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Renewable Energy from Palm Oil Empty Fruit Bunch

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1. Introduction

The world economy is the key driver for global primary energy consumption. According to the economic recovery in 2010, the world primary energy consumption is rebounded which was accounted for 12,002.4 Mtoe, increased by 28 % from year 1998 (BP, 2010). The important primary energy sources are fossil fuels, e.g. crude oil, natural gas, coal, whereas the renewable energy source has a small share. If the world population, world economy and consequently the world energy consumption are still growing rapidly, in spite of there are more than 1,000 thousands million barrel proved oil reserved in 2010 (BP, 2010), the world will face to problem of oil price crisis and also oil diminishment in the near future. Beyond that crisis, the utilization of fossil fuel will lead to an increase in carbon dioxide emission in the atmosphere. In 2007, global carbon dioxide emission was accounted for 29.7 billion metric ton (U.S. Energy Information Administration [US IEA], 2010), increased approximately 1.7 % from previous year (29.2 billion metric ton in 2006 (US IEA, 2006)) and it was predicted that the concentration of carbon dioxide still increases by an average of 0.1 % annually for OECD countries and an average of 2.0 % per year for non-OECD countries until 2035 (US IEA, 2010). The high concentration of carbon dioxide causes the greenhouse effect and consequently, the global warming which becomes the serious problem to human race.

Nowadays there are many efforts to reduce both the use of fossil fuel and the carbon dioxide emission by using renewable energy as a substitute to fossil fuel. This renewable energy includes solar energy, wind energy, hydro energy as well as energy derived from biomass, tide and geothermal. These renewable energy sources can be used not only for heat and power generation but also for liquid transportation fuel production. During four consecutive years from end-2004 to end-2008, the global solar photovoltaic had increased six-fold to more than 16 GW_e, while the global wind power generation had risen by 250 % to 121 GW_e. More than 280 GW_e had been produced from hydro, geothermal and biomass power plants which increased 75 % from the last four year. In the same time interval, the heat production from solar heating was also doubled to 145 GW_{th}. In the perspective of biofuel production, biodiesel production increased six-fold to 12 billion liters per year, whereas ethanol production was doubled to 67 billion liters per year (Renewable Energy Policy Network for the 21st Century [REN21], 2009).

Analogy to global energy situation, Thailand has faced to the problem of energy crisis, especially oil price crisis. Thailand has been relying on fossil fuel as the primary source of energy which has to be imported from foreign countries, and simultaneously Thailand energy consumption has been increased rapidly and continuously. This chapter will focus on the energy situation in Thailand, the energy policy plan and finally the possibility of using renewable energy sources as alternative energy to energy from fossil fuel.

1.1 Energy situation in Thailand

Thailand is a developing country located at the middle of Southeast Asia with a population of 63.5 million in 2009 (Department of Provincial Administration [DOPA], 2010), increased 2.3 % from 2005. During the same period, the Gross Domestic Product (GDP) increased from 7,092,893 million Baht in 2005 to 9,041,551 million Baht in 2009 (Office of National Economic and Social Development Board [ONESDB], 2009) (1 US$ ~ 31 Baht) or equal to the increasing rate of 2.7 %. There exists a two way casual relationship between economic/population growth and energy consumption in case of Southeast Asia (Wianwiwat & Adjaye, 2011). That is the higher level of economic growth and population growth will result in the higher energy consumption. Identical to other countries in Southeast Asia, the economic and industrial developments as well as the growth in population lead to the higher energy consumption. In 2009, domestic final energy consumption was accounted for 69,177 ktoe (Energy Policy and Planning Office [EPPO], 2010) which increased 2.9 % from previous year. Table 1 shows the final energy consumption in Thailand from 2005 to 2009.

Year	Consumption (ktoe)	Increasing Rate (%)
2005	63,061	-
2006	62,904	-0.25
2007	65,950	4.62
2008	67,256	1.98
2009	69,177	2.86

Table 1. Domestic final energy consumption from 2005 to 2009 in Thailand (EPPO, 2010)

The primary energy sources consumed in Thailand are mostly derived from fossil fuels, e.g. petroleum, natural gas and coal which contributed to 56,693 ktoe in 2009 (EPPO, 2010) or equivalent to 82 % of the final energy consumption, whereas renewable energy covered only 18 %. Figure 1 illustrates the final energy consumption by types in 2009.

Most of commercial energy source used in Thailand is petroleum product which was equal to 31,959 ktoe in 2009. Diesel, gasoline and liquid petroleum gas are the major petroleum products used in transportation sector. Diesel and gasoline consumption accounted for the share of 46 % and 19 %, respectively, whereas liquid petroleum gas consumption was amounted to 17 % (EPPO, 2010). Natural gas was mainly used as fuel for power generation, holding a share of 68 % of the total consumption in 2009. The remainder was used in gas separation plant, with the share of 17 %; in industries with 11 % and in transportation sector for 4 % (EPPO, 2010). The share of coal and lignite consumption as fuel in power generation sector was almost at the same level as its consumption in industrial sector.

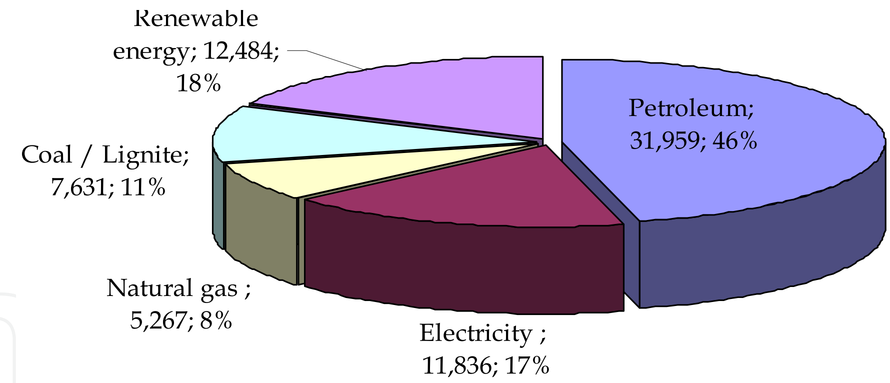


Fig. 1. Final energy consumption in 2009 by types in ktoe; percent (EPPO, 2010)

Unfortunately, Thailand has insufficient crude oil or good quality fossil fuels, these energy sources have to be imported from foreign countries, especially Middle East countries for oil import. In 2009, Thailand imported a substantial amount of commercial energy sources, approximately 59,333 ktoe which costed more than 760 billion Baht (EPPO, 2010). Figure 2 shows the expense for final energy import in 2009.

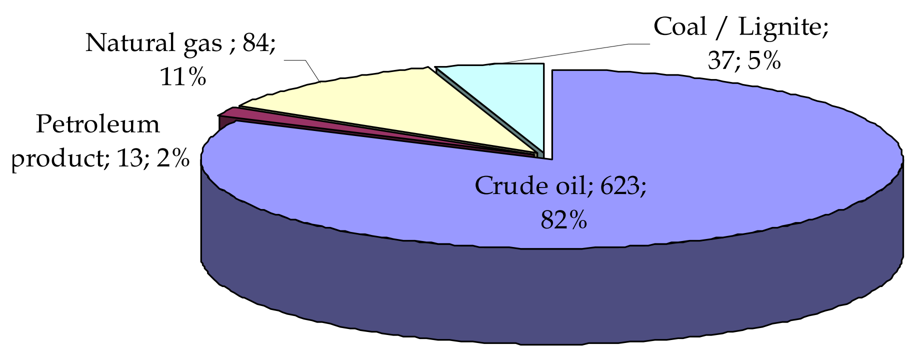


Fig. 2. Final energy consumption in 2009 by types in billion Baht; percent (EPPO, 2010)

Considering greenhouse gas (GHG) emission, carbon dioxide emission in Thailand during the last five years increased from 192,486 kton in 2005 to 208,476 kton in 2009 which is listed in more detail in Table 2.

Year	Amount (kton)	Increasing Rate (%)
2005	192,486	-
2006	193,136	0.34
2007	200,439	3.78
2008	203,181	1.37
2009	208,476	2.61

Table 2. Carbon dioxide emission from 2005 to 2009 in Thailand (EPPO, 2010)

The main sources of carbon dioxide emission are oil, natural gas and coal which are significantly used as fuel for energy production via combustion process. It is expressed that the direct combustion of these fossil fuel is the largest source of GHG emission from human activities (Sawangphol & Pharino, 2011). These fossil fuels are used in industrial, power generation and transportation sector. Figure 3 and Figure 4 show the amount of carbon dioxide emission in 2009 by sources and by sectors, respectively.

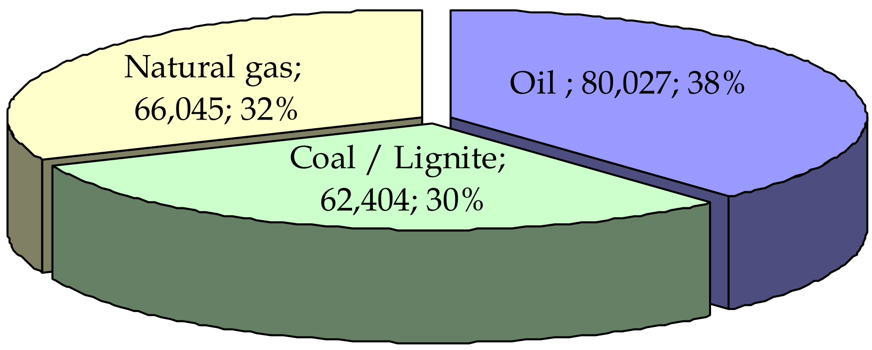


Fig. 3. Carbon dioxide emission in 2009 in Thailand by sources in kton (EPPO, 2010)

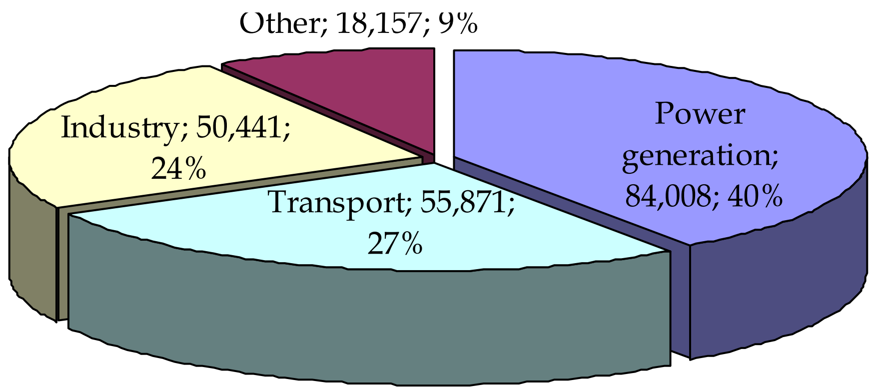


Fig. 4. Carbon dioxide emission in 2009 in Thailand by sectors, in kton (EPPO, 2010)

1.2 Energy policy and plan

Since Thailand has spent a large amount of money for importing commercial energy sources, Thai government as well as private and public organizations have realized about that, Ministry of Energy of Thailand has promoted the use of renewable energy, including biomass, municipal solid waste, biogas, wind and solar power for power generation or transportation fuel production by announcing the 15-Years of Alternatives Energy Development Plan (AEDP, 2009) on January 28, 2009. The objective of this AEDP is to strengthen and promote the utilization of renewable energy in order to replace the oil import. The main target of AEDP is to increase the portion of using alternative energy to 20 % of national final energy consumption by 2020. The plan will be implemented into three phases: short-term from 2008 to 2011, mid-term from 2012 to 2016 and long-term from 2017 to 2020.

