

Bagasse based high pressure co-generation in Pakistan

Roman Ahmad

Department of Mechanical Engineering, UET Taxila, Pakistan

Abstract: *The paper reports on the assessment of the use of bagasse in sugar industry for high pressure cogeneration. Study was done on a sugar mill which has recently adopted this technology. This paper investigates the efficiency of season and off season operation of sugar mill, high pressure cogeneration technology is much more efficient in bagasse to steam ratio. During seasonal operation CHP efficiency is 76.8% and during offseason its value is 29.9%. Project initial cost is high but payback period is low. It will encourage other sugar mills in Pakistan for the development of high pressure co-generation system to meet increasing energy demands in the country.*

Keywords: *Bagasse Cogeneration, CHP Efficiency, Pakistan, Steam, Sugar Mills*

I. INTRODUCTION

Cogeneration, the concept of utilizing the same fuel resource for meeting with the requirements of both thermal and electrical energy, is gaining wide acceptance and encouragement world over. Cogeneration is widely practiced in the process Industries and any process industry which employs low pressure steam for the process has the potential to become a virtual power house. With increasing concern on global warming, the use of renewable energy, which has the positive effect of not adding to the global warming, is being looked at with renewed interest. The Cogeneration cycle with its higher cycle efficiency, compared to the power cycles, ensures that the scarce natural resources are put to better use.

Currently Pakistan has an installed electric generation capacity of about 20,000 MW, with the demand far exceeding this installed capacity and the access to electricity in Pakistan is about 62%. With a fast-growing economy and demography, the projection for the demand in 2030 is forecast to be 100,000 MW [1]. This calls for a tremendous growth rate in the power sector. The Government of Pakistan is making all out efforts to increase the generation capacity by tapping all conventional and non-conventional sources of electricity generation. Born out of this Government's initiative to augment the generation through non-conventional energy sources is the "National Policy for Power Cogeneration by Sugar Industry" promulgated in January 2008 [2]. The Government of Pakistan has recognized that Bagasse based Cogeneration can play a significant role in the country's efforts to augment the electricity generation.

Bagasse based cogeneration for power export to grid is considered as a reliable source of getting grid quality power and hence has been adopted by many countries. Each sugar mill can become a Power Generation Company to export power to the electricity grid by installation of high pressure boilers and extraction condensing turbo generators. Cogeneration plants with high pressure boilers and matching turbo generators, exporting power to grid, have been installed in sugar industries in India, Mauritius, Thailand, Re-Union Islands, United States, etc.

With the advantages like no transportation of fuel, reduction in transmission losses, eco-friendly power generation, etc. sugar plants could perform as supplementary power generating companies and make any country move towards self-reliance in power sector. Sugar Industry in Pakistan is ranked as country's second largest agro based industry after textiles. Presently there are about 83 sugar mills in Pakistan producing about 3.5 million Metric Tons of sugar per annum and total crushing capacity 597900TCD, which can produce approximately 3000 MW during crop season [3].

The subsequent sections of the study highlights the RSML's Cogeneration project, features of the plant and equipment, estimate the price at which it could sell its electricity and estimate of the capital cost etc. The results of this study could then be used by other environmentally conscious companies.

II. RSML's Background

RSML with the daily crushing capacity of 12,000 MT is one of the bigger mills in the sugar industry. Before the use of high pressure technology RSML produced combined heat and power from three 240 TPH boilers with operating parameters of 23 bar and 350C. All three boilers have power dumping grate stoker with pneumatic spreader system for fuel burning having bagasse firing efficiency of 82%. 110 TPH steam was used in process house and the remaining 130 TPH was used for 15 MW power generation using three turbo generators of capacity 4MW each and one with 6MW generation capacity. This whole power was consumed within the facility without any export to national grid.

III. Bagasse Production

The cane residue, what remains after the juice is squeezed out, is called the bagasse and is an excellent fuel. Ramzan Sugar Mills Limited (RSML) is a 12,000 TCD sugar plant operating for about 120 days in a year. The factory has a crushing capacity of about 500 TCH (on 24 hour basis). By considering utilization factor 90%, the total cane crushed for 120 days is 1296000 Tons. The bagasse generation in the plant is 30% on cane. After a deduction of 1% towards the use of bagacillo (fine bagasse used for enhancing filtration) in the sugar process and towards losses, a bagasse quantity of 29% on the cane crushed is available for use in the boilers. So, the total bagasse production is 375840 Tons. Using this bagasse, the company currently generates 60 MW of electricity for 150 days including crushing period of 120 days.

