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ISSN: 0976-3031

International Journal of Recent Scientific Research
Vol. 4, Issue, 7, pp.1098– 1102, July, 2013

International Journal of Recent Scientific Research

REVIEW ARTICLE

BAGASSE POWER IN INDIA: MEETING CHALLENGES OF ENERGY, ENVIRONMENT AND SUSTAINABLE DEVELOPMENT

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ARTICLE INFO

Article History:

Received 11th, June, 2013
Received in revised form 24th, June, 2013
Accepted 18th, July, 2013
Published online 30th July, 2013

Key words:
Bagasse, conventional fuels, power generation, renewable, emission.

ABSTRACT

As the conventional fuels such as coal, petroleum etc. are limited in the nature therefore, alternate sources of the energy for the fulfillment of the future demand is required. India, which accounts for around 85% of South Asian electricity generation, is facing serious power problems with current generation being about 30% below the demand. New options now have to meet the challenges and needs for generating more electricity and investing heavily in sector. Overall, Indian power demand is projected to increase to 1,192 billion-kilowatt hours (BkWh) in 2020, around three times, 378 BkWh consumed in 1996. India, one of the leading sugarcane producers in the world realizing the potential of bagasse, a by-product of the sugar industry, for power generation, has come up with various programs and incentives to boost the sector. India produces nearly 40 million metric tonne (MMT) of bagasse, which is mostly used as a captive boiler fuel other than its minor use as a raw material in the paper industry. The paper aims to explain the conversion of bagasse into electric power. An extensive review of the existing literature reveals that the sugar mills have been able to export power in the season as well as in the off-season by using bagasse. The electricity production through bagasse, is more easily adoptable and can be easily applicable to most part of the country. Electricity through this source is cheaper than the electricity produced by the conventional fuels and also the emission is very low and this small amount of the emission can be easily controlled as compared to its counterpart. It has benefited the environment by reducing the greenhouse gases (GHGs) in the atmosphere in terms of the usage of biomass as fuel. An effort is made here to study and analyze keeping the availability and environmental pollution in view of this resource in the country. Therefore, Bagasse, a renewable resource, can play a major role in substituting fossil fuels for the future power generation.

INTRODUCTION

Conventional fuel such as coal is limited and its demand for generation of electricity is increasing thereby emphasizing the need for new renewable sources such as use of biomass to be explored for the production of electricity and meeting the demand. Of the 1.4 billion people of the world who have no access to electricity in the world, India accounts for over 300 million. In December 2011, over 300 million Indian citizens had no access to electricity. Over one third of India's rural population lacked electricity, as did 6% of the urban population .Also, coal emissions cause urban smog, which causes respiratory ailments, and coal-fired power plants also contribute to global climate change. Coal plants emit 73 percent of the carbon dioxide from electricity generators. By releasing the energy stored in coal, large quantities of carbon dioxide stored in the coal for millions of years are released into the atmosphere thus increasing the threat of global warming. India, one of the leading sugarcane producers in the world realized the potential of bagasse, a by-product of the sugar industry, for power generation. The sugar industry has the potential to generate about 960 MW per year from bagasse based on the average of 20 million tons of sugar cane crushed per year. The use of bagasse for electricity generation is important as it presents an energy security solution whilst contributing to reduction of greenhouse gas (GHG) emissions from power generation. It also contributes to economic development and poverty reduction in the rural communities in which most of the sugar factories are based. [1]

Bagasse

Bagasse is the by-product of the cane crushing in the sugar mills. The bagasse percentage can varies from 23% to 37%. This depends on the fiber percentage cane, which normally ranges from 12% to 19%. The rest of the bagasse is made up of trapped dissolved matter, trash and water. It is the fibrous material and it contains moisture in large amount approximately 48-50 %. Its moisture content can be reduced by better de-watering, improved processing or by simply leaving the bagasse to dry. The calorific value of bagasse depends upon the moisture content and the amount of the sucrose present in the bagasse. The drier system is introduced to increase the steam fuel ratio thereby saving bagasse and also to increase the boiler efficiency. As 10-12% of water is evaporated from the bagasse in the drier, excess air

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requirement is reduced to a certain extent; thereby flue gas volume is reduced. Hence, power consumed by the ID fan is also reduced considerably.

Method

Traditionally, bagasse was burned in specially designed furnaces for raising process steam and for producing motive power for the manufacture of raw sugar. This was basically done for disposal of the bagasse to avoid additional handling cost rather than as a fuel-saving alternative. Production efficiency and process optimization for energy production were not taken into account. Due to the high cost of imported energy and, to some extent, concern about the environmental implications of using various sources of fossil energy, it was found crucial to review the use of bagasse and to optimize its energy potential. It has now become not only an energy source for the manufacture of raw sugar, but also an energy source which goes beyond the sugar factory boundaries as the extra electricity is exported. Initially turbo alternators were used to enable the production of exportable electricity. Sugar-factory-based power generation for export can only be achieved if the energy generated from bagasse exceeds the process energy requirement. The two major parameters which needs to be considered while optimizing energy production at a sugar factory are-

1. The steam to bagasse ratio ***(r_{sb})*** and
2. The specific steam consumption (SSC).

The first ratio r_{sb}, is a measure of the yield of steam per unit weight of bagasse, thus representing the efficiency of steam production. The second ratio SSC is a measure of weight of steam required per unit of cane being processed and is a measure of the efficiency of steam utilization for the manufacture of raw sugar. Operating parameters influencing r_{sb} as: (1) moisture and fiber content of bagasse; (2) excessair ratio; (3) flue gas temperature; and (4) furnace temperature and boiler pressure. Thermodynamically it may be possible to increase r_{sb} up to 4.0 and reduce SSC down to 0.3 as pointed out by HareI. High efficiencies of steam generation (high r_{sb}) and low process steam utilization (low SSC) would demand the use of equipments such as high-pressure boilers, boiler feed water treatment plants, condensing turbines and modifications of the process steam cycles. [2]

Cogeneration Systems

Advanced cogeneration systems are employed for simultaneous generation of process steam and electricity. They run by employing high pressure boilers and condensing cum extraction turbines. These sugar mills have been able to export power in the season as well as in the off-season by using bagasse. Off-season operation has been more lucrative.

High technology has made these sugar mills efficient by improving the economic viability of the mills in terms of higher production of units of electricity per unit of bagasse. It has become standard to produce both the steam and the electricity necessary for driving the sugar processes. This sequential generation of electrical power and thermal energy (steam) is referred to as the production of combined heat and power or cogeneration. The two cycles used in the cogeneration systems are:

The Topping Cycle, whereby primary heat at higher temperature end of the Rankine cycle is used to generate high-pressure and high temperature steam and electricity, is widely used in the sugar industry. The ratio of heat to electricity generated varies depending on the type of arrangement. The steam-electric power plant with the extraction-condensing turbine is widely used because it can be arranged to give a wide range of ratios to suit the processing requirements of the sugar factory. The current technology involves sugar milling and extraction using tandem mills. When the sugar has been extracted, the remaining residue after dewatering called bagasse is conveyed to the boilers for burning as fuel or to storage facilities. Its moisture content is around 45–55% [3,4]. The sugar processes use low-pressure steam from the turbo-generators/alternators and other prime movers like shredders, de-watering mills, drying off mills and steam-feed pumps. In some plants, high-pressure steam is used for sugar processing and by ethanol plant after cooling it can reduce its pressure. This use of pressure reducing valves wastes energy, which can be used to power a turbo-alternator. At zero moisture, bagasse calorific value is about 19.25 MJ kg^{-1}. The net calorific value of bagasse with a moisture content of 50% is 7.62 MJ kg^{-1} [4]. The bagasse is burnt in boilers that are normally designed to use both bagasse and/or coal. The average steam to bagasse ratio is normally 2.2. At a density of 130 kg m^{-3}, storing bagasse takes a lot of space, hence the need to use boilers that burn as much of it as possible [3]. The boilers generally range from 35 to 150 ton of steam per hour, at pressures varying from 15 to 82 bar (a bar is 100 kPa) and temperatures ranging from 300◦C to 525◦C [5].

Traditionally, cogeneration was adopted as a means of incinerating bagasse in a useful way by generating steam in boilers for process heating and electricity generation. This was regarded as an intelligent way of converting waste into useful energy and efficiency was not a priority. Higher efficiency created safety problems since bagasse has low density, is highly flammable, ferments and loses calorific value when stored for very long periods. Over time conventional sugar factories within integrated power plants evolved. The boiler and turbine were transformed to high efficiency units by changing the steam condition that is increasing the temperature to between 440◦C and 460◦C and the pressure to between 45 and 60 bar and by using extraction/ condensing steam turbines. Generation is at 200 kWhton $^{-1}$ bagasse and 1440 kWhton $^{-1}$ coal in this case, giving thermodynamic efficiencies of the order of 25% [5,6]

Case Study- Sugar Industries of Uttar Pradesh [8]

The electricity generated by bagasse is calculated as follows:

Formula for Calorific value

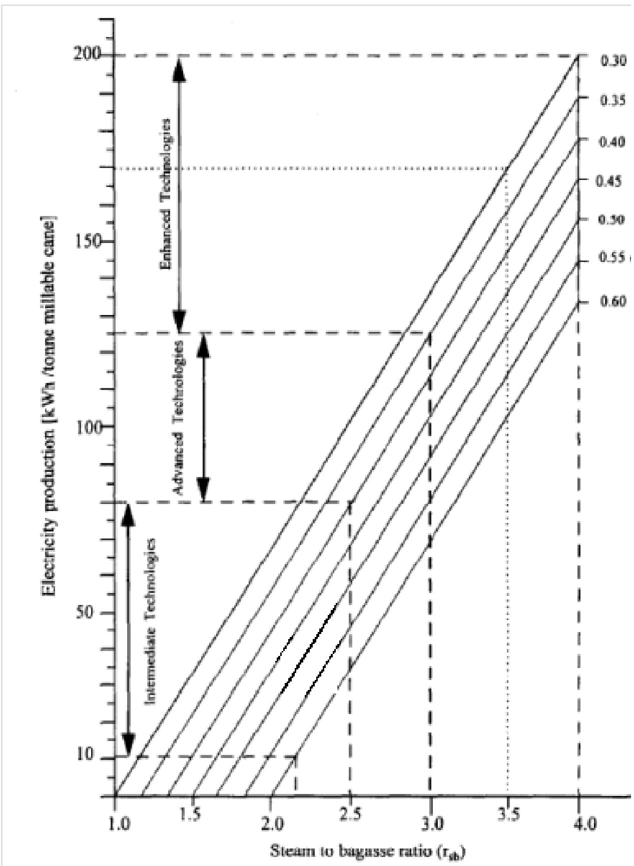
GCV = 4600-12s-46w
NCV = 4250-12s-48.5w
Where, s- Sucrose % in bagasse
w- Moisture % in bagasse
If s and w expressed in per unit of bagasse then:
GCV= 4600(1-w)-1200s
NCV= 4250-4850w-1200s

Power Generation by Bagasse

India is the second largest producer of sugarcane in world and in India; Uttar Pradesh alone produces 38.77% of the gross production of sugarcane.

Technology	Steam utilization features	Steam generation features	Specific steam consumption(SSC)	Steam to bagasse ratio(r_{sb})
Conventional	Multi pass juice heaters, quadruple effect evaporators, batch boiling(three boiling systems)	Generally old boilers with operating pressures below 2.0MPa	0.60 or greater	2.0-2.2
Intermediate	Plate-type juice heaters, pre-evaporator to improve evaporation efficiency, two boiling system for steam economy	Boiler pressure at around 3.0 MPa, condensing steam turbine	0.40-0.60	2.2-2.5
Advanced	Same as for intermediate and introduction of continuous vacuum pans and continuous centrifugals	Boiler pressure at around 6.0MPa, condensing extraction steam turbines	0.35-0.40	2.5-3.0
Enhanced	All the above and complete automation and rigorous efficiency control	High pressure boiler between 6.0MPa and 8.0MPa, condensing extraction steam turbines, water treatment plant, almost complete recycling of condensates	0.30-0.35	3.0-4.0

Technologies for energy management in cogenerating sugar factories [2]



Electricity production as a function of r_{sb} and SSC

According to a case study carried out by JP Yadav and BR Singh, Uttar Pradesh produces 130 million tones of the sugarcane. 40 % of sugarcane is used for gur and khandsari and 60% sugarcane used for crystalline sugar. And it is known that approximately 30% is the bagasse by weight in sugarcane.

Sugarcane used for sugar production = (130 * 60)/100
=78 million tones

Therefore total bagasse = (78 * 30)/100
= 23.4 MT

Since mill wet bagasse contains approximately 50% moisture and if plant with drier which uses temperature of flue gases to dry the bagasse and easily the moisture content will become 43% and it increase the steam fuel ratio and therefore power generation.

Calorific value of bagasse by formulae

GCV= [4600(1-w) – 1200 s] kcal/kg

NCV = [4250 – 1200 s – 4850 w] kcal/kg

We are considering that power plant is equipped with the dearator, economizer and drier etc.

Calorific value with drier

GCV = 4600 (1-w) – 1200 s
= 4600 (1-0.43) – 1200 × 0.02
= 2598 kcal/kg

Where w is moisture content s is % of sucrose per unit bagasse

NCV = 4250–1200 s – 4850 w
=4250 – 1200 × 0.02 – 4850 ×0.43
= 2140.5 kcal/kg

Calorific value without drier

GCV = 4600 (1-w) – 1200 s
= 4600 (1-0.5) – 1200 ×0.02
= 2276 kcal/kg

NCV = 4250 – 1200 s – 4850 w
= 4250 – 1200 × 0.02 –4850 × 0.5
= 1850 kcal/kg

Power for Uttar Pradesh

The input parameters used for the purpose of analysis are given below [8]:

Enthalpy values at 6.5 MPa and 510°C, h1 = 3440.11 kJ/kg

Entropy at 6.5 MPa & 510°C, s1 = 6.8687 kJ/kgK

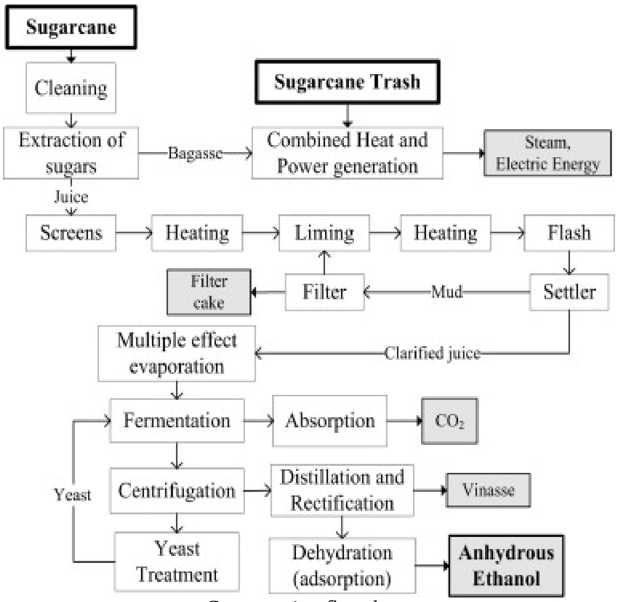
Condenser pressