POTENTIAL OF COGENERATION IN THAI PALM OIL MILLS

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ABSTRACT

Large palm oil mills cogenerate heat and power for their internal consumptions. Spent fibre, kernel shells and empty fruit bunches are used as the boiler fuel in the steam cogeneration plants of the palm oil mills. As the boiler pressures are not high and surplus steam from the turbine is exhausted to atmosphere, efficiencies of the existing cogeneration plants are low and electricity has to be partially imported from the national grid.

A feasibility study, based on a large mill with a milling capacity of 30 tons of fresh fruit bunches per hour, shows that a high-pressure cogeneration plant could generate 1207 kWe from which 607 kWe should be available for export, if surplus steam is used to preheat feed water. If the cost of fuel is not included, the costs of electricity and steam based on exergy are 1.99 USC/kWh and 0.555 USC/MJ.

1. Introduction

In 1988, Thailand produced 160,000 tons of palm oil from 179,000 acres of plantation. It is estimated that by 1991, the production of palm oil will increase to about 200,000 tons. The government policy at present is to limit the total area for palm oil plantation in order to avoid excessive deforestation. However, new plantations have been added and the total plantation area is currently about 341,500 acres [1]. An average fresh fruit bunch (FFB) consists of 21% crude palm oil, 6.5% kernel, 14.5% fibre, 6.5% shells and 23% empty fruit bunches (EFB), by mass. A fresh fruit bunch weighs 10-15 kg and contains about 67% of fruits [2].

About thirty one palm oil mills exist in Thailand. A few large mills produce both crude palm oil from palm fibre and palm kernel oil from kernels. Smaller mills normally produce only crude palm oil and sell kernels to other factories to process. The kernel oil accounts for about 25 % of the total palm oil production. Crude palm oil from the mills are refined in palm oil processing factories to produce cooking oil, margarine and cosmetic oil.

2. Cogeneration Systems

Palm oil mills require steam for sterilization of palm oil fruits and oil purification process. Electricity is also needed mainly to run screw presses for fibre and kernels. Large palm oil mills, with annual palm oil outputs over 6,000 tons,install topping-cycle steam cogeneration systems to satisfy all of their energy requirement during their normal operations when only crude palm oil is produced from palm fibre. However, during the peak operation when the palm kernel oil is also produced, additional amount of electricity has to be purchased from the national grid.

On the average, the annual capacity of a large palm oil mill in Thailand is about 96,000 tons of fresh fruit bunches and the power generating capacity is about 530 kWe [1]. Most large palm oil mills operate 16 hours per day and about 300 days per year.

Boilers in palm oil mills operate at about 24 bars and use spent palm fibre and kernel shells as their base fuel for the normal operation. During the peak operation, empty fruit bunches are used as an additional fuel. As the boiler fuel contains a high moisture content, boiler efficiencies range only 48-56% [2,3]. The turbo-generation load during the normal operation is about 60% of the load at peak operation and as a result, turbo-generator efficiencies are very low at 34-37% [3].

Spent palm fibre contains 31.3% C and 3.9% H. Its higher heating value in about 11.7 MJ/kg [2]. Kernel shells comprise 41.9% C and 5.9% H. The higher heating value is approximately 19.2 MJ/kg. The mixed fuel for the mill-boiler has an average higher heating value of 12.5 MJ/kg and moisture content of 29%. Based upon the total plantation area of 341,500 acres, the annual production of fresh fruit bunches would be about 2.56 M tons from which 0.704 M tons of spent fibre and shells would be available as the boiler fuel [1]. In addition, 0.594 Mtons of empty fruit bunches could also used as the boiler fuel.

3. Potential for Excess Electricity Generation

Most of the cogeneration systems in the palm oil mills have very low efficiencies as the boilers and the turbo-generators are not properly matched and the boiler pressures are not high enough. The average cogeneration system efficiency is only about 30-47% [2,3]. However, with proper efficiency improvement such as preheating of feed water by excess steam, drying of wet fuel by the flue gas and proper matching between the boiler and turbo-generator [2], the efficiency of an existing cogeneration system could be doubled and excess electricity could be made available for feeding back into the national grid.

