

Combustion properties of Thai biomass

Witchaya Pruksakit^{1,2,*}, Suthum Patumsawad³

¹The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Bangkok, Thailand

²Center of Energy Technology and Environment, Ministry of Education, Thailand

³Department of mechanical Engineering, King Mongkut's University of Technology North Bangkok, Bangkok, Thailand

Abstract:

The design and operation of biomass combustion systems rely substantially on several biomass characteristics, namely, heating value, moisture, ash content, density and elemental composition. This worked provides information on heating values, proximate analysis ultimate analysis, ash deposition and thermal behavior of biomass. Heating values of biomass vary between 13-22 MJ/kg (dry basis). Biomass has high volatile matter (60-90%) and low fixed carbon compare with fossil fuel. High oxygen concentration was found in biomass (40-50% d.a.f.). Mineral matter deposition in biomass created slagging, fouling and high temperature corrosion in boiler. Each type of biomass has individual characteristic and required specific suitable operation condition setting for efficiency energy utilization.

Keywords: Biomass; properties of biomass; Heating value; proximate analysis; ultimate analysis

*Corresponding author. Tel.: +66-84-8720372

E-mail address: witchaya.pruksakit@hotmail.com

1. Introduction

Due to concern about CO₂ emission which case of global warming and decreased of fossil fuel, use of biomass fuel for renewable energy are considered and attention currently. However, characteristic of biomass such as heating value, moisture content, chemical composition, mineral deposition etc., are various depend of type of biomass, local, age etc. Thermochemical conversion of biomass such as pyrolysis, gasification and combustion required specific operation condition depend of biomass characteristic for efficiency energy utilization. This work present Thai biomass characteristic and basis assessment for use of biomass for support decision making in terms of energy conversion technology selection and suitable condition operation setting.

2. Material and methods

Biomass characteristic were analysed, tested and presented as followed: heating value, proximate analysis, ultimate analysis, ash and thermal behaviour of biomass.

2.1 Heating Value

High heating values (HHV): total energy release during combustion process when water in flue gas (product from combustion process) condenses into liquid form. Low heating values (LHV): total energy release when water in flue gas isn't condensed. The lower heating value is less than the higher value by the latent energy of water vaporization. HHV of biomass varies between 13-22 MJ/kg (dry basis). For wet biomass, moisture in the fuel will reduce both heating values, because there is less dry fuel per unit mass wet fuel and lower hating value reduce from heat to vaporize moisture in to vapor phase (Wakil, 1984).

In Fig. 1 when increased percentage of moisture content in biomass. At 87.12 percent of moisture content, LHV of bagasse is equal zero which mean heat for vaporize moisture content equal total heat release for biomass combustion. In Fig. 2 showed mass of biomass compare with fossil fuel per unit heat (kg/GJ). Biomass requires high feed stock value compare with fossil but require less air supply form combustion because high oxygen content in lignocellulosic structure. Jenkins et al. (1998), discussed about combustion properties of biomass. They explained quality of the fuel not depend only heating value. For example, maximum work available and incorporates the entropy effects of

the second law as an ingredient of the measure not depend on heating value.

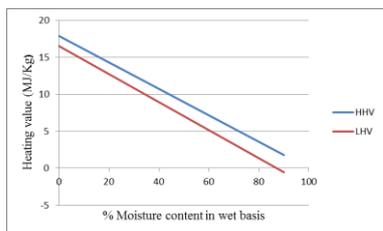


Fig. 1 Comparative between LHV and HHV of bagasse at different percentage of moisture content (Prusakit, 2014).

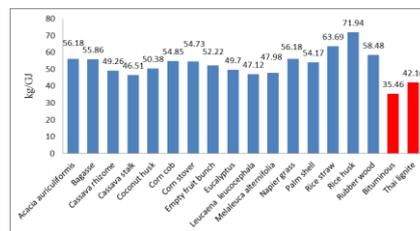


Fig. 2 Compare mass of fuels per unit heat (kg/GJ) (Prusakit, 2014).

