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The Estimate of Energy Generation Potential of Biomass Residue from Oil Palm Industries in Southern Thailand

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Abstract: The purpose of this research is to study the potential of biomass in Southern Thailand, material and energy balance for feasibility of biomass gasification to quantity of empty fruit bunch residue from industries was majority of biomass in Southern Thailand. However, results showed that the Empty Fruit Bunch (EFB) had the most biomass residue and high heating value, kernel shell had the highest heating value. So, kernel shell and Empty Fruit Bunch (EFB) is appropriate for gasification. Result from proximate analysis showed that palm kernel was consisted of 12.99% moisture, 2.73% ash, 70.96% volatile and 13.31% fixed carbon. Whereas, EFB was composed of 11.28% moisture, 3.06% ash, 68.06% volatile and 17.60% fixed carbon. Result from ultimate analysis showed that palm kernel was consisted of 46.51% carbon, 5.55% hydrogen and 35.85% oxygen. Whereas EFB was composed of 43.83% carbon, 5.82% hydrogen and 39.15% oxygen. Analysis from bomb calorimeter revealed heating value of palm kernel were HHV 4,152.13 kcal/kg and LHV 3,966.46 kcal/kg. Whereas those of EFB were HHV 3,990.31 kcal/kg and LHV 3,802.52 kcal/kg. Material and energy balance calculation indicated that syngas production from gasification process of kernel shell and empty fruit bunch were 0.88 kg/kg dry feed and 0.49 kg/kg dry feed, heating value of syngas was 3,200.63 kcal/kg dry feed and 1,393.81 kcal/kg dry feed for kernel shell and EFB, respectively. While 0.02 kg/kg dry feed and 0.32 kg/kg dry feed of tar were produced for kernel shell and empty fruit bunch gasification, respectively. The processes also obtained 0.08 kg/kg dry feed and 0.04 kg/kg dry feed of char for kernel shell and empty fruit bunch, respectively.

Key words: Biomass, dowdraft gasifier, gasification, kernel shell, fruit bunch

INTRODUCTION

Energy consumption has been global crisis problem as world population has increased. Major source of energy fuels in Thailand are imported. Thailand has large areas of agriculture, resulting in huge amount of biomass residue from both agricultural lands and industries. The average growing areas of palm oil in 2009-2013 were approximately 3.5 acres (ONS, 2012) in Southern Thailand. Biomass residue from oil palm industries was roughly 9.21-9.68 million tons in 2013 (Jungniyom, 2008). These biomass be converted to energy by combustion pyrolysis and gasification process (Krerkkaiwan, 2008). Gasification is a partial oxidation between solid fuel and air (oxygen) and/or steam convert to flue gas as showed in Eq. 1-6 (Krerkkaiwan, 2008). Products of gasification process include char, tar and syngas (Mohammed *et al*., 2011). Syngas are mix gas with high heating value that composed of Hydrogen (H_2), Carbon monoxide (CO), Methane (CH_4) and Carbon dioxide (CO_2) (Wang *et al*., 2008). Combustion reaction:

$$C+O_2 \rightarrow CO_2 \quad (1)$$

$$2H_2+O_2 \rightarrow 2H_2O \quad (2)$$

Boudouard reaction:

$$C+CO_2 \rightarrow 2CO+172 \text{ MJ/kmol} \quad (3)$$

Water gas reaction:

$$C+H_2O \rightarrow CO + H_2+131 \text{ MJ/kmol} \quad (4)$$

Methanation reaction:

$$C+2H_2 \rightarrow CH_4-75 \text{ MJ/kmol} \quad (5)$$

Water gas shift reaction:

$$CO+H_2O \leftrightarrow CO_2+H_2-41 \text{ MJ/kmol} \quad (6)$$

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The main problem of biomass gasification is by product of tar. Tar are a mixture of large hydrocarbon molecules which causes thermal defficiency of gasification and also damage gas engine. Tar can be reduced with catalytic reaction in downdraft gasifier. Downdraft gasifier can reduce more 10% of tar than using updraft gasifier. Syngas flows into heating zone and tar is cracked into gas (Klaimukh, 2002). The purpose of this study is to estimate potential of energy generation from biomass residue in southern Thailand and to remove tar from gasification process of oil palm residue. Semi-batch downdraft gasifier was design and constructed for the study.

