Performance Analysis of Bagasse Based Sugar Cogeneration Power Plant in Grid Electricity Generation

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Abstract: Cogeneration power plants in sugar factories utilize bagasse to simultaneously produce steam and electricity. The electricity generated in bagasse cogeneration units is primarily used for internal consumption, with a significant portion supplied to the state grid at a predetermined price, influenced by local demand and supply conditions. To maximize the economic viability of these operations, continuous analysis of input-output power balance is essential. The efficiency of cogeneration systems is crucial to their success. This paper investigates the electricity generation potential from bagasse produced at the Pravara Sugar Factory (PSF) in Ahmednagar district. The 30 MW sugar plant has a total installed capacity of 72,000 TCD and produces an average of 233,280 MT of bagasse over a 160 to 180-day operational period. This substantial bagasse output highlights a significant opportunity for electricity generation, which could help alleviate power shortages in the region. The paper evaluates the electricity generation capabilities of the Pravara Sugar Factory, demonstrating its potential to contribute to the local electricity supply.

Keywords: Cogeneration, cane sugar production, bagasse, electricity, Pravara Sugar Mill.

1) I. INTRODUCTION

Cogeneration refers to the simultaneous production of two forms of energy from a single fuel source, typically heat and either electrical or mechanical energy. In traditional power plants, fuel combustion in a boiler generates high-pressure steam, which drives a turbine connected to an alternator for electricity generation. The exhaust steam is usually condensed back into water for reuse in the boiler. However, this process results in a significant loss of heat, limiting the efficiency of conventional power plants to around 35%. In contrast, cogeneration plants can achieve efficiency levels between 75% and 90%. This increased efficiency is made possible because the low-pressure exhaust steam is utilized for heating purposes, rather than being wasted in the condensation process.

In India, sugar mills utilize their own bagasse to operate during the milling season, generating steam to power their boilers and turbines, while also producing electricity for internal use. Any surplus energy can be exported to the distribution grid. Bagasse, a byproduct of sugarcane milling, has considerable energy potential as a combustion fuel for power generation. Sugarcane cultivation occurs in various tropical and subtropical regions of India, with harvesting typically taking place every 9 to 24 months, depending on the variety and growing conditions.

A typical sugar factory requires significant electricity for steam generation, operating at high pressures of 99 bars, which can yield approximately 130 kWh per tonne of cane processed. Evaluations of bagasse cogeneration demonstrate that the cost of electricity generated within the sugar industry is competitive with that of fossil fuels. This positions the sugarcane industry as a key player in the transition to sustainable energy solutions. The Pravara Sugar Factory began with a milling capacity of 4,000 tonnes of cane per day (TCD), which has now increased to 7,200 TCD, resulting in an optimal sugar production of 884 tonnes per day (TPD).

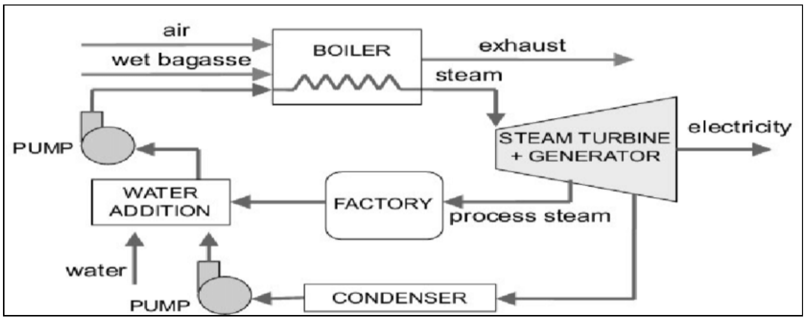


Fig.1 shows cogeneration in sugar plant

II . PRAVARA COGENERATION POWER PLANT CAPACITY

The primary objectives for establishing the 30 MW bagasse cogeneration plant by Pravara Sugar Company included utilizing excess bagasse as fuel to generate additional power for sale to the grid, thus creating a supplementary revenue stream alongside sugar sales. This initiative aimed to achieve self-sufficiency in electricity generation and supply by selling surplus power to the state grid. Additionally, the plant sought to mitigate the environmental impact and costs associated with disposing of excess bagasse. Commissioned in April 2018, the 30 MW cogeneration plant successfully addressed the internal electricity demand of 6.5 MW, while generating an excess of 18 MW for sale to the grid.