2.2 Proximate Analysis

Proximate analysis of biomass and fossil fuel were showed in Fig. 3. Fossil fuels have high fixed carbon content (40-60% db.) and low volatile matter, in contrast, biomass has high volatile matter (60-80% db.) and low fixed carbon (10-20% db.). Increases of 1% of ash reduce heating value approximately 0.17 MJ/kg dry basis. Similarly estimation values which report by Jenkins, B.M. (1989), he present increase 1% elevating the heating value by approximately 0.2 MJ/kg (dry basis). In contrast to ash content, fixed carbon showed increase 1% elevating the heating value by approximately 0.2 MJ/kg (dry basis)

2.3 Ultimate Analysis

Biomass is low sulfur solid fuel and benefit when apply biomass for thermal conversion equipment. Fossil fuels showed low oxygen concentration (10-40% d.a.f.) in composition and separate from biomass group which high oxygen content (40-50% from lignocellulose structure) as showed in Fig. 4. Carbon content of biomass is varied between (40-50% d.a.f.). Both of biomass and coal contain hydrogen around 3-6%. Other composition such as nitrogen and chlorine contain in biomass below 5%. Quantities of main element composition in biomass have high correlation with heating value. 1% increased of carbon in composition showed increased of heating value approximately 0.34 MJ/kg (d.a.f.). This value is close to result that found by Jenkins, B.M. (1989), he discuss that each 1% increase in carbon elevating the heating value by approximately 0.39 MJ/kg (d.a.f.). While oxygen content in biomass is directly reduce heating value. Each 1% increased of oxygen translates roughly into a decrease of 0.36 MJ/kg (d.a.f.) because oxygen is not a reactive element.

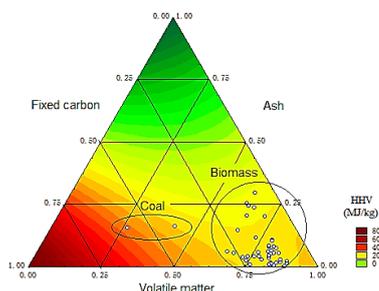


Fig. 3 Triangular of proximate analysis of biomass (Prusakit, 2014).

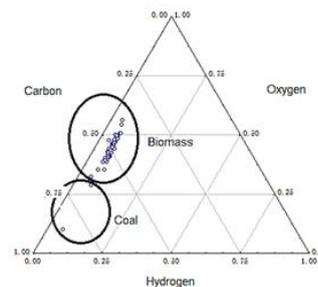


Fig. 4 Triangular of Carbon, Hydrogen and Oxygen contain in biomass (Prusakit, 2014).

2.4 Ash

Ash is the impurities which content in biomass. Fouling, slagging and fireside corrosion associated of ash effect during thermal process. In Fig 5, Thai lignite showed highest ash content and corncob showed lowest ash content when compare ash deposition per heat unit (kg ash/GJ). Ash deposition in fuel per heat unit of eucalyptus, empty fruit bunch, coconut husk, corn cob and bagasse are lower

than bituminous which high grade fossil fuel. Rice husk, rice straw, eucalyptus bark, corn straw and Thai have high ash content and tend to risk of ash problem. However, for high accuracy prediction slagging, fouling and high temperature corrosion problem have to consider mineral deposition, chlorine and sulfur content in biomass. Element deposition in ash can be classified into two main groups follows as (BISYPLAN, 2012):

Minor elements include As, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Sb, V and Zn. In term of minor element stems very small concentrations in fuel and their mostly relate environmental concern. Major elements include Al, Ca, Fe, Mg, P, K, Si, Na and Ti. Major elements less significant environmental issue, however, major impact on ash melting behavior. Group of Melting and tendencies of biomass ashes can be classified as follow (Miles et al., 1996):

- High silica and alkalis rich ashes, with low melting temperatures.
- Low silica and high calcium ashes, with high melting temperatures.
- Phosphorous-rich biomass/waste fuels. Ash melting behavior of phosphorous rich solid fuels is very complex and depends on the concentrations of other elements. Depending on the fuel ash chemistry the low melting K-rich phosphates and higher melting K-Ca/Mg phosphates can be formed. Uncertainties of ash composition were found in all type of biomass. Low sulfur content is biomass characteristic which different form fossil fuels. However, herbaceous plants have high chorine content. Ash content in biomass can be case of slagging, fouling and high temperature corrosion at fireside in boiler/furnace.

