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Efficient cogeneration scheme for sugar industry

M Premalatha[1]*, S Shanmuga Priya[1] and V Sivaramakrishnan[2]

[1]Centre for Energy & Environmental Science And Technology (CEESAT), National Institute of Technology,
Tiruchirappalli 620 015
[2]Mechanical Engineering Department, Saranathan College of Engineering, Tiruchirappalli 620 012

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Present work is a case study on sugar industry and economics is worked out for advanced cogeneration power system. By replacing low efficiency mill turbines with hydraulic drives and DC motors, cogeneration power increases in sugar mill to operate at high efficiency (65-70%). This replacement can aid increase of power to grid, resulting in additional revenue for sugar plant.

Keywords: Bagasse, Environment, Power, Sustainable development

Introduction

India[1] produces sugarcane (290 million tonnes/y, 67.44 tonnes/ha) from an area of 4,300,000 ha, yielding nearly 40 million metric tonnes (MMT) of bagasse, which is mostly used as a captive boiler fuel and as a raw material in paper industry. India has potential for electricity production using bagasse 29,000 GWh/y. More efficient power generation can be achieved if sugar mills follow advanced cogeneration systems by employing high - pressure boilers and condensing cum extraction turbines for processing steam. A typical 2500 TCD (tonnes of crushed sugarcane per day) sugar mill having a cogeneration potential of 22 MW exports nearly 0.3 million units of electricity in the season with a gross generating capacity of more than 150 million kWhs in a year and thus can offset nearly 0.166 million tonnes of carbon dioxide (CO_2).

In this case study on sugar industry, economics is worked out for advanced cogeneration power system. Sugar mill chosen is a unit of Tamil Nadu Sugarcane Corporation Ltd and run by Government of Tamil Nadu as a public sector sugar mills, installed in 1977 with 1250 TCD and capacity increased to 2500 TCD in 1989-1990 (area, 39537 acres; crushing period, 172 days/y; season crushing, 430000 tonnes). A 2500 TCD sugar mill has two numbers of 600 HP mill turbines and one number of 900 HP mill turbine. Average steam consumption per mill (average load of 300 kW) was about 6.5 TPH (tones per hour) steam @ 21 ata for two mills and 4.5 TPH steam @ 31 ata. Steam driven mill drives had an efficiency of about 25%, in case of single-stage turbine and about 50%, in case of two stage turbines. To commission a commercial cogeneration plant, low efficiency steam turbine driven mills will be replaced with DC motors to maximize cogeneration potential[3].

Proposed System for Sugar mill

In a sugar mill, steam turbines are typically single stage impulse type turbines[2] (efficiency 25-30%). One of the methods of increasing cogeneration power in a sugar mill is to replace smaller low efficiency mill turbines with better efficiency drives such as DC motors or hydraulic drives. Multi-stage steam turbines can operate at efficiencies of 65-70%. Hence, equivalent quantity of steam saved by installation of DC motors or hydraulic drives, can be passed through power turbine, to generate additional power. This replacement can aid in increase of power to the grid, resulting in additional revenue for the sugar plant.

Electric DC Motors

These have much higher efficiency than the steam turbines and with better control and cleaner operations,

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*Author for correspondence
E-mail:manic_prem@yahoo.co.in, latha@nitt.edu

Table 1 — Comparison of steam driven mills and electric DC motor mills

Parameter	Steam turbine	Electrical DC motors
Main drive efficiency, %	35	90
Overall efficiency, %	26	40-50
Range of speed	Low	Wide
Control of speed	Not precise	Not precise
Torque limitation	Yes	No limitation
Maintenance	High	Less
Space requirement	Large area	Small area

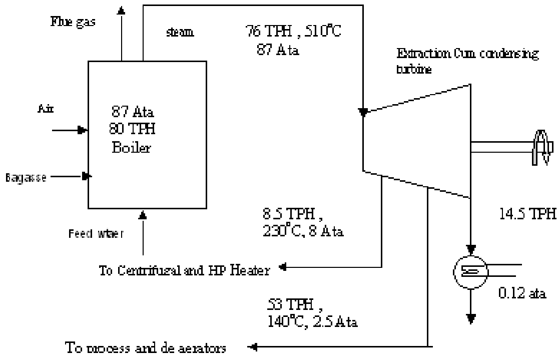

Fig 1 — Season flow diagram

are easily adaptable into power system. DC drive also avoids primary high-speed reduction gearbox, resulting in a higher overall efficiency (51%). Steam turbines have been replaced with electric DC drives, resulting in considerable benefits in many sugar plants (Table 1).

Installation of 17.5MW Commercial Cogeneration Plant

Cogeneration or combined heat and power (CHP) are sequential generation of two different forms of useful energy from a single primary energy source, typically mechanical energy and thermal energy. Overall efficiency of energy use in cogeneration mode can be up to 85% and more[3].