MATERIALS AND METHODS

The study consists of 3 step study the potential of biomass in Southern part of Thailand and database analysis using Geographic Information System (GIS), Feasibility studies of gasification use material and energy balance and design and construct semi-batch downdraft gasifier.

Potential study of biomass in Southern Thailand: Potential study of biomass in Southern Thailand was performed based on database from office of Agricultural Economic. Data gathering and analysis in this study including crop production, biomass residue from agriculture and industries in southern Thailand. Top three of must biomass residue were further examined for their energy potential (ONS, 2012). Result was display using Geographic Information System (GIS). Moisture content and proximate composition of selected biomass was estimated, according to ASTM standard 2002. Ultimate analysis was evaluated by CHN-O analyze (Thermo Quest brand, Flash EA 1112). Heating value of biomass was examined by Bomb calorimeter (Automatic calorimeter 3088) (Meesuk, 2008).

Material and energy balance calculation of gasification of oil palm biomass residue: Material and energy balance of each kernel shell and EFB gasification process was evaluated at 900°C in downdraft gasifier. Basis of calculation was 1 kg of feed with 0.15 kg of water (Moisture in feed) at 20°C 1 atm. High heating value of biomass was determined using Dulong's equation (Zakaria *et al*., 2013). Power generation from dry syngas was calculated by Eq. 7:

$$\text{Electricity output} = (\text{HHV})(m)(\eta)(\text{Conversion factor}) \quad (7)$$

Where:
m = Mass of dry syngas
η = Electricity production efficiency

In the calculation, dry syngas was supplied to gas engine while char was as fuel in steam turbine to generate power.

Design and construct of semi-batch downdraft gasifier: Downdraft gasifier was designed and constructed for this study. Flow diagram of gasification process as show in Fig. 1. As seen in Fig. 2 system includes of three units; gasifier, filtration and catalytic reactor. Gasification was constructed with insulated steel. Produced gas was filtrate with woodchip and produced to catalytic reactor for tar removal.