If the cogeneration system in a large palm oil mill consists of a high-pressure super-heated boiler, an efficient turbo-generator and a feed-water pre-heater, it would be technically possible to generate a large amount of excess electricity for export by using spent fibre and shells as the boiler fuel. Based upon a feed rate of 30 tons per hour of fresh fruit bunches and a boiler raising steam at 50 bars, 400 C, the improved cogeneration system would be able to generate 1207 kWe from which 607 kWe or about 50% would be available for export. Details of the technical and economic assumptions are shown in Tables 1 and 2. Calculation procedure and the technical potential for excess electricity generation are shown in Table 3.

If it is assumed that the estimated amount of 0.704 Mtons of spent fibre and kernel shells would be available annually form the palm oil industry, the total potential of electricity generating capacity would be 19.7 MWe from which 9.9 MWe are the excess capacity.

4. Economic and Financial Assessment

As the two energy outputs from a cogeneration system, namely heat and power, have different qualities, assessment of the costs of process heat and power should take into account the difference in energy quality. The economic assessment based on exergy is suggested as follows.

Table 1. Technical Assumptions

General Description:

Typical milling capacity/mill	30 tons of FFB/hr
Fibre production (14%)	4.2 tons/hr
Shell production (6%)	1.8 tons/hr
Empty fruit bunch (23%)	6.9 tons/hr
Annual working time	4,800 hr

Internal Energy Requirement:

Electricity	20 kWh/ton FFB
Or, for the typical mill	600 kWe
Process heat	1150 MJ/ton FFB

Boiler Characteristics:

Delivery pressure	50 bars
First law efficiency	60 %
Steam temperature	400 C
Feed water temperature	120 C
Higher heating value of dry fibre and shells	12.5 MJ/kg

Turbo - Generator:

First law efficiency	85 %
Back pressure	3 bars
Exhaust condition	dry, saturated

Table 2. Economic Assumptions

Capital Costs:

Cogeneration	1500 USD/kWe
Fuel Cost	10 USD/ton

General:

Useful life of the system	20 years
Annual rate of interest	12 %
Annual O&M cost	3 % of capital cost
Salvage value	10% of capital cost
Average price of state electricity	0.061 USD/kWh
Average buy-back rate	0.033 USD/kWh
Boiler credit	702,853 USD
Operating cost of existing boiler	15,678 USD/year

Escalation Rate	1993/92	1994/93	1994 Onwards
Fibre and shell, %	5.84	5.14	5.14
General Inflation, %	5.00	4.00	4.00
Buy-Back Rate, %	6.05	5.04	5.04

Table 3. Technical Feasibility

Boiler:

Moisture content of fibre and shells = 35 %

Higher heating value of fuel, as fired = 12.5 (1 - 0.35) = 8.13 MJ/kg
Hourly heating value of fibre and shells = 10^3(4.2 + 1.8) 8.13 = 48.78 GJ/hr

Enthalpy of feed water = 503.7 kJ/kg
Enthalpy of delivery steam = 3195.7 kJ/kg

Hourly production of steam = 0.60 x 48.78 x 10^6/(3195.7-503.7)
= 10.87x10^3 kg/hr

Environment state is assumed at 1.01 bar, 30°C
Entropy of delivery steam = 6.646 kJ/kg.K

Exergy of delivery steam = 3195.7 - 125.8 - 303(6.646-0.437)
= 1880 kJ/kg

Turbo - Generator:

Enthalpy of exhaust steam = 2725.3 kJ/kg

Turbine output = 0.85 (3195.7-2725.3) = 399.8 kJ/kg
= 399.8 x 10.87x10^3 = 4346x10^3 kJ/hr
= 1207 kWe