Heat-to-Power Ratio

Heat-to-power ratio is the ratio of thermal energy to electricity required by energy consuming facility. Steam turbine cogeneration system can offer a large range of heat-to-power ratios. Cogeneration is likely to be most attractive under the following circumstances: a) The demand for both steam and power is balanced; b) A single plant or group of plants has sufficient demand for steam and power to permit economics of scale to be achieved; and c) Peaks and troughs in demand can be managed or, in the case of electricity, adequate backup supplies can be obtained from the utility company. The ratio of heat to power required by a site may vary during different times of the day and seasons of the year.

Cogeneration Power Plant in Sugar Mill

Parameters for cogeneration power plant in sugar mill are as follows: plant crushing capacity, 111 TCH; no of season days, 172; plant down time, 8%; annual crushing, 4.30 lakh tonnes; capacity, 17.5 MW; boiler, 80 TPH (87 ata, 510°C, 72% efficiency); turbine (extraction cum condensing turbine), 17.5 MW; condenser, 75 TPH; and steam / bagasse ratio, 2.43. Old boilers are to be replaced by a new high-pressure boiler. A multistage turbine replaces all the small turbines. Mill turbines are replaced by a DC motor drive (Fig. 1).

Bagasse Availability

Bagasse calculations are: bagasse in cane, 28%; bagasse generated, 32.2 tonnes/h; Bagacilo, 0.47 tonnes/h; bagasse losses, 0.1 tonnes/h; net bagasse, 31.63 tonnes/h; 1 tonne bagasse produce, 2.43 tonnes steam at 87 ata; fuel required, 31.3 tonnes/h; surplus bagasse, 0.33 tonnes/h.

Steam Balance

Steam at various locations in the plant is as follows (Table 2): Steam entering into turbine, 76 TPH; steam extraction at 8 ata, 8.5 TPH; steam extraction at 2.5 ata, 53 TPH; steam to condenser, 14.5 TPH; steam for HP heaters 8 ata, 5TPH; steam for centrifugal 8 ata, 3.5 TPH; steam for deaerator 2.5 ata, 4.5 TPH; steam to process at 2.5 ata, 49.5 TPH.

Power Output from Turbine

Work output = $m_1 (h_1 - h_2) + (m_1 - m_2)(h_2 - h_3) + (m_1 - m_2 - m_3)(h_3 - h_4)$

where, m_1, 76 TPH or 21.11 kg/s; m_2, 8.5 TPH or 2.362 kg/s; m_3, 53 TPH or 14.72 kg/s; m_4, 14.5 TPH or 4.02 kg/s. Therefore, work out put = 21.11* (3415-2905.6) + 18.75* (2905- 2760) + 4.03* (2760- 2355.97) = 15.12 x 10^6 W.

Table 2 — Parameters of steam at various locations in the plant

Location	Steam condition	Pressure, ata	Temperature, °C	Enthalpy, kJ/kg
At boiler's exit	Super heated	87	510	3415
At turbine's inlet	Super heated	8	510	3415
At extraction point for Hp heaters	Super heated	2.5	170	2760.5
At turbine's outlet	Liquid-vapor mixture	0.12	49	2355.97
At condenser's outlet	Condensate liquid	1.3	49	188.4

Table 3 — Plant parameters

Particulars	Location	Pressure	Temperature, °C	Enthalpy, kJ/kg
Feed water	At de-aerator's outlet	1.3 ata	115	482.06
Make-up water	At de-aerator'sInlet	Atmospheric	30	125.7

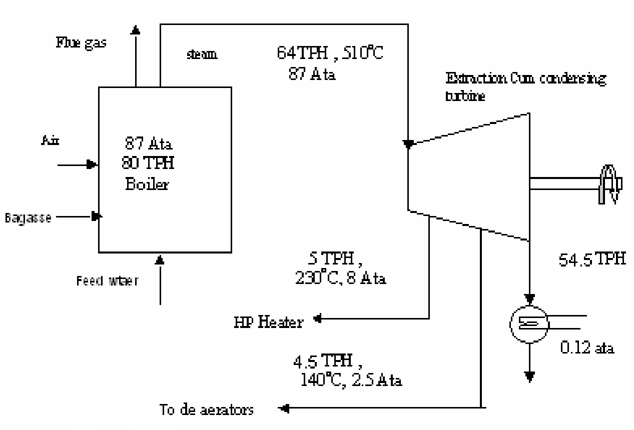

Fig 2 — Off season flow diagram

Other parameters are as follows: theoretical power output, 15.12 MW; efficiency of generator, ($\eta_{turbine}$), 98%; efficiency of generator, ($\eta_{generator}$), 98%; power generated, (*$\eta_{turbine}$ 15.12, *$\eta_{generator}$ 14.5 MW); power needed for plant operation, 4.5 MW; and power exported to grid, 10 MW. Net power out put = (power generated + exhaust steam to process).

