Intensification of power generation in sugar mills through modernization

RA Chandgude and PG Patil

*Sugar Engineering Division, Vasantdada Sugar Institute, Pune, India; ra.chandgude@vsisugar.org.in*

**Abstract**  
Biomass-based cogeneration in the sugar industry is a useful alternative to meet the shortfall of energy by using sugarcane residue, an environment friendly fuel available with sugarcane mills across the globe. The energy obtained from biomass is renewable energy or green energy. This paper presents data collected from cogeneration plants in Indian sugar mills and its analysis. The observations and findings of this study will be helpful in improving technical parameters in other sugar mills. Power generation, captive power consumption and power export to grid per tonne of cane crushed are the key factors used for comparison. Power export depends on steam flow cycle, energy conservation in terms of process steam and captive/in house power consumption. Power generation and power export to grid increases with the installation of high-pressure boilers with pressures of 67 bar, 87 bar, 110 bar and 125 bar and temperatures of 520-560°C. Modernization related to cogeneration in existing and new sugar mills can be implemented to reduce the in-house power and process steam consumption. Energy efficiency in cogeneration plants can be achieved by installation of high-efficiency modern equipment, reactive power management, optimum steam pressure and temperatures, and appropriate loading on turbo generator sets. Hence, economically, bagasse based co-generation is a viable alternative to meet the ever increasing energy demand in India. By improving machinery performance, power generation is increased and in-house power consumption is reduced, which results in higher power export to grid. Installation of cogeneration plants in sugar mills increases the revenue of sugar mill and subsequently improves the rural and national economy. The capital investment is about INR 50 million per megawatt with a payback period of around 5 years.

**Key words**  
Biomass, surplus power, cogeneration, high-pressure boilers

**INTRODUCTION**

India’s significant and continued economic growth is placing a heavy demand on electrical energy and this has increased the shortage of power. The average electricity shortage in 2015-16 (up to October 2015) is at 2.4% of the normal energy requirement and about 3.4% at peak load. Electricity production in India is predominantly coal based, and this has high pollution potential and there are losses associated with transmission and distribution. The focus has now shifted to decentralized and renewable energy generation. The role of renewable energy should be considered as alternative sources to the existing fossil fuel sources to become a key solution to the energy needs of the country. Biomass is one of the main sources of renewable energy and bagasse is an important biomass available in abundance in the sugar industry. The increase in bagasse based cogeneration by sugar mills has had a positive impact on the rural economy.

This paper presents data collected from cogeneration plants in Indian sugar mills and its analysis. The observations and findings of this study will be helpful in improving technical parameters in other sugar mills.

**GREEN POWER FROM SUGARCANE**

Biomass is a source of renewable energy and can be easily converted into energy. The major biomass, i.e. sugarcane residue, is an environmental friendly fuel (Anthony et al. 1994) available from sugar mills, and in India, the states of Uttar Pradesh, Maharashtra, Karnataka Tamil Nadu Andhra Pradesh, Bihar, Gujarat, Punjab and Haryana have many sugar mills. Bagasse is considered as the main source of fuel in sugarcane-based power generation. Sugarcane trash, i.e. the dry and green leaves left in the field at time of harvesting, can also be collected along with the cane to provide additional 7.5-10% biomass on cane as additional fuel to boost cogeneration (Morris and Waldheim 2001). Roots of cane also have significant fibers, if considered for power generation; they can add a further 2-3.5% additional fiber when made available.
It is estimated that total thermal energy available in cane is 640-860 kWh/t of cane. The present power generation level is 110-162 kWh/t of cane (Reddy 1994). The sale price of electricity ranges from INR 4.50 to 6.59 kWh of electricity, depending upon the tariff fixed by the respective State Electricity Regulatory Commission.

INDIAN COGENERATION POTENTIAL AND STATUS

There were 538 operational sugar mills in India during the season 2015-16, with a crushing capacity of 2.3 Mt/day with sugar production capacity of over 30 Mt per year. About one-third of these sugar mills also have by-product units. The average crushing capacity of these sugar mills is 4000 t/day/unit; they are in private, public and cooperative sectors. In the near future, 161 new sugar mills will be established.

The potential from these 538 operating and 161 proposed sugar mills stands at 16,404 MW of installed capacity of power generation and 10,846 MW exportable surplus power capacity during the seasonal operation. Currently, cogeneration has been commissioned in 276 sugar mills with installed cogeneration capacity of 5,424 MW and 3,539 MW exportable capacity during seasonal operation. There is potential for cogeneration of about 10,979 MW and 7,307 MW of exportable surplus during seasonal operation.

State and Central Governments have encouraged this by:
- A Renewable Energy Certificate mechanism that provides a market-based instrument that can be traded freely for additional income.
- A subsidy from the Ministry of New and Renewable Energy up to INR 80.0 million per project.
- An income-tax subsidy for 10 years from the State Government of Maharashtra.
- An exemption on cane purchase tax at 3% on cane price for 10 years.
- Equity participation of 5% of project cost by the State Government of Maharashtra.
- Switchyard and transmission line subsidies from State Governments.

COGENERATION PRINCIPLE

Cogeneration is the installation of steam turbines and high-pressure boilers for efficient surplus power generation that is to be exported to the grid. The exhaust of steam turbines is used as process heat, utilized in removing water from juice in order to make dry products such as sugar and molasses. The energy in the exhaust steam is utilized for the process heat requirements. The application, in which fuel meets the demand of process heat requirement and electrical power, is known as cogeneration.

The major advantages of simultaneous production of heat and power energy are:
- Environment friendly.
- Reduced dependency on fossil fuel.
- Lower fuel transportation cost.
- Lower gestation period.
- Reduction in electrical transmission losses.
- Increase in local employment.
- Helps bridge the gap between demand and supply of electricity.
- Facilitates improved viability and profitability for sugar mills.

COGENERATION ROUTES ADOPTED IN INDIAN SUGAR MILLS

In Indian sugar mills, cogeneration is carried on through two mechanisms, back pressure and the extraction-cum-condensing route.

Back-pressure route

Here, steam enters the turbine chamber at high pressure and expands to low or medium pressure. While generating power, it also meets process steam demand. This is highly efficient cogeneration route resulting in maximum saving in bagasse.
There are two types:
- **Straight back pressure**: This is the most widely used back-pressure type turbine. Its aim is to expand the available steam through the turbine stages and use it for process.
- **Uncontrolled extraction back pressure**: In an uncontrolled extraction type, a tap is provided at a predetermined stage for drawing out the steam for process heating. The uncontrolled extraction steam is used for process and low pressure heating applications such as a de-aerator.

**Extraction-cum-condensing route**

Here, the extraction-cum-condensing turbines are used as captive generating sets where there is variation in process steam demand as well as variation in cane crushing. The surplus steam condenses in the surface condenser. The excess steam passes through the condenser, resulting in heat loss in the condenser. This route can be operated in-season and off-season.

There are three types:
- **Straight condensing**: In a straight condensing type steam turbine, the heat energy of the steam is completely converted into kinetic (mechanical energy - torque) energy. The mechanical energy is utilized to generate power. The straight condensing type finds application in industries where power generation is prime objective, e.g. a captive power plant.
- **Uncontrolled extraction condensing**: In an uncontrolled extraction type, a tap is provided at a predetermined stage and a partial stream of steam is drawn out of the turbine. The uncontrolled extraction of steam is deployed for process applications (with smaller quantity of steam flow and set temperature requirements) and low pressure heating application such as a de-aerator and process. This turbine setup is usually deployed in independent power plants, captive power plants and cogeneration plants.
- **Controlled extraction condensing**: A control valve integrated with the steam path is provided at a predetermined stage. A partial steam flow is drawn out of the turbine at a constant pressure as per the process requirement. There are basically two types control valves, i) diaphragm/grid; and ii) passing/throttle valve, that control the flow of steam at a preset pressure accommodating the seasonal variation in turbine load. In some cases a nozzle/port is provided at a predetermined stage and an uncontrolled high-pressure steam flow/bleed is drawn out of the turbine. This tap is provided before the controlled extraction in the steam path of turbine. Its utility is found mainly in low-pressure heating requirements like de-aerator and process.

**RESULTS FROM COGENERATION PLANTS**

Vasantdada Sugar Institute conducted a critical analysis of the performance of 34 cogeneration projects in Maharashtra during the 2012-13 and 2013-14 seasons. We based this on data from the government-approved energy auditing agencies. Based on these results, some sugar mills were selected for further present study. The configuration and working results of these sugar mills are given in Figure 1 and Tables 1-3, and calculations based on standard assumptions are given in Table 4; the study assumes a 3500 t/d basis sugar plant operating on a 22-h basis, different boiler pressures, mill wet bagasse having GCV 9.5 MJ/kg, steam 40% on cane, bagasse 28% on cane and turbine extraction-cum-condensing route.

![Fig. 1. Pressure versus fixed, variable and total costs.](image)
Table 1. Configuration of some sugar mills.

<table>
<thead>
<tr>
<th>Sugar factory</th>
<th>Crushing capacity (t/d)</th>
<th>Boiler details (rated parameters)</th>
<th>TG set details</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pressure bar</td>
<td>Temperature °C</td>
</tr>
<tr>
<td>Kranti SSK.</td>
<td>5000</td>
<td>45</td>
<td>440</td>
</tr>
<tr>
<td>Rajarambapu Patil SSK</td>
<td>2500</td>
<td>45</td>
<td>500</td>
</tr>
<tr>
<td>Shree Pandurang</td>
<td>4500</td>
<td>67</td>
<td>485</td>
</tr>
<tr>
<td>Malegaon SSK</td>
<td>4000</td>
<td>67</td>
<td>515</td>
</tr>
<tr>
<td>Rajarambapu Patil SSK</td>
<td>4200</td>
<td>67</td>
<td>515</td>
</tr>
<tr>
<td>Daund Sugars</td>
<td>3500</td>
<td>67</td>
<td>515</td>
</tr>
<tr>
<td>Someshwar</td>
<td>4200</td>
<td>110</td>
<td>540</td>
</tr>
<tr>
<td>Shankar SSK</td>
<td>2500</td>
<td>110</td>
<td>540</td>
</tr>
<tr>
<td>Private Sugar Mill</td>
<td>5000</td>
<td>125</td>
<td>550</td>
</tr>
</tbody>
</table>

BP- Back pressure; DEC- Double extraction-cum-condensing; TEC- Triple extraction-cum-condensing.

Table 2. Working results cogeneration sugar mills for season 2014-15.

<table>
<thead>
<tr>
<th>Sugar factory</th>
<th>Steam % cane</th>
<th>Power generated</th>
<th>Auxiliary power consumption</th>
<th>Export power</th>
<th>Project cost INR Million/MW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sugar</td>
<td>Cogen</td>
<td>Total</td>
<td>kWh/t of cane</td>
</tr>
</tbody>
</table>

Table 3. Parameters from mills under study.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Maximum (%)</th>
<th>Minimum (%)</th>
<th>Benchmark / Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant load factor (PLF)</td>
<td>94</td>
<td>46</td>
<td>More than 60% (As per MERC)</td>
</tr>
<tr>
<td>Export power efficiency</td>
<td>82</td>
<td>40</td>
<td>More than 65%</td>
</tr>
<tr>
<td>Auxiliary power consumption for cogeneration plant (% on cogeneration installed power)</td>
<td>10.24</td>
<td>6.55</td>
<td>8.5% (As per MERC)</td>
</tr>
<tr>
<td>Auxiliary power consumption for sugar Plant (kWh/t of cane)</td>
<td>23.09</td>
<td>19.58</td>
<td>23 to 24 kWh/t</td>
</tr>
<tr>
<td>kWh generated per t of cane</td>
<td>115</td>
<td>70</td>
<td>100 to 110 kWh/t</td>
</tr>
<tr>
<td>Steam % on cane</td>
<td>48.59</td>
<td>36</td>
<td>40- 42%</td>
</tr>
<tr>
<td>Overall cogeneration plant efficiency</td>
<td>85</td>
<td>60</td>
<td>70- 75%</td>
</tr>
<tr>
<td>Station heat rate (kcal/kWh)</td>
<td>6101</td>
<td>3098</td>
<td>4400 - 4700 kcal/kWh</td>
</tr>
<tr>
<td>Project cost/ capital expenditure (INR Million/MW)</td>
<td>54.5</td>
<td>33.5</td>
<td>38.5 - 67 to 87 bar</td>
</tr>
</tbody>
</table>

MERC- Maharashtra Electricity Regulation Commission.
Observations based on these data are:

- Power generation and power export are directly proportionate to pressure and temperature of boilers (Verbanck et al. 2001).
- In-house power consumption increases with increase in boiler pressure and temperature. There is increase in fixed costs with an increase in pressure, but variable costs decrease simultaneously. Total operating costs decrease with increases in boiler pressure and temperature.
- Revenue generation in a 87 bar boiler is INR 189.94 per t of cane - revenue generation is 13.25% higher for a 110 bar boiler and 28.12% higher for a 125 bar boiler.

**PERFORMANCE IMPROVEMENTS IN COGENERATION PLANTS**

The key areas that have major impact on power generation and export are:

- Use of an efficient cogeneration route.
- Reduction of process heat energy.
- Reduction of internal use of electrical energy in sugar process and cogeneration.
- Heat recovery from all waste steam for process and cogeneration.

As the sugar industry is a highly energy-intensive sector and consumes energy in all its forms, viz. heat, mechanical and electrical, there is considerable loss of energy during the process of conversion from one form to the other and the correct selection of the system, technology and equipment play a vital role in the overall energy conservation.

Adoption of modern concepts, such as high pressure boilers, TG sets, condensing and cooling systems, automation, VFD drives, energy efficient motors, reactive power management, choice of transmission gears, high-efficiency pumps, correct sizing of all equipment, reducing energy losses due to leakages, radiation, friction and reduction in downtime etc., are the important aspects to be taken care of while aiming at energy conservation.

By implementing above measures, there will be increase in overall efficiency of sugar mill as well as cogeneration plant, mainly resulting into increase in power generation and export per tonne of cane.
ENERGY CONSERVATION MEASURES

By installing high-pressure boilers and turbo-generator sets, the power generation in cogeneration can be increased (Kong Win et al. 2001) up to 110-162 kWh/t of cane. By installing efficient machinery, captive power consumption can be reduced (Mydur 1994) to 20-22 kWh/t of cane and for cogeneration 5.5-6% on installed power for the back-pressure route and 8-8.5% on installed power for the condensing route. Such phase-wise modernization and energy conservation methods brought down the steam % cane to 32-38% from 50% on cane (Avram-Waganoff 1994).

Electrical energy conservation measures:
- Installation of AC VFD drives for mills in place of steam turbines.
- Installation of AC or AC VFD drives for fiberizer/shredder in place of steam turbines and slip ring motors.
- Installation of AC VFD for ID/FD/SA fans, boiler feed water pumps, transfer pumps, bagasse and coal feeders, cooling tower circulation pumps and fans.
- Installation of AC or AC VFD drives for cane preparatory devices, cane handling system, feeder tables, cane carriers, inter rake carriers, fuel and ash handling system, screened juice pumps, raw and sulphur juice pumps, massecuite and magma pumps for B and C continuous pans.
- Installation of planetary gear boxes for mills, crystallizers, cane carriers, rake carriers, pug mills, sugar mixers, massecuite pumps, sugar conveying system.
- Carrying out reactive power management by installing capacitors/harmonic filters in the form auto power factor correction for power factor improvement and harmonic separation.
- Installation of energy efficient motors.

Thermal energy conservation measures:
- Configuration of the evaporator to be converted to a quadruple/quintuplet effect with extensive vapour bleeding arrangement (Mason 2001).
- Raw juice primary heating by vapor line juice heater.
- Raw juice secondary juice heating with condensate.
- Sulphited juice heating in two stages with vapors from 2nd and 3rd body of evaporator set.
- Flash heat recovery.
- Clear juice heating by vapors from first body evaporator set.
- Utilization of 3rd body vapors for A and B pans.
- Low head batch pans with multi downtake to improve circulation ratio at low vapour pressures and temperatures with mechanical circulators.
- Utilization of 2nd body vapors for boiling C pans.
- Installation of plate heat exchangers for preheating the boiler make up water with 3rd body condensate.
- Continuous pans for B and C massecuites.
- Waste heat recovery for sulphur burners.
- Sugar washing superheated water by 1st body condensate.

Schemes that determine overall efficiency of cogeneration and sugar plant are:
- Fiber % Cane - In India, fiber % cane (Mason 1995) varies between 12.5 and 18.0% depending upon the variety of the cane, age of the cane, time lag between harvesting and crushing, etc. The cane that has high fiber content will have a lower sugar content but it will generate more power. Hence, using a fiber-rich variety for the sake of enhancing the power output is profitable in case of low sugar prices.
- Exhaust Steam Pressure and Temperature - The process exhaust steam pressure and temperature (Reddy 1994) varies between 1.5 bar and 123°C to 3.0 bar and 130°C. At the time of starting the sugar mills, the exhaust pressure is very low and after 40 to 45 days the exhaust pressure is on higher side. Higher the processes exhaust pressure and temperature, lowers the power generation. Ultimately it affects the power export. To improve power export efficiency always keep clean heating surfaces of process equipment. A standby evaporator set should be considered in cogeneration sugar plant to avoid cleaning period.
- Bagasse Saving - In sugar mills, about 0.75% bagcillo is used for vacuum filter, but by installing decanters instead of vacuum filters, this bagcillo can be saved and used to generate additional power.
- Installation of High Pressure Heaters - High pressure heaters in boiler circuit will increase the boiler feed water temperature. By keeping continuous optimum inlet pressure and temperature, minimum blow down, good quality of feed water, keeping internal and external surface clean, etc will also save bagasse.
- Bagasse Drying - Bagasse drying increases calorific value (Nanda Kumar et al. 2001; Maranhao 1994). The last mill bagasse with a 50% moisture content has a net calorific value of 7.54 MJ/kg, but dried bagasse with 10%...
moisture content possess calorific value of 15.7 MJ/kg - drying to 10% moisture content almost doubles the net energy value. Every 1% reduction in moisture of bagasse increases boiler thermal efficiency around by 0.5%.

- Diffuser Technology - The major electrical energy consuming section in sugar mill is the Juice Extraction Plant. In a standard 3500 t/d milling plant, the power consumption is 2050 kWh whereas in a 3500 t/d diffuser plant power consumption in 1475 kWh. The reduction in power consumption is about 575 kWh.
- VFD for Fibrizer and Shredder – Conventionally, a fibrizer is installed with steam turbines and 11 kV slip ring motors and rotor resistance starter. Currently, a fibrizer is installed with cage motors and VFD drives. The losses on account of slip resistance and low power factor in conventional methods are eliminated in the VFD drive system. In addition, the conventional operating rpm of a slip ring motor is improved in VFD system, resulting in an improved preparatory index, mill extraction and reduction in power consumption of the mill station.
- Juice and Water Flow Meters - By replacing the conventional juice and water weighing scales with flow meters, power consumption of pumps for raw juice and imbibition water can be saved.
- Planetary Gears - The transmission efficiency of the worm and worm-wheel drive is about 50-55% and that of enclosed worm and worm-wheel gear is about 60%. Installing planetary gear by changing inefficient gear system the energy transmission loss can be reduced.

CONCLUSIONS

There is growing interest in using a higher proportion of sugarcane biomass for renewable energy generation because of the rising prices of fossil fuels and concern about climate change. Bagasse-based surplus power generation has proved to be an economically viable alternative to meet the existing shortfall of electrical energy in India.

During the fiscal year 2015-2016, the utility sector had an electricity shortfall of 23.6 million MWe. Electricity from cogeneration is an important alternative to meet this shortfall. The current export of power from sugar mills in India is 3,539 MWe and the total potential is 10,846 MWe.

High-pressure boilers show higher efficiency and revenue generation. It is thus recommended to install boilers with pressure 87-125 bar and temperature 520-560°C for cogeneration in sugar mills. By improving machinery performance, power generation is increased and captive power consumption is reduced ultimately resulting in more power export to grid. Hence, sugar mills can increase their profitability by installing cogeneration and subsequently undergoing modernization.

ACKNOWLEDGEMENT

We thank Director General Shri Shivajirao Deshmukh for encouraging the study on ‘Intensification of Power Generation in Sugar Mills by Modernization’.

REFERENCES

Intensification de la production d’énergie dans les sucreries par la modernisation

Résumé. La cogénération dans l’industrie sucrière est une alternative intéressante pour répondre à la pénurie d’énergie en utilisant les résidus de canne à sucre, un carburant favorable pour l’environnement et disponible dans les sucreries à travers le monde. L’énergie obtenue à partir de la biomasse est une énergie renouvelable ou énergie verte. Cet article présente les données recueillies des centrales de cogénération en sucreries indiennes et leurs analyses. Les observations et les conclusions de cette étude seront utiles pour l’amélioration des paramètres techniques dans d’autres sucreries. La production d’électricité, la consommation locale d’énergie et l’exportation de puissance sur la grille par tonne de canne écrasée sont les principaux facteurs utilisés pour la comparaison. L’exportation de puissance dépend du cycle de débit de vapeur, de la conservation de l’énergie en termes de vapeur de vapeur et de la consommation d’énergie locale. La production d’électricité et l’exportation vers la grille augmentent avec l’installation de chaudières à haute pression (67, 87, 110 et 125 bar, et 520-560°C). La modernisation, associée à la cogénération dans les sucreries existantes ou nouvelles, peut être implémentée pour réduire la demande locale d’énergie et de vapeur. L’efficacité énergétique des centrales de cogénération peut être atteinte par l’installation de matériel moderne de haute efficacité, par la gestion de l’énergie, des pressions et températures de vapeur optimales, et l’opération appropriée des turbo générateurs. Par conséquent, sur le plan économique, la cogénération basée sur la bagasse est une alternative viable pour répondre à la demande toujours croissante d’énergie en Inde. En améliorant les performances des machines, la production d’énergie est accrue et la consommation interne est réduite, ce qui se traduit par l’exportation de puissance plus élevée sur la grille. L’installation de centrales de cogénération dans les sucreries augmente le revenu et améliore l’économie rurale et nationale. Les investissements en capital sont approximativement de INR 50 millions par mégawatt avec une période de récupération d’environ 5 ans.

Mots-clés: Biomasse, excédent d’énergie, cogénération, chaudières à haute pression

Sentences from the text:

- La cogénération dans l’industrie sucrière est une alternative intéressante.
- L’énergie obtenue à partir de la biomasse est une énergie renouvelable ou énergie verte.
- Les données recueillies des centrales de cogénération en sucreries indiennes.
- Les observations et les conclusions de cette étude seront utiles pour l’amélioration des paramètres techniques.
- La production d’électricité, la consommation locale d’énergie, et l’exportation de puissance sur la grille.
- L’efficacité énergétique des centrales de cogénération peut être atteinte par l’installation de matériel moderne.
- En améliorant les performances des machines, la production d’énergie est accrue.
- Les investissements en capital sont approximativement de INR 50 millions.
- La période de récupération est environ 5 ans.