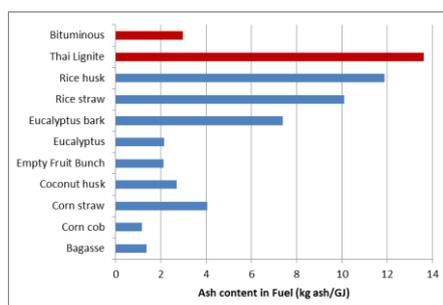


Fig. 5 Slagging index of solid fuel. (Pruksakit, 2014)

2.5 Slagging/Fouling Predictive Methods

Normally, ash indices are used for apply preliminary assessment for predict ash behavior, initial develop from coals, and have high accuracy in their prediction. However, due to different in ash composition of biomass, their result is contrast. For biomass, correlation available which can determine the slagging indices for biomass unequivocally (Gulyurtlu et al., 2008; Munir et al., 2010). Alkaline index (AI) has become popular in recent years as a threshold indicator for fouling and slagging. Alkaline index developed by coal industrial involves calculating the weight in alkali oxides ($K_2O + Na_2O$) per heat unit, kg/GJ and was apply for assent rate solid fuels for slagging or fouling. The calculation is made by

$$AI = \frac{0.1 \times [(\%ash) \times (\%alkali \text{ in } ash)]}{HHV(MJ/kg)} = \frac{kg \text{ alkali}}{GJ} \quad (1)$$

An index range of 0-0.17 kg/GJ is low slagging risk: 0.17-0.34 kg/GJ indicates the material will probably slag and over 0.34 kg/GJ is rick slagging formation. For Biomass, alkali index is incomplete as a descriptor of fouling behavior, however, and is useful principally as a general guide (Jenkins et al., 1998). Different in composition of biomass case of less accuracy prediction when apply slagging/fouling indices. For biomass fuels, common index is based on ratio of $(Na+K)/(2S+Cl)$ elements present in the fuel. If this ratio is lower than 1.0, this index presence of enough S and Cl to form alkaline sulphates and chlorides (Plaza, 2013). Another one is ratio of silica and alumina to alkali metals in ash $(Si+Al)/(Na+K)$ allowing the assessment of the potential of the silica/alumina based ashes or

additives for capturing alkali metals. Pruksakit (2014), applied slagging indices with various type of biomass. His results showed each index consider in different element composition. Used of multiple indices will make the assessment more accurate. Slagging/fouling tendency cannot depend of ash composition alone. Operation condition and boiler design play significant for ash behavior.

Table 3 Slagging/fouling indices (Pruksakit, 2014)