From Table 3, it can be noticed that the main target of AEDP until 2020 is the utilization of biomass for electricity and heat production. In addition to electricity and heat, biomass can also be used as feedstock for biofuel production. Considering cost of electricity and heat generated from renewable energy, electricity and heat produced from solar and wind energy has a higher cost with more complicated technology for Thailand than electricity and heat from produced from biomass (Bull, 2001; Owen, 2006).

Besides the reduction of primary energy sources importing, using biomass as alternative fuel can contribute to the reduction of GHG emission, since biomass is carbon neutral which emits no net carbon dioxide. Therefore, this study will emphasize only on the energy production from biomass.

	Potential	Existing	2008-2011		2012-2016		2017-2020	
Electricity	MW	MW	MW	ktoe	MW	ktoe	MW	ktoe
Solar	50,000	32	55	6	95	11	500	56
Wind	1,600	1	150	17	400	45	700	78
Hydro	700	50	165	43	281	73	324	85
Biomass	4,400	1,597	2,800	1,463	3,235	1,682	3,700	1,933
Biogas	190	29	60	27	90	40	120	54
MSW	320	5	100	60	130	87	160	96
Hydrogen			0	0	0	0	3.5	1
Total		1,714	3,330	1,616	4,231	1,938	5,508	2,303
Heat	ktoe	ktoe		ktoe		ktoe		ktoe
Solar	154	2.3		5		17		34
Biomass	7,400	2,344		3,544		4,915		6,725
Biogas	600	79		470		540		600
MSW	78	1		16		25		35
Total		2,426.3		4,035		5,497		7,394
Biofuels	Ml/day	Ml/day	Ml/day	ktoe	Ml/day	ktoe	Ml/day	ktoe
Ethanol	3.30	1.00	3	816	6.20	1,686	9	2,447
Biodiesel	3.30	1.39	3	944	3.64	1,145	4.50	1,416
Hydrogen			0	0	0	0	0.1 M kg	124
Total			6	1,760	9.84	2,831	13.50	3,987
Total energy demand (ktoe)		65,420		72,539		88,389		112,046
Total renewable energy demand (ktoe)		3,411.80		7,411		10,266		13,684
Portion of renewable energy use		5.2 %		10.2 %		11.6 %		12.2 %
Natural gas (mmscfd)		91.5	345	3,045	826	7,290	1,035	9,135
Total alternative energy demand (ktoe)				10,456		17,556		22,819
Portion of alternative energy used				14.4 %		19.9 %		20.4 %

Table 3. 15-Years of Alternatives Energy Development Plan (AEDP, 2009)

1.3 Biomass potential in Thailand

Since Thailand is the agricultural base country, there are a lot of agricultural crops, e.g. paddy rice, sugarcane, cassava and palm oil. During the harvesting and processing of these agricultural crops, some residues are left over, e.g. rice straw and rice husk from paddy rice, bagasse and sugarcane leave from sugarcane, cassava rhizome from cassava as well as palm oil shell, palm oil fiber and palm oil empty fruit bunch from palm oil fruit. These residues can further be used as the substitute to fossil fuel for energy production and, consequently, can solve the problem of high energy price as well as global warming. The amount of residues from these agricultural products can be estimated by their productivities, Crop-to-Residual-Ratio (CRR) and Surplus-Availability-Factor (SAF). The CRR is expressed as the amount of residues generated per 1 unit mass of an agricultural product and the SAF is the amount of unused residues or residues left-over which are not used for any purposes. The potential of bio-energy from these agricultural products is then calculated from the quantity of biomass residues and the lower heating value of biomass. The office of Agricultural Economic reported the production of four main agricultural products in 2009 as followed: paddy rice 32,116 kton, sugarcane 68,808 kton, cassava 22,006 kton and palm oil fruit 8,223 kton (OAE, 2010). Table 4 shows the amount of residues and energy potential from domestic main agricultural products based on productivity in 2009.

Agricultural product	Residues	Productivity (kton)	CRR (Papong et al., 2004)	SAF (Papong et al., 2004)	Quantity of residues (kton)	LHV (MJ/kg) (Prasertsan & Sajjakulnukit, 2006)	Total Energy (PJ)
Paddy rice		32,116					
	Rice husk		0.23	0.493	3,641.63	14.27	51.97
	Rice straw		0.447	0.684	9,819.40	10.24	100.55
Sugarcane		68,808					
	Bagasse		0.291	0.227	4,545.25	8.31	37.77
	Sugarcane leaves		0.302	0.986	20,489.10	8.70	178.26
Cassava		22,006					
	Cassava rhizome		0.49	0.98	10,567.28	5.50	58.12
Palm oil fruit		8,223					
	Shell		0.049	0.037	14.91	18.46	0.28
	Fiber		0.147	0.134	161.98	17.62	2.85
	Empty fruit bunch		0.250	0.584	1,200.56	17.86	21.44
	Frond		2.604	1.00	21,412.69	9.83	210.49
Total							661.73

Table 4. Energy potential of main agricultural residues in Thailand

From Table 4, the energy potential of agricultural residues generated from four main agricultural products in 2009 was accounted for 661.73 PJ. The energetic potential of rice straw, sugarcane leaves and palm oil frond is very high compared to other types of biomass, 100.55 PJ, 178.26 PJ and 210.49 PJ, respectively; however the utilization of these residues as a renewable source for energy production has hardly been found. Rice straw is normally used for animal fodder, soil cover material and paper industry, while palm oil frond is also served as soil cover material. Sugarcane leave is normally left in field and burnt. Currently only rice husk, bagasse and palm oil shell are widely used as feedstock in stand-alone or co-firing power plant for heat and power production (Papong et al., 2004; Prasertsan & Sajjakulnukit, 2006). Not only for heat and power production, rice husk, bagasse and palm oil shell can be used in several industries, e.g. animal fodder and paper industry. Despite there are a large quantity of sugarcane leave and cassava rhizome, their heating value is very low compared to other biomass. This study will not focus on such biomass. Although the quantity of Palm Oil Empty Fruit Bunch (PEFB) available is in the sixth rank of all biomass, the energetic quality is high due to its high heating value and it is not yet mainly used as alternative fuel due to its high moisture and volatile matter with low ash melting temperature, therefore the scope of this study focuses on renewable energy utilization from PEFB.

2. Utilization of palm oil empty fruit bunch

The main content of this following section deals with the utilization of palm oil empty fruit bunch as renewable energy. However, this section will provide an important information about palm oil and its plantation as well as a brief discussion about its utilization for non-energetic purposes prior to go deeply in more detail of its utilization for energetic purposes.

2.1 Oil palm plantation

There are two families of oil palm, *Elaeis guineensis* which is native to western Africa and *Elaeis oleifera* whose origin is in tropical Central America and South America. The palm family which is widely cultivated in Thailand is Elaeis guineensis. It was first introduced to Thailand in 1968 (Prasertsan & Sajjakulnukit, 2006). Nowadays, the plantation of palm oil in Thailand is continuously increased because Thai government announced the policy of producing palm oil based biodiesel as renewable energy, as already mention in Table 3. The Office of Agricultural Economics (OAE, 2010) reported the oil palm plantation area in 2009 was accounted for 3,165,000 Rai (1 Rai = 1,600 m^2) which increased by 56 % from the last five years and the target of 10 million Rai should be achieved by 2029 (Yangdee, n.d.). The oil palm production is increased by 64 % from 5,003,000 ton in 2005 to 8,223,000 ton in 2009. More than 90 % of palm oil plantation area in Thailand is located in Southern part of Thailand, especially in Chumporn, Surat Thani and Krabi.

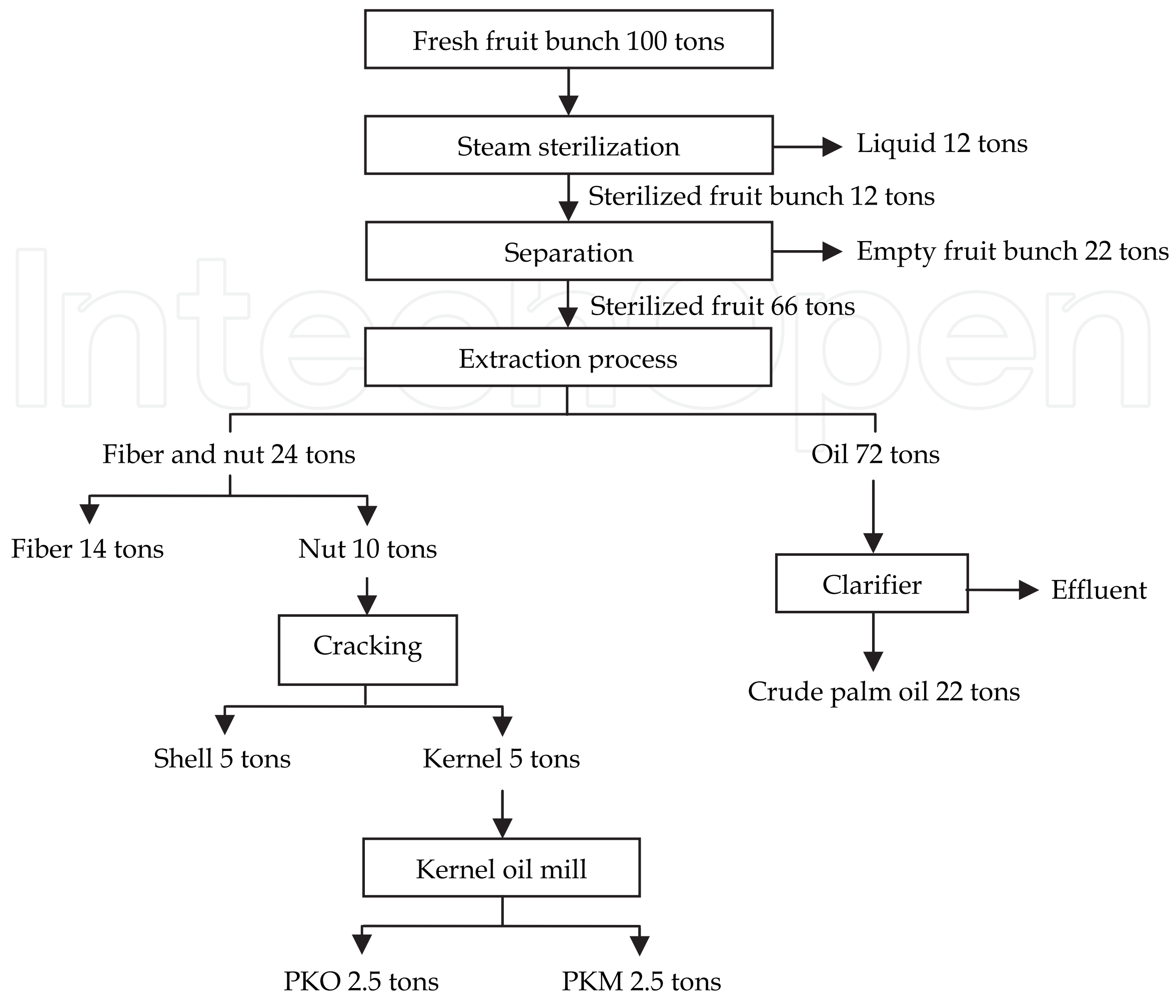
Elaeis guineensis is vertical trunk and the feathery nature of leaves. There are 20-40 new leaves, called “frond” developed each year. The fruit bunches develop between trunk and base of the new fronds. Typically the first commercial crop can be harvested after 5-6 years of plantation and can provide fresh fruits for 25-30 years (Perez, 1997). The weight of compact fruit can varies from 10 to 40 kilograms. Each fruit is sphere in shape, dark purple, almost black before it ripens and turns to orange-red when ripe (Katamanee, 2006). Figure 5 illustrates oil palm tree and fresh fruit bunch.

