and a promising alternative to fossil fuels due to the fact that biomass leads to the reduction in producing greenhouse gases and limiting the formation of pollution. Biomass fuels also contain low sulphur content thus low SO_x emission. Thailand, as an agricultural country constantly provides varieties of biomass, especially from the agricultural and wood industry. Most of biomass has been used in direct combustion, which converts solid state of biomass into heat [1], for further small- to medium-sized electricity production in either in-house usage or consumption in rural areas. Acacia is one of the fast-growing crops found all over Thailand. It is considered as one of the potential biomass, because it provides high heating value [2]. The area of the Royal Thai Navy at Sattahip, Chonburi Province, there grows a large number of acacia wood, but it has not been in use. Hence, we have brought those negligent crops into the investigation of combustion properties and other details in order to use them as main fuels in our small-scale biomass power plant for electrification within the navy area.

Fluidized bed technology has been extensively used in both combustion ([3]-[8], [10]) and gasification ([1], [9], [10]) due to its high efficiency in energy conversion from biomass. Bubbling fluidized bed and circulating fluidized bed combustors and gasifiers have been in attention of many

researchers in the recent years. The first kind is attractive due to its capability of thorough mixing of fuel particles and air inside the bed; thus, the design of air distributor becomes crucial for the air inside the bed [6]. In spite of low NO_x emission, both kinds of fluidized bed technologies experience high CO emission. Therefore, many researchers pay attention to this problem and have been striving to solve, e.g. employing air staging [4], which helps the circulating fluidized bed combustors reduce CO emission.

There are numerous attempts of studies of the combustion of wood chips in order to figure out properties of the material of biomass fuels themselves and heating values including the efficiencies of the combustion. Khan et al. [7] summarized the processes of wood chip combustion as follows, after heating wood, its constituents start to hydrolyze, oxidize, dehydrate and pyrolyse causing the elevated temperature and combustible volatiles, tar and reactive char. In addition, they presented the process in a detailed schematic chart describing a process at each temperature level. Han et al. [3] investigated both cypress pellets and sawdust, and found that despite the fact that the sawdust led to higher combustion efficiency and heating value [8], its combustion produced significant amount of unburned carbon and CO in its fly ash, and was difficult to operate at higher temperature than 650°C . Ammendola et al. [10] studied the effect of the mechanical strength on fuel particles of wood chips and pellets under combustion and gasification. They reported that the wood pellets confronted less fragmentation than the chips, but gave approximately 40% higher lower heating value and less moisture content. In addition, the attempts of pollutant reduction such as NO , CO , N_2O and SO_x caused by biomass combustion have been widely studied.

The objectives of this investigation is to figure out the optimum values of parameters related to the combustion of acacia wood chips in order to obtain high combustion efficiency and produce less pollutants. The studies parameters include feed air flow rate, ash content, size of the wood chips, and feed fuel flow rate. The chip moisture content is kept constant throughout the study.

II. EXPERIMENTAL PROCEDURE

A. Experimental Setup

Fig. 1 presents the schematic diagram of the bubbling fluidized bed system. The fluidized bed was made of a metal sheet of 6mm thickness, and was lined with refractory bricks

Thanapong Suriyea and Teeratas Pornyungyuen are with Defence Technology Institute (Public Organisation), Office of the Permanent Secretary of Defence Building (Changwattana) 4th floor, 43/473 Moo 3, Banmai Pakkret, Nontburi 11120 Thailand (e-mail: thanapong.s@dti.or.th, teeratas.p@dti.or.th)

Koonlaya Kanokjaruvijit is with Department of Mechanical Engineering, Naresuan University, Phitsanulok, Thailand (e-mail: koonlaya@gmail.com).

and insulator bricks with the thickness of 0.25m. The combustion chamber was 2.5m in height with the insulated ceiling, and the air distributor was 10mm thick consisting of 12 nozzles and 4 bubble caps for feeding the fuel from underneath. The bed filled with silica sand was heated for start-up by a pilot burner using LPG. 12 type-K thermocouples connected with a digital thermometer readout were embedded in the combustor. The air supply system to the chamber consisted of the main duct connected with the blower and 3 spargers with globe valves. Each station of the fluidized bed system is described as follows. The screw feeder driven by a motor delivered the wood chips toward the combustor, where there was high velocity air flow through a nozzle injecting the chips down to the sand bed. This was to prevent the reverse air and fuel. Air was supplied to the fluidized bed combustor by two fans with different functions. A force draft fan was used to feed the air from underneath, and an induced draft fan for suction of the air on the top of the fluidized bed combustor. Fly ash as a product of combustion was collected at the exit of the cyclone.