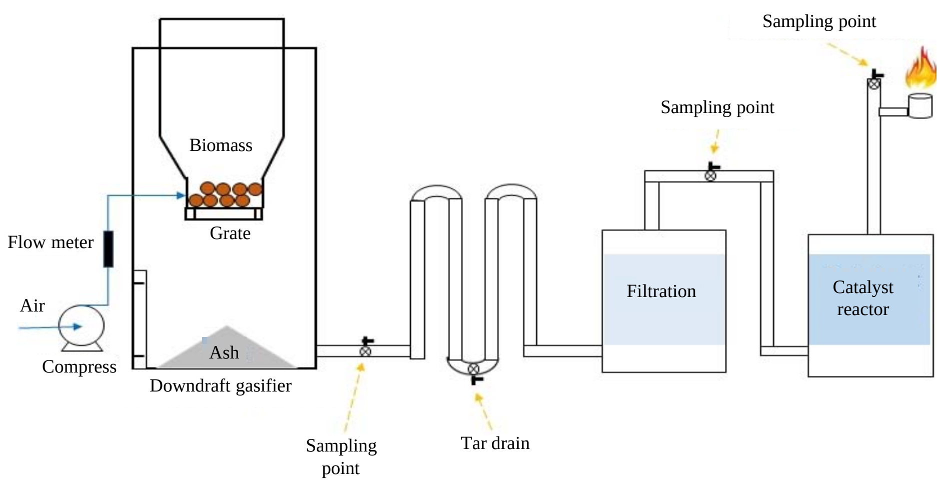


Fig. 1: Schematic of catalytic air gasification for biomass

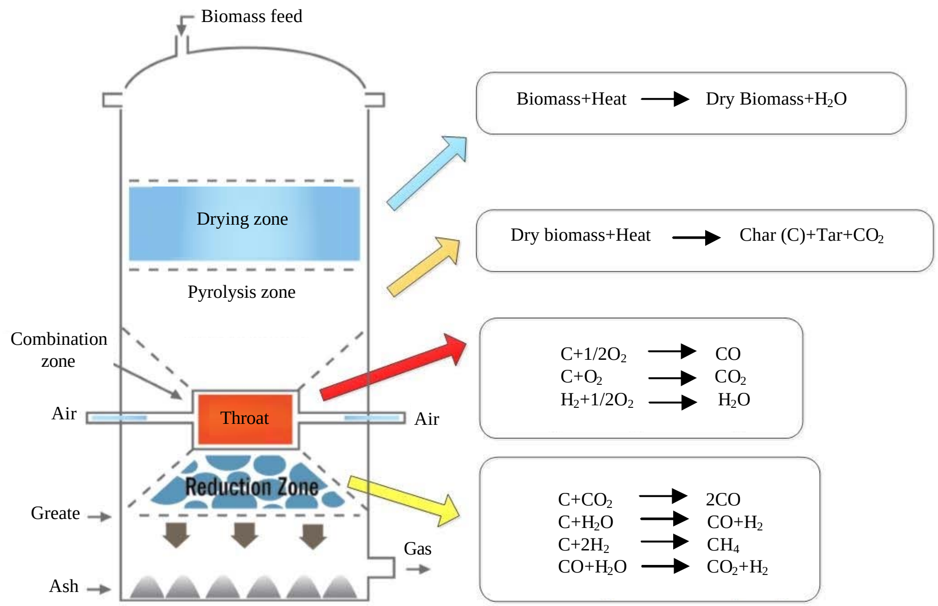


Fig. 2: Reaction of gasification (Klaimukh, 2002)

RESULTS AND DISCUSSION

The potential of biomass in southern part of Thailand biomass: There are several crop production in Southern Thailand, majority are oil palm, coconut, rubber tree and rice. Their harvesting and industrial process resulting in huge amount of biomass residue as shown in Table 1. These biomass residue can be further utilized such as fertilizer, animal feed and fuel source. Table 1 lists the most top three of crop production and their biomass residue including heating value from year 2013-2015.

Figure 3-5 show GIS data of biomass residue from oil palm, coconut and rice in Southern Thailand in year 2015. As seen in Fig. 3, residue from oil palm was the highest amount in most areas. Therefore, Fig. 4 and 5 display biomass residue from kernel shell and empty fruit bunch for 14 provinces. From GIS data can be identified that there are vast amount of biomass residue which can be further processed as energy source.

Proximate analysis: The result analyze substance are moisture, ash, volatile matter and fixed carbon with proximate analysis 1 that analyze at Walailak University Laboratory show in Table 2.

Table 2 shows result for proximate analysis using ASTM standard. The major composition of both kernel shell and EFB was volatile matter. Where as fixed carbon was approximately 13-18%, moisture content was roughly 12%. Result from this analysis suggests that both kernel shell and EFB can be potentially combusted to generate energy because of their high amount of volatile matter.

Ultimate analysis: Elemental analysis was performed using a CHN-O analyzer (Thermo Quest brand, Flash EA 1112 model). The result show in Table 3.

The result indicates that kernel shell and empty fruit bunch used in this study are suitable to be need as raw materials for gasification, since they have carbon, hydrogen and oxygen compositions dose to those need in past research study.

Heating value: High Heating Values (HHV) and Low Heating Values (LHV) were obtained Bomb Calorimeter measurement. An automatic calorimeter (3088 model) was used in the experiment (Table 4).

Heating value result shows that the HHVs and LHVs of the kernel shell and EFB used in this study are very dose to those of the previous study. The combustion properties of the selected materials should be comparable between the two studies. Therefore, it is convinced that the raw materials used in this study are appropriate for the proposed gasification process.

Material and energy balance for gasification: Material and energy balance for gasification of kernel shell and empty fruit bunch at 900°C calculate volume of product and heating value show Table 5 and Fig. 6.

Material and energy balance calculations indicated that the syngas obtained from gasification process of kernel shell and empty fruit bunch could be produced at the rate of 0.88 kg/kg dry feed and 0.49 kg/kg dry feed, respectively. However, tar which is an undesirable by product was also produced at rate 0.02 kg/kg dry kernel shell and 0.32 kg/kg dry EFB.