2.2 Palm oil empty fruit bunch (PEFB)

Palm oil empty fruit bunch (PEFB) is waste residue generated from palm oil industries. After harvesting fresh fruit bunches from oil palm tree, these bunches are sterilized in a horizontal steam sterilizer to inactivate enzymes present in pericarp and loosen fruits from bunches. The sterilized bunches are fed into a rotary drum thresher in order to remove the sterilized fruit from bunches. These bunches without fruit are called as empty fruit bunch (EFB) which are conveyed to the damping ground, whereas the sterilized fruits are further used as feedstock for palm oil production in palm oil extraction process by means of screw type press. The effluents from screw type press are nuts and fibers which are separated from each other by cyclone. After this separation, nuts are cracked into shells and kernels. The former are solid waste and left unused, the latter are sent to the kernel oil mill (Mahlia et al., 2001; Prasertsan & Sajjakulnukit, 2006). It was reported that 20-22 tons of empty fruit bunch, 14 tons oil-rich fiber and 5 tons of shell are generated from 100 ton of fresh fruit bunch (Perez, 1997; Katamanee, 2006), as illustrated in Figure 6.

Source: Available from http://gardendoctor.files.wordpress.com/2010/05/elaeis_guineensis.jpg (1 Sep 2010)

Fig. 5. Oil Palm Tree and fresh fruit bunch



Source: Adapted from (Perez, 1997)

Fig. 6. Palm Oil Empty Fruit Bunch as waste from Palm mill industry

PEFB is a dry brown bunch with non-uniform shape and low bulk density. Its length and width depend on the size of fresh fruit bunch and can vary from 17-30 cm long and 25-35 cm wide.

Fig. 7. Palm Oil Empty Fruit Bunches

Elemental compositions and some properties of PEFB are different by sources of feedstock. Table 5 shows and compares proximate and ultimate analysis of PEFB from Thailand and Malaysia.

		Thailand (air-dried) (Own investigation)	Malaysia (air-dried) (Hamzah, 2008)
Proximate analysis			
Moisture	% wt.	8.34	8.75
Volatile matter	% wt.	73.16	79.65
Fix carbon	% wt.	12.20	8.60
Ash	% wt.	6.30	3.00
Ultimate analysis			
C	% wt.	43.8	48.79
H	% wt.	6.20	7.33
O	% wt.	42.64	40.18
N	% wt.	0.44	0
S	% wt.	0.09	0.68
Others	% wt.	0.53	0.02
Ash	% wt.	6.30	3.00
Lower Heating Value	MJ/kg	19.24	18.96

Table 5. Proximate and ultimate analysis of PEFB from different countries

From Table 5, it can be noticed that there is no significant difference in composition of PEFB by sources. Moisture content is measured to be approximately 8 % wt. based on air dried basis. Volatile matter and fix carbon varied from 73 to 80 % wt. and 8 to 12 % wt., respectively, while ash content in PEFB from Thailand is higher than ash content in PEFB from Malaysia. The chemical composition of PEFB from Thailand calculated by ultimate analysis is $C_{3.6}H_{6.2}O_{1.3}$, whereas the chemical composition of PEFB from Malaysia is $C_{4.1}H_{7.3}O_{1.3}$. The lower heating value of PEFB from sources is almost identical and is around 19 MJ/kg.

2.3 Utilization of PEFB

The utilization of PEFB can be divided into two groups: PEFB utilization for non-energetic purposes and PEFB utilization for energetic purposes.

2.3.1 PEFB utilization for non-energetic purposes

PEFB contains a variety of nutrients, e.g. phosphorus (P), potassium (K), magnesium (Mg), Nitrogen (N), etc. It is reported that the nutrients in PEFB consist of 0.06 % P, 2.4 % K, 0.2 % Mg and 0.54 % N (Heriansyah, n.d.; Prasertsan & Sajjakulnukit, 2006). As a result of this, PEFB is a good source of organic matter. By which PEFB is widely used in Thailand as a substrate for mushroom cultivation and as an organic mulch as well as supplementary fertilizer for oil palm plantation. As a substrate for mushroom cultivation, PEFB is pressed in a rectangular block and mushroom spores are inoculated into PEFB block. Finally the block is covered by plastic sheet to maintain moisture content and limit sunlight. PEFB mulching material on soil surface for oil palm plantation can reduce soil temperature and conserve soil moisture to improve growth and crop yield. The residue from mushroom cultivation or mulching material for oil palm plantation is the composting PEFB which can further be served as organic fertilizer. After a long duration of composting, the nutrients containing in PEFB will substantially increase, e.g. after 32 weeks composting N, P and Mg in PEFB increase from 0.54 %, 0.06 % and 0.19 % to 2.22 %, 0.355 % and 0.67 %, respectively (Heriansyah, n.d.). Another possibility is the utilization of PEFB ash as fertilizer or soil conditioner. However, this method is non-preferable because white smoke caused from high moisture content in PEFB has an aesthetic effect to the environment (Yusoff, S., 2006).

Since the PEFB has a highest fiber yield and its fibers are clean, biodegradable and compatible than other wood fibers, besides using for agricultural purposes, fiber of PEFB can be served as raw material for pulp and paper, fiberboard, mattress, cushion, building material, etc. (Law et al., 2007; Nasrin et al., 2008; Prasertsan & Sajjakulnukit, 2006; Ramli et al., 2002). Anyways, there are some limitations of using PEFB fiber. The fiber must be dried to the moisture content of 15 % and oil content has to be removed from fiber in order to improve the mechanical and physical properties of PEFB fiber.

Although, there are many applications of PEFB fiber, the utilization of PEFB fiber as raw material receives only few interests in Thailand, because there are a lot of agricultural products used for this purpose available and gain the technical knowledge in commercial scale, such as eucalyptus for pulp and paper industry, rubber wood or other wood species for fiberboard and particle board, coconut fiber for mattress.

2.3.2 PEFB utilization for energetic purposes

According to the increase in crude oil price, depletion of crude oil reserves and environmental concerns, especially global warming, many studies focus on the attempt of looking for alternative energy sources to partly replace crude oil. There are many processes for converting biomass to energy, including mechanical process, thermo-chemical process and biological process, as shown in Figure 8.

In mechanical process, as received PEFB is dried, grounded and fed into pelletting/briquetting machine in order to produce pellets/briquettes. These PEFB pellets/briquettes has good properties for using as fuel in conventional stove or co-firing plant compared to as received PEFB. It exhibits high energy content due to the decrease in moisture content, uniform size and superior combustion behavior as well as high mechanical strength (Nasrin et al., 2008). Although there are several pathways of thermo-chemical process, the direct use of PEFB in commercial plants has rarely been found. Currently, thermo-chemical technology for converting PEFB into energy has been studied in laboratory or bench scale. Many studies nowadays focus on the pyrolysis of PEFB for bio-oil production in lab-scale, both fixed bed and fluidized bed reactor and it can be evidenced that the maximum yield of bio-oil produced from pyrolysis of PEFB without catalysts occurs at the temperature of about 500 °C and the lower heating value of bio-oil is approximately 20 MJ/kg (Abdullah & Bridwater, 2006; Abdullah et al., 2007; Azizan et al., 2009; Sukiran et al., 2009; Yang et al., 2006). The utilization of catalyst can promote the pyrolysis reaction and the maximum bio-oil can be obtained at lower temperature of about 300-350 °C with shorter residence time (Amin & Asmadi, 2008). Due to its higher moisture and ash content, lower energy content compared to palm oil shell or some types of biomass feedstock as well as its non-uniform shape (Knoef, 2005), there are a large amount of experimental studies and modeling focusing on combustion, co-firing as well as gasification of PEFB in order to investigate the feasibility of using above mentioned technologies to convert PEFB into energy in term of operating conditions, configuration of reactor, emission and efficiency (Hussain et al., 2006).