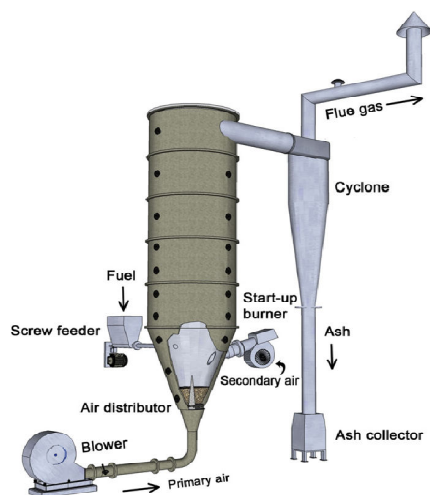


Fig. 1 Schematic diagram of experimental set-up

B. Experimental Procedure

Throughout the research, experiments were repeated 5 times for the statistical reliability, and the average as well as the standard deviation was reported. The sundried acacia wood chips with 19% moisture of 25mm diameter were put in each bag of 500g in order to record the amount of the fuel particles and time fed to the fluidized bed combustor. Then, the air flow rate was set by adjusting glove valves at the air supply pipes as shown in Table I. The chamber temperature was kept constant within $800 \pm 10^\circ\text{C}$. The fluidized velocity was fixed at 0.65m/s. Exhaust gas was analyzed by a gas analyzer (Testo 335, Germany) to measure gas concentrations (CO , CO_2 , N_2 , O_2 and SO_2). The measurement uncertainties were $\pm 0.5^\circ\text{C}$ for the temperature, $\pm 5\%$ for CO , $\pm 0.2\%$ for CO_2 , 0.2% by volume for O_2 and $\pm 10\text{ppm}$ for SO_2 . Furthermore, ash was collected from the dust-collecting cyclone for the heating value analysis. Finally, material and energy balances were

carried out in order to calculate the thermal efficiency of the combustion as shown below:

$$\eta = \frac{(Q_{in} - Q_{ash} - Q_{CO}) \times 100}{Q_{in}} \quad (1)$$

where η represents combustion efficiency in percentage.

Q_{in} is the input heat to the combustion system, kJ, obtained from the heat of combustion of the acacia wood chips with 19% moisture plus the heat of hot feed air.

Q_{ash} is heating value of the fly ash obtained from the combustion, kJ.

Q_{CO} is the heating value of carbon monoxide, kJ.

TABLE I
FEED RATE TO THE FLUIDIZED BED

Feed	Unit	Experiment No.				
		1	2	3	4	5
Fuel feed rate	kg/hr	25.48	25.48	25.48	25.48	25.48
Air flow rate	m^3/s	0.00433	0.00467	0.00500	0.00583	0.00633
Air-fuel ratio	-	0.71	0.76	0.82	0.95	1.03

III. RESULTS AND DISCUSSION

Table II reports the average values of constituents contained in the exhaust gas at 380°C . The heating value of the fly ash is quite high, and was thought to be used as a recovery energy in the future work. The concentration of SO_2 was quite low; however, CO content was found higher than the benchmark for the lab scale fluidized bed of approximately 800ppm [6]. This problem is left for our future research focusing on the CO and NO_x emission control. In addition, in this study, NO_x emission was expected to be quite acceptably low. This was probably because the bubbling fluidized bed operated at the temperature lower than 1300 K, at which N_2 and O_2 were dissociated and formed NO_x . More detailed information from Table II is to be discussed in the following sections.

