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Assessment of the Performance and Potential Export Renewable Energy (RE) From Typical Cogeneration Plants Used in Palm Oil Mills

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Abstract: Cogeneration or combined heat and power is one of the proven economically approaches to produce >1 useful of energy simultaneously from the single energy source. Malaysia is fortunate to have plentiful supplies of biomass mainly from milling sector of the oil palm industry. Due to that biomass based cogeneration plant is used in palm oil mills in Malaysia to generate steam and electricity. In this study, the assessment of cogeneration plant efficiency was conducted in six palm oil mills with processing capacities ranged from 20-54 ton h^{-1}. In addition to determining boiler, turbine and overall cogeneration plant efficiencies, the study also focused on developing the baseline data of energy utilization and generation in palm oil mills and estimated the potential excess energy from the available palm biomass generated in palm oil mills. It was found that most of the boilers and turbines used in palm oil mills have moderate efficiencies which were <80 and 35%, respectively, compared to conventional operational unit used in fossil based power plants. Besides that, most of the mills used excessive specific energy to generate steam and electricity compared to the optimum industrial designed data. In terms of the potential excess electricity, it was found that the potential excess electricity that could be generated for export ranged from 113 kW for the 20 ton h^{-1} mill to 900 kW for the 54 ton h^{-1} mills. The details of technical findings and potential economic benefits are discussed in this report. As the project is in line with the Government's programme in promoting renewable energy and energy efficiency, millers should take this opportunity to operate the cogeneration plant in an energy efficient manner, earn additional income besides managing the waste in an environmental friendly approach.

Key words: Cogeneration, biomass, renewable energy, palm oil mill, turbines, Malaysia

INTRODUCTION

Energy supply and environmental issues are among the major concerns of the world today. Utilization of the renewable energy resources is a measure to counter and overcome these problems. Malaysia is blessed with enormous amounts of biomass, mainly generated from the palm oil industry. As the world 2nd largest palm oil producer after Indonesia, Malaysia produced 17.56 and 2.01 million ton of crude palm oil and palm kernel oil, respectively in 2010 (MPOB, 2010). The industry also produced a vast abundantly amount of biomass mainly from the palm oil mills in forms of Empty Fruit Bunch (EFB), mesocarp fibre, shell and Palm Oil Mill Effluent (POME). All these resources have long been identified and utilized as sustainable Renewable Energy (RE) fuels in the country. The types and amount of these palm biomass generated in year, 2010 are shown in Table 1. Palm oil mills deploy a cogeneration approach to cater for steam and electricity demands for milling process.

Table 1: Palm biomass generated in year, 2010

Biomass	Quantity (million ton)	Moisture content (%*)	Calorific value (kJ kg^{-1}*)	Main uses
Fibre	10.8	37.0	19068	Fuel
Shell	4.8	12.0	20108	Fuel
Empty fruit bunches	19.11	67.0	18838	Mulch/fuel
POME (biogas)	54.00 (1512 million m^3)		20000 kJ m^{-3}	Mulch/fuel

*(Vijaya *et al*., 2004)

Cogeneration is a process of producing two forms of energy simultaneously using one source of fuel (Kanoglu and Dincer, 2009). The cogeneration plant (Fig. 1) employed by palm oil mills consists mainly of steam boilers, turbines, generators and back pressure receivers (Shuit *et al*., 2009).

Utilization of oil palm biomass in cogeneration plant is also known as a direct combustion of thermo-chemical process where biomass is directly burnt in the presence of air to convert chemical energy stored in biomass into heat (Goyal *et al*., 2008). In palm oil mills, the palm biomass mainly a mixture of mesocarp fibre and shell is burnt in the

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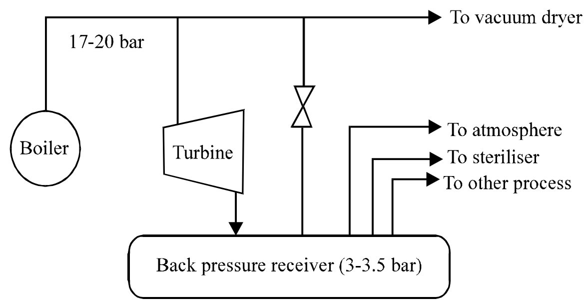

Fig. 1: The typical cogeneration system in a palm oil mill

Table 2: Estimated steam and electricity consumptions in palm oil mills

Process/operation unit	Steam consumption (kg ton^{-1} FFB)
Sterilization	250-300
Digester	70-100
Depricarper	100-175
Kernel dryer	25
Clarification	150
Total steam	600-650
Electricity	15-20 kW h ton^{-1}

boiler furnace and the heat is transferred to the water to produce pressurized saturated or superheated steam. The typical final steam produced is saturated steam with pressure and temperature <21 bar and 210°C, respectively. The high pressure steam from the boiler enters the back pressure turbine at 250-300 psig or 17-20 bar and expands through the turbine blades for the mechanical works.

The low pressure steam that leaves the steam turbine at 3 bar will be stored in the backpressure receiver or vessel (PTM, 2000). The accumulated steam will be discharged to the atmosphere when its pressure is >3.5 barg. The steam will be used for the palm oil milling process such as sterilization, kernel drying, digestion and clarification of CPO. The typical industrial data for steam and electricity consumption in palm oil mills is shown in Table 2. In 2010, based on 85.09 million ton of Fresh Fruit Bunch (FFB) processed at 20 kW h ton^{-1} FFB, the off-grid electricity generated from 418 mills nationwide was about 1702 GW h. At average monthly processing hours of 400 h month^{-1}, this amounted to 356 MW of total off grid generating capacity.

The power that is produced is normally more than sufficient to be used in the palm oil mill. Therefore, the cogeneration system is also used by the millers for biomass disposal in palm oil mills. Most of the mills are in a position to generate more power and supply electricity to nearby staff quarters and residential areas. Besides abundant palm biomass, the mills install >1 boiler, steam turbine with capacities varying from 400-2000 kW. The existing energy generation capacity would enable the mills to produce and export the electricity. This can be done by supplying the excess energy to the internal distribution line or selling it via Small Renewable Energy Power Programme (SREP).

SREP which was launched in 11th May, 2001 is one of the government's programmes to accelerate the development of Renewable Energy (RE) project (Shuit *et al.*, 2009). In the 8th Malaysian plan, RE was identified as the 5th fuel in the new Five Fuel strategy in the country's energy supply mix. The target was that RE will contribute 5% of the country's electricity demand by the year, 2010 or approximately equivalent to 350 MW (Badriyah, 2010). The target is expected to increase to 985 MW by the year, 2015.

With the SREP implementation, the RE developers which utilize RE sources such as biomass, solar and landfill can sell their electricity to Tenaga Nasional Berhad (TNB) through the national grid with the maximum power export limited to be not >10 MW each. As of June, 2010 the total RE capacity connected to the national grid was only 56 MW which mainly from biomass, biogas, mini hydro and solar photovoltaic (Badriyah, 2010). This study examined the present status on the cogeneration performance operated in palm oil mills and estimated the potential export energy that could be supplied to the national grid from available palm biomass in the mills without modifying or upgrading the present co-generation system.

MATERIALS AND METHODS

Monitoring and data collection of cogeneration plant performance was carried out at six palm oil mills. Formulas, definitions and nomenclature for the calculations involved were shown in Table 3 and 4. Data obtained from the assessment of the cogeneration plants was used to develop a baseline data of energy generation and utilization in palm oil mills. The definition of the specific energy requirement in palm oil mills is shown in Table 5. The thermodynamic properties of water and formula were also based from Fundamental of classical thermodynamics 4th edition, 2000. Data obtained from the baseline data was used as reference to estimate the potential excess energy available in the palm oil mill to be supplied to the national distribution grid. The following assumptions were used in the calculations:

- Calorific values for EFB, shell and fibre are 18960, 20093 and 18795 (dry basis)
- EFB, shell and fibre ratio to FFB processed are 23, 6 and 13%
- Ratio of shell separation using LTDS (dry separation) and wet technique is 2-4, respectively

Table 3: Summary of formulas and definition for cogeneration plant efficiency

Terms	Definition	Formula
Boiler efficiency	Ratio of energy in steam to the energy supplied from the burning of palm biomass	Percentage = $m_s (h_2 - h_1)/m_f$ CV
Turbine efficiency	Ratio of actual to isentropic enthalphy drop in the turbine	Percentage = $(h_2 - h_3)/(h_2 - h_{s3})$
Thermal efficiency	Ratio of actual steam goes to the process to energy input	Percentage = $m_s (h_3 - 603)/m_f$ CV
Electrical efficiency	Ratio of electrical output to the energy input to the boiler	Percentage = P (3600)/m_f CV
Cogeneration efficiency	The sum of electrical and thermal efficiencies	Percentage = Elec. % +Thermal

Table 4: Nomenclature

Symbols	Definition
m_s	Steam flowrate (kg h^{-1})
h_1	Enthalpy of feedwater (kJ kg^{-1}) (saturated)
h_2	Enthalpy of steam (kJ kg^{-1}) (saturated or superheated)
m_f	Fuel flowrate (kg h^{-1})
CV	Calorific value (kJ kg^{-1})
h_3	Enthalpy of steam at outlet pressure of turbine (kJ kg^{-1})
h_{s3}	Isentropic sp. enthalpy of steam at outlet pressure of turbine (kJ kg^{-1})
P	Electrical output (kW)
603 kJ kg^{-1}	Enthalphy of discharge/leave back pressure receiver at 4 bar

Table 5: Definition of the specific energy used in palm oil mills

Definition	Unit
Specific energy used to generate 1 kg of steam	kJ kg^{-1} of steam
Specific steam used to generate 1 kw h	kg kw h^{-1}
Specific steam used to process 1 ton of FFB	kg ton^{-1} of FFB
Specific power used to process 1 ton of FFB	kW ton^{-1} of FFB

RESULTS AND DISCUSSION

Technical specifications of cogeneration plants used in six palm oil mills were shown Table 6 which shows that cogeneration plants in these palm oil mills are over-designed where the installing capacities are more than requirement. The generating capacities of the cogeneration plants were vary from 32-62% or on average 40% from the total installed capacities. Besides for back-up security and future expansion of the mills, all these surplus installed capacity may be used to generate excess energy for grid connection provided there is sufficient supply of palm biomass as fuel.

Assessment on the calorific value and fuel used: The amount of palm biomass used as fuels were technically assumed, sampled and re-calculated at 70-100% of its utilization rate. Ratio of fibre and shell used was found in average of 70:30. Some mills reduced the usage of shell due to a good market demand to be used as fuel in other industrial sectors. The use of treated EFB as fuels could substitute or reduce shell content in the boiler mixed fuels as being practiced by the Mill B. Table 7 and 8 show the summary of the palm biomass generated and used in those palm oil mills.

Assessment of POM cogeneration plants: Table 9 shows the summary of the boiler efficiency for the palm oil mills. Except for the Mill A, all palm oil mills use water-tube boilers. Mill A uses combi-boiler which is known as high efficient boiler. The efficiencies which were calculated based on the direct method show that most of the boilers have low efficiencies compared to those working on the fossil fuels. Besides the poor characteristics of palm biomass fuel, the low efficiencies were also contributed by excessive use of fuel for the disposal purpose. Densification of oil palm biomass can improve the biomass fuel quality and makes the combustion in boilers more efficient.

Turbine efficiency: The steam turbines normally used in palm oil mills are one or two stage impulse turbine. The ranges of inlet and outlet pressures of the steam turbine are 18-20 and 2.9-3.2 bar. The average efficiency was 24.8 which lower than condensing conventional turbines used in power plants. The low turbine efficiency is mainly due to high exhaust steam pressure of 3 bar as compared to fully condensing turbine which was <0.25 bar. The 3 bar steam still has a great deal of energy. Besides that the low efficiency also contributed by the dryness fraction of the steam which was <0.9 indicated by the wet steam in turbine (Husain *et al*., 2003). The presence of water or wet steam in the main steam line also decrease in the overall cogeneration system efficiency. Improving dryness of steam can be done by producing superheated steam (Bhatt, 2000). Mill A and B have high turbine efficiencies as the mill utilized superheated steam for cogeneration system operation. The efficiencies of the back pressure steam turbines used in palm oil mills are shown in Table 10.

Electrical, thermal and cogeneration plant efficiencies in palm oil mills: From the assessment of the system used in palm oil mills, the cogeneration plant efficiencies ranged from 57-70%. Thermal efficiencies were lower than boiler efficiencies as it calculated total usage of steam generated from boiler to turbines and processes as well as steam discharge to the atmosphere. In the case of boiler efficiencies, the values only reflects thermal efficiency of boiler to the turbine. Except for Mill A, electrical efficiencies for most of the mills were between 2.84-3.25%. Table 11 shows the efficiency of cogeneration plant in the palm oil mills.

Development of database of mill energy generation and utilization: Database was developed based on the

Table 6: Technical specifications and operating data of POM cogeneration plants

Mill	Average processing capacity (ton h^{-1}) (designed capacity)	Boiler: Working pressure, barg (designed)	Boiler: Steam flow rate (steaming capacity) and temperature (°C)	Boiler: Steam condition	Steam turbine: No. of unit	Steam turbine: Total caacity (kW)	Steam turbine: Current running (kW)	Steam turbine: Inlet pressure (barg)	Steam turbine: Outlet pressure (barg)
A	20 (20)	20 (23)	14 (20) 217	Superheated	2×750	1500	550	19.5	2.9
B	30 (30)	30 (35)	18 (35) 250	Superheated	1×1000	1000	623	29.0	3.2
C	40 (45)	20 (20)	22 (30) 212	Saturated	1×1000				
					1×900	1900	660	19.0	3.0
D	40 (40)	19 (20)	21 (30) 210	Saturated	1×1200				
					1×600	1800	580	19.0	2.9
E	50 (54)	19 (20)	31.5 (45) 212	Saturated	2×600				
					1×1800	2400	840	18.2	3.1
F	54 (54)	18.9 (20)	33.4 (45) 212	Saturated	3×650	1950	900	18.0	3.2

Table 7: Production palm biomass in palm oil mills

Mill	FFB processing capacity (ton h^{-1})	Fibre (ton h^{-1})	Shell (ton h^{-1})	EFB (ton h^{-1})
A	20	2.60	1.20	4.60
B	30	3.90	1.80	6.90
C	40	5.20	2.40	9.20
D	40	5.20	2.40	9.20
E	50	6.50	3.00	11.50
F	54	7.02	3.24	12.42

Table 8: Utilization of palm biomass, fuel ratio and calorific value of fuel in palm oil mills

Mill	FFB processing capacity (ton h^{-1})	Utilization % (ton h^{-1}): Fibre	Shell	EFB	Total (ton h^{-1})	Ratio (F:S:EFB)	**CV (kJ kg^{-1})
A	20	90 (2.34)	80 (0.96)	-	3.30	71:29:0	13535.00
B	30	80 (3.12)	10 (0.18)	60 (3.04)	6.34	49:3:48	10882.00
C	40	75 (3.90)	70 (1.68)	-	5.58	70:30:0	13594.00
D	40	73 (3.77)	68 (1.62)	-	5.39	70:30:0	13594.00
E	50	85 (5.25)	60 (2.1)	-	7.35	71:29:0	13535.00
F	54	80 (5.62)	60 (2.27)	-	7.89	71:29:0	13535.00

CV (kJ kg^{-1}) for Fibre:11841 @ 37% Moisture Content (MC); Shell: 17682 @ 12% MC and EFB: 9480 @ 50% MC

Table 9: Efficiency of the boiler

Mill	Processing capacity (ton h^{-1})	Working pressure, barg (designed)	Steam flow rate (steaming capacity) and temperature (°C)	Steam condition	Feed water enthalpy (h_f, kJ kg^{-1})	Steam enthalpy (h_1, kJ kg^{-1})	Fuel consumption (ton h^{-1})	Calorific value (kJ kg^{-1})	Efficiency (%)
A	20	20 (23)	14 (20) 217	Superheated	125.7	2806	3.30	13535	84.00
B	30	30 (35)	18 (35) 250	Superheated	125.7	2856	6.34	10882	71.20
C	40	20 (20)	22 (30) 212	Saturated	125.7	2798	5.58	13594	77.50
D	40	19 (20)	21 (30) 210	Saturated	125.7	2797	5.39	13594	76.60
E	50	19 (20)	31.5 (45) 212	Saturated	431.0	2798	7.35	13535	74.90
F	54	18.9 (20)	33.4 (45) 212	Saturated	431.0	2798	7.89	13535	74.10

Table 10: Efficiency of back pressure turbine

Mill	Inlet pressure (barg)	Outlet pressure (barg)	Inlet enthalpy (h_1, kJ kg^{-1})	Outlet enthalpy (h_2, kJ kg^{-1})	Isentropic enthalpy (h_{2s}, kJ kg^{-1})	Steam quality (x)	Efficiency (%)
A	19.5	2.9	2815	2723	2463	0.88	25.8
B	29.0	3.2	2861	2728	2469	0.88	33.9
C	19.0	3.0	2797	2723	2461	0.88	22.1
D	19.0	2.9	2797	2723	2461	0.88	22.1
E	18.2	3.1	2796	2726	2489	0.89	22.8
F	18.0	3.2	2795	2727	2490	0.89	22.0

Table 11: Cogeneration plant efficiencies in palm oil mills

Mill	Efficiency (%): Thermal	Electrical	Cogeneration
A	66.4	4.43	70.80
B	53.9	3.25	57.15
C	61.5	3.13	64.63
D	60.8	2.84	63.64
D	67.2	3.03	70.23
E	66.4	3.03	69.43

efficiencies calculated of mill's cogeneration plant. The database is important as a reference for further expansion of the mill capacity or tool to determine potential export energy from the palm oil mills.

Data obtained from the field shows higher rate compared to the published or industrial design data. Although, it is not comprehensive due to several factors basically on inconsistency of individual cogeneration

Table 12: Palm oil mills-energy generation and utilization

MILL (ton h^{-1})	Specific energy consumption (kJ kg^{-1} steam)	Specific steam consumption (kg kW h^{-1})	Specific fuel consumption (kg kW h^{-1})	Electricity consumption (kW ton^{-1} FFB)	Steam consumption (kg ton^{-1} FFB)
A (20)	3190	25.50	6.00	27.50	700
B (30)	3832	28.89	10.17	20.76	600
C (40)	3448	33.33	8.45	16.50	550
D (40)	3489	36.20	9.23	14.50	525
E (50)	3158	37.70	8.75	16.80	630
F (54)	3197	35.00	8.76	16.70	619
Average	3385	32.77	8.56	18.79	604
Industrial standard*	2600-2700	27-30	N.A	Max. 20	Max. 650

Arrieta *et al.* (2007) and Fonade (1976)

Table 13: Amount of palm biomass and energy from palm oil mills

Mill	Fibre (ton h^{-1})	Shell (ton h^{-1})	EFB (ton h^{-1})	Energy fibre (kJ h^{-1})	Energy shell (kJ h^{-1})	Energy EFB (kJ h^{-1})	Total energy (kJ h^{-1})
A	2.60	1.20	4.60	30786600	21218400	43608000	95613000
B	3.90	1.80	6.90	46179900	31827600	65412000	143419500
C	5.20	2.40	9.20	61573200	42436800	87216000	191226000
D	5.20	2.40	9.20	61573200	42436800	87216000	191226000
E	6.50	3.00	11.50	76966500	53046000	109020000	239032500
F	7.02	3.24	12.42	83123820	57289680	117741600	258155100

Table 14: Potential export energy from palm oil mills based on the developed energy database

Mill	Total potential steam (kg h^{-1})	Total potential electricity capacity (kW)	Mill consumption, capacity (kW)	Parasite and EFB treatment plant usage (kW)	Total potential electricity (kW)	Profit RM/h @ RM 0.21 kW h^{-1}	Profit RM/year @ 4800 h $year^{-1}$
A	28246.09	863.7947	400	350	113.7947	23.90	114,705.0
B	42369.13	1295.6920	600	350	345.6920	72.60	348,457.5
C	56492.17	1727.5890	800	350	577.5893	121.30	582,210.1
D	56492.17	1727.5890	800	350	577.5893	121.30	582,210.1
E	70615.21	2159.4870	1000	350	809.4867	170.00	815,962.6
F	76264.43	2332.2460	1080	350	902.2456	189.50	909,463.6

plant efficiencies and calorific values, it is considered as technically feasible baseline data developed from actual monitoring of information from the sites. All data were scientifically reasonable except for the steam and electricity required to process 1 ton FFB for mill A which was obviously higher. This was due to of the installation and operational of the pilot plants and latest operation units in Mill A.

Theoretically when FFB processed increased, specific energy required of mills reduces. Therefore, the bigger the mill capacity, the less energy is required per tonne FFB. However due to the installation of the extra operational units in the mills such as EFB treatment plants and tertiary plant of POME, these may increase the specific energy required. The data will be used to determine potential excess energy available from the mills. Table 12 shows the summary of the developed database.

Potential of power export from palm oil mills: Generating more power in palm oil mills than the normal requirement of milling process can be done through the following options:

- Using all palm biomass available in palm oil mill as boiler fuels including treated EFB, provided that the mill's existing cogeneration plant has reserve margin capacity to deal with all the palm biomass
- Tapping biogas from palm oil mill effluent for power generation
- Replacing existing backpressure turbine with extraction condensing turbine

These options are considered as technically feasible approaches without jeopardizing the present milling activity as well as steam and electricity generated from the mills. The study discuss the above options in increasing the potential of export electricity from palm oil mills by utilizing all the oil palm biomass available in palm oil mills using the typical cogeneration plant. Energy database which was developed from this assessment was used to determine the potential excess energy using the typical cogeneration plant used in palm oil mills. Potential of export energy by maximizing the palm biomass usage in palm oil mills is shown Table 13 and 14.

From the study, it was found that by using a current cogeneration system which is low in efficiency, more than sufficient energy is generated for mill utilization as well for grid connection. However, this subject to the sufficient (reserve margin) capability and capacity of the mill's existing cogeneration plant to handle the full load of palm biomass. This potential energy would be much higher if the utilization of biogas as well as the extraction condensing turbine are considered in the palm oil mills. The assumptions used in analysing this option are tabulated as:

- Percentage of fibre, shell and EFB (65% MC) to FFB are 13, 6 and 22.5%, respectively
- Calorific values (kJ kg^{-1}) for fibre, shell and EFB are 11841, 17682 and 9480 (wet basis)
- Specific energy required to produce 1 kg of steam is 3021 kJ (data based on the 6 sites)
- Specific steam required to generate 1 kW of electricity is 32.77 kg (database)
- Specific electricity required to process 1 ton of FFB is 20 kW h
- Auxiliary power, power for EFB treatment plant and parasite energy is 350 kW h

If all the palm biomass is utilized in palm oil mills, the total additional electricity generated from 20-54 ton h^{-1} of FFB processing capacity mill are 113 and 900 kW. The present price of electricity sold to the National's utility company, Tenaga Nasional Berhad is RM 0.21 kW h^{-1} and this can generate RM 23.90 h^{-1} for the 20 ton h^{-1} mill or RM 114,705 $year^{-1}$ with the average annual processing hours of 4800.

The millers are expected to gain more with the recent announcement of feed-in Tariff by the government which is expected to come into effect by year, 2011 (Badriyah, 2010).

CONCLUSION

Palm biomass based cogeneration plants used in palm oil mills are capable to produce more than sufficient steam and electricity for the milling process. By utilizing all the oil palm biomass generated from the milling process, the existing cogeneration plants could generate and sell surplus energy in the form of electricity to the national grid. This effort will enable palm oil mills to become small power producers by participating in SREP. This potential energy would be much higher if the utilization of biogas and installation of the extraction condensing turbine to replace present back pressure turbine is considered in the palm oil mills. Though, cogeneration plant used in palm oil mills have low efficiency compared to conventional power plant, the improvement in terms of its design, efficiency and the technology may increase the energy generated.

RECOMMENDATIONS

Besides that surplus biomass generated from the efficient plants should be commercially exploited to make the palm oil industry more sustainable. With the support of government policy and programmes, millers may grab the opportunity to generate additional income by managing their energy in a profitable manner. The approach also helps the country to reduce the GHG emissions to the environment and could gain additional income through carbon trading (CDM). The utilization of palm based RE enhances the green image of the oil palm industry beside meeting the national target in diversifying energy sources in the country.

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