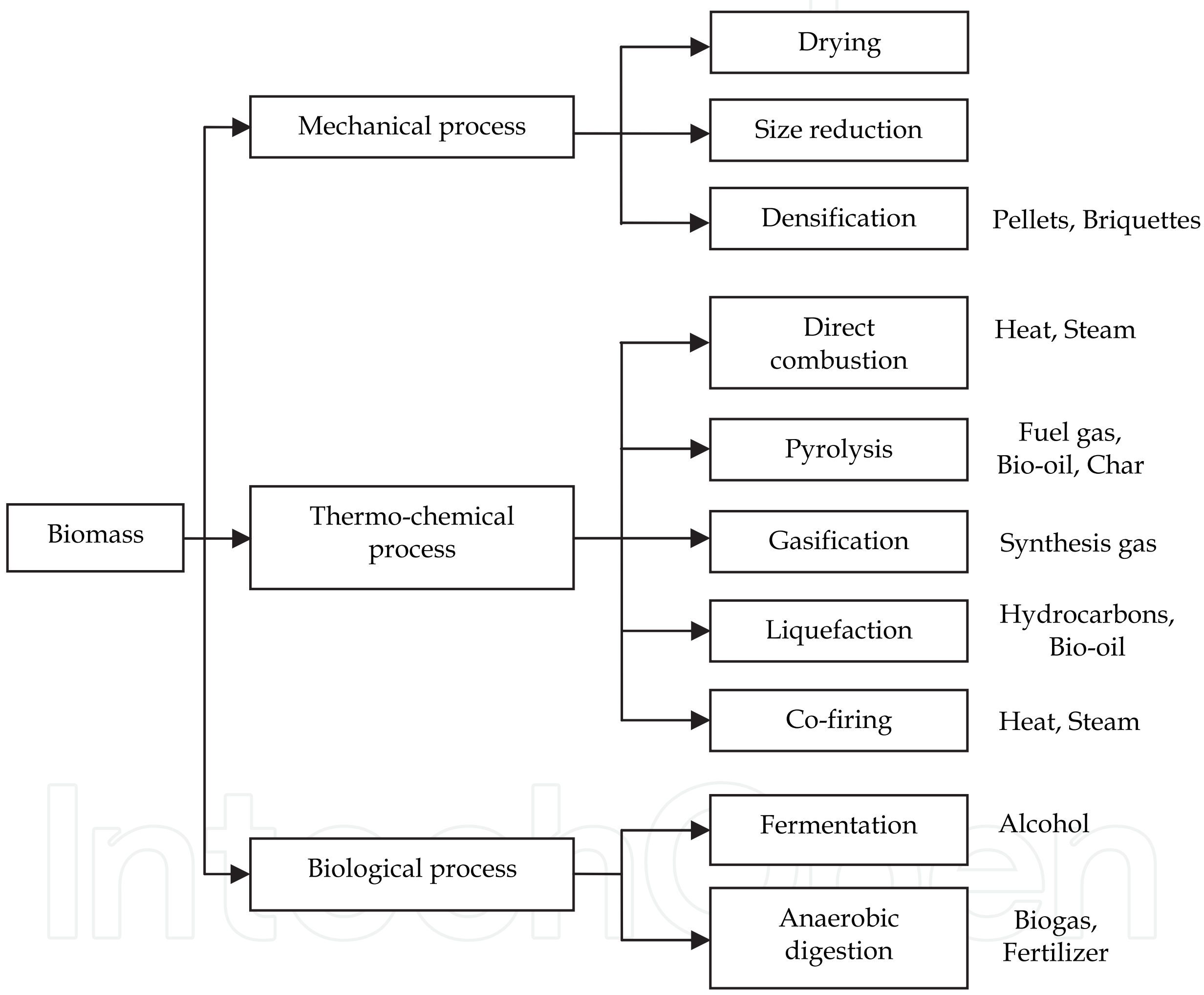


Fig. 8. Pathway for energetic utilization of biomass

3. Experimental study of PEFB gasification in a lab-scale downdraft gasifier

As mentioned in section 1.3, there is a large amount of PEFB leftover at the palm oil mills. Gasification is the prominent technology to recover energy from PEFB for heat and power production. Gasification is a thermo-chemical process to convert solid fuel into combustible gases under the sub-stoichiometric condition. The gasifier can be classified into 3 main types by the moving characteristic of bed material: fixed bed, fluidized bed and entrained flow gasifier. Table 6 shows the operating conditions of each gasifier type.

Parameter	Unit	Fixed bed	Fluidized bed	Entrained flow
Temperature	°C	300-900	700-900	1,200-1,600
Pressure	MPa	0-5	0.1-3	0.1-3
Gasification agent	-	Air/steam-oxygen mixture	Air/steam-oxygen mixture	Oxygen
Reaction time	s	600-6,000	10-100	≤ 0.5
Particle size	mm	1-100	1-10	≤ 0.5

Table 6. Operating condition for each gasifier type (Schaidhauf, 1998).

In this study, a fixed bed downdraft gasifier was chosen as the suitable technology because it has the following advantages (Belgiorno et al., 2003; Knoef, 2005; Laohalidanond, 2008; Obernberger & Thek, 2008):
- Variable fuel size (1-100 mm) and wide range of moisture content in fuel (< 20 %),
- Clean producer gas with the lowest tar content among other types of gasifier,
- Suitability for 1 MW electricity,
- Ease for operation and
- Low investment and operating cost

The experiments about PEFB gasification were carried out in a 10 kg/hr downdraft gasifier in order to identify the behavior of producer gas formation in term of producer gas yield, producer gas composition, heating value of producer gas and cold gas efficiency. Additionally, the temperature profile along the height of gasifier was also investigated.

3.1 Feedstock and feedstock preparation

Feedstock used in this study is PEFB collected from the palm oil mill in Chonburi province which is located in Eastern part of Thailand. After collecting process, PEFB is prepared before being used as feedstock. The important properties of solid fuel for using as feedstock in gasification process are proximate analysis, ultimate analysis, bulk density and heating value as shown in Table 7. The proximate analysis was determined according to ASTM D 5142, the ultimate analysis, e.g. carbon, hydrogen and nitrogen was investigated using ASTM D 5373 and sulfur containing in PEFB was analyzed by ASTM D 4239 (Miller & Tillman, 2008). Because of the complexity in determining oxygen directly, it was determined by difference, i.e. subtracting the total percentage of carbon, hydrogen, nitrogen and sulfur. The heating value was determined by an adiabatic bomb calorimeter as described in ASTM D 5865 (Miller & Tillman, 2008).

	Unit	Value
Proximate analysis		
Moisture (as received after solar drying)	% wt.	8.34
Volatile matter	% wt.	79.82
Fix carbon	% wt.	13.31
Ash	% wt.	6.87
Ultimate analysis		
C	% wt.	43.80
H	% wt.	6.20
O	% wt.	42.65
N	% wt.	0.44
S	% wt.	0.09
Other properties		
Bulk density	kg/m^3	112.04
Lower Heating Value	MJ/kg	19.25

Table 7. Proximate analysis, ultimate analysis and other properties of PEFB (dry basis)

Regarding to the proximate analysis, the volatile matter of PEFB is rather high with the value of 79.82 %. Volatile matter indicates the portion driven off in gas or vapor form which comprises mainly hydrogen, oxygen, carbon monoxide, methane and other hydrocarbons (Miller & Tillman, 2008). The use of fuel with high volatile matter results in the low combustion temperature because some parts of heat is used to vaporize volatile matters in fuel. PEFB contains 8.34 % wt. moisture, 13.31 % wt. fixed carbon and 6.87 % wt. ash. The amount of fixed carbon represents the combustible residue after driving off the volatile matter (Miller & Tillman, 2008) and plays an important role on the amount of CO produced in the reduction zone, which is the main composition of producer gas. From the ultimate analysis, PEFB contains 43.80 % wt. carbon and 6.20 % wt. hydrogen. Both carbon and hydrogen effect the thermo-chemical conversion and then the producer gas composition. PEFB has low sulfur content of about 0.09 % wt. which indicates the tendency of SO_2 and H_2S formation. Other important parameters are bulk density and heating value which affect the gasification behavior and also the quality of producer gas.

In this study both *as received PEFB* and *pelletized PEFB* were used as feedstock. In order to prepare feedstock, as received PEFB was solar dried and cut into small size of 2 cm x 5 cm x 5 cm by cutting machine. In case of using pelletized PEFB as feedstock, pelletizing machine is used for preparing feedstock and the pelletized PEFB has a final diameter of approximately 5.5 cm and a length of 6 cm, as illustrated in Figure 9. The physical properties of pelletized PEFB compared to as received PEFB is listed in Table 8.

(a) (b)

Fig. 9. PEFB before (a) and after (b) pelletizing

Physical properties	Before pelletizing	After pelletizing
Dimension (cm)	Width 2 cm Length 5 cm Height 5 cm	Diameter 5.5 cm Length 6 cm
Density (kg/m^3)	112.04	293.65
Moisture content (%)	8.34	4.9

Table 8. Physical properties of pelletizing PEFB

From Table 8, it can be obviously observed that after pelletizing PEFB is denser and has higher density than as received PEFB because bulk PEFB is pressed and its structural bound attached to each other. This is the advantages of pelletized PEFB because it is cheap to handle, transport and store. Apart from handling and storing behavior, the bulk density is important for the performance of biomass gasification in fixed bed reactor (Knoef, 2005). During the pelletizing process some water containing in PEFB is driven out. These can lead to the decrease in moisture content of PEFB.

3.2 Experimental setup

A 10 kg/hr lab-scale downdraft gasifier which is belonging to the Waste Incineration Research Center (WIRC) and located at Department of Mechanical and Aerospace Engineering, King Mongkut's University of Technology North Bangkok, Thailand is a vertical reactor with fuel feeding system. The reactor is 2,000 mm height and has a diameter of 600 mm. It can be separated into 4 parts as followed: fuel hopper, pyrolysis chamber, reaction chamber and ash chamber, as shown in Figure 10. The temperature in pyrolysis chamber ranges between 200-500 °C, whereas the reaction chamber has the temperature of 500-1200 °C. The temperature in ash chamber is about 300-1000 °C. There are totally 11 type-K thermocouples installed over the height of gasifier: 5 thermocouples in pyrolysis chamber, 4 thermocouples in reaction chamber and 2 thermocouples in ash chamber.

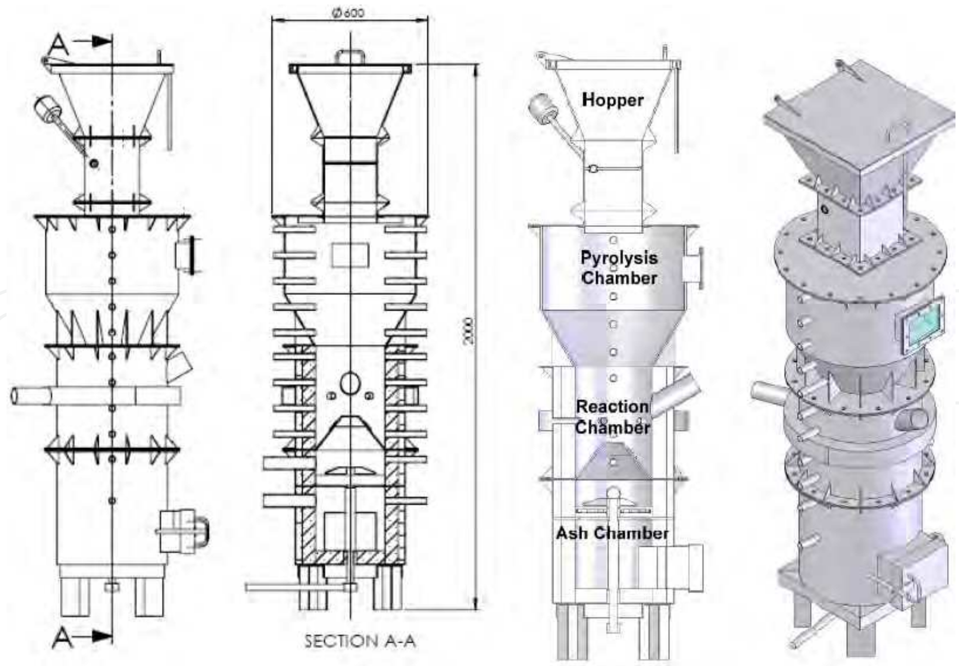


Fig. 10. A 10 kg/hr lab-scale downdraft gasifier

In additional to a downdraft gasifier which is the core component, a lab-scale gasifier system consists of air blower, air pre-heater, gas cleaning unit, weighing apparatus and data logger. Figure 11 shows the process diagram of a lab-scale gasifier system.