TABLE II
EXHAUST GAS ANALYSIS AND HEATING VALUE FOR EXPERIMENTS

Property	Unit	Average	SD
Exhaust gas temperature	$^\circ\text{C}$	380.93	19.35
O_2 content	%	13.06	3.19
CO_2 content	%	7.18	3.75
CO content	ppm	1,094.40	67.6
N_2 content	%	49.13	12.02
SO_2 content	ppm	8.2	17.78
Ash heating value	kJ/kg	6,193.01	90.21

A. Heating Value

The ash heating value decreased with the air flow rate as displayed in Fig. 2. The relationship shows a spline trend line of a very good curve fit with R^2 of 0.993. This could be explained by the fact that as the flow rate was increased, the particle fuels inside the bed was vigorously stirred, and thoroughly mixed. Furthermore, the more amount of air increased the chance for the particles to contact with the air

leading to better burning. Increasing air flow also enhanced the continuous combustion with the ash above the bed, and this caused the drop of the heating value. This was because increasing the air flow caused the hot air temperature to become equal to the bed one, and the higher bed temperature gave rise to better ash combustion; thus the heating value was reduced.

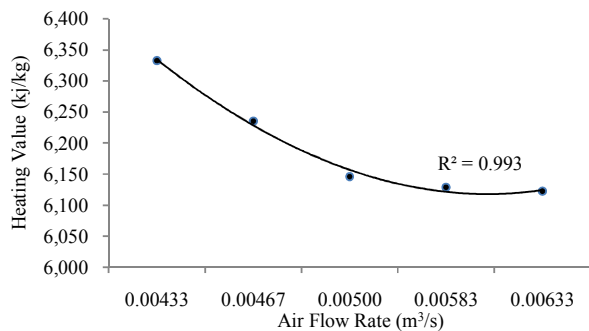


Fig. 2 Relationship between air flow rate and ash heating value

B. Combustion Efficiency

With a fixed bed temperature of 800°C, the combustion efficiency was increased linearly with the air flow rate as shown in Fig. 3. This was due to the fact that the sand moved aggressively allowing oxygen to be more in contact with the wood chips leading to better reaction. Nonetheless, feeding too much air may affect the efficiency, because there would be more bed voidage leading to less contact area between the biomass particles and oxygen. Therefore, within this research, the feed air was slightly deficient (see Table I).

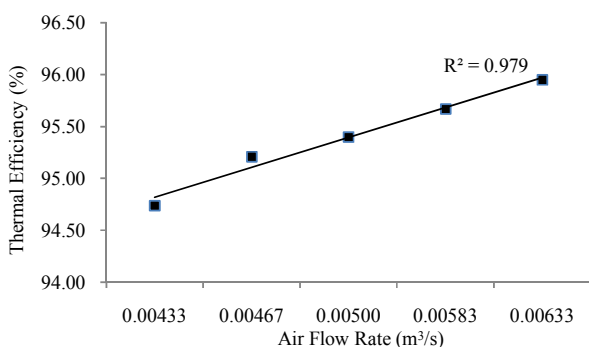


Fig. 3 Linear relationship between thermal efficiency and air flow rate

C. Analysis of Exhaust Gas

Fig. 4 shows the distributions of flue gas emissions in different air flow rates. The trend lines of concentrations of CO₂, CO and SO₂ are similar viz., increasing the air flow rate reduced their concentrations, especially for SO₂, when the flow rate was greater than 0.004659 m³/s, its concentration went towards zero. This could be explained by the fact that higher air flow rate, in other words, higher O₂ concentration, and helped better combustion. However, the trend lines of concentration of O₂ and N₂ shows similarity, because as the air flow rate was increased to 0.005065

m³/s, their concentrations was decreased, then they remained nearly constant when the flow rate lay between 0.005065 and 0.005875 m³/s. Finally, for the flow rate greater than 0.005875 m³/s, the concentrations soared. This was simply explained by some values in Table III such as air-fuel ratio (A/F ratio) showing the air deficiency for the flow rates between 0.004254 and 0.005875 m³/s, whereas at 0.006280 m³/s the excess air played important role.