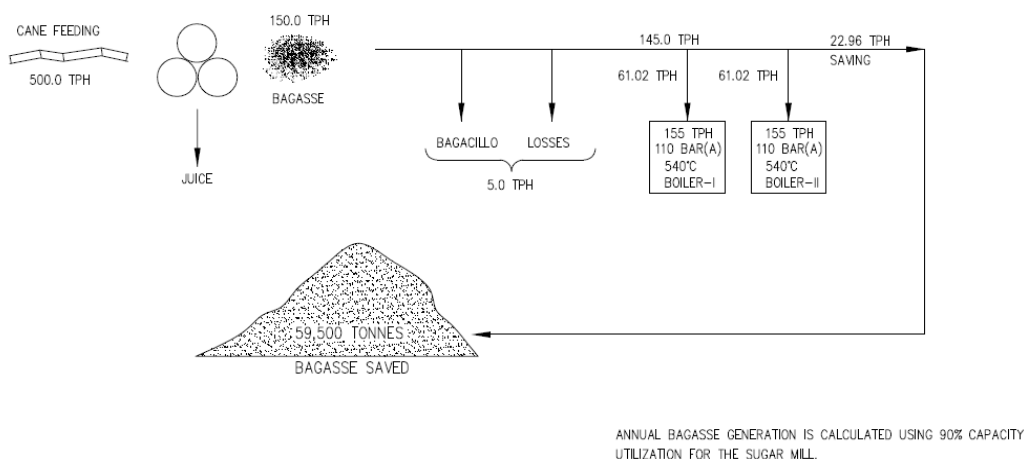


Figure 1: Fuel balance-season operation

IV. Design Fuels for the new Cogeneration Plant

The design and guarantee fuels for the cogeneration plant will be bagasse generated from the sugar mill and imported coal. The bagasse generated per hour will be 150 TPH. This 150 TPH bagasse will be with 50 % moisture content. Out of the generated bagasse, 5 TPH will be used for meeting the process requirements and the balance of 145 TPH will be made available for the Cogeneration boilers operation.

The design fuels, namely the bagasse and the imported coal, are with the HHVs of 9311.44 kJ/kg and 23,550.75 kJ/kg respectively. As the plant efficiencies, referred by the Regulatory Authorities are based on the Lower Calorific Value (LCV) of the fuels, the following gives the calculation of the LCVs from the HHVs for the design fuels. For solid fuels the HHV and the LCV, in SI units, are related by the following formula:

$$LCV = HHV - (218.55 * H_2\% + 24.28 * H_2O\%)$$

$$\text{For Bagasse, } LCV = 9311.44 - (218.55 * 2.895 + 24.28 * 50)$$

$$LCV = 7457.09 \text{ kJ/kg}$$

$$\text{For Design Coal, } LCV = 23,550.75 - (218.55 * 3.5 + 24.28 * 8.5)$$

$$LCV = 22,470.2 \text{ kJ/kg}$$

Table 1 gives the ultimate analysis of design bagasse and imported coal (As Fired Basis)

Table 1: Bagasse and Coal Ultimate Analysis

Bagasse		Coal	
Carbon	23.96%	Carbon (wt %)	58.50%
Hydrogen	2.93%	Hydrogen (wt %)	3.00%
Oxygen	21.36%	Nitrogen (wt %)	0.90%
Moisture	50%	Sulfur (wt %)	0.33%
Nitrogen	0.07%	Oxygen (wt %)	4.00%
Ash	1.55%		
Sulphur	0.15%		
Total	100%		
HHV	2224kcal/kg		

V. High pressure Cogeneration design for RSML

The Cogeneration scheme proposed, at REL, envisages two identical units of 30 MW capacity each. Each unit will be designed with a 155 TPH capacity boiler with the outlet steam parameters of 110 bar (a) and 540 Deg.C, with the feed water inlet temperature of 210 Deg.C. Each of the Turbogenerators will be of 30 MW nominal capacity and designed with an extraction (with two uncontrolled extractions and one controlled extraction) condensing turbine. The Cogeneration plant will be designed with all the auxiliaries for the new boilers and the turbo generators and with all the auxiliary plant and systems like the fuel and ash handling system, Cooling water system, feed water system, Raw water and DM water system, Instrument air system, Electrical system for its successful operation. The plant will be capable of meeting all the process steam and power requirements of RSML's sugar mill's expanded capacity at 12,000 TCD crushing. Operating in synchronization with the sugar mill and with the national electricity grid and using the bagasse generated in the sugar mill during the season operation, the Cogeneration plant will export power to the sugar mill and to the grid. During the off season the sugar mill does not operate but the Cogeneration power plant will operate, in full power generation mode, on the saved bagasse and / or on coal to export bulk of the power generated to the grid.

The net electrical output of the power plant during the season operation will be 54,364 kW, considering the auxiliary power consumption of 5300 kW in the Cogeneration plant. However a Cogeneration plant gives both electrical and thermal energy outputs. The thermal energy output is supplied through the process steam supplied to the sugar plant. The total process steam supplied to the sugar mill is 205 TPH at the parameters of 3 bar (a) and 8 bar(a) With thermal energy of 2719.33 kJ and 2779.62 kJ. The fuel supplied for the operation of both the boilers will be 122.04 TPH of bagasse with LCV value of 7457.09 kJ/kg. The Fuel heat input to the boilers per hour will be 910.063 GJ /hr.

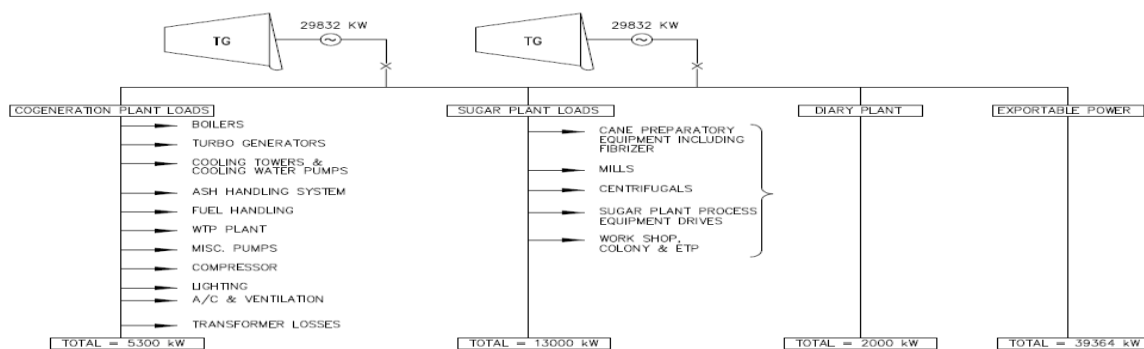


Figure 2: Power balance-season operation

The Cogeneration plant efficiencies are expressed in many ways. The electric efficiency of the plant is the plant will be electrical energy generated as a percentage of the total fuel heat input. This is not the true reflection of the plant efficiency as this omits the thermal energy output from the plant altogether. However the net electric efficiency of the plant will be 21.51% ($54364 \times 3600 \times 1000 / 910.063 \times 10^9$). This is the efficiency during the season operation of the Cogeneration plant. Taking into consideration the thermal energy supplied from the Cogeneration plant, the efficiency, called the Combined Heat and Power (CHP) Efficiency can be calculated as

The net electric power : 54,364 kW: 195.71 GJ/hr.
 Heat energy supplied to Sugar process : 585.26 GJ/hr
 Heat Energy returned to Cogeneration plant : 81.62 GJ/hr
 Net Thermal Energy Supplied : (585.26-81.62) per Hour : 503.64 GJ.
 CHP Efficiency: $((195.71+503.64)/910.063) \times 100$: 76.85%

During the off-season operation there will be no requirement of process steam for the sugar mill and hence there will be no thermal energy output from the plant to the sugar mill. The Cogeneration plant will supply electric power to the sugar mill for the maintenance work of the sugar mill and also for meeting with the requirements of the colony and the offices. The power export to the grid will be 52,000 kW. The fuel supplied for the operation of both the boilers, under bagasse and coal firing will be 94.26 TPH and 32.42 TPH. The Fuel heat input to the Cogeneration power plant, based on LCV of bagasse and coal, per hour of off-season operation will be 702.903 GJ/hr and 728.48 GJ/hr. The net electric efficiency of the plant, based on LCV, under bagasse firing will be 28.02% ($54,700 \times 3600 \times 1000 / 702.903 \times 10^6$). The net electric efficiency of the plant, based on LCV under coal firing will be 27.03% ($54,700 \times 3600 \times 1000 / 728.487 \times 10^6$).

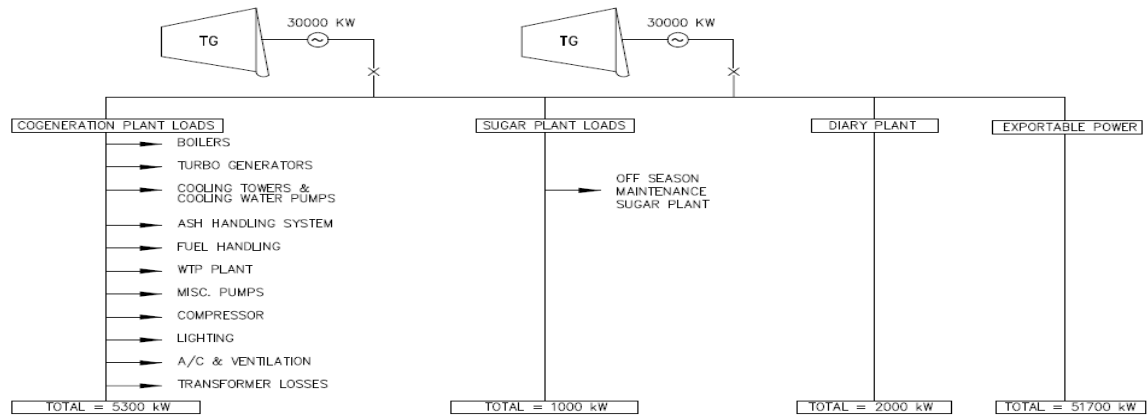


Figure 3: Power balance-off season operation

Under the off-season operation also, the CHP efficiency is applicable, as the plant will be supplying 5 TPH of 8 bar (a) steam to the Dairy unit attached with sugar mill. The respective CHP efficiencies under bagasse and coal firing will be 29.99% under bagasse firing and 28.94% under coal firing.

VI. ON Season Operation and Off Season Operation

According to system readings during sugar mill season operation, bagasse consumed by each Boiler is 61.02 TPH and Steam produced by each Boiler is 155 TPH, so 1TPH bagasse produces 2.54 TPH steam. 310 TPH steam from two boilers produces 59.6MWh. Hence 1 MWh is generated by 5.2 TPH steam. From above results 1 MW production requires approximately 2.045 TPH of Bagasse, by taking 3000PKR per ton of bagasse we get per unit fuel price of 6.1pkr during on season. Total generation during sugar mill season operation is 59.664 MW with Sugar Mill, dairy and auxiliary loads 13 MW, 2MW, 5.3MW respectively. Hence the total power exported to grid is 39.364 MW. Since the cogeneration unit also exports power to sugar mill and dairy so, Total Exportable Power is 54.364 MW. The total exportable units with 90 % capacity utilization and 120 days 24 hr operation comes out to be 14, 09, 11,488 KWh.

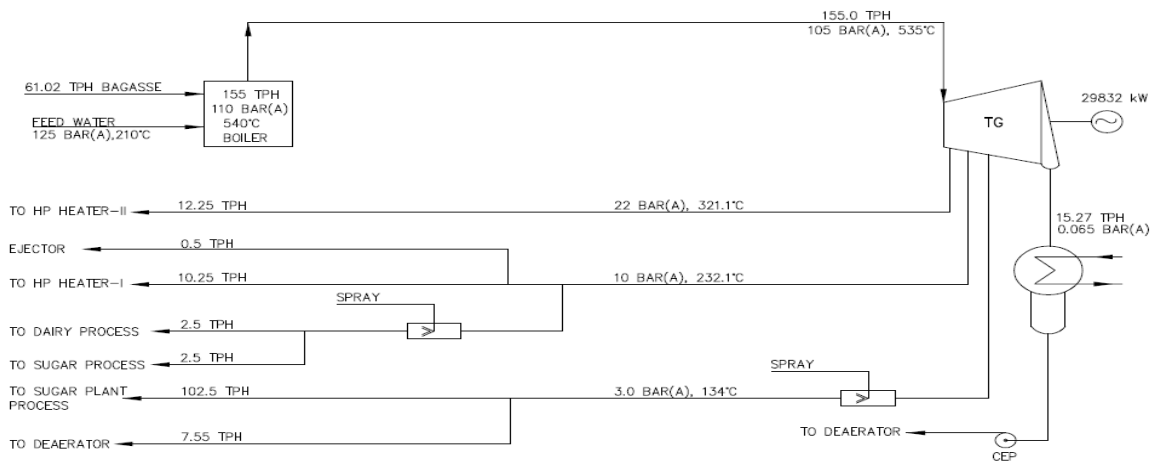


Figure 4: Cogeneration scheme-season operation

During off season bagasse consumed by each Boiler is 47.13 TPH and Steam produced by each Boiler is 118.3 TPH, so 1TPH bagasse produces 2.51 TPH steam. 236.6 TPH steam from two boilers produces 60 MWh. Hence 1 MWh is generated by 3.9 TPH steam. From above results 1 MW production requires approximately 1.57 TPH of Bagasse, by taking 3000PKR per ton of bagasse we get per unit fuel price of 4.7 PKR during off season.

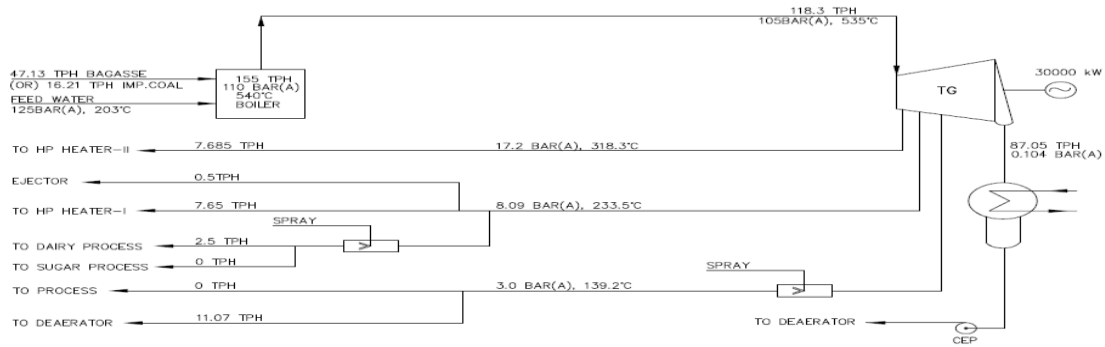


Figure 5: Cogeneration scheme-Off season operation

After 120 days of season operation plant will run for 29 more days on saved bagasse, with a target of total 180 operational days we have to buy bagasse for remaining 31 days or it will run on imported coal by mixing it with saved bagasse. Total generation during sugar mill off season operation is 60 MW with Sugar Mill, dairy and auxiliary loads 1 MW, 2MW, 5.3MW respectively. Hence the total power exported to grid is 51.7 MW. Since the cogeneration unit also exports power to sugar mill and dairy so, Total Exportable Power is 54.7 MW. The total exportable units with 90 % capacity utilization and 120 days 24 hr operation comes out to be 7, 87, 68,000KWh.

VII. Assessment of Cogeneration system

Overall Plant Performance using single unit of boiler and turbine [4]

- a. Overall Plant Heat Rate (kCal/kWh)
 $[Ms \times (hs-hw)] / \text{Power output (kW)} = [155000 \times (826.15-215.13)] / 30000 = 3156 \text{ kcal/kwh}$
 Where,
 Ms = Mass Flow Rate of Steam (kg/hr)
 hs = Enthalpy of Steam (kCal/kg)
 hw = Enthalpy of Feed Water (kCal/kg)

- b. Overall Plant Fuel Rate (kg/kWh)
 $\text{Fuel consumption (kg/hr)} / \text{power output (kW)} = 59400 / 30000 = 1.99 \text{ kg/kwh}$

VIII. Total Project Cost

This section gives the project cost for the proposed Cogeneration power plant. Table 2 gives the details of the costs for the civil, mechanical and electrical works. These costs included in the Table cover the complete civil, mechanical and electrical works of the complete Cogeneration plant. The costs include the equipment design, procurement, manufacturing, supply and the erection and commissioning of the complete plant. No taxes and duties are included in the costs.