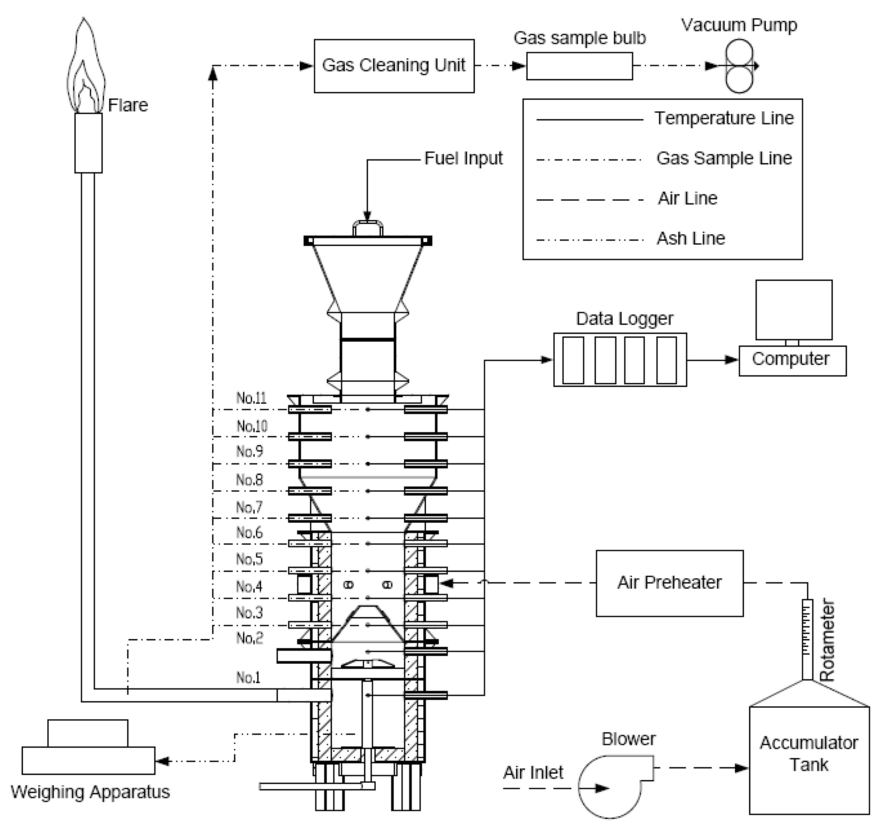


Fig. 11. Process diagram of a lab-scale downdraft gasifier system

3.3 Experiment procedure

In case of as-received PEFB, 2 to 3 kg of PEFB was fed into a 10 kg/hr downdraft gasifier per batch. After feedstock feeding, the lid at the top of gasifier was closed and the feedstock inside the gasifier was ignited by a burner. When feedstock started to be ignited, the gasification air was introduced into gasifier and the gasification process was taken place. When the first batch of feedstock was almost completely gasified, 2-3 kg of feedstock was then introduced again into the gasifier. This step was repeated until the total amount of approximately 25 kg PEFB was fed into gasifier in the whole period of time. In case of pelletized PEFB, 25 kg of it was fed into hopper in one time. During the gasification process, the temperatures inside the gasifier at each position were continuously recorded. If the gasification temperature reached the constant value, the volume flow rate of producer gas were measured. A little amount of producer gas was taken out as gas sample in order to further be investigated, while the remaining producer gas was flared at the stack outlet. The gasification process terminated, when the fuel was completely burnt and the reactor was naturally cooled down. The ash remaining in the reactor was then taken from the reactor and measured the weight in order to determine the percentage of ash production. The air flow rates of 6, 9, 12, 15 and 18 Nm^3/hr for as-received PEFB gasification and the air flow rate of 15, 18, 21, 27 and 33 Nm^3/hr for pelletized PEFB gasification were varied for each experiment.

After each experiment, producer gas composition, in which only H_2, CO, CO_2, CH_4, N_2 and O_2 were taken into account, was investigated by gas chromatography according to ASTM. Lower heating value of producer gas was also calculated according to Equation 1 and cold gas efficiency was determined by Equation 2.

$$LHV_G = \Sigma v_i \cdot LHV_i \tag{1}$$

$$\eta = \frac{LHV_G \times \dot{V}_G}{LHV_F \times \dot{m}_F} \tag{2}$$

LHV is the lower heating value. The subscript G, i and F refers to the producer gas, each combustible gas component and PEFB, respectively. V_i is the fraction of each combustible gas component in producer gas by volume. $\dot{V}_G$ and $\dot{m}_F$ are producer gas yield by volume and PEFB consumption rate by mass, respectively.

3.4 Results and discussions

3.4.1 Producer gas composition and its lower heating value

The composition of producer gas obtained from air gasification of both as received PEFB and pelletized PEFB is shown in Figure 12 and Figure 13, respectively.

From Figure 12, it can be seen that the concentration of CO increases with increasing air flow rate and its increasing rate is slow down at the higher air flow rate. The concentration of CO_2 decreases until the air flow rate of 9 Nm^3/hr and further increases with the air flow rate. H_2-concentration is very fluctuated and cannot predict its tendency from Figure 12, whereas there is no significant change in the concentration of CH_4 for all air flow rates.

Compared Figure 13 to Figure 12, it can be noticed that the concentration of each gas composition is not fluctuated. The tendency of each gas can be predicted from Figure 13. Due to the high density of pelletized PEFB, the fuel is more homogenous and the fuel flow is more stable. Consequently, the reactions between air and fuel during gasification process are more stable and can reach their equilibriums. In case of pelletized PEFB (Figure 13), the concentration of CO and H_2 increases with increasing air flow rate. The increasing rate is more rapid at the air flow rate until 21 Nm^3/hr and for further increase in air flow rate from 21 Nm^3/hr, the concentration of both gases increases slowly or almost remains constant. In contrast to H_2 and CO, the concentration of CO_2 decreases with the air flow rate until its minimum point at the air flow rate of 21 Nm^3/hr. With further increase in air flow rate, CO_2-concentration increases. The concentration of CH_4 in case of pelletized PEFB is almost constant.

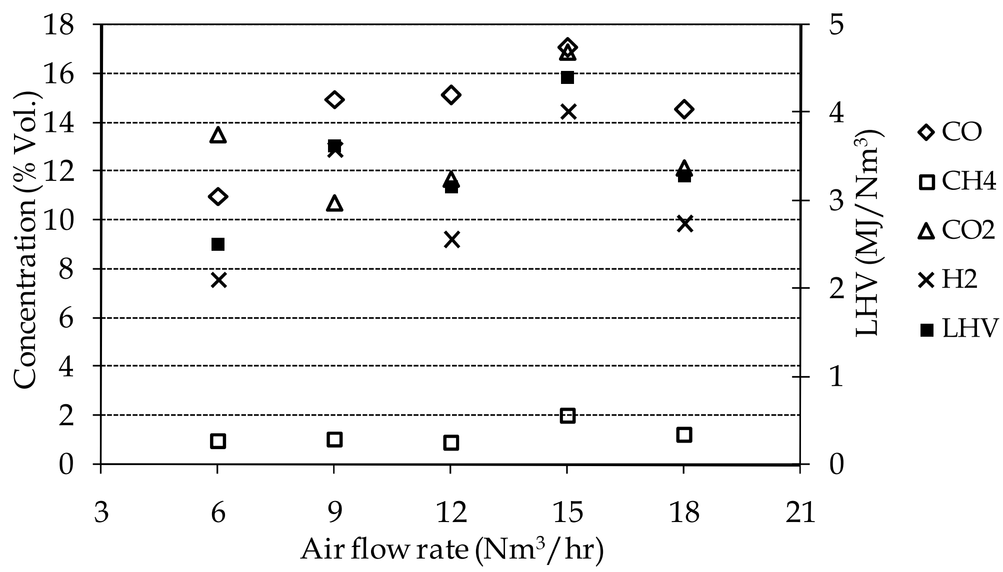


Fig. 12. Producer gas composition with different air flow rates for as-received PEFB

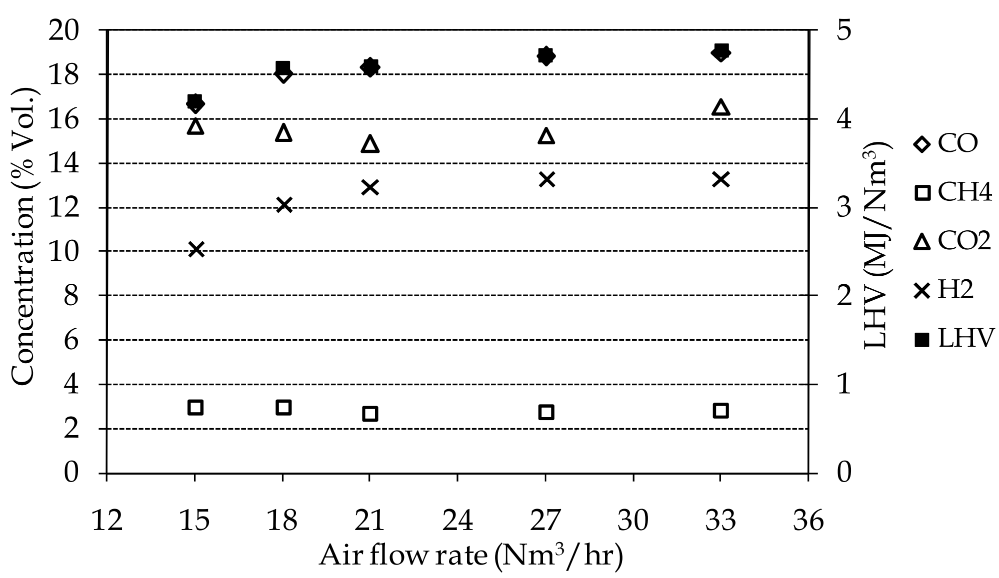


Fig. 13. Producer gas composition with different air flow rates for pelletized PEFB