1) A. Characteristics of Bagasse

The bagasse that exits the factory mills consists mainly of a fibrous outer layer and an inner portion known as "prit," which is a soft, smooth parenchymal tissue that exhibits high hygroscopic properties. Prit primarily contains sugars, cellulose, pentosans, hemicellulose, and lignin, along with traces of wax and minerals. The properties of bagasse are influenced by the type of sugarcane, its age, and the harvesting method employed. On average, bagasse generated has a moisture content of 49-52%, a fiber content of 47.4%, and 2.3% solute materials. At a moisture content of 50%, bagasse possesses a gross calorific value (GCV) of 9,600 kJ/kg and a net calorific value of 7,600 kJ/kg. When completely dried, bagasse exhibits a GCV of 19,400 kJ/kg.

The average fiber content in sugarcane ranges from 10% to 17% by mass, typically falling between 12% and 15%, while the amount of bagasse produced accounts for approximately 24% to 30% of the weight of the sugarcane. Bone-dried bagasse has a gross calorific value of 17,632 kJ/kg, while at 50% moisture content, its net calorific value is measured at 8,816 kJ/kg. The following table provides a detailed composition of mill bagasse.

Table 2.1 Sugar plant bagasse compositions.

Compositions	Percentage	Average composition
Moisture	46-52	50
Fibre	43-52	47.7
Soluble solids	2-6	2.3

From **Table 1**, it is observed that bagasse primarily consists of moisture and fiber, with traces of soluble solids. The following physical properties of bagasse are also noteworthy:

i)It is odorless.
ii) It has a specific weight of 250 kg/m³.
iii) Its color ranges from white to light green. Compared to conventional fuels, bagasse has a relatively lower energy value. However, its availability at the factory and the reduced transportation costs associated with using it make bagasse a more suitable energy source for sugar factories, especially at lower moisture content levels.

2) B. Sugar Manufacturing Process

The natural sugar stored in sugarcane is extracted through a series of processes known as the sugar manufacturing process. This process typically involves several key steps, including juice extraction, juice clarification, evaporation, centrifugation, and drying and packaging. The main steps are as follows:

1. **Weighing and Preparation**: The cane is first weighed and then processed into small pieces using a fiberizer, which transforms the cane into a thin, fibrous form. The prepared cane is then transported to the milling set through a conveyor.
2. **Juice Extraction**: The prepared cane is crushed in the mill, where hot water (at temperatures of 60 °C to 70 °C) is added to extract as much juice as possible, leaving behind the bagasse. The bagasse is subsequently used as fuel in the boiler to produce steam.
3. **Steam Generation**: The steam produced is utilized to drive the prime movers of power turbines, mills, and fiberizers. The juice collected from the mills is referred to as "Mixed Juice," which is pumped into an auto-weighing tank.

4. **Juice Clarification**: The "Mixed Juice" is heated to 60 °C to 70 °C for clarification. During this process, it is mixed with milk of lime and sulfur dioxide (SO_2) gas. The pH of the juice is maintained between 6.9 and 7.1, resulting in what is known as "sulphited juice."
5. **Settling and Separation**: The sulphited juice is then heated to 100 °C to 105 °C and directed to settler vessels called clarifiers, where the mud settles at the bottom, and clear juice is obtained at the top of the chamber.

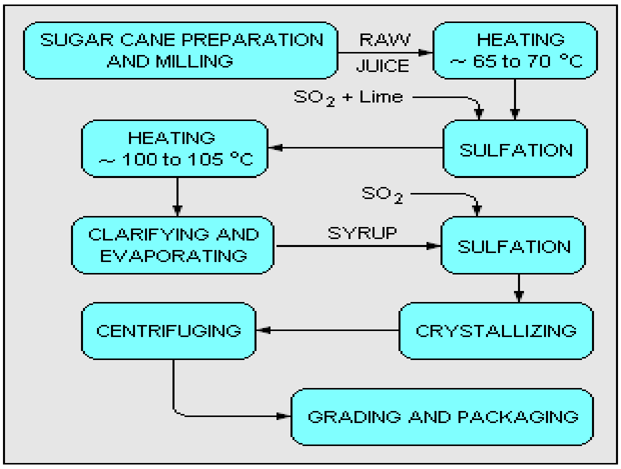


Figure 2. 1: Sugar manufacturing process

• The muddy juice is then pumped to a filter where the mud is removed and sent back to the "Mixed Juice." The separated mud is referred to as "Filter Cake," which is utilized as manure. The syrup is again treated with SO_2 gas, maintaining a pH level between 4.9 and 5.1.

- The sulphited syrup is then transferred to the supply tanks of the pan station. After being boiled under vacuum in the pan, small sugar crystals form, along with molasses, resulting in a product known as "Massecuite."
- After leaving the pan, the Massecuite is allowed to cool in a crystallizer before being pumped to centrifugal machines.
- In the centrifugal machines, sugar and molasses are separated. The sugar is then passed through a hopper to remove excess moisture, with hot and cold air applied via a blower.
- The separated molasses is collected in storage tanks.
- The final sugar product is sorted by passing it through graders of different mesh sizes. The sorted sugar is then packed into gunny bags, weighed, and sent to storage facilities.