Table 1: Rop production in Southern part of Thailand

Crop	Crop production (ton) (years) 2013	2014	2015	Biomass	Biomass residue (ton) (years) 2013	2014	2015	Heating value (MJ/kg)
Oil palm	10,432,872	11,432,402	11,432,318	Frond	2,837,741	3,109,613	3,109,590	09.83
				Empty fruit bunch	1,309,951	1,435,452	1,435,442	17.86
				Fiber	208,302	228,259	228,258	17.62
				Kernel shell	18,915	20,727	20,727	18.46
Coconuts	553,864	531,320	526,964	Husk	119,297	114,441	113,503	16.23
				Frond	100,818	96,713	95,921	16.00
				Empty bunches	22,878	21,947	21,767	15.40
				Kernel	33,498	32,134	31,871	17.93
Rice	652,479	623,836	624,882	Straw	218,684	209,085	209,435	10.24
				Paddy husk	72,698	69,507	69,623	14.27

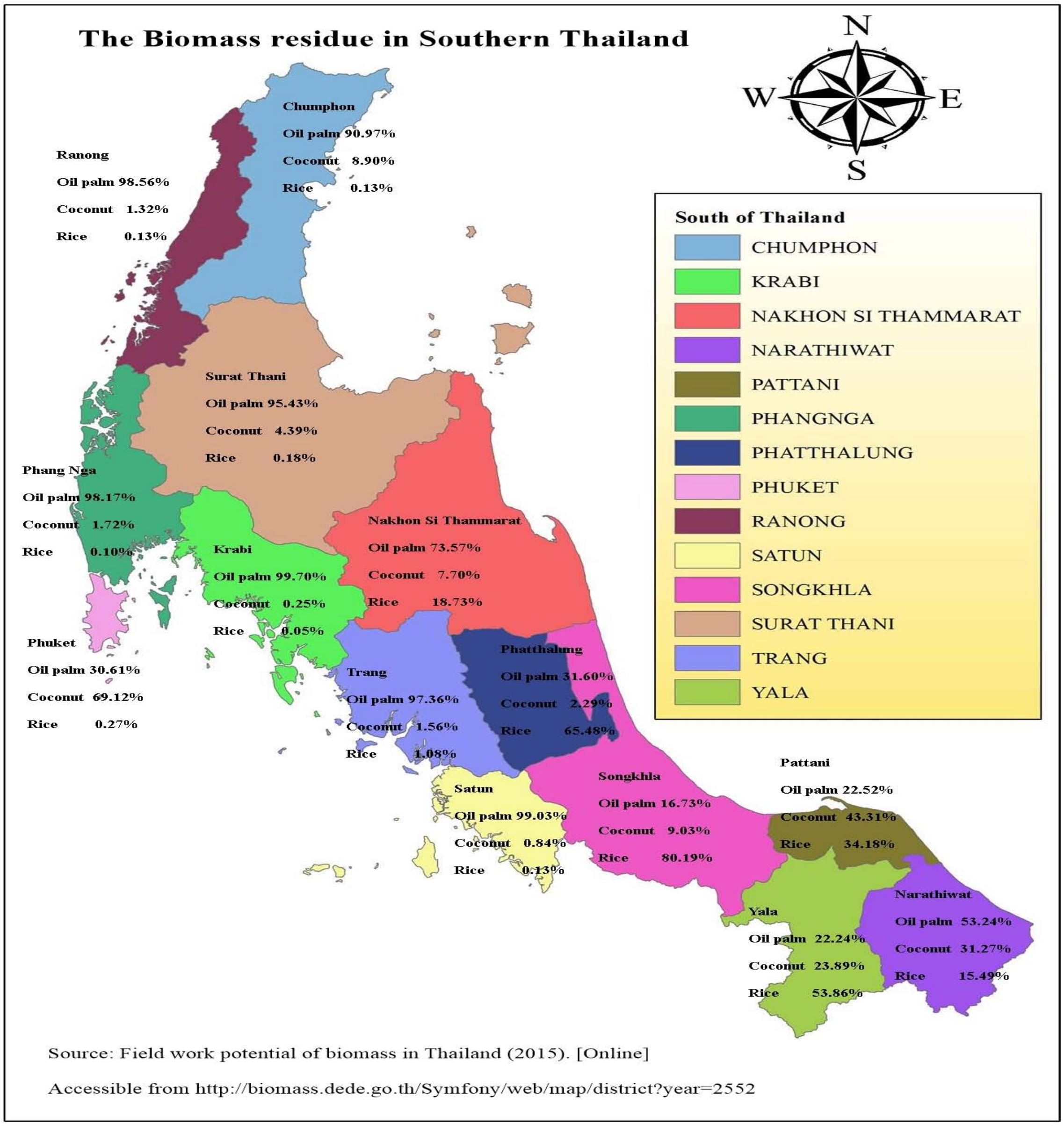


Fig. 3: Geographic Information System (GIS) for biomass residue in Southern Thailand

