OPPORTUNITY OF SELLING THE EXCESS ELECTRICITY FROM THAI SUGAR MILLS: LEVELISED COST ANALYSIS BASED ON AVAILABILITY

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ABSTRACT

Sugar industry is a very important agro-industry in Thailand. Most of the sugar mills in Thailand use low pressure bagasse-fired boilers with back pressure steam-turbo-generator to provide electricity, power and process heat for the mill.

In the near future, privately-generated electricity in Thailand will be allowed to sell back to the state power company. This study estimates the technical feasibility of using excess bagasse and cane trash to generate the electricity. It is found that a large sugar mill which has 10,000 tons of cane per day capacity, could generate about 2.4 MWe for sale during milling season and 6.3 MW during non-milling season.

A levelised analysis based on availability shows that the cost of electricity and process heat in the exhaust steam will be about 0.045 USD/kWh and 0.0032 USD/MJ if only bagasse is used and 0.029 USD/kWh and 0.0045 USD/MJ if both bagasse and available cane trash is used.

BACKGROUND

Sugar production from cane has been known to exist in Thailand since the fifteenth century. At presents, there are 46 sugar mills in Thailand with a total capacity of 338,000 tons of cane per day [1]. The fibrous residue of sugar cane left after the extraction of juice is called bagasse and is approximately 30% by weight of the sugar cane crushed. The major part of bagasse is burned in boilers to produce powers, heat and electricity while the surplus bagasse can be used to generate extra electricity. The amount of excess bagasse strongly depends on the efficiency of the mill.

The existing sugar mills in Thailand based their design concept on "generate adequate electricity and burn all bagasse to prevent the disposal problem". Therefore, the fuel utilization efficiency of the mill is quite low. At present, the design concept has been changed to obtain higher efficiency due to the bagasse requirement in paper and particle board factories. Moreover, according to a new government regulation for power production in Thailand, the private power generators will be soon allowed to sell electricity back to the state power companies or sell directly to electricity consumers. The incentive to improve the efficiency of cogeneration system in sugar mills thus become evident.

The power plants in existing sugar mills in Thailand normally consist of boilers which produce steam at 22 bars and back pressure steam turbo-genderators. The efficiency of the cogeneration system is quite low compare to the high pressure extraction-condensing steam turbines widely used in the sugar mills in developed countries.

This work suggests a method to evaluate the cost of electricity and process heat being produced by back pressure steam power plant of a Thai sugar mill based on second law of thermodynamic. Actual data of a sugar mill with 10,000 tons of cane par day capacity was used as a case study.

To increase the generating capacity of the sugar mill, the available cane tops and leaves, cane trash, will be collected from the sugar cane field. The cane trash will be used to generate the additional electricity during non-milling season when the bagasse is not available.

A study on cane trash utilization [2] suggested that 0.24 ton of cane trash at 30% moisture content can be collected for each ton of sugar cane harvested. This cane trash can be used with existing or modified sugar mill power plant. A study on technical potential of using cane trash in existing sugar mills [3] show that the surplus generation capacities of the mills vary from 4.9 to 117 GWh per year. If the boilers in the existing sugar mills are replaced with high pressure boilers together with double extraction-condensing turbines the maximum surplus generation capacity will increase to 428 GWh per mill per year.

AVAILABILITY ANALYSIS

The costs of electricity and steam generated from a steam cogeneration system can be analysed by several methods. However methods based upon energy contents in the steam and electricity are not quite satisfactory, owing to the following reasons:

i) electricity is a high-grade energy in comparison to process heat from steam,
ii) energy (or enthalpy) in high-temperature steam has greater potential to generate work (or electricity) than low-temperature steam.

If energy (enthalpy) in the process steam is first converted to potential work or availability (or exergy) which has the same quality as work (electricity), the costs of electricity and process steam would then be comparable and more logically analysed.

Availability in the Steam [4]

The availability in the steam from the boiler includes the availability to generate the electricity and the availability to produce process heat.