Considered the reactions occurred in a downdraft gasifier, PEFB is firstly dried and the moisture containing in PEFB is driven off as steam. During pyrolysis process, PEFB is thermally decomposed into gaseous products, tars and chars, as written in Equation 3. Tar which is heavy hydrocarbon compound is also thermally cracked into light hydrocarbons and other gases, as written in Equation 4 (Rui et al., 2007).

$$\text{PEFB} \rightarrow \text{gas} + \text{tar} + \text{char} \quad (3)$$

$$\text{Tars} \rightarrow \text{light and heavy hydrocarbons} + CO + CO_2 + H_2 \quad (4)$$

Gases and the remaining PEFB pass through the oxidation zone where oxidation process occurs. In this zone, combustible gas and combustible material are oxidized to be steam and CO_2 by oxygen containing in gasification air. Equation 5 to Equation 7 shows the examples of oxidation process (Kaltschmitt & Hartmann, 2001; Schmitz, 2001). As the air flow rate increases, the oxidation process is accelerated by increasing amount of O_2 in gasification air and results in the higher reaction temperature (exothermic reactions).

$$H_2 + \frac{1}{2}O_2 \leftrightarrow H_2O \quad \Delta H = -241.8 \text{ kJ/mol} \quad (5)$$

$$CO + \frac{1}{2}O_2 \leftrightarrow CO_2 \quad \Delta H = -283.0 \text{ kJ/mol} \quad (6)$$

$$C_mH_n + \left(m + \frac{n}{2}\right)O_2 \leftrightarrow mCO_2 + \frac{n}{2}H_2O \quad (7)$$

With further increase in air flow rate, the reactions almost approach their equilibriums. therefore the concentration of each gas composition remains constant. The products of oxidation process react further with other gases and un-reacted fuel in reduction zone. The increase or decrease in composition of producer gas is resulted from reactions in this zone. The increase in CO and H_2 from the experiments is resulted from endothermal Boudouard reaction (Equation 8) and endothermal heterogeneous water gas shift reaction (Equation 9) (Kaltschmitt & Hartmann, 2001; Laohalidanond, 2008; Schmitz, 2001).

$$C + CO_2 \leftrightarrow 2CO \quad \Delta H = 159.9 \text{ kJ/mol} \quad (8)$$

$$C + H_2O \leftrightarrow CO + H_2 \quad \Delta H = 118.5 \text{ kJ/mol} \quad (9)$$

With increasing air flow rate, the gasification temperature raises as a result of exothermal oxidation. The endothermal Boudouard reaction and endothermal heterogeneous water gas shift reaction are then shifted to the right hand side, consequently, CO and H_2 in producer gas increase. The above mentioned reactions take also the responsibility for the decrease in CO_2 concentration in producer gas.

With respect to the heating value of producer gas, the lower heating value of producer gas yields from as received PEFB is fluctuated and the tendency cannot be predicted because of the non-equilibrium reactions. Taken the results from gasification process of pelletized PEFB into account, it can be remarkably seen that the heating value of producer gas varies with the air flow rate. At the air flow rate of 15 Nm^3/hr, the producer gas has the lower heating value of 4.20±0.31 MJ/Nm³ and the lower heating value increases to 4.77±0.29 MJ/Nm³ at the air flow rate of 33 Nm³/hr. The increase in the lower heating value is resulted from the increase in combustible gases, e.g. H_2 and CO with increasing air flow rate.

From the experiments with both as received PEFB and pelletized PEFB, it can be concluded that using pelletized PEFB can provide more stable gasification process than using as-received PEFB and the relevant reactions can approach their equilibriums; hence, pelletized PEFB is more proper to be used as fuel in gasification process than as-received PEFB. Since the producer gas will further be used as fuel in a combustion engine generator for electricity production, the heating value of producer is the major parameter to be concerned. The maximum heating value of 4.77±0.29 MJ/Nm³ is achieved from gasification of pelletized PEFB at the air flow rate of 33 Nm³/hr.

3.4.2 Overall results

This section shows the overall results of experiments with pelletized PEFB at different air flow rates in term of producer gas yield, feedstock consumption rate and cold gas efficiency. Table 9 presents the overall results for pelletized PEFB at different air flow rates.

Air flow rate (Nm³/hr)	Producer gas yield (Nm³/hr)	Fuel consumption rate (kg/hr)	Lower heating value (MJ/Nm³)	Cold gas efficiency (%)
15	24.50	10.74	4.20±0.31	49.71
18	28.70	12.24	4.58±0.29	55.76
21	34.80	15.65	4.60±0.26	53.15
27	41.24	21.64	4.73±0.55	46.80
33	48.89	26.66	4.77±0.29	45.42

Table 9. Overall results for pelletized PEFB at different air flow rates

From Table 9, although the maximum heating value of 4.77±0.29 MJ/Nm³ is taken place at the air flow rate of 33 Nm³/hr, the maximum cold gas efficiency of 55.76 % occurs at the air flow rate of 18 Nm³/hr. In additional to heating value, the ratio of producer gas yield to fuel consumption plays an important role on cold gas efficiency, as clearly seen from Equation 2. At the air flow rate of 33 Nm³/hr, 1 kg of pelletized PEFB can produce 1.83 Nm³ of producer gas, whereas 1 kg of pelletized PEFB can produce 2.34 Nm³/hr of producer gas at the air flow rate of 18 Nm³/hr which is the condition that the maximum producer gas can be yielded from 1 kg of feedstock.

3.4.3 Temperature distribution

To identify the temperature distribution in each reaction zone, the gasification process of pelletized PEFB is only investigated and the result is shown in Figure 14.

The reaction zone for the experiments with different air flow rates is almost identical. Drying zone for moisture removal taking place at the top of gasifier (a height of 70-80 cm) has the temperature of less than 200 °C for all air flow rates. Next reaction zone is pyrolysis zone, 50-70 cm high, which has the pyrolysis temperature of 200-600 °C for all air flow rates. At the height of 30-50 cm, where air is introduced into gasifier, the combustion process occurs and the combustion temperature is 600-1000 °C. At the bottom of a downdraft gasifier (10-30 cm), where the reduction process is taken place, the temperature in the reduction zone is considerable reduced to 400-800 °C.

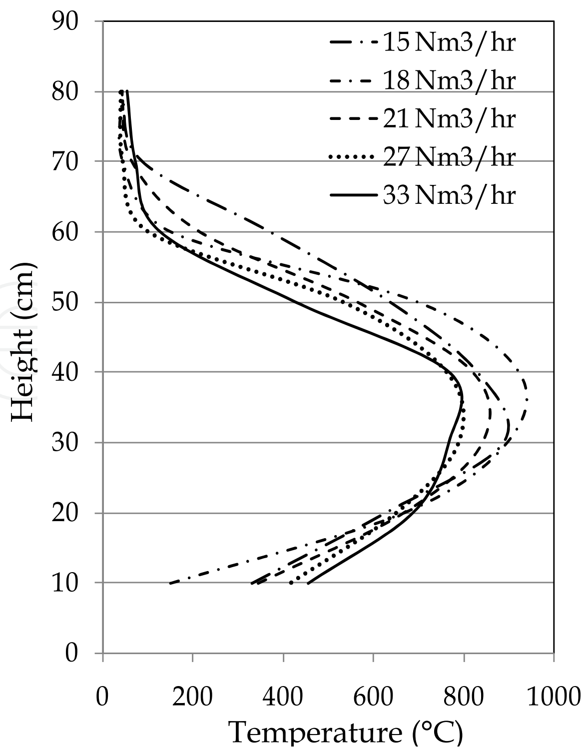


Fig. 14. Temperature distribution along the height of gasifier at different air flow rates

3.5 Conclusion

From the experiments in a laboratory scale downdraft gasifier, it can be implied that both as received and pelletized PEFB has a potential to be used as fuel for producer gas production. However, pelletized PEFB is more suitable than as received PEFB because their reactions in gasification process are more stable and can approach equilibrium. The producer gas obtained from gasification of pelletized PEFB at the air flow rate of 33 Nm^3/hr which is the most suitable operating condition consists of 19.02 % wt. CO, 13.32 % wt. H_2, 2.78 % wt. CH_4 and 16.58 % wt. CO_2. It heating value of 4.77 MJ/Nm^3 can be achieved with the cold gas efficiency of 45.42 %. The reaction temperature has been classified on 4 different zones; less than 200 °C for drying zone, 200-600 °C for pyrolysis zone, 600-1000 °C for oxidation zone and 400-800 °C for reduction zone.

4. Experimental study of PEFB gasification in a protoype-scale downdraft gasifier

After it is proven that pelleitzed PEFB has a high potential to be used as fuel for producer gas production via gasification process in the previous section, this section aims to conduct the feasibility of using pelletized PEFB as fuel for power generation via gasification process.

4.1 Feedstock and feedstock preparation

Feedstock used for the experiments in a prototype scale gasifier is pelletized PEFB which was prepared by the same method as described in section 3.1. The proximate and ultimate analyses of feedstock as well as other physical properties have already been shown in Table 7 and Table 8, respectively.

4.2 Experimental Setup

A 50 kg/hr prototype downdraft gasification plant is also belonging to WIRC and located in Saha Pathana Industrial Park in Kabin Buri, Prachinburi province, Thailand. This plant consists mainly of 5 parts, as in the following: fuel preparation system, downdraft gasifier, heat exchanger, gas cleaning unit and internal combustion engine-generator, as shown in Figure 15.

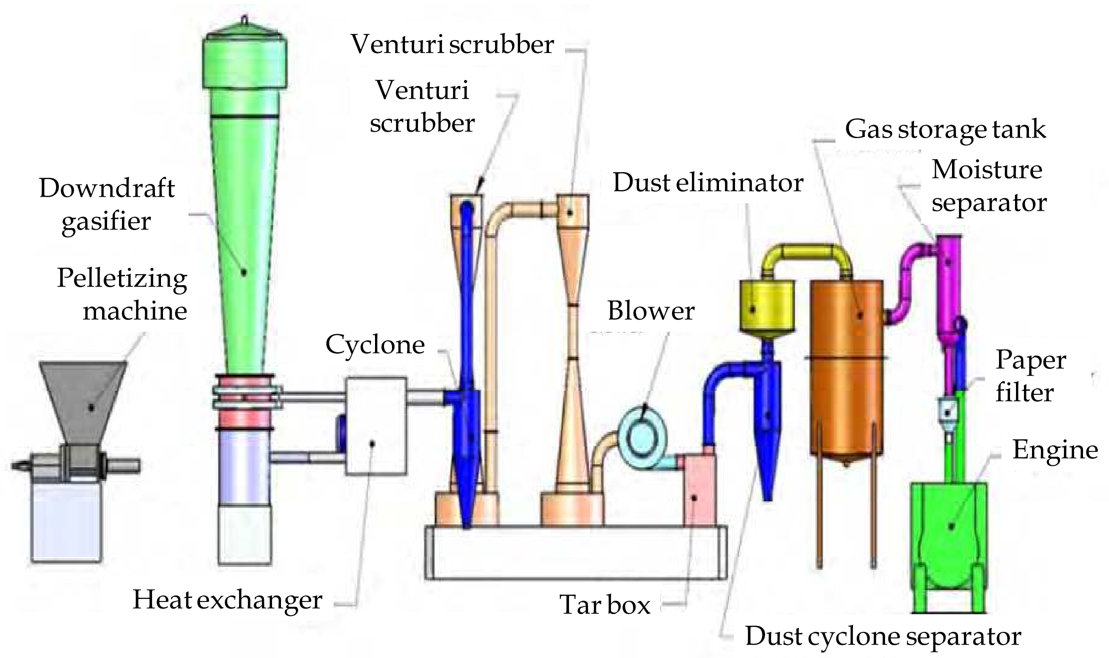


Fig. 15. A 50 kg/hr prototype downdraft gasification plant

The downdraft gasifier can be divided into fuel hopper, reaction zone and ash discharging zone and has a capacity to load fuel about 50 kg/hr for 7 hours operation continuously. Shell and tube heat exchanger is applied in order to preheat the air which is served as gasification agent. Gas cleaning system consists of cyclone, venturi scrubber, and dust removal unit. The internal combustion engine-generator for power generation is a 4-strokes diesel engine with 4- cylinders and can produce 50 kW electricity, 380/400 V and 50/60 Hz, as illustrated in Figure 16.