The estimated cost of Civil works is US\$ 5.5.00 Million
 The estimated Cost of Mechanical works is US\$ 30.00 Million
 The estimated cost of electrical & instrumentation works US\$ 7.00 Million
 Total Works Cost US\$ 42.5.00 Million

Table 2: Total project cost

Serial No.	Description	Total Cost in Million USD
1	Project works cost	42.5
2	Contingency @ 5%	2.10
3	O & M mobilization cost	0.3
4	Fuels for commissioning and Testing Cost	0.25
5	Development & Pre-operative cost	2.5
6	Cost of insurance during construction	0.4
7	Land cost	0.05
8	Financing Charges	0.5
9	Interest during construction	0.2

IX. Expenses and Profit

The RSML's cogeneration project life is 25 years. During operation there are two types of expenses, fixed Operation & Maintenance cost and other one is variable Operation & Maintenance cost. The project tariff is set on the basis of fuel cost, fixed & variable O&M cost, working capital, insurance, and return on equity, loan repayment and interest. Considering all these factors and taking payback period of five years, the tariff rate is decided to be 10.50 PKR for 180 days operation.

X. Conclusion

The paper is written to encourage other sugar mills in Pakistan for the development of high pressure cogeneration system adopted by RSML, Pakistan to meet increasing energy demands in the country. The crushing capacity of RSML is 10,000 TCD and this could be achieved through 24 hours of operation of the plant. RSML had adequate steam and power generation capacities for meeting the total steam and power requirements of the sugar plant.. The boilers used in past were with the steam parameters of 24 bar (a) and 350 deg.C, which was on the lower side compared to the modern day sugar mill boilers. The total aggregate steam generation capacity in the sugar mill was 240 TPH. Although these boilers were not very old, the fuel consumption in the boilers was quite high with the steam to fuel ratio of about 2. Even though the fuel was generated in-house, considering the fuel value of bagasse and realizing the available potentials for the better utilization of bagasse, the above consumption in the boilers was quite high and the operation was inefficient compared to modern day standards. All the existing turbo generators in the plant operated with an inlet steam parameters of around 21 bar (a) and 340 Deg.C. Here again the turbines were of older design and not comparable to the new generation of turbines with regard to the efficiency.

The sugar Industry, world over, is passing through a difficult period. The sugar prices are low and on the other hand the cost of the basic raw material which is the sugar cane and the production costs keep increasing. The sugar industry can hope to come out of this situation only by cutting down the cost of production, by adopting energy efficient processing, and going in for Cogeneration of Power and for the better utilization of molasses and bagasse, the by-products from sugar manufacturing.

Under the above scenario, where there is a potential to improve the energy efficiency of the sugar plant by retiring inefficient boilers and turbo generators, it is prudent for the sugar mills to go in for new high pressure and high efficiency boilers and matching turbo generators. Such systems, in-addition to generating additional power for export which improves the bottom line of the sugar mill operations, improves the energy efficiency of the sugar mill process itself. Although initial cost is high but it is one time investment and the payback period of project is short which favours its implementation in sugar industry. With the selection of the controlled extraction cum condensing turbines for such applications, as the extraction steam requirements are very large in the sugar mill applications, the extraction steam pressure is maintained almost constantly and this helps in larger vapor production and less use of the exhaust steam in the process.

References

- [1] https://en.wikipedia.org/wiki/Electricity_sector_in_Pakistan
- [2] <http://www.ppib.gov.pk/Co-Generation%20Policy%202008.pdf>
- [3] <http://www.pres.org.pk/2013/3000-mw-electricity-can-be-generated-from-83-sugar-mills/>
- [4] Yunus A. C and Michael A. B. (1994). *Thermodynamics: an Engineering Approach second Edition*; McGraw Hill. New York
- [5] Hugot E. (1986). *Handbook of Cane engineering, third edition, Elsevier Science Publishers*, New York, April 1986
- [6] Bagasse-based co-generation at Hippo Valley Estates sugar factory in Zimbabwe, *Journal of Energy in Southern Africa*, Vol 23 No 1, February 2012