The rate of flow availability in the steam from the boiler can be evaluated as:

$$F(b) = m_b (h_s-h_w) - m_b T_o (s_s-s_w)$$

Where,

m_b = flow rate of steam from the boiler
h_s = specific enthalpy of steam from the boiler

h_w = specific enthalpy of the feed water to the boiler

$m_b(h_s-h_w)$ = rate of enthalpy in the steam from the boiler

T_o = absolute temperature of the environment

s_s = specific entropy of the steam from the boiler

s_w = specific entropy of the feed water to the boiler

The rate of availability to generate the electricity, F(e)

$$F(e) = m_e (h_s-h_e) - m_e T_o (s_s-s_e)$$

Where,

m_e = flow rate of steam passing through steam turbine,

h_e = specific enthalpy of exhaust steam from the turbine

s_e = specific entropy of exhaust steam from the turbine.

The rate of availability in the process steam, F (h)

$$F(h) = m_h(h_e-h_w)-m_hT_o(S_e-S_w)$$

Where,

m_h = flow rate of process steam.

Cost Analysis [5]

In term of the availability, the energy in the steam and electricity are now converted into equal-grade energy. Thus the total cost of steam generation can be proportionally separated into cost of steam that produces process heat and cost of steam that generates the electricity.

Annual cost of steam from the boiler,

A(b) = annual first cost of the boiler
+ annual fuel cost
+ annual 0 & M cost.

Annual cost of steam to produce electricity

$$= A(b) \cdot \frac{F(e)}{F(b)}$$

Annual cost of steam to produce process heat

$$= A(b) \cdot \frac{F(h)}{F(b)}$$

If the break- down cost of the boiler and turbo generator of the cogenerations 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.

Annual costs of electricity generation

$$= AC. \frac{E}{E + F(h)}$$

Where,

E = annual amount of electricity generated

F(h) = annual amount of flow-availability produced for the process heat, and defined already.

Annual cost of process steam

$$= AC. \frac{F(h)}{E+F(h)}$$

FEASIBILITY STUDY

1. TECHNICAL ASSUMPTIONS

1.1 Sugar Mills

Mill capacity	10,000 tons cane/day
Bagasse production	2,980 tons/day
Average milling days	65/year
	(1,560) hrs/year
Available cane trash	156,000 tons/year

1.2 Internal Energy Requirement

Electricity	20.7 kWh/ton cane
	(8,625 kWe)
Mechanical Drive	74,520 kJ/ton cane
Total Power	149,040 kJ/ton cane
Process heat	1,639,440 kJ/ton cane
Heat/Power	11

1.3 Boiler Characteristic

Delivery Pressure	22 bar
1st law efficiency	65%
Steam temperature	360 C
Makeup water temperature	30 C
Higher heating value of bagasse	8.8 MJ/kg(50%MC)
Higher heating value of cane trash	12.3 MJ/kg (30%MC)

1.4 Turbo-Generator

1st law efficiency	85%
Back pressure	1.2 bar
Exhaust temperature	140 C
Installed capacity	11 MW

2. ECONOMIC ASSUMPTIONS

2.1 System First Cost

Boiler, generator etc.	1,050 USD/kw
Cane trash preparation system	84.95 USD/ton cane

2.2 Fuel Cost

Bagasse	5.9 USD/ton
Cane trash	10 USD/ton

2.3 General

Useful life of the system	20 years
Annual rate of interest	17.5%
Annual O&M cost	3% of system first cost
Salvage value	10% of system first cost
Average price of state electricity	0.061 USD/kWh

RESULTS

Technical Feasibility

Electricity production	$= 94.2 \times 10^3$ GJ
Use bagasse only	= 26.2 GWh/year
	$= 232 \times 10^3$GJ
Use bagasse & cane trash	= 64.4 GWh/year

Process heat production	
Use bagasse only	$= 959.6 \times 10^3$ GJ
Use bagasse & cane trash	$= 1996 \times 10^3$ GJ
Process heat need for sugar mill	$= 738 \times 10^3$ GJ
Excess process heat	
Use bagasse only	$= 220 \times 10^3$ GJ
Use bagasse & cane trash	$= 1258 \times 10^3$ GJ
Total heat/electricity ratio	
Use bagasse only	= 10.2
Use bagasse & cane trash	= 8.6
Internal heat/electricity ratio	
Use bagasse only	= 7.8
Use bagasse & cane trash	= 3.2

