

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. The financial analysis based upon the non-firm buy back rate yields the electricity cost at USc 2.8/kWh with 50% of the boiler cost credited.

Based on the assumption that 0.538 M tons of spent fibre and kernel shells would be available annually, the total potential of generating capacity for all palm oil mills would be 22.5 MWe.

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 oil palm 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 fruit [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 is 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 30-40%. 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 0.538 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 be 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 is a large palm oil mill consists of a high-pressure super-heated boiler, and 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 0.538 Mtons of spent fibre and kernel shells would be available annually from the palm oil industry, the total potential of electricity generating capacity would be 22.5 MWe from which 11.3 MWe are the excess capacity. The estimated potential would not however be realized in practice unless all small mills can be merged into a few larger mills.

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 kW
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 system	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	= $0.60 \times 48.78 \times 10^6 / (3195.7 - 503.7)$ = 10.87×10^3 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 = $399.8 \times 10.87 \times 10^3 = 4346 \times 10^3$ 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	= $1,207 \times 4,800 = 5.794 \times 10^6$ 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 process exergy	= $631.3 \times 10.87 \times 10^3 \times 4800$ = $32,716 \times 10^6$ kJ

Total Generating Capacity of Palm Oil Industry:

Based on the assumptions that the annual production of spent fibre and shell is 0.538 Mtons, or 112 tons/hr for the whole country,

Total potential of generating capacity	= $1.207 \times 112 / 6 = 22.5$ MWe
Total excess generating capacity	= $22.5 \times 0.503 = 11.3$ MWe

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.

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],

$$Eh = m(h_e - h_c) - mT_o(s_e - s_c) \dots \dots \dots (1)$$

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

$$= [h_e - h_c - T_o(s_e - s_c)] / (h_e - h_c) \dots \dots \dots (2)$$

Cost Analysis

Annual cost of steam from the boiler,

ACb = annual first cost of the boiler + annual fuel cost + annual O&M cost.....(3)

Annual cost of steam to produce electricity

$$= ACb \frac{Ee}{Eb} \dots \dots \dots (4)$$

Where, Eb = exergy of steam from the boiler,

$$= m[(h_s - h_w) - T_o(s_s - s_w)] \dots \dots \dots (5)$$

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

$$= m[(h_s - h_e) - T_o(s_s - s_e)] \dots \dots \dots (6)$$

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.

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

$$\begin{aligned} \text{Cost of steam/kg for process heat,} \\ = \frac{ACb}{m} \frac{Eh}{Eb} \end{aligned}$$

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 + annual O&M cost of the system.....(8)

If E = annual amount of electricity generated,

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

$$\text{Annual cost of electricity generation} = \frac{AC \cdot E}{Eh + E} \dots \dots \dots (9)$$

$$\text{Annual cost of process steam} = \frac{AC \cdot Eh}{E + Eh} \dots \dots \dots (10)$$

$$\begin{aligned} \text{Cost per kg of process steam} = \\ \frac{AC \cdot Eh}{m(E + Eh)} \end{aligned}$$

If the condition of the steam exhausted from the turbine is not available, it would 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 quarter 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.

Financial Analysis

(1) Internal rate of return (IRR)

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

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)

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

Where, p = simple payback period (years).

(3) Levelized annual cost

$$LAC = AC/AEO$$

Where, AC = 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.

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 non-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.

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	4.0	3.7

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 0.538 Mtons for the whole palm oil industry, the potential of the total electricity generating capacity is 22.5 MWe from which 11.3 MWe could be exported as the excess capacity.

The cost analysis based on exergy indicates that the costs of electricity produced by the proposed cogeneration system are cheaper than the average production cost of electricity generated by the Electricity Generating Authority of Thailand whether the cost of fuel is included or excluded. The financial analysis also confirms that the cost of electricity from the proposed system is lower than that from EGAT if the cost of fuel is excluded and a part of the boiler cost is credited for steam generation.

6. References

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Appendix

$$\begin{aligned}
 \text{Total first cost} &= 1500 \times 1207 \\
 &= 1,810,500 \text{ USD} \\
 \text{Annual first cost} &= 1,810,500 (\text{CRF}, 12\%, 20) \\
 &= 242,481 \text{ USD} \\
 \text{Salvage value} &= 1,810,500 \times 0.10 \\
 &= 181,051 \text{ USD} \\
 \text{Annual salvage value} &= 181,050 (\text{SFF}, 12\% 20) \\
 &= 2513 \text{ USD} \\
 \text{Annual O\&M costs} &= 1,810,500 \times 0.30 \\
 &= 54,315 \text{ USD} \\
 \text{Total annual cost} &= 242,481 + 54,315 - 2513 \\
 &= 294,283 \text{ USD} \\
 \text{From equation (9), the cost of electricity} &= \frac{294,283}{5.794 \times 10^6 \times 32,716 \times 10^6 / 3600} \\
 &= 0.0199 \text{ USD/kWh} \\
 \text{From Equation (10), the cost of process steam} &= \frac{294,283}{5.794 \times 10^6 \times 3.6 \times 32,716 \times 10^3} \\
 &= 0.00555 \text{ USD/MJ} \\
 \text{Annual fuel cost} &= (4.2 + 1.8) \times 4800 \times 10 \\
 &= 288,000 \text{ USD} \\
 \text{The total annual cost} &= 294,283 + 288,000 \\
 &= 582,283 \text{ USD}
 \end{aligned}$$

The cost of electricity

$$\begin{aligned} &= \frac{582,283}{5.794 \times 10^6 + 2.088 \times 10^6} \\ &= 0.0391 \text{ USD/kWh} \end{aligned}$$

The cost of steam

$$\begin{aligned} &= \frac{582,283}{20.873 \times 10^6 + 32.716 \times 10^6} \\ &= 0.0109 \text{ USD/MJ} \end{aligned}$$