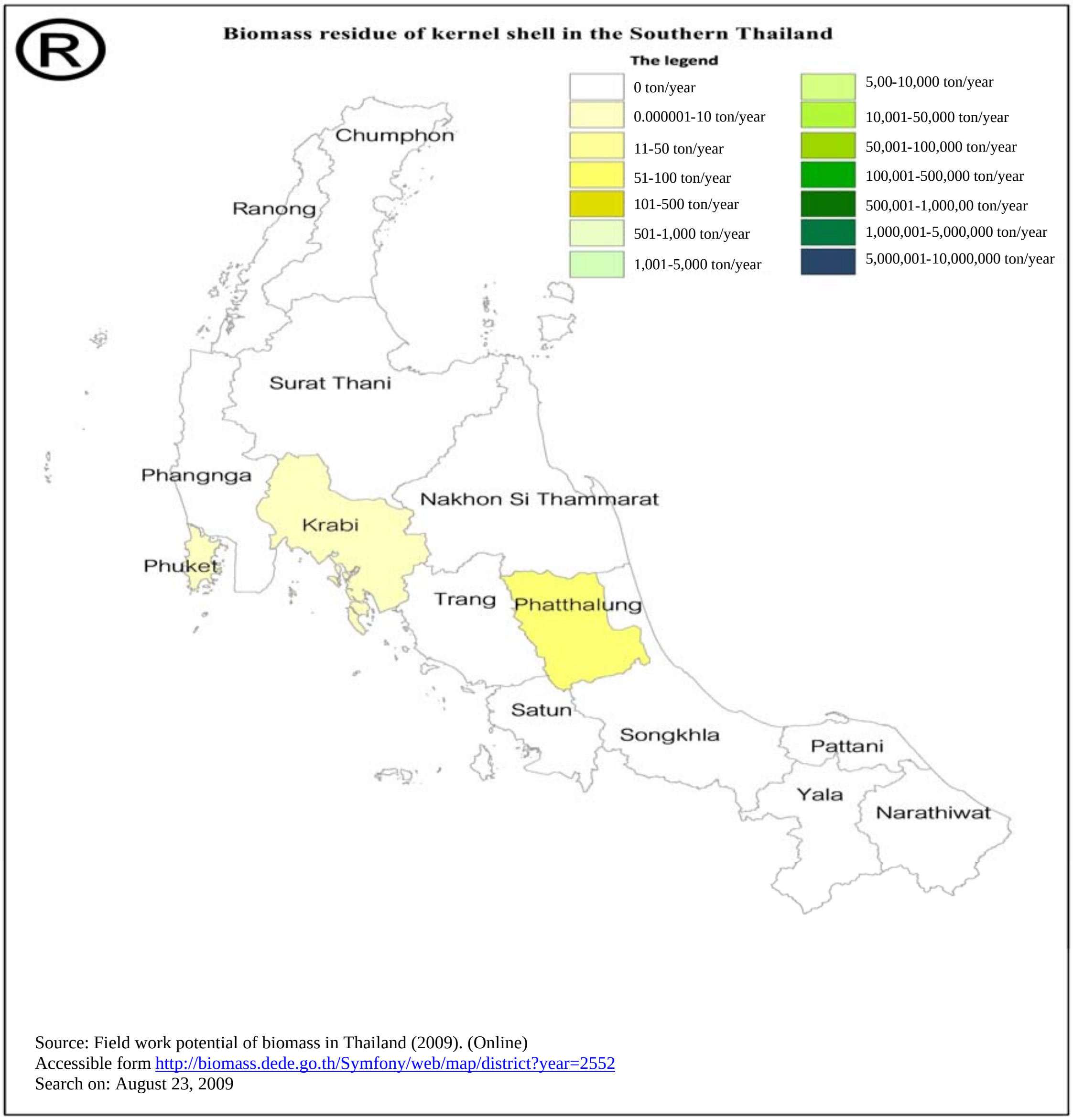


Fig. 4: Geographic Information System (GIS) for kernel shell

Table 2: The result of proximate analysis

Biomass	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)
Kernel shell	12.99	2.73	70.96	13.31
Empty fruit bunch	11.28	3.06	68.06	17.60

Table 3: The result of ultimate analysis

	Element (%)			
Biomass	C	H	O	N
Kernel shell	46.51	5.55	35.85	0.200
Empty fruit bunch	43.83	5.82	39.15	0.040
Kernel shell[a]	44.90	5.51	49.54	0.000
Empty fruit bunch[b]	36.75	5.17	56.92	1.140