Excess generating capacity = 1207 - 600 = 607 kWe

Percentage of excess generating capacity = 607/1207 = 50.3%

Annual amount of electricity production = 1,207 x 4,800 = 5.794 x 10^6 kWh

Process Heat:

Available process heat = 2725.3 - 125.8 = 2599.5 kJ/kg

Exergy of exhaust steam = 2725.3 - 125.8 - 303(6.992-0.437)
= 631.3 kJ/kg

Annual amount of process exergy = 631.3 x 10.87x10^3 x 4800
= 32,716 x 10^6 kJ

Total Generating Capacity of Palm Oil Industry:

Based on the assumptions that the annual production of spent fibre and shell is 0.704 Mtons, or 2347 tons/day for the whole country,

Total potential of generating capacity = 1.207 x 2347/144 = 19.7 MWe

Total excess generating capacity = 19.7 x 0.503 = 9.9 MWe

If m = flow rate of steam exhausted from the steam turbine,
h_e = specific enthalpy of steam exhausted from the turbine,
h_c = specific enthalpy of condensate from process,

The rate of enthalpy in the process steam = $m\ (h_e - h_c)$

The rate of exergy in the process steam [4],

$$Eh = m\ (h_e - h_c) - m\ T_o\ (s_e - s_c) \quad \text{(1)}$$

Where T_o = absolute temperature of the environment,
s_e = specific entropy of the steam exhausted from turbine,
s_c = specific entropy of condensate.

Factor to convert the process heat to exergy

$$= [h_e - h_c - T_o\ (s_e - s_c)]/(h_e - h_c) \quad \text{(2)}$$

Cost Analysis

Annual cost of steam from the boiler,

$$ACb = \text{annual first cost of the boiler + annual fuel cost + annual O\&M cost} \quad \text{(3)}$$

$$\text{Annual cost of steam to produce electricity} = ACb\ \frac{Ee}{Eb} \quad \text{(4)}$$

Where, Eb = exergy of steam from the boiler,

$$= m\ [(h_s - h_w) - T_o\ (s_s - s_w)] \quad \text{(5)}$$

and Ee = net exergy of steam used for electricity generation,

$$= m\ [(h_s - h_e) - T_o\ (s_s - s_e)] \quad \text{(6)}$$

Where, m = annual flow rate of steam,
h_s = specific enthalpy of steam from the boiler,
s_s = specific entropy of steam from the boiler,
h_w = specific enthalpy of feed water,
s_w = specific entropy of feed water.

$$\text{Annual cost of steam to produce process heat} = ACb\ \frac{Eh}{Eb} \quad \text{(7)}$$

Cost of steam/kg for process heat,

$$= \frac{ACb}{m}\ \frac{Eh}{Eb}$$

If the break-down costs of the boiler and turbo-generator of the cogeneration system are not available, the following approximation is recommended:

Annual cost of a cogeneration system, AC,

= annual first cost of the system + annual fuel cost +

If E = annual amount of electricity generated.
Eh = annual amount of exergy produced for the process heat, and defined already.

$$\text{Annual cost of electricity generation} = \frac{AC \, . \, E}{Eh + E} \quad \ldots\ldots\ldots\ldots \quad (9)$$

$$\text{Annual cost of process steam} = \frac{AC \, . \, Eh}{E + Eh} \quad \ldots\ldots\ldots\ldots \quad (10)$$

$$\text{Cost per kg of process steam} = \frac{AC \, . \, Eh}{m(E + Eh)}$$

If the condition of the steam exhausted from the turbine is not available, it would not be possible to estimate the exact value of the exergy. A further approximation has to be made and in this study, it is proposed that the exergy in the exhaust steam is about a quater of the amount of the process heat required.

In general, the value of the exergy in the process steam should vary between one half to a quarter of the process heat. For example, in order to compare the combined cycle power plant, the state power companies in Thailand suggest a factor of one half to be used for the process steam. The exact value will depend upon the type of cogeneration system used and can be determined by the conversion factor from Equation (2).