Process Heat Calculation

Steam values are as follows: steam entering into turbine, 64TPH; steam extraction at 8 ata, 5 TPH; steam extraction at 2.5 ata, 4.5 TPH; and steam to condenser, 55.5 TPH.

Steam for centrifugal at 8 ata and 230°C = 3.5TPH or 0.972 kg/s. Steam to process at 2.5 ata and 140°C = 49.5 TPH or 13.75 kg/s. Therefore, heat input to process application = (0.972* 2760.5) + (13.75* 2355.97) = 35.5MW. Net power output = 50 MW. Overall efficiency of proposed cogeneration plant = 65 %.

Off season Output

During off-season period (Fig. 2), there is no need of steam for the process. Therefore, power output from the turbine will be more. Steam values are as follows: Steam for HP heaters at 8 ata, 5 TPH; steam for centrifugal 8 ata, 0 TPH; steam for deaerator at 2.5 ata, 4.5 TPH; and steam to process at 2.5 ata, 0 TPH. Table 3 shows plant parameters.

Power output from Turbine

Work output = $m_1 (h_1 - h_2) + (m_1 - m_2)(h_2 - h_3) + (m_1 - m_2 - m_3)(h_3 - h_4)$

where, m_1, 64 TPH or 17.77 kg/s; m_2, 5 TPH or 1.39 kg/s; $m_{3,}$ 4.5 TPH or 1.25 kg/s; m_4, 55.5 TPH or 15.41 kg/s. Therefore, work out put = 17.77*(3415-2905.6) + 16.38* (2905- 2760) + 15.13(2760- 2355.97) = 16.97 x 10^6 W.

Other parameters are: theoretical power output, 16.97 MW; efficiency of turbine($\eta_{turbine}$), 98%; efficiency of generator($\eta_{generator}$), 98%; power generated (16.97* $\eta_{turbine}$ * $\eta_{generator}$), 16.3 MW ; power needed for plant operation, 1.3 MW; and power exported to grid, 15 MW.

Techno-Economic Analysis

Economic analysis gives: revenue from bagasse in the existing mill, 6,00,000 units/y; purchase power from TNEB grid, Rs 4.5/unit; cost of purchased power, Rs 27 lakhs; bagasse sell to TNPL, Rs 750/tonne; cost acquired by bagasse sell to TNPL, Rs 75 lakhs; and revenue in the existing mill, Rs 48 lakhs.

Cost Benefit Analysis

Season data is as follows: period, 172 days; power export to grid, 10,000 units/h; power cost given by TNEB using bagasse as a fuel, Rs 3.15/unit; total sales during season, Rs 13 crores; wheeling charges to TNEB, Rs 0.26 crores; and net saleable cost; Rs 12.74 crores.

Off season data is as follows: period, 100 days; power export to grid, 15,000 units /h; power cost given by TNEB using bagasse and coal as a fuel, Rs 2.90/unit ; total sales during off season, Rs 10.44 crores; wheeling charges to TNEB, Rs 0.26 crores; and net saleable cost; Rs 10.24 crores.

Payback period Analysis

Payback period analysis is as follows: total revenue per year, Rs 22.98 crores; coal + biomass cost during off season, Rs 5 crores; interest for capital investment, Rs 5 crores; maintanence, Rs 0.25 crores; contingency; Rs 0.25 crores, total expenses, Rs 10.5 crores; net profit; Rs 12.48 crores; project cost, Rs 60 crores; and payback period, 4 years 9 months.

Environmental Benefit Analysis

It is as follows: power export to grid during season (172 days), 41.28 GWh; power export to grid during off season (100 days), 36 GWh; total power exported in one year, 77.28 GWh; emission reduction, 62950.75 tonnes/y; and annual revenue at Rs 270 / tonne of CO_2 reduction, Rs 1.7 crores.

Conclusions

Cogeneration in sugar mill (2500 TCD) study provides that electricity generation capacity can be increased from 3 MW to 15 MW during the season periods and plant can generate 16.5 MW during the off-season period. Hence, plant can export nearly 41 million units of electricity in the season (172 days) and nearly 36 million units of electricity in the off-season (100 days). Thus, sugar mill in one year can offset nearly 62950.75 tonnes of CO_2. Payback period of project is 4 years 9 months. Project if considered for CDM will get revenue of Rs 1.7 crores per year.

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Nomenclature

m_1 - Mass flow rate of steam to turbine
m_2 - Mass flow rate of steam from first extraction
m_3 - Mass flow rate of steam from second extraction
m_4 - Mass flow rate of steam to condenser
h_1 - Enthalpy of super heated steam at turbine's inlet
h_2 - Enthalpy of steam at first extraction
h_3 - Enthalpy of steam at second extraction
h_4 - Enthalpy of steam at turbine's outlet
h_{ca} - Enthalpy of condensate leaving the condenser
TNEB - Tamil Nadu Electricity Board
TNPL - Tamil Nadu Newsprint and Paper Limited

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