[a]Jungniyom (2008): [b]Krerkkaiwan (2008)

Table 4: Heating value of kernel shell and empty fruit bunch

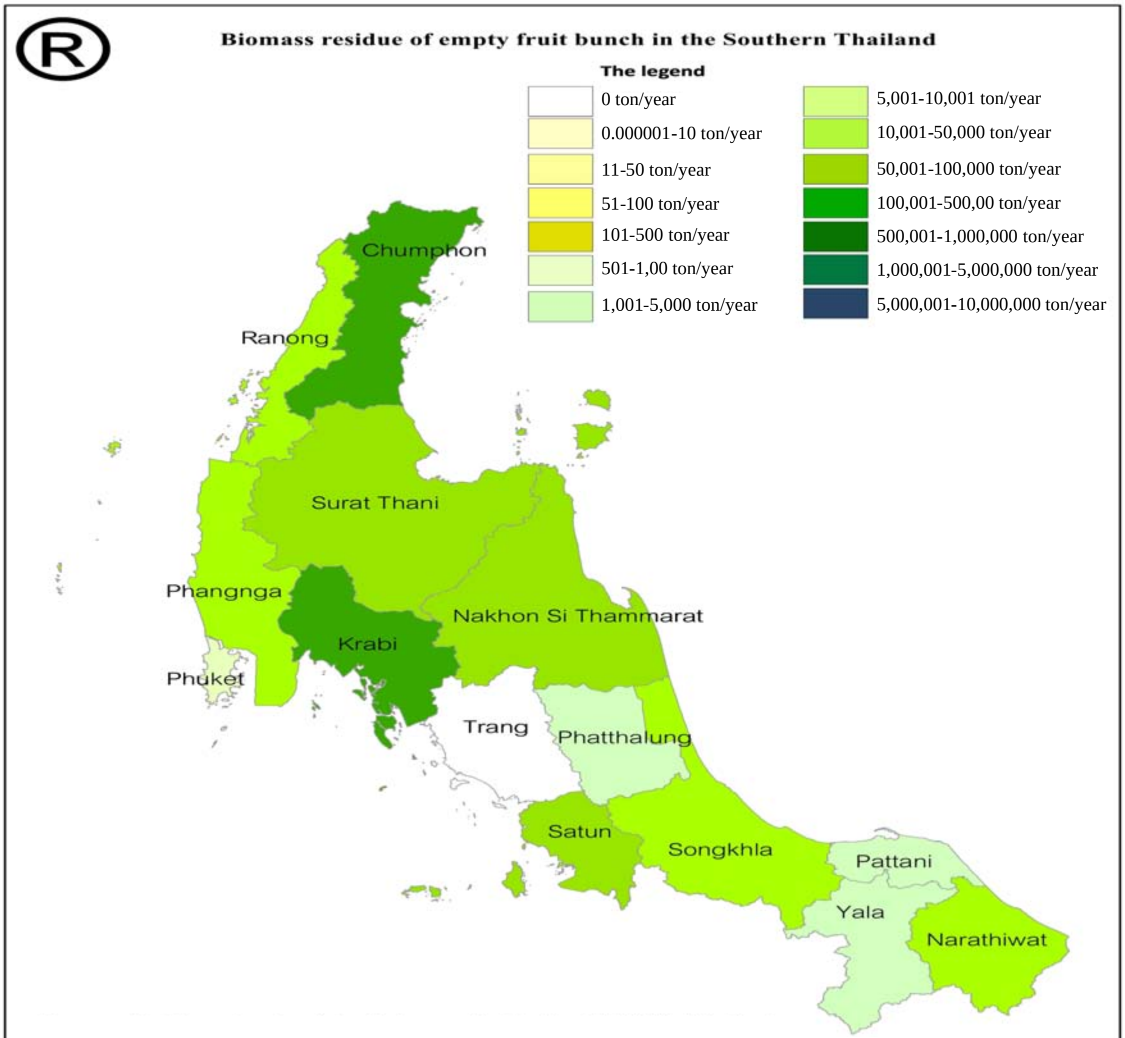
Biomass	HHV (kcal/kg)	LHV (kcal/kg)
Kernel shell	4,152.13	3,966.46
Empty fruit bunch	3,990.31	3,802.52
Kernel shell[c]	4,349.29	4,023.81
Empty fruit bunch[c]	2,189.52	1,723.81