Fig. 16. Internal combustion engine-generator for power generation

4.3 Experiment procedure

The experiment prodecure is as same as described in Section 3.3 of this chapter but only pelletized PEFB was used as feedstock. The air flow rate for the experiments in a prototype downdraft gasifier was varied from 90 to 120 Nm^3/hr with an interval of 10 Nm^3/hr. Distinguish from Section 3.3 was that the producer gas obtained from a prototype downdraft gasifier at the most suitable condition was further used as fuel in the internal combustion engine-generator. The electrical load, in this case: electrical heater, varied from 18 to 36 kW with the step of 6 kW. The consumption of both diesel and producer gas was recorded and the rate of diesel replaced by producer gas in percent can be calculated by Equation 10. Finally, the overall efficiency for power production from pelletizing PEFB is calculated by Equation 11.

$$R = \frac{\left(\dot{m}_{d,o} - \dot{m}_{d,d}\right)}{\dot{m}_{d,o}} \tag{10}$$

$$\eta_T = \eta_E \cdot \eta_G \tag{11}$$

Where R is the rate of diesel replaced by producer gas, $\dot{m}_{d,o}$ is the mass flow rate of diesel consumption in case of using diesel as single fuel and $\dot{m}_{d,d}$ is the mass flow rate of diesel consumption in case of using dual fuel. η_T, η_E and η_G represent the overall efficiency, engine efficiency and cold gas efficiency, respectively.

4.4 Results and discussions

4.4.1 Producer gas composition and its lower heating value

The composition and heating value of producer gas obtained from air gasification of pelletized PEFB in a protoype downdraft gasifier are shown in Figure 17.

From Figure 17, the concentration of H_2, CO and CH_4 increases with increasing air flow rate until the air flow rate of approximately 100-105 Nm^3/hr and decreases with higher air flow rate. At the air flow rate of 100 Nm^3/hr, the highest concentration of CO and CH_4 can be obtained, consequently, the maximum heating value of 6.99 MJ/Nm^3 also occurs.

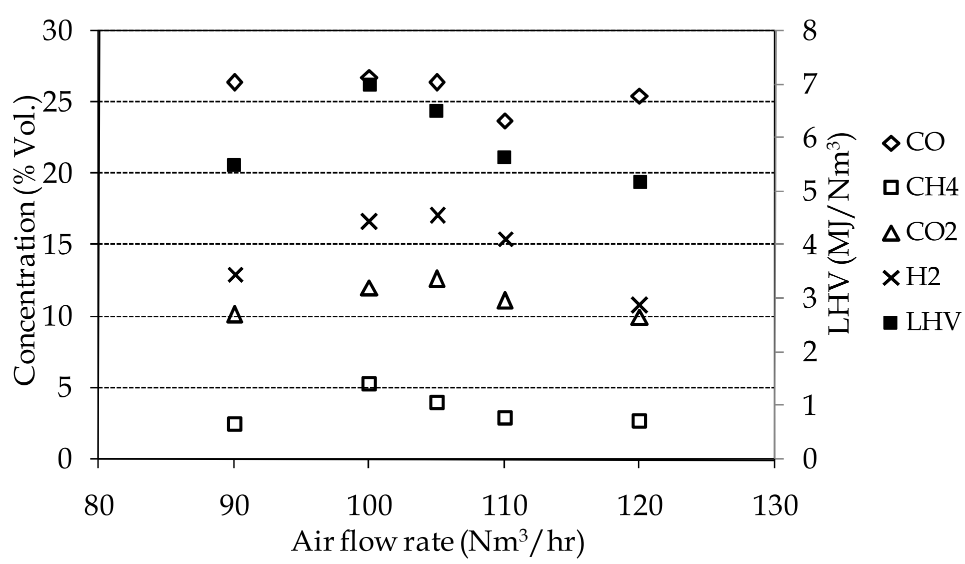


Fig. 17. Producer gas composition with different air flow rates for pelletized PEFB in prototype gasifier

4.4.2 Overall results

Table 10 shows the overall results for pelletized PEFB at different air flow rates, in term of producer gas yield, fuel consumption rate and cold gas efficiency.

Air flow rate (Nm^3/hr)	Producer gas yield (Nm^3/hr)	Fuel consumption rate (kg/hr)	Lower heating value (MJ/Nm^3)	Cold gas efficiency (%)
90	111.40	45.08	5.49±0.10	70.47
100	129.44	61.57	6.99±0.29	76.34
105	176.73	74.82	6.50±0.15	79.73
110	182.19	80.58	5.64±0.23	66.21
120	191.76	88.09	5.18±0.40	58.55

Table 10. Overall results for pelletized PEFB at different air flow rates in prototype gasifer

From Table 10, the maximum heating value of 6.99±0.29 MJ/Nm^3 is observed at the air flow rate of 100 Nm^3/hr which correspondances to the cold gas efficiency of 76.34 %. From the observation during the experiments, although at the air flow rate of 100 or 105 Nm^3/hr the heating value of producer gas and the cold gas efficiency reach the maximum value, the producer gas was unstable and non-continuously formed. Instead, at the air flow rate of 110 Nm^3/hr, the producer gas was continuously and uniformly generated. Therefore, for testing of using producer gas as fuel in the internal combustion engine-generator, the air flow rate of 110 Nm^3/hr is selected as optimum operating condition.

4.4.3 Testing of producer gas in an internal combustion engine-generator

Table 11 shows the results of testing of producer gas in the internal combustion engine-generator with the electrical loads of 18, 24, 30 and 36 kW. At the beginning, only diesel fuel was used as fuel in order to examine the diesel consumption rate. Later, the experiments of using dual fuel, in this case: diesel fuel and producer gas, were carried out.

Load (kW)	Diesel fuel	Dual fuel			
	Diesel consumption (kg/hr)	Producer gas consumption (Nm^3/hr)	Diesel consumption (kg/hr)	Diesel replacing rate (%-wt.)	Engine efficiency (%)
18	5.41	37.63	2.49	53.97	20.01
24	6.44	53.60	1.05	83.69	24.72
30	7.78	53.60	2.19	71.85	26.96
36	9.12	39.91	4.32	52.63	30.95

Table 11. Results for testing of producer gas in the internal combustion engine-generator

It can be noticed that the producer gas consumption increases with increasing electrical load until the electrical load of 30 kW and for the higher electrical load, the producer gas consumption decreases. It means the producer gas can replace diesel fuel successfully if the electrical load is increased but at the higher electrical load, the producer gas cannot further replace diesel fuel due to the low heating value of producer gas which is not sufficient to sustain the higher load. The maximum diesel replacing rate of 83.69 % is taken place at the electrical load of 24 kW, by which the engine efficiency is accounted to be 24.72 %. At this point, the overall efficiency for power generation from pelletizing PEFB via gasification process is calculated to be 16.36 %.

4.5 Conclusion

From the experiments in a prototype downdraft gasifier, it can be concluded that the producer gas obtained from pelletized PEFB can be used as a substitute fuel to conventional diesel fuel. The optimum air flow rate for gasification process is 110 Nm^3/hr, by which the producer gas was continuously and uniformly generated. The producer gas contains 23.74 % wt. CO, 15.48 % wt. H_2, 2.97 % wt. CH_4 and 10.01 % wt. CO_2. The heating value is 5.64±0.23 MJ/Nm^3 and the cold gas efficiency is 66.21 %. After using this producer gas in an internal combustion engine-generator, it can be found that the diesel fuel consumption can be reduced by more than 80 % at the electrical load of about half-load (24 kW) and the overall efficiency of 16.36 % can be achieved at this load.

5. General conclusion

As Thailand is an agricultural base country, there are a lot of agricultural residues left over. These residues can be used as alternative fuel to replace the conventional fuel which needs to be imported from foreign countries. PEFB is one of the most available agricultural residues generated from palm oil industry. From this study, it can be found that PEFB, especially pelletized PEFB, has a very high potential to be used as alternative fuel for power production via gasification process. The producer gas obtained from a laboratory scale downdraft gasifier at the air flow rate of 33 Nm^3/hr consists of 19.02 % wt. CO, 13.32 % wt. H_2, 2.78 % wt. CH_4 and 16.58 % wt. CO_2. Its heating value of 4.77 MJ/Nm^3 can be achieved with the cold gas efficiency of 45.42 %. The reaction temperature has been classified on 4 different zones; less than 200 °C for drying zone, 200-600 °C for pyrolysis zone, 600-1000 °C for oxidation zone and 400-800 °C for reduction zone. The producer gas obtained from a prototype scale downdraft gasifier posses a very high heating value varied from 5.18-6.99 MJ/Nm^3 depending on the air flow rate. At the optimum air flow rate of 110 Nm^3/hr, the producer gas contains 23.74 % wt. CO, 15.48 % wt. H_2, 2.97 % wt. CH_4 and 10.01 % wt. CO_2. The heating value is 5.64 MJ/Nm^3 which can effectively replace the diesel consumption in the internal combustion engine-generator. The diesel replacement rate of more than 80 % can be obtained at the electrical load of 24 kW and the overall efficiency is 16.36 %. From this study, it can be concluded that PEFB can be used as alternative fuel for heat or electricity production, for eco-friendly and sustainable development in Thailand.