Based upon the economic assumptions in Table 2 and Equations (1), (9) and (10), the costs of electricity and process steam generated by the cogeneration system of the typical palm oil mill are assessed based on exergy without the fuel cost and with the fuel cost if the market for fuel exists. Results are shown in Table 4.

In the financial analysis, the price of the electricity consumed internally is assumed at the average selling price of the Provincial Electricity Authority and the price of the surplus electricity is assumed at the average firm buy-back rate of the Electricity Generating Authority of Thailand. The boiler cost is allocated either at 25% or 50% for the generation of the process steam. With economic and financial assumptions from Table 2, the cost of electricity is assessed with and without the fuel cost. Results are shown in Table 5.

5. Conclusions

As energy production in most Thai palm oil mills are inefficient even in large ones, additional electricity is often purchased from the national grid. Several efficiency improvement measures on cogeneration systems in palm oil mills are possible, for example, preheating of feed water by the surplus steam, proper matching between boilers and turbo-generators, installation of high-pressure cogeneration system.

This study shows that, with the above improvement measures, a typical palm oil mills at a capacity of 30 tons of fresh fruit bunches per hour could generate 600 kWe for its internal use and 607 kWe for export. If it is assumed that the annual production of spent fibre and kernel shells is 0.594 Mtons for the whole palm oil industry, the potential of the total electricity generating capacity is 18.4 MWe from which 9.3 MWe could be exported as the excess capacity.

Table 4. Costs of Electricity and Steam Based on Exergy.

Cases	Electricity USc/kWh	Steam USc/MJ
Without fuel cost	1.99	0.56
With fuel cost	3.91	1.09

Table 5. Cost of Electricity Based on Energy, in USc/kWh

Cases	Boiler Cost Credited 25%	50%
Without fuel cost	3.1	2.8
With fuel cost	3.7	4.0

6. References

(1) "ASEAN-EC Cogen. Programme: Technological Potential of Thailand", A Research Report, School of Energy & Materials, KMITT, August 1992.

(2) Wibulswas P. and Thavornkit A., "A case study of cogeneration in the Thai palm oil industry", Proc. of Conf. on Energy Efficiency Strategies, University Press of America, Lanham, 1988, pp. 387-401.

(3) Wibulswas P. and Terdyothin A., "Energy and availability analysis of biomass-fired cogeneration system in a palm oil mill", Proc. of World Renewable Energy Congress, Reading, Pergamon Press, Oxford, 1990, pp. 1942-1946.

(4) Moran M. J., "Availability Analysis", Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1982.

(5) Prida Wibulswas, "Feasibility of cogeneration using rice husk as fuel", Proc. of Energy'91, Natural Resources Division, ESCAP, Bangkok, October 1991.

Appendix 1

1. Internal rate of return (IRR)

$$\sum_{t=1}^{n} \frac{[R(t) - FC(t) - OMC(t) - SC(t)]}{(1+i)^t} + \frac{SV(n)}{(1+i)^n} = TIC \qquad (1)$$

where,
n = useful life of system, years,
t = 1,2,.......n,
$R(t)$ = total revenue of displaced electricity, fuel and operating & maintenance cost of existing generated steam,Baht/year,
$FC(t)$ = fuel cost of the cogeneration system, Baht/year,
$OMC(t)$ = operating & maintenance cost of the cogeneration system, Baht/year,
SV = salvage value, Baht,
TIC = total installed cost, Baht,
i = internal rate of return.

2. Simple payback period (p)

$$\sum_{t=1}^{p} [R(t) - FC(t) - OMC(t) - SC(t)] = TIC \qquad (2)$$

where, p = simple payback period (years).

3. Levelized annual cost

$$LAC = AC/AEO \qquad (3)$$

where,
LAC = levelized annual incremental cost of cogeneration system over generated steam cost of existing system, Baht/year,
AEO = levelized annual electricity output, kWh/year.

