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EXHAUST STEAM FOR BIOMASS DRYING - POTENTIAL EFFICIENCY ENHANCEMENT OF PALM OIL MILL COGENERATION PLANT

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ABSTRACT

Most of the local palm oil mill cogeneration plants in Malaysia were built 20 years ago. Since the boilers were designed for the purpose to burn the biomass residue, the efficiencies of these plants are low. With the current emphasis by the government to exploit the use of biomass for renewable energy, the plant owners realised that their plants could benefits if the plants efficiencies are enhanced through biomass drying using the exhaust steam. By drying of biomass residue the thermal energy that could be generated by the plants could be increased and thus increasing of available power which could be sold to the grid. This study assessed this potential. The data of existing cogeneration was used to evaluate the additional energy that could be generated by dried biomass, which is dried using the exhaust steam from the steam turbine. Based on the mill capacity of 20 ton/hr, 30 ton/hr and 45 ton/hr respectively, it was estimated thermal energy that could be made available to dry the biomass are 3.46 ton/h, 2.96 ton/hr, 4. 44 ton/hr. respectively.

Keywords: cogeneration, biomass, palm oil mill.

INTRODUCTION

Palm oil mill cogeneration plant is fueled by biomass residue from processing the palm oil fruit. The residues from palm oil mill such as palm fiber, palm shell, empty fruit bunch (EFB), palm kernel cake and palm oil mill effluent can be converted into fuel for boiler combustion. The heat and power that was produced by the palm oil mill cogeneration plant is more than sufficient to meet the entire processing demand [1]. As such, most palm oil mill cogeneration plants intentionally had been designed to serve the purpose of to burn all the residue which was the cheapest way to dispose the residue [2]. According to the survey done by Shaharin *et al*. [3] and the study done by Sulaiman *et al.* [4], the boiler efficiencies that had been installed in palm oil mill cogeneration plants were having efficiencies as low as 60% and 70% respectively. With the push for higher productivity, the low efficiencies need to be addressed.

In order to align to industrial productivity and government regulation on environmental policy, the cogeneration plantsneed to enhance efficiencies. This is also in line with the government policy in adopting energy sustainability as reported by Haslenda Hashim *et al*. [5].

Minimization of fuel consumption and efficient production are important factors in minimising the available resources and reduce the impact to the environment. For instance, the government has enforced the Renewal Energy Act 2011 and the Sustainable Energy Development Authority 2011 to promote and encourage the industry to participate in renewal energy program. Parallel to that, Feed in Tariff, has been introduced on 1st December 2011. This is to guarantee the purchase of electricity with fixed price within a certain period of time. These programs provide opportunity for the palm oil mill to be an independence power producer and potential to generate additional revenue.

For the case of local palm oil mill cogeneration plants, the study by Z. Hussain *et al*. [6] noted that low boiler efficiencies, with the average efficiency of about 73%, was mainly due to in homogeneity of fuel, improper fuel mix, incomplete combustion and high moisture content. Tesfaldet *et al*. [7] also reported that high moisture content in biomass residue resulted in decreased combustion efficiency and caused other operational issues. Hence it is crucial to reduce moisture content to optimum level as low as 10-15% wt% as quoted by Ross *et al*. [8]. This study is assessing the option of reducing the moisture content through drying using the energy to be recovered from the exhaust steam of steam turbine (ST).

METHODOLOGY

The standard palm oil mill cogeneration plant is designed to consume only palm fiber and shell or the mixture between two [9, 10]. Since it is also known that the EFB has the potential to be used as fuel to the boilers, studies are ongoing to explore this potential.

In this study, the total energy available from wet and dried biomass was assessed. For the of existing cogeneration plant, the fuel saving from using dried EFB was analyzed. The analysis included analysis of low heating value (LHV) of dried palm fiber and shell, and evaluation of available energy which could be used for drying of biomass.

Lower heating value (LHV) of dried fiber and shells

Dulong's equation [11], as per equation (1), was used to calculate the LHV for dried palm fiber and shell. The equation does not account the effect of moisture content. For biomass with moisture content, equation (2) was used for evaluating LHV.

$$LHV = \left[2.31\left(14093C + 61095\left(H - \frac{O}{8}\right)\right)\right] \tag{1}$$

$$\mathrm{LHV_{wet}} = \mathrm{LHV_{dry}}(1-\mathrm{X}) - \left[\left(\mathrm{T_{evp}} - \mathrm{T_{ref}}\right)\mathrm{CP_w} + \mathrm{LHV_w}\right]\mathrm{X} \tag{2}$$

where;

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X $= fraction\ of\ moisture\ content$
T_{evp} $= 100°C$
T_{ref} $= 25°C$
CP_w $= 2.08\ kJ/kg°C$
LHV_w $= 2255.252\ kJ/kg$

The fuel from the case study mill were collected and tested in the laboratory to determine the physical and chemical composition. The results were compared with results from [11, 12] using ASTM method. The physical and chemical composition for EFB as shown in Table-1 were based on the results obtained from [13].