3) III. PLANT ENERGY CONSUMPTION PROFILE

a) A. Energy Description of the Plant

Preliminary data collected from the plant aims to determine the specific energy consumption to analyze energy utilization and identify potential improvements in energy efficiency through benchmarking with similar industries worldwide. This data will help establish strategies for efficiency improvements in the factory.

The factory's primary energy consumption consists of electricity and steam, both generated from bagasse (a by-product of the sugar manufacturing process) and heavy furnace oil (HFO). Energy data—including electricity generated, steam produced, and the electricity imported and exported to/from the national grid—along with the quantity of cane crushed and sugar produced for the year 2021-22, has been collected from the factory using a specially developed data collection worksheet for energy utilization analysis and efficiency improvement assessment.

b) B. Energy Consumption Profile

The main sources of energy in the plant for the sugar manufacturing process are electricity and steam. The factory operates one steam turbine generator (cogeneration power plant) with a capacity of 30 MW. Of this, 3 MW is used for the sugar processing, 1 MW for the distillery, 0.5 MW for the colony, and 2 MW for auxiliary drives, such as DC motors, pumps, cooling fans, and variable frequency drives (VFDs).

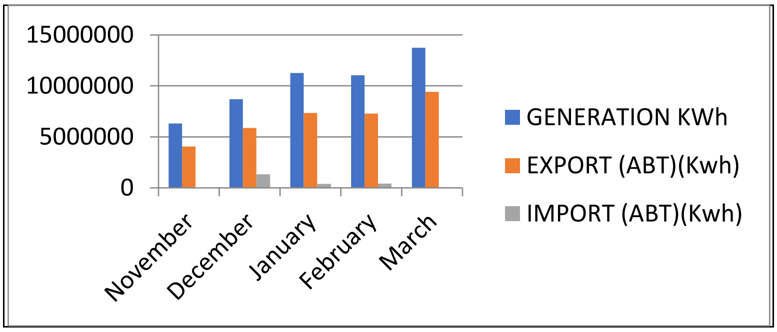
The monthly electricity generated by the plant, as well as the electricity imported and exported to the grid during the production period from October 2021 to June 2022, is summarized in the following table.

Table3.1:-2021-22 productionperiod electricityprofileofthe factory

Month 2021-22	GENERATIONKWh	EXPORT (ABT)(Kwh)	IMPORT (ABT)(Kwh)	COGEN (Kwh)	SUGAR Process (Kwh)
November	6320206	4062600	55800	746006	1564771
December	8687261	5869800	1315800	1284592	2808421
January	11261689	7358400	392400	1362412	2866998
February	11034827	7286400	433800	1292463	2797817
March	13755435	9403200	70200	1427518	2973003

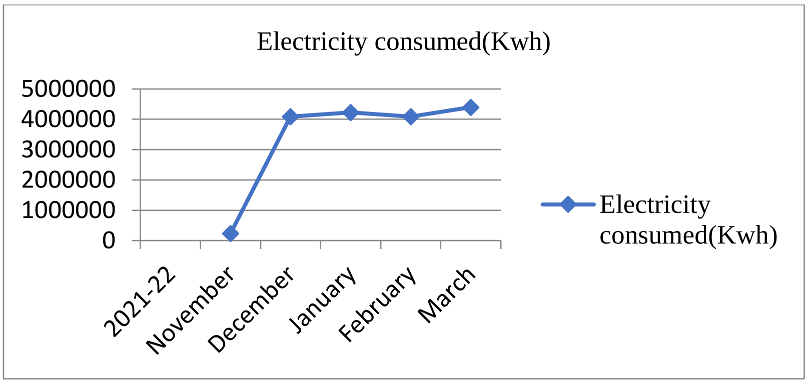
Generally total electricity formula as,

Generation+ Import=Electricity in Cogeneration + Electricity Sugar process+ Electricity export



Above graph shows electricity generation and export / import of energy profile .

The import and export balance of electricity indicated on above table is electricityconsumed bytheplant.Thetrendoftheelectricityconsumptionoftheplantisindicatedbelowonthefollowinggraph (figure 3.2)



B. *Figure3.2: PSF Electricity consumptionprofile(Oct.2021-22)*

Table 3.2 showsbagasseproduced,Sugarproduced,steam produced and electricity consumed in Mwh per month during production Period of the factory is indicated in the following table.