The unit cost of generated electricity in 1992 was the present value of levelized annual cost of generated electricity, which included the effect on electricity escalation rate.

Appendix 2

Total first cost = 1500 x 1207 = 1,810,500 USD
Annual first cost = 1,810,500 (CRF, 12%, 20)
= 242,481 USD
Salvage value = 1,810,500 x 0.10 = 181,051 USD
Annual salvage value = 181,050 (SFF, 12%, 20)
= 2513 USD
Annual O&M costs = 1,810,500 x 0.03 = 54,315 USD
Total annual cost = 242,481 + 54,315 - 2513
= 294,283 USD

From equation (9), the cost of electricity

$$= \frac{294{,}283}{5.794\text{x}10^6 + 32{,}716\text{x}10^6/3600} = \underline{0.0199}\ \text{USD/kWh}$$

From Equation (10), the cost of process steam

$$= \frac{294{,}283}{5.794\text{x}10^6 \text{ x } 3.6 + 32{,}716\text{x}10^3} = \underline{0.00555}\ \text{USD/MJ}$$

Annual fuel cost = (4.2 + 1.8) x 4800 x 10
= 288,000 USD
The total annual cost = 294,283 + 288,000
= 582,283 USD

The cost of electricity $= \dfrac{582{,}283}{5.794 \text{ x } 10^6 + 2.088 \text{ x } 10^6}$
$= \underline{0.0391}$ USD/kWh

The cost of steam $= \dfrac{582{,}283}{20.873 \text{ x } 10^6 + 32.716 \text{ x } 10^6}$
$= \underline{0.0109}$ USD/MJ

Summary of economic assessment

Case	Capacity, MWe		Energy, GWhe		Capital	Elec. Price, ($/kWh)		Inc. Fuel+O&M ($/kWh) + Stand. Charge	PBP	IRR	Unit cost
	Displaced	Export	Displaced	Export	($/kWe)	Displaced	Export		(year)	(%)	($/kWh)
Existing steam cost subtracted from cogeneration cost:											
PALM-B-NF	0.6	0.607	2.88	2.914	918	0.061	0.033	0.007	4.1	27.26	0.023
PALM-50%B-NF	0.6	0.607	2.88	2.914	1,209	0.061	0.033	0.007	5.2	21.39	0.028
PALM-25%B-NF	0.6	0.607	2.88	2.914	1,354	0.061	0.033	0.007	5.8	19.31	0.031
PALM-B-F	0.6	0.607	2.88	2.914	918	0.061	0.033	0.015	5.1	22.11	0.032
PALM-50%B-F	0.6	0.607	2.88	2.914	1,209	0.061	0.033	0.015	6.4	17.24	0.037
PALM-25%B-F	0.6	0.607	2.88	2.914	1,354	0.061	0.033	0.015	7.1	15.48	0.040
PALM-NB-F	0.6	0.607	2.88	2.914	1,500	0.061	0.033	0.015	7.7	14.00	0.043
No existing steam cost subtracted from cogeneration cost:											
PALM-NS-NF	0.6	0.607	2.88	2.914	1,500	0.061	0.87	0.009	6.7	16.57	0.036
PALM-NS-F	0.6	0.607	2.88	2.914	1,500	0.061	0.87	0.059	>20	N.A	0.086

Note:

1). Capital, electricity price, fuel, o&m, and unit cost are in 1992 constant price.
2). PALM-B-NF: boiler credit, excluded fuel cost.
3). PALM-50%B-NF: 50% of boiler credit, excluded fuel cost.
4). PALM-25%B-NF: 25% of boiler credit, excluded fuel cost.
5). PALM-B-F: boiler credit, included fuel cost.
6). PALM-50%B-F: 50% of boiler credit, included fuel cost.
7). PALM-25%B-F: 25% of boiler credit, included fuel cost.
8). PALM-NB-F: no boiler credit, included fuel cost.
9). PALM-NS-NF: no existing steam cost subtraction, excluded fuel cost.