Economic Feasibility

Availability in process steam	
Use bagasse only	$= 192 \times 10^3$ GJ/year
Use bagasse & cane trash	$= 400.6 \times 10^3$ GJ/year
Ratio of process heat/availability	
Use bagasse only	= 3.85
Use bagasse & cane trash	= 4.99
Cost of electricity	
Use bagasse only	= 1,184,342 USD/year = 0.045 USD/kWh
Use bagasse & cane trash	= 1,961,145 USD/year = 0.029 USD/kWh
Cost of process heat	
Use bagasse only	= 2,415,122 USD/year = 0.0033 USD/MJ
Use bagasse & cane trash	= 3,379,359 USD/year = 0.0046 USD/MJ

DISCUSSION AND CONCLUSIONS

During the milling season, the bagasse will be used to generated the electricity at full capacity. The exhaust steam from the steam turbo-generator together with exhaust from others mechanical-drive turbines will be further used in the process. At the end of milling season, we assume that no process heat is needed. To generate the electricity during non-milling season, the exhaust steam from steam turbo-generator is considered to be excess heat. Thus the internal heat/electricity ratio become lower.

The cost analysis based on availability shows that the costs of electricity and process heat ae 0.045 USD/kWh and 0.0033 USD/MJ if only bagasse is used and 0.029 USD/kWh and 0.0046 USD/MJ if both bagasse and available cane trash is used.

The tentative electricity buy-back rate is 0.044 USD/kWh which is not attractive for the sugar mill that generates electricity from bagasse only. On the otherhand, the cost of electricity generation of the sugar mill using both bagasse and cane trash is lower than the buy-back rate. Thus, the sugar mill may be interested to adopt this program.

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APPENDIX

1. TECHNICAL FEASIBILITY

1.1 Steam Turbine:

Enthalpy of entering steam	= 3152 kJ/kg
Enthalpy of exhaust steam	= 2755 kJ/kg
Turbine output	= 0.85 (3152-2755)
	= 337.45 kJ/kg

1.2 Boiler:

Annual heating value from bagasse	$= 2980 \times 65 \times 8.8\ 10^6$
	$= 1.705 \times 10^{12}$ kJ
Annual production of steam from bagasse	$= 0.65 \times 1.705 \times 10^{12}/(3152\text{-}461.3)$
	$= 411.8 \times 10^6$ kg
Annual steam for electricity generator	$= 267.4 \times 10^6$ kg
Annual heating value from cane trash	$= 156{,}000 \times 12.3 \times 10^6$
	$= 1.919 \times 10^{12}$ kJ
Annual production of steam from cane trash	$= 0.65 \times 1.919 \times 10^{12}/(3152\text{-}461.3)$
	$= 463.5 \times 10^6$ kg
Total steam for electricity generation	$= 730.9 \times 10^6$ kg

1.3 Electricity Production

During milling season	$= 11000 \times 65 \times 24$
	= 17.16 GWh
	= 61,776 GJ
Steam use	$= 61.776 \times 10^6/337.45$
	$= 183.1 \times 10^6$ kg
Steam left	$= 730.9 \times 10^6 - 183.1 \times 10^6$
	$= 547.8 \times 10^6$ kg
Electricity generation during non milling season	$= 170.1 \times 10^3$ GJ
	= 51.3 GWh
Annual operating time	$= (350\text{-}65) \times 24$
	= 6840
Electricity generating capacity	$= 51.3 \times 10^3/6840$
	= 7.51 MW
Total electricity generation	
Use bagasse only	$= 61.8 \times 10^3 + 95.9 \times 10^6 \times 337.45$
	$= 94.2 \times 10^3$ GJ
Use bagasse & cane trash	$= 61.8 \times 10^3 + 170.1 \times 10^3$
	$= 231.9 \times 10^3$ GJ
Excess generating capacity	
During milling season	= 2.4 MW
During non-milling season	= 6.3 MW

1.4 Process Heat Production

Use bagasse only	$= 206.4 \times 10^3 (2755\text{-}461.3) \times 24 \times 65$
	$+ 95.9 \times 10^6 \times (2755\text{-}461.3)$

	$= 738.6\times10^3 + 220.0\times10^3$ GJ
	$= 958.6\times10^3$ GJ
Use bagasse & cane trash	$= 958.6\times10^3 + 451.9\times10^6 \times (2755-461.3)$
	$= 1994.6\times10^3$ GJ

1.5 Heat/Electricity Ratios

Total heat/electricity ratios

Use bagasse only	$= 958.6\times10^3/94.2\times10^3$
	$= 10.2$
Use bagasse & cane trash	$= 1994.6\times10^3/231.9\times10^3$
	$= 8.6$

Internal heat/electricity ratios

Use bagasse only	$= 738.6\times10^3/94.2\times10^3$
	$= 7.8$
Use bagasse & cane trash	$= 738.6\times10^3/231.9\times10^3$
	$= 3.2$

2. ECONOMIC FEASIBILITY

Levelized cost analysis based on Exergy.

2.1 Without cane trash

	USD
Annual system first cost	$= 1{,}050\times11{,}000\times CRF(17.5\%,20)$
	$= 2{,}102{,}100$
Annual O&M cost	$= 1{,}050\times11{,}000\times0.03$
	$= 346{,}500$
Annual fuel cost	$= 2980\times65\times5.9$
	$= 1{,}142{,}830$
Annual salvage value	$= 1{,}050\times11{,}000\times0.1\times SFF(17.5\%, 10)$
	$= 8{,}360$
Total annual cost	$= 3{,}599{,}790$ USD
Exergy in process steam	$= (2755-461.3) - 303(7.475-1.4184)$
	$= 459.46$ kJ/kg
	$= 192.0\times10^3$ GJ/year
Ratio of Process heat/exergy	$= 738.6\times10^3/192.0\times10^3$
	$= 3.85$
Cost of electricity	$= 3{,}599{,}790\times(32.4\times10^3+61.8\times10^3/(32.4\times10^3+61.8\times10^3+192.0\times10^3)$
	$= 1{,}184{,}342$ USD/year
	$= 0.0453$ USD/kWh
Cost of process heat in steam	$= 3{,}599{,}790\times192.0\times10^3/(32.4\times10^3+61.8\times10^3+192.0\times10^3)$
	$= 2{,}415{,}122$ USD/year
	$= 0.00327$ USD/MJ

2.2 With cane trash

	USD
Annual system first cost	$= 1{,}050\times11{,}000\times CRF(17.5\%,20) + 84.95\times10{,}000\times CRF(17.5\%,20)$
	$= 2{,}256{,}714$
Annual O&M cost	$= (1{,}050\times11{,}000 + 84.95\times10{,}000)\times0.03$
	$= 371{,}985$

Annual fuel cots	$= 2{,}980 \times 65 \times 5.9 + 156{,}000 \times 10$
	$= 2{,}702{,}830$
Annual salvage value	$= (1{,}050 \times 11{,}000 + 84.95 \times 10{,}000)$
	$\times\ 0.1 \times SFF(17.5\%, 20)$
	$= 8{,}975$
Total annual cost	$= 5{,}340{,}504$ USD
Exergy in process steam	$= (2755-461.3)-303(7.475-1.4184)$
	$= 459.5$ kJ/kg
	$= 399.6 \times 10^3$ GJ/year
Ratio of Process heat/exergy	$= 738.6 \times 10^3 + 1257 \times 10^3 / 399.6 \times 10^3$
	$= 4.99$
Cost of electricity	$= 5{,}340{,}504 \times 231.9 \times 10^3 /$
	$(231.9 \times 10^3 + 399.6 \times 10^3)$
	$= 1{,}961{,}145$ USD/year
	$= 0.0288$ USD/kWh
Cost of process heat in steam	$= 5{,}340{,}504 \times 399.6 \times 10^3 /$
	$(231.9 \times 10^3 + 399.6 \times 10^3)$
	$= 3{,}379{,}359$ USD/year
	$= 0.00458$ USD/MJ