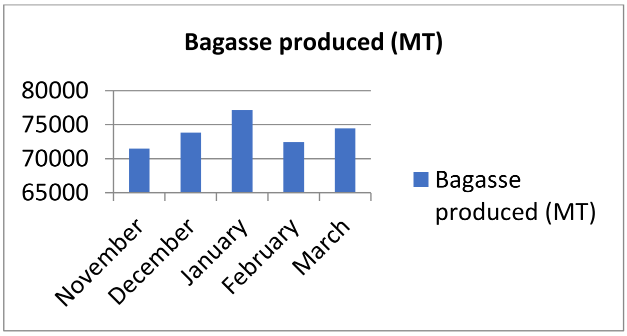
Table**3**.2 as below

Months 2021-22	Cane crashed (MT))	Bagasse produced (MT)	Steam produced (MT)	Electricity consumed (Kwh)	Sugar produced (MT)
November		71500	119400	231077	29870
December		73846	125647	4093013	30855
January		77192	137420	4229410	32550
February		72443	128150	4090280	31776
March		74470	137320	4400521	34310
Yearly/total	**1296000**	**369881**	**648000**	**17044301**	**159361**

The months of October and July are considered as the production months (from October to July) of the factory in a year, but there are no production registered in those months.

IV. BAGASSE SUPPLY AND ELECTRICITY GENERATION

A bar graph showing the total amount of monthly bagasse supplied to the plant.



From Figure 4.1, it is evident that the supply of bagasse to the plant is sufficient for electricity generation. However, a reduction in the amount of bagasse supplied directly impacts electricity generation. The plant is designed to burn more than 100 metric tons of bagasse per hour at optimal performance levels. Unfortunately, due to insufficient bagasse supply, the plant can no longer operate at its peak efficiency. This reduction in power output has led to a decrease in the electricity exported to the national grid, subsequently affecting revenue generation from power exports for the company.

The bagasse cogeneration plant is designed to operate with a single, high-volume boiler and a single high-capacity furnace. The steam generated is used to drive a single turbine, which has the capacity to generate up to 30 MW of power. Operating on a single furnace and boiler complicates cost control for plant operations. For instance, the costs of generating 10 MW and 30 MW are essentially the same, as the plant maintains constant operational conditions regardless of output levels. Consequently, it is economically unfeasible to run the plant at lower outputs, especially given the significant initial investment required for its setup.

Furthermore, if there is a breakdown or damage to any part of the system, regardless of how minor, the entire plant must be shut down for repairs. This is in contrast to other power plants composed of multiple units, which can continue to operate even if one unit is offline. Consequently, the plant becomes unavailable for power generation during repair and maintenance periods, rendering it unreliable in supplying power to the national grid.

1) V. CONCLUSION

This study concludes that the Pravara Sugar factory, with a designed cane crushing capacity of 7200 TCD, has substantial electricity generation potential of approximately 30 MW. However, this potential is not fully realized due to poor plant availability, primarily caused by breakdowns and a shortage of sugarcane for milling. To enhance steady milling and electricity generation, the plant should aim to increase its availability to around 90%. Investments in efficient electric drives, as opposed to steam turbine drives, and new high-efficiency boilers could position the sugar company favorably for electricity export generation.

Bagasse is the primary fuel for the cogeneration plant; therefore, its operation depends heavily on the availability of bagasse. The cogeneration plant has faced numerous challenges, particularly when MSEB disconnected electricity supply due to high electricity bills resulting from penalties accrued from the plant's failure to meet the terms of the power purchase agreement.

Cogeneration has been severely impacted by fuel shortages due to supply interruptions caused by strikes and cane shortages, leading to extended outages of the sugar mills and the cogeneration plant. The amount of bagasse produced from crushed cane has been insufficient to sustain boiler operation and ensure continuous power generation. Therefore, it is crucial to motivate cane suppliers to remain engaged in cane farming to ensure a consistent supply of bagasse for the cogeneration plant's operation.

The design of the cogeneration plant to utilize a single fuel source poses a significant challenge to sustainable cogeneration. Implementing multi-fuel boilers that can operate on more than one type of fuel could guarantee continuous power generation, particularly as cane farming and supply to the factory have deteriorated and are no longer sustainable.

The cogeneration plant, with a capacity of 30 MW, relies on a single high-capacity boiler and a single turbine prime mover. This design presents operational and maintenance challenges in maintaining consistent power generation since the entire plant must be shut down whenever repairs or maintenance are required. Additionally, the single boiler's high fuel demand means that when bagasse supplies are low, the entire plant must cease operations, ultimately affecting both cogeneration and sugar production within the factory.

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