[c]Mohammed *et al*. (2011)

The heating value of the product gas were observed not to be insignificantly different at the value of 4,025.24 kcal/kg kernel shell and 4,025.61 kcal/kg EFB, respectively. It is to note the syngas containing low tar and having high heating value is ideal to be need with gas engine

Table 5: Volume of product and heating value from material and energy balance for gasification of kernel shell and empty fruit bunch

	Kernel shell (kg/kg dry feed)		Empty fruit bunch (kg/kg dry feed)	
Composition	Heat	Weight	Heat	Weight
Reactant				
Dry Biomass	1.00	3,731.95	1.00	3,426.65
Water	0.15	0	0.13	0
Total	1.15	3,731.95	1.13	3,426.65
Product				
Dry syngas	0.88	3,200.63	0.49	1,393.81
Heavy tar	0.01	108.7	0.16	1,216.37
Light tar	0.01	99.87	0.16	1,117.60
Water	0.01	0	0.16	0
Char	0.08	616.04	0.04	297.8300
Steam	0.15	0	0.13	0
Total	1.15	4,025.24	1.13	4,025.61
Enthalpy difference	-	-293.29	-	-598.960



Source: Field work potential of biomass in Thailand (2009). (Online)
Accessible form http://biomass.dede.go.th/Symfony/web/map/district?year=2552
Search on: August 23, 2009

Fig. 5: Geographic Information System (GIS) for empty fruit bunch

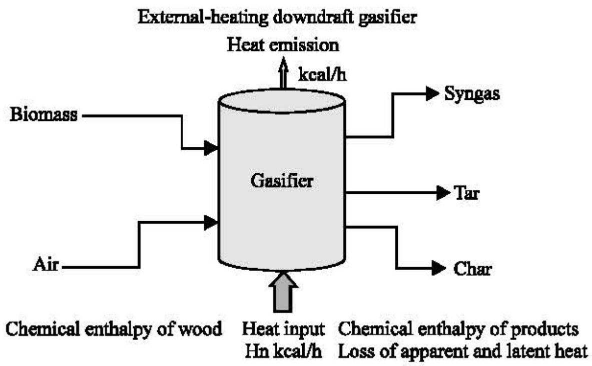


Fig. 6: Flow diagram of air gasification for kernel shell and EFB

Table 6: Production capacity of electricity from gasification with kernel shell (basis 100 kg)

Process	Electrical power efficiency (η) (%)	Electricity (Wh/kg) Syngas	Char
Gas engine	89.3[d]	3,321.82	-
Steam turbine	29[e]	1,078.78	207.63

Table 7: Production capacity of electricity from gasification with empty fruit bunch (basis 100 kg)

Process	Electrical power efficiency (η) (%)	Electricity (Wh/kg) Syngas	Char
Gas engine	89.3[d]	1,446.59	-
Steam turbine	29[e]	469.780	100.38

[d]Wang *et al*. (2008), [e]Klaimukh (2002)

turbine to generate electricity. For the syngas produced from the gasification process in this study, the potential of electricity generation from a gas engine turbine was estimated to be 3,32182 Wh/kg kernel shell and 1,446.59 Wh/kg EFB, assuming the efficiency coefficient (η) of the turbine at 89.3% (Table 6 and 7).

CONCLUSION

Palm kernel and Empty Fruit Bunch (EFB) found to be a suitable source of biomass that can be used in air gasification process to produce the useful syngas. The material and energy balance of the process shows that the productions of the syngas were achieved at the rate of 0.88 kg/kg dry kernel shell and 0.49 kg/kg EFB, respectively. The heating values of the produced gases were approximately 4,025 kcal/kg dry feed for both materials.

The estimation of electricity generation from a gas engine powered by the produced gas from the gasification was reported approximately 3.3 kWh/kg dry kernel shell and 1.4 kWh/kg EFB. It is convincing that palm kernel shell and empty fruit bunch are appropriate to be used raw material in gasification to produce syngas with acceptable quality for electricity production. However, the gasification process has to be well optimized in order to achieve high quality syngas. Our future study will focus on designing a downdraft gasifier suitable for handling kernel shell and EFB. The conditions effecting the quality of the produced gas such as type of catalyst and biomass to feed ratio will be of interest as well.

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