Table-1. Physical and chemical composition of palm fibre, shell and EFB.

Element	Palm fibre			Shell			EFB	
	Case study %	Literature %		Case study %	Literature, %		Case study %	Lit., %
		[11]	[12]		[11]	[12]		[13]
Moisture	35	40	39.5	12.1	10	10.9	55	67
Carbon	45.2	47.2	45.1	46.8	52.4	55.4	NA	43.8
Hydrogen	1.27	6	9.14	3.63	6.3	5.08	NA	6.2
Oxygen	30.82	36.7	43.8	35.0	37.3	49.4	NA	42.6

Estimated available energy

Total energy that can be generated by the palm oil mill cogeneration plant depends on the biomass that are available and the calorific value of the biomass. In addition, the biomass fraction and mixture of each biomass need to be known. For the case of the understudy plant, the published data from other study were used to calculate the mass fraction and moisture content.

In order to estimate the potential power that could be generated from available biomass, the efficiencies of the boiler and steam turbine (ST) were based on the actual performance of the boiler and ST of the case study plant. The published data from literature were used for validation as shown in Table-2. The efficiencies of the boiler and ST selected were 72% and 64% respectively.

Table-2. Boiler and turbine efficiencies.

Parameter	Case study	Literature			
		[4]	**[6]**	**[14]**	**[15]**
Boiler Efficiency, %	72	70	73	80	NA
ST Efficiency, %	64	NA	68.5	NA	NA
ST Steam Rate, kg/kWh	22.5	NA	28.2	NA	27-30

Equation (3) was used to calculate the total steam that could be produced [6].

$$m_s = \frac{(\eta_b m_f LCV)}{(h_1 - h_f)} \quad (3)$$

where;
η_b $= boiler\ efficiency, \%$
m_f $= fuel\ rate, kgs^{-1}$
h_1 $= enthalpy\ at\ steam\ produced, kJkg^{-1}$
h_f $= enthalpy\ at\ feed\ water, kJkg^{-1}$

Equation (4) was used to calculate the total electrical power that could be generated [6].

$$P = \eta_t m_s (h_1 - h_2) \quad (4)$$

where;
η_t $= turbine\ efficiency, \%$
m_s $= steam\ flow\ rate, kgs^{-1}$
h_1 $= enthalpy\ at\ steam\ inlet, kJkg^{-1}$
h_2 $= enthalpy\ at\ steam\ outlet, kJkg^{-1}$

Biomass drying

The process flow for the proposed process is as shown in Figure-1. The figure indicates the low pressure exhaust steam from low pressure steam header is diverted to biomass dryer for drying of wet palm fibre and wet EFB. The values of steam inlet and outlet at the boiler, ST and biomass dryer respectively are included in Table-3.

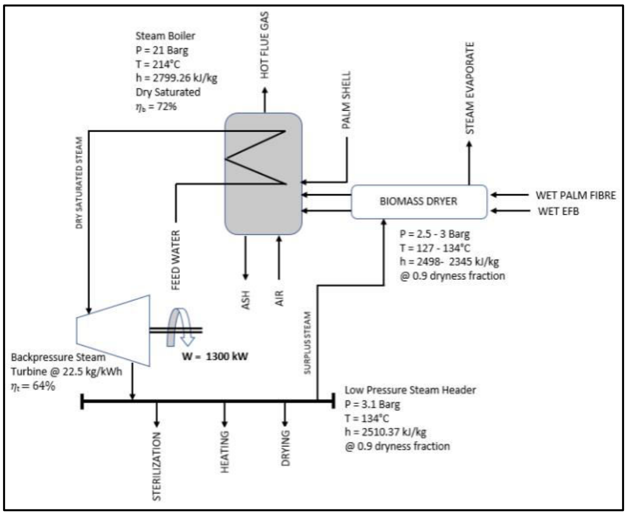

Figure-1. Proposed process of drying biomass using exhaust steam.

Table-3. The parameters for inlet and outlet steam.

Parameter	Steam inlet			Steam outlet		
	P (barg)	**T** (°C)	**DF*** (%)	**P** (barg)	**T** (°C)	**DF*** (%)
Boiler	-	-	-	21	214	100
Steam Turbine	20	212	98	3.1	135	90
Biomass Dryer	2.5	127	90	0.5	80	30

*DF = Dryness Fraction

For this case study it was assumed that the analysed moisture contents of the palm fibre and EFB were 40% and 55% respectively. While the palm shell moisture content was assumed at minimum level of 10% to 15% as published by [8].

The potential of heat recovery from energy surplus of the ST was evaluated using Equation (5), [6];

$$Q_{moisture\ in\ fuel} = m_{f[Cp_w(T_{evp}-T_{ref})+LHV_w]X} \quad (5)$$

where;

m_f $= fuel\ rate, kgh^{-1}$
Cp_w $= 2.08\ kJ\ kg°C^{-1}$
LHV_w $= 2255.252\ kJkg^{-1}$

RESULTS AND DISCUSSIONS

Estimated energy available at the plant

Results on calorific value for 100% dried biomass of the case study were lower than literature. One possible reason was due to an error in measuring the chemical composition as tabulated in Table-1.

The values quoted by Z. Hussian *et al.* [6] for the dried palm fibre and shell were at 19,188 kJ kg^{-1} and 21,430 kJ kg^{-1} respectively. While Vijaya *et al.* [9] and Nasrin *et al.* [16] reported calorific values for dried palm fibre and shell were 19, 068 kJ kg^{-1} and 20,108 kJ kg^{-1} respectively. The results reported by T.M.I Mahlia [11] appeared to be closer to the estimation in comparison to other researchers. The values were used for further calculation as presented in Table 4. For calorific value of the EFB, the result from Y.P. Olisa *et al.* [13] was used for analysis.

Table-4. Low calorific value of 100% dried biomass.

	Palm fibre			**Shell**			**EFB**	
	Case study	**Literature**		**Case study**	**Literature**		**Case study**	**Literature**
		[10]	[11]		[10]	[11]		[13]
LHV, MJ/kg	11.07	17.36	19.85	14.18	19.37	16.49	NA	15.49

Table-5 shows the average figure for mass fraction of palm fibre, shell and EFB. The values are reasonable with that of literatures. The average figure for moisture content are also reasonable. These figures were used for the analysis. However, for EFB moisture content the figure from the case study was used as it is more reasonable. Generally, the shredded EFB is used for boiler fuel and it should undergo the mechanical pressing.

Table-5. Mass fraction and moisture content wet mass.

Parameter	Case study	Literature				Average
		[5]	[11]	[12]	[13]	
Fibre, wt%	15	14-15	13.5	14	13	14
Shell, wt%	3.34	6-7.0	5.5	5	7	5.5
EFB, wt%	22	NA	22	NA	20	21
Fibre, Moisture%	35	40	39.5	NA	NA	38
Shell, Moisture%	12.1	10	10.92	NA	NA	11
EFB, Moisture%	65	NA	67	NA	NA	66

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Table-6 shows the LHV of wet and dried biomass. It is noted that with drying, the biomass calorific value improved. The calorific values of palm fibre and EFB increased by 45% and 126% respectively, when the moisture content was lowered to 15%.

Table-6. LHV of wet and dried biomass.

Element	Case	Shell	Palm fibre	Shredded EFB
Moisture Content, %	Wet Biomass	11	38	55
LHV, kJ/kg		16973.82	9846.51	5642.10
Moisture Content, %	Dried Biomass	11	15	15
LHV, kJ/kg		16973.82	14393.75	12800.63

The analysis of energy availability shows that a substantial amount of energy is available from wet biomass as shown in Table-7. The estimated energies for mill capacities from 20 tons per hour to 60 tons per hour were from about 20 MW to 58 MW. Fibre contributes the highest amount of energy.

When the moisture content of the palm fibre and EFB decreased to 15%, reduction on fuel rate is noted, as shown in Table-8. This indicates that the biomass becomes lighter after dried and easier to handle. The mass reduction decreased by 27%. Hence drying of biomass had led to energy enhancement. Total energy available had increased by 9% for the wet biomass. Tesfaldet *et al.* [7] reported that by having a dried biomass, the boiler efficiency increased by 10% as a result of efficient burning.

Table-7. Estimated total available energy from wet biomass.

Parameter	Mill Capacity, ton h^{-1}			
	20.00	**30.00**	**45.00**	**60.00**
Fibre, ton h^{-1}	2.80	4.20	6.30	8.40
Shell, ton h^{-1}	1.10	1.65	2.48	3.30
EFB, ton h^{-1}	4.20	6.30	9.45	12.60
Fibre; Energy Available, MW	7.66	11.49	17.23	22.98
Shell; Energy Available, MW	5.19	7.78	11.67	15.56
EFB; Energy Available, MW	6.58	9.87	14.81	19.75
Wet Biomass; Total Energy Available, MW	19.43	29.14	43.71	58.28

Table-8. Total energy available from dried biomass.

Parameter	Mill capacity, ton h^{-1}			
	20.00	**30.00**	**45.00**	**60.00**
Fibre, ton h^{-1}	2.04	3.06	4.60	6.13
Shell, ton h^{-1}	1.10	1.65	2.48	3.30
EFB, ton h^{-1}	2.22	3.34	5.00	6.67
Fibre; Energy Available, MW	8.17	12.25	18.37	24.50
Shell; Energy Available, MW	5.19	7.78	11.67	15.56
EFB; Energy Available, MW	7.91	11.86	17.79	23.72
Dried Biomass; Total Energy Available, MW	21.26	31.89	47.83	63.78

Potential energy generated

From the case study data of the cogeneration plant, the boiler and turbine thermal efficiencies as listed in Table-2 were seen realible to be used in estimating the thermal and electrical energy which could be converted by the plant. Table-9 shows the estimated potential energy that could be generated from wet and dried biomass.

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Table-9. Estmated potential energy that could be generated from wet and dried biomass.

Parameter	Case	Mill capacity, ton h^{-1}			
		20	30	45	60
Steam Production, ton h^{-1}	Wet Biomass	20.09	30.14	45.21	60.28
Electricity Generated, MW		0.89	1.34	2.01	2.68
Steam Production, ton h^{-1}	Dried Biomass	21.99	32.98	49.47	65.96
Electricity Generated, kW		0.98	1.47	2.20	2.93

Table-9 indicates that the total potential electricity that could be produced ranging from 1 MW and up to 3 MW depending on the mill capacity. Thus there aresubstantial amount of surplus electricity available, after mill requirements of 22 kWh/ton EFB had been fullfilled. The potential power that could be traded to grid ranging from 0.54 MW and up to 2.42 MW. This oppurtunity will works for the new design of the plam oil mill cogeneration plant.

For the existing plant which was designed based on the own consumption, the limitation of the equipment capacity is the constraint for trading of electricity. Eventhough the existing plant is able to improve quality of biomass through fuel saving, the surplus electricity could not be traded.

Potential biomass drying

In this study, the energy used for biomass drying was analysed from the surplus of low pressure steam from exhaust turbine. For biomass drying, besides thermal energy the processalso required electrical energy to drive the mechanical parts. The estimated electrical consumption for the biomass drying ranges from0.44 MW to1.32 MWdepending onmill capacity. THIS is shown in Table-10.

The positive results from the biomass drying can be seen from the fuel that can be saved as shown by Table-11. If all the EFB is to be used for fuel which has the lowest value in price, the fuel saving is substantial and the shell could be saved.

Table-10. Surplus steam for plant with wet biomass.

Parameter	Case	Mill capacity, ton h^{-1}			
		20.00	30.00	45.00	60.00
Boiler Capacity, ton h^{-1}	Wet Biomass	15.00	20.00	30.00	35.00
Steam Required, ton h^{-1}		9.89	14.84	22.26	29.68
Electricity Required, MW		0.44	0.66	0.99	1.32
LP Steam Surplus, ton h^{-1}		3.46	2.96	4.44	1.47

Table-11. Estimated fuel saving on using dried biomass.

Parameter	Case	Mill capacity, ton h^{-1}			
		20.00	30.00	45.00	60.00
Steam Required, ton h^{-1}	Dried Biomass	10.68	15.63	23.39	31.26
Electricity Required, MW		0.48	0.70	1.04	1.39
LP Steam Surplus, ton h^{-1}		2.67	2.17	3.31	-0.11
Fuel Saving, (Shell) ton h^{-1}		1.10	1.65	2.48	3.30
Fuel Saving, (Fibre) ton h^{-1}		1.44	2.25	3.39	4.50

Based on the plot in Figure-2, results indicate that the mill with capacity of 20 ton/hr could dry all the biomass with available surplus energy. For bigger capacities palm oil mills, the mills could only dry either the entire palm fibre or about 70% of the shredded EFB. For the case study mill with the capacity of 60 ton/hr, it is not feasible to be integrated with biomass drying due to zero energy surplus. This is highly depending in the boiler capacity.

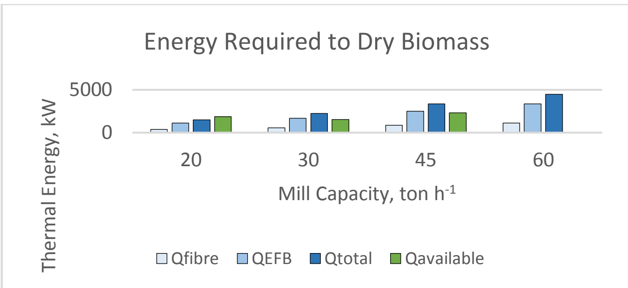

Figure-2. Energy required for biomass drying.

CONCLUSIONS

Palm oil mill cogeneration plant is an established technology, utilizing renewal energy for operations. Nonetheless, no serious effort been made in increasing its efficiency as the original design was on the energy self-sufficient. With increasing drive for process efficiency and stringent local regulation on discharge parameters, more energy is required to operate the plant, the requirement for increasing plant efficiency is more severe.

The available fuel in palm oil mill is substantial. The current steam boiler with efficiency as low as 70% could produce steam just enough to generate electrical energy from 1 MW and up to 4 MW from wet biomass. There is surplus energy that could be exported to the grid. Significant energy could be generated if condensing turbine is used or even condensing extraction steam turbine, CEST.

Drying biomass can enhance boiler efficiency by at least 5% to 10%. It also has a potential to increase the electrical energy by 9% and has a potential to save significant amount of fiber and shell.

The case study demonstrated that the available surplus energy is sufficient to dry the entire palm fiber from 38% to 15% moisture content using steam-air heater with the minimum required efficiency of 60%.

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REFERENCES

[1] Muhammad Ansori Nasutiona, Tjahjono Herawana, Meta Rivania. 2014. Analysis of Palm Biomass as Electricity from Palm Oil Mills in North Sumatera, Energy Procedia. 47: 166-172.

[2] Ezahar Abas, Fuel and Steam Balance. 2009. Diploma in Palm Oil Milling Technology and Management, MPOB.

[3] Mohd Shaharin Umar. 2014. Philip Jennings, Tania Urmee, Sustainable electricity generation from oil palm biomass wastes in Malaysia: An industry survey. Energy. 67: 496e505

[4] Sulaiman F, Abdullah N, Gerhauser H, Shariff A. 2011. An outlook of Malaysian energy, oil palm industry and its utilization of wastes as useful resources. Biomass Bioenergy. 35: 3775e86.

[5] Haslenda Hashim, Wai Shin Ho. 2011. Renewal energy policies and initiatives for a sustainable energy future in Malaysia. Renewal and Sustainable Energy Review. 15: 4780-4787.

[6] Z.Husain, Z.A. Zainal, M.Z. Abdullah. 2003. Analysis of biomass-residue-based cogeneration system in palm oil mills, Biomass and Bioenergy. 24: 117-124.

[7] Tesfaldet Gebreegziabher a, Adetoyese Olajire Oyedun b, Chi Wai Hui. 2013. Optimum biomass drying for combustion e A modeling approach. Energy. 53: 67e73.

[8] Roos CJ. 2008. Biomass Drying and Dewatering for Clean Heat & Power. Olympia, WA: WSU Extension Energy Program.

[9] Vijaya S, Ma AN, Choo YM, Nik Meriam NS. 2008. Life cycle inventory of the production of crude palm oil – a gate to gate case study of 12 palm oil mills. J Oil Palm Res. 20: 484-94.

[10] Yap AKC, Menon RN. 2012. Palm biomass fuel utilisation in palm oil mills. Palm Oil Eng Bull. 103: 9-13.

[11] T.M.I. Mahlia. 2000. An Alternative Energy Source from Palm Wastes Industry for Malaysia and Indonesia, University of Malaya.

[12] Soh Kheang Loh. 2016. The potential of the Malaysian oil palm biomass as a renewable energy Source, Energy Conversion and Management.

[13] Y.P. Olisa, K.W. Kotingo. 2014. Utilisation of palm empty fruit bunch (PEFB) as solid fuel for steam boiler, European Journal of Engineering and Technology. 2(2).

[14] Prasertsan S, Prasertsan P. 1996. Biomass residues from palm oil mills in Thailand: an overview on quantity and potential usage. Biomass and Bioenergy.

[15] F.R.P. Arrieta. 2007. Cogeneration potential in the Columbian palm oil industry: Three case studies, Federal University of Itajuba.

[16] Nasrin AB, Ravi N, Lim WS, Choo YM, Fadzil AM. 2011. Assessment of the performance and potential export renewable energy (RE) from typical cogeneration plants used in palm oil mills. J. Eng. Applied Sci. 6(6): 433-439.