6. Acknowledgements

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7. References

Abdullah, N.; Bridgwater, A.V. (2006), Pyrolysis Liquid Derived from Oil Palm Empty Fruit Bunches, *Journal of Physical Science*, Vol.17, No.2, pp. 117-129, ISSN 1992-1950

Abdullah, N.; Gerhauser, H.; Bridgwater, A.V. (2007), Bio-oil from Fast Pyrolysis of Oil Palm Empty Fruit Bunches, *Journal of Physical Science*, Vol.18, No.1, pp. 57-74, ISSN 1992-1950

Amin, N.A.S.; Asmadi, M. (2008), Optimization of Empty Palm Fruit Bunch Pyrolysis over HZSM-5 Catalyst for Production of Bio-oil, In: Universiti Tecknologi Malaysia, 5 March 2011, Available from: http://eprints.utm.my/5125

Azizan, M.T.; Yusup, S.; Laziz, F.D.M.; Ahmad, M.M. (2009), Production of Bio-oil from Oil Palm's Empty Fruit Bunch via Pyrolysis, *Proceedings of the 3rd WSEAS International Conference on Renewable Energy Sources*, ISBN 978-960-474-093-2, Spain, July 2009

Belgiorno, V.; De Feo, G.; Della Rocca C.; Napoli, R.M.A. (2003), Energy from Gasification of Solid Wastes, Waste Management, Vol.23, No.1, (January, 2003), pp. 1-15, ISSN 0956-053x

BP (2010), BP Statistical Review of World Energy June 2010, Available from: www.bp.com

Bull S.R. (2001), Renewable Energy Today and Tomorrow, *Proceedings of the IEEE*, Vol.89, No.8, (August 2001), pp. 1216-1226, ISSN 0018-9219

Department of Provincial administration (2010), Population Statistic of Thailand, In: *Department of Provincial administration*, May 2011, Available from: www.dopa.go.th

Energy Policy and Planning Office (2010), Energy Statistic of Thailand 2010, In: Energy Policy and Planning Office, 25 January 2011, Available from: www.eppo.go.th/ info/cd-2010/index.html

Hamzah, M.M.B. (2008), The production of ecofiber from palm oil empty fruit bunch, In: *Universiti Malaysia Pahang*, 5 February 2011, Available from: http://umpir.ump. edu.my/521

Heriansyah (n.d.), Optimizing the use of oil palm by-product (EFB) as fertilizer supplement for oil palm, In: *BW Plantation*, 2 September 2010, available from: http://www.bw plantation.com/document/Optimizing%20The%20Use%20of%20Empty%20Fruit% 20Bunch%20(EFB).pdf

Hussain, A.; Ani, F.N.; Darus, A.N.; Mokhtar, H.; Azam, S.; Mustafa, A. (2006), Thermo-chemical Behaviour of Empty Fruit Bunches and Oil Palm Shell Waste in a Circulating Fluidized-Bed Combustor (CFBC), *Journal of Oil Palm Research*, Vol.18, No. 1, (June 2006), pp. 210-218, ISSN 1511-2780

Kaltschmitt, M. ; Hartmann, H. (2001), *Energie aus Biomasse – Grunglagen, Techniken und Verfahren*, VDI-Verlag, ISBN 978-354-064-8536, Germany

Katamanee, A. (2006), Appropriate technology evaluation for oil palm product utilization in Krabi province, In: *Mahidol University*, 1 February 2011, Available from: www.li.mahidol.ac.th/thesis/2549/cd388/4637145.pdf

Knoef, H.A.M. (2005), Practical aspects of biomass gasification, In: *Handbook of biomass gasification*, BTG biomass technology group BV, pp. , Druckerij Giehoorn ten Brink, ISBN 978-908-100-6811, Natherlands

Laohalidanond, K. (2008), *Theoretische Untersuchungen und thermodynamische Modellierungen der Biomassevergasung und der Fischer-Tropsch-Synthese zur Herstellung von Diesel kohlenwasserstoffen aus thailaendischen Biomassen*, Shaker Verlag, ISBN 978-383-227-8250, Germany

Law, K.N.; Daud, W.R.W.; Ghazali, A. (2007), Morphological and Chemical Nature of Fibre Strands of Oil Palm Empty Fruit Bunch (OPEFB), *Bioresources*, Vol.2, No.3, pp. 351-362, ISSN 1930-2126

Mahlia, T.M.I.; Abdulmuin, M.Z.; Alamsyah, T.M.I.; Mukhlishien, D. (2001), An alternative energy source from palm waste industry for Malaysia and Indonesia, *Energy Conversion and Management*, Vol.42, No.18, (December 2001), pp. 2109-2118, ISSN 0196-8904

Miller, B.G. ; Tillman, D.A. (2008), Coal Characteristics, In: *Combustion engineering issues for solid fuel systems*, Miller, B.G. ; Tillman, D.A., Elsevier, pp. 33-82, ISBN978-012-373-6116, United State of America

Nasrin, A.B.; Ma, A.N.; Choo, Y.M.; Mohamad, S.; Rohaya, M.H.; Azali, A.; Zainal, Z. (2008), Oil Plam Biomass As Potential Substitution Raw Materials For Commercial Biomass Briquettes Production, *American Journal of Applied Science*, Vol.5, No.3, pp. 179-183, ISSN 1554-3641

Obernberger, I.; Thek G. (2008), Combustion and gasification of solid biomass for heat and power production in Europe state-of-the-art and relevant future development, *Proceedings of the 8th European Conference on Industrial Furnaces and Boilers*, ISBN 978-972-993-0935, Portugal, April, 2008

Office of Agricultural Economic (2010), In: *Agricultural Statistical Data*, 20 December 2010, Available from: www.oae.go.th

Office of the National Economic and Social Development Board (2009), National income of Thailand 2009 edition, In: *Office of the National Economic and Social Development Board*, 29 June 2011, Available from: www.nesdb.go.th

Owen A.D. (2006), Renewable energy: Externality costs as market barriers, *Energy Policy*, Vol.34, No., (), pp. 632–642, ISSN 0301-4215

Papong, S.; Yuvaniyama, C.; Lohsomboon, P.; Malakul, P. (2004), Overview of Biomass Utilization in Thailand, *ASEAN Biomass Meeting*, Bangkok, 2004

Perez, R. (1997), Feeding pigs in the tropics, In: *Food and Agriculture Organization of the United Nations Rome*, 1 February 2011, Available from: www.fao.org/docrep/003/w3647e/W3647E00.htm

Prasad, B.V.R.K.; Kuester, J.L. (1998), Process analysis of a dual fluidized bed biomass gasification system. *Journal of Industrail & Engineering Chemistry Research*, Vol.27, No.2, (February 1988), pp. 304-310, ISSN 0888-5885

Prasertsan, S.; Sajjakulnukit, B. (2006), Biomass and biogas energy in Thailand: Potential, opportunity and barriers, *Renewable Energy*, Vol.31, No.5, (April 2006), pp. 599-610, ISSN 0960-1481

Ramli, R.; Shaler, S.; Jamaludin, M.A. (2002), Properties of medium density fibreboard from oil palm empty fruit bunch fibre, *Journal of Oil Palm Research*, Vol.14, No. 2, (December 2002), pp. 34-40, ISSN 1511-2780

Renewable Energy Policy Network for the 21st Century (2009), Renewables Global Status Report 2009 update, In: *Renewable Energy Policy Network for the 21st Century, 13 December 2010*, Available from: http://www.ren21.net/pdf/RE_GSR_2009_update.pdf

Rui, X.; Baosheng, J.; Hongcang, Z.; Zhaoping, Z.; Mingyao, Z. (2007), Air gasification of polypropylene plastic waste in fluidized bed gasifier, *Energy Conversion and Management*, Vol.48, No.3, (March 2007), pp. 778-786, ISSN 0196- 8904

Sawangphol, N.; Pharino, C. (2011). Status and outlook for Thailand's low carbon electricity development, *Renewable and Sustainable Energy Reviews*, Vol.15, No.1, (January 2011), pp. 564-573, ISSN 1364-0321

Schmitz, W. (2001), *Konversion biogener Brennstoffe fuer die Nutzung in Gastubinen*, VDI-Verlag, ISBN 978-318-345-9063, Germany

Shuit, S.H.; Tan, K.T.; Lee, K.T.; Kamaruddin, A.H. (2009), Oil Palm Biomass as a sustainable energy source: A Malaysian Case Study, *Energy*, Vol.34, No.9, (September 2009), pp. 1225-1235, ISSN 0360-5442

Sukiran, M.A.; Chin, C.M.; Baker, N.K.A. (2009), Bio-oil from Pyrolysis of Oil Palm Empty Fruit Bunches, *American Journal of Applied Science*, Vol.6, No.5, pp. 869-875, ISSN 1546-9239

U.S. Energy Information Administration, 2006. World Carbon Dioxide Emissions from the Consumption and Flaring of Fossil Fuels 1980-2006, In: *International Energy Annual 2006*, 30 April 2011, Available from: www.eia.gov/iea/carbon.html

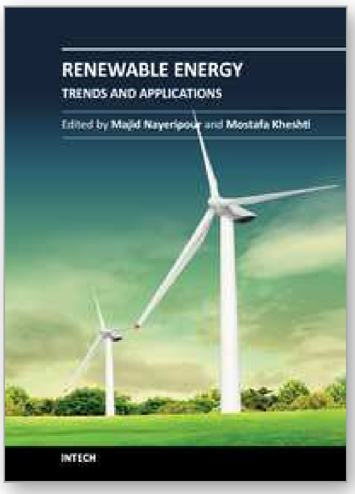
U.S. Energy Information Administration, 2010. Energy-related carbon dioxide emission, In: *International Energy Outlook 2009*, 30 April 2011, Available from : www.eia.doe.gov/oiaf/ieo/emissions.html

Wainwiwat, S.; Asafu-Adjaye, J. (2011). Modelling the promotion of biomass use: A case study of Thailand, *Energy*, Vol.36, No.3, (March 2011), pp. 1735-1748, ISSN 0360-5442

Yang, H.; Yan, R.; Chen, H.; Lee, D.H.; Liang, D.T.; Zheng, C. (2006), Mechanism of Palm Oil Waste Pyrolysis in a Packed Bed, *Energy & Fuels*, Vol.20, No.3, (April 2006), pp. 1321-1328, ISSN 0887-0624

Yangdee, B. (n.d.), Ten million rai of oil palm plantation: A catastrophe for the Thai people, In: *World rainforest movement*, 1 February 2011, Available from: www.wrm.org.uy/countries/Thailand/Catastrophe.pdf

Yusoff, S. (2006), Renewable energy from palm oil innovation on effective utilization of waste, *Journal of Cleaner Production*, Vol. 14, No.1, pp. 87-93, ISSN 0959-6526



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Increase in electricity demand and environmental issues resulted in fast development of energy production from renewable resources. In the long term, application of RES can guarantee the ecologically sustainable energy supply. This book indicates recent trends and developments of renewable energy resources that organized in 11 chapters. It can be a source of information and basis for discussion for readers with different backgrounds.