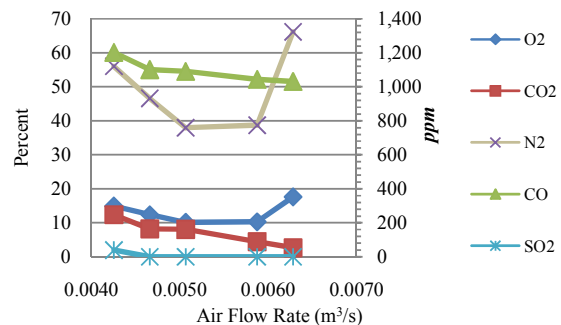


Fig. 4 Exhaust gas constituents at different air flow rates

TABLE III
OPERATING CONDITION AND FLUE GAS ANALYSIS

Condition	Unit	Test No.				
		1	2	3	4	5
Air flow rate	m ³ /s	0.00425	0.00466	0.00507	0.00588	0.00628
A/F Ratio	-	0.71:1	0.76:1	0.82:1	0.95:1	1.03:1
O ₂ Content	% V	14.9	12.4	10.1	10.3	17.6
CO ₂ content	% V	12.4	8.2	8.1	4.5	2.7
CO content	ppm	1,203.0	1,101.0	1,092.0	1,044.0	1,032.0
N ₂ content	% V	56.05	46.65	38	38.75	66.21
SO ₂ content	ppm	40	0	0	1	0

IV. CONCLUSIONS

The combustion of acacia wood chips of 19% moisture content was carried out in a bubbling fluidized bed with fluidized velocity of 0.65m/s. The combustion efficiencies in all cases were higher than 94%, whereas the ash heating values were high enough to be thought for recovery in the future work. Flue gas was analyzed and found that the concentration of carbon monoxide was higher than the benchmark of 800ppm; hence, the problem of CO reduction was left to our future research, whereas the concentration of sulphur dioxide was touching zero. The combustion produced 474.76 kWth and electricity of 0.131 kW-hr. This can be concluded that the acacia wood chip combustion in the bubbling fluidized bed has high potential for being a renewable energy source for the Royal Thai Navy in Sattahip, Chonburi province, Thailand.

REFERENCES

- [1] Pipatmanomai, S., "Overview and Experiences of Biomass Fluidized Bed Gasification in Thailand", *J.Sustainable Energy & Environmental Special Issues*, 2011, pp. 29-33.
- [2] Haruthaithanasan, M., Haruthaithanasan, K., Thanawat, A., Phromlert, S. and Baysangchan, A., " The potential of *Leucaena leucocephala*, *Eucalyptus camaldulensis*, *Acacia mangium* and *Acacia* spp. (*mangium* x *auriculaeformis*) as plantation crops for energy," *Proceedings of the 48th Kasetsart University Annual Conference*, Kasetsart, 3-5 March, 2010.
- [3] Han, J., Kim, H., Cho, S., Shimizu, T., "Fluidized bed combustion of some woody biomass fuels", *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, 30(13), 2008.
- [4] Lyngfelt, A., Leckner, B., "Combustion of wood-chips in circulating fluidized bed boilers - NO and CO emissions as functions of temperature and air-staging", *Fuel*, 78, 1999, pp. 1065-1072.
- [5] Liu, H., Gibbs, B.M., "Modelling of NO and N₂O emissions from biomass-fired circulating fluidized bed combustors", *Fuel* 81, 2002, pp. 271-280.
- [6] Kuprianov, V.I., Kaewklum, R., Chakrithakul, S., "Effects of operating conditions and fuel properties on emission performance and combustion efficiency of a swirling fluidized-bed combustor fired with a biomass fuel", *Energy*, 36, 2011, pp. 2038-2048.
- [7] Khan, A.A., de Jong, W., Jansens, P.J., Spliethoff, H., "Biomass combustion in fluidized bed boilers: Potential problems and remedies", *Fuel Processing Technology*, 90, 2009, pp. 21-50.
- [8] Suranani, S., Goli, V.R., "Combustion Characteristics of Sawdust in a Bubbling Fluidized Bed", 2011 International Conference on Chemistry and Chemical Process, IPCBEE 10, 2011, pp. 167-172.
- [9] Lim, M.T., Alimuddin, Z., "Bubbling fluidized bed biomass gasification - Performance, process findings and energy analysis", *Technical Note, Renewable Energy* 33, 2008, pp. 2339-2343.
- [10] Ammendola, P., Chirone, R., Ruoppolo, G., Scala, F., "The effect of pelletization on the attrition of wood under fluidized bed combustion and gasification conditions", *Proceedings of the Combustion Institute*, 34, 2013, pp. 2735-2740.