| Indices | Equation | Description |
|--|--|--|
| Slagging (basic to acidic compounds ratio) index | $\frac{B}{A} = \left(\frac{Fe_2O_3 + CaO + Na_2O + K_2O + MgO}{SiO_2 + Al_2O_3 + TiO_2} \right)$ | B/A < 0.5, low slagging inclination 0.5 < B/A < 1.0, medium B/A = 1.00, high B/A ≥ 1.75, severe |
| Slagging index plus phosphorous | $\frac{B}{A+P} = \left(\frac{Fe_2O_3 + CaO + Na_2O + K_2O + MgO + P_2O_5}{SiO_2 + Al_2O_3 + TiO_2} \right)$ | B/A _p < 0.5, low slagging inclination 0.5 < B/A _p < 1.0, medium B/A _p = 1.00, high B/A _p ≥ 1.75, severe |
| Simplified B/A | $R(B/A) = \left(\frac{Fe_2O_3 + CaO + MgO}{SiO_2 + Al_2O_3} \right)$ | 0.75 < R _(B/A) low slagging |
| Bed agglomeration index (Fluidize bed reactor) | $BAI = \left(\frac{Fe_2O_3}{K_2O + Na_2O} \right)$ | Bed agglomeration occurs when BAI values become lower than 0.15 |
| Slagging (Babcock) index | $R_s = \left(\frac{B}{A} \times S \right)$ Where S = % of sulfur on dry basis | R _s < 0.6, low slagging R _s = 0.6 – 2.0, medium R _s = 2.0-2.6, high R _s > 2.6, extremely high |
| Fouling index | $F_u = \left(\frac{B}{A} \right) \times (Na_2O + K_2O)$ | F _u ≤ 0.6, low fouling F _u = 0.6-40, high fouling F _u > 40, extremely high |
| Slag viscosity index | $S_R = \left(\frac{SiO_2}{SiO_2 + MgO + CaO + Fe_2O_3} \right) \times 100$ | S _R > 72, low slagging 72 ≥ S _R ≥ 65, medium S _R ≤ 65 high slagging |

Table 4 Slagging indices of some type of biomass (Pruksakit, 2014)

| Type | B/A | B/A _p | R _{B/A} | BAI | F _u | S _R | AI (GJ/kg) |
|-------------------|------|------------------|------------------|------|----------------|----------------|------------|
| Bagasse | 0.40 | 0.44 | 0.34 | 2.86 | 1.98 | 67.99 | 0.08 |
| Corn cob | 1.42 | 1.55 | 0.15 | 0.03 | 68.11 | 86.77 | 0.55 |
| Corn straw | 0.72 | 0.77 | 0.39 | 0.14 | 13.52 | 70.08 | 0.76 |
| Coconut husk | - | - | 1.07 | 0.17 | - | 21.20 | 0.03 |
| Empty Fruit Bunch | - | - | 2.061 | 0.07 | - | 30.35 | 1.17 |
| Eucalyptus | - | - | 1.024 | 0.17 | - | 47.96 | 0.06 |
| Eucalyptus bark | 6.10 | 6.28 | 5.31 | 0.10 | 68.04 | 12.58 | 0.82 |
| Rice straw | 0.25 | 0.27 | 0.07 | 0.06 | 3.30 | 93.01 | 1.34 |
| Rice husk | 0.07 | 0.08 | 0.03 | 0.09 | 0.32 | 97.50 | 0.52 |
| Thai Lignite | 0.99 | 0.99 | 0.93 | 5.44 | 2.67 | 46.54 | 0.37 |
| Bituminous | 0.15 | 0.15 | 0.14 | 5.97 | 0.16 | 80.29 | 0.03 |

- Data collection not available for calculation

2.6 Thermal behavior of biomass

Degradation behavior of biomass is importance for operation design. Thermal degradation of biomass depends on two predominant factors: heat transfer and kinetic of reaction. Particle size dominates the influence of heat transfer which small particle heating rapidly and coarser and large particle heating more slowly (Jenkins et al., 1998). Dynamic thermogravimetric analysis (TGA), measure mass degradation of sample versus temperature or time at constant heating rate and atmospheric air/nitrogen environment, is widely used for study thermal behavior of solid fuel. Thermal behavior during combustion of biomass can be classified into three main stages. First stage describes moisture release from biomass. Second staged (> 120°C), which high mass degradation, descript volatile matter combustion (decomposition of hemi-cellulose and cellulose) and last stage (> 300°C) is main combustion of lignin and char combustion stage. Combustion behaviors of some biomass are showed in Fig. 8. Each type of biomass showed different degradation behavior because different in lignocellulosic composition contain in biomass. However, degradation behavior of biomass not depends on pseudo-composition alone. Vamvuka et al. (2006), investigated effect of mineral matter on pyrolysis and combustion under TGA. They conclude mineral matter such as calcium, magnesium, potassium and silicon minerals acted as inert materials, inhibiting the pyrolysis and combustion rates of the samples.

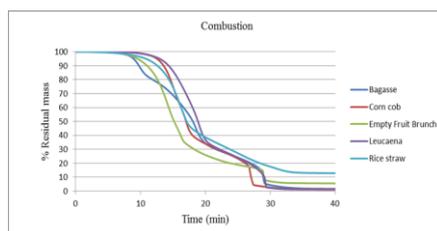


Fig. 8 Compare thermal behavior of biomass samples combustion at heating rate 10°C/min (Pruksakit, 2014).

3. Conclusion

Various thermochemical properties of biomass samples were present in this work. Biomass are low heating value solid fuel and vary depend on type of biomass. From proximate analysis, biomass showed high volatile matter (60-90% dry basis) and low fixed carbon compare with coal. Chemical composition, biomass has high oxygen content (40-50% d.a.f.) and low carbon (40-60% d.a.f.) different from fossil fuel which high carbon content. Hydrogen found in biomass around 5-6% (d.a.f.). Ash is the impurities which content in biomass case of fouling, slagging and fireside corrosion problem. Degradation behavior of biomass is importance for operation design. Dynamic thermogravimetric analysis is widely used for study thermal behavior of biomass. Different type of biomass has individual characteristic and required specific suitable operation condition setting for efficiency energy utilization.

4. Acknowledgement

The authors would like to thanks the Joint Graduate School of Energy and Environment for financial support of this study.

5. References

- BISYPLAN. 2012. The ash composition, in The Bioenergy System Planners Handbook.
- EI-Wakil, M.M. 1984. Powerplant Technology. Singapore: McGraw-Hill, Inc.
- Gulyurtlu, I., Teixeira, P., Lopes, H., Lapa, N., Freire, M., Galhetas, M. and Cabrita, I. 2008. Prediction of slagging and fouling tendency of biomass co-firing in fluidized bed combustion. in Proceedings of Proceedings of 9th International Conference on Circulating Fluidized Beds. 2008.
- Jenkins, B. 1989. Physical properties of biomass. Biomass handbook: 860-891.
- Jenkins, B., Baxter, L.L., Miles, T.R. Jr., Miles T.R. 1998. Combustion properties of biomass. Fuel processing technology 54(1): 17-46.
- Jenkins, B.M. and Ebeling J.M. 1985. Thermochemical properties of biomass fuels. California Agriculture 39(5/6): p. 14-16.
- Miles, T., Miles Jr., T.R., Baxter, L.L., Bryers, R.W., Jenkins, B.M. and Oden, L.L. 1996. Alkali deposits found in biomass power plants: a preliminary investigation of their extent and nature: Vol I, SAND96-8225, Vol. 2 and NREL. TP-433-8142.
- Munir, S. 2010. Potential slagging and fouling problems associated with biomass-coal blends in coal-fired boilers. Journal of the Pakistan Institute of Chemical Engineers 38(1).
- Plaza, P. 2013. The development of a slagging and fouling predictive methodology for large scale pulverised boilers fired with coal/biomass blends. Cardiff University.
- Prusakit, W. 2014. A Comparison of Thermal Behavior of Selected Biomass in Thailand for Effective Energy Utilization under Thermogravimetric Analysis, in The Joint Graduate School of Energy and Environment. King Monkut's University of Technology Thonburi.
- Sirijanusorn, S., Sriprateep, K. and Pattiya, A. 2013. Pyrolysis of cassava rhizome in a counter-rotating twin screw reactor unit. Bioresource Technology 139(0): 343-348.
- Vamvuka, D., Troulinos, S. and Kastanaki, E. 2006. The effect of mineral matter on the physical and chemical activation of low rank coal and biomass materials. Fuel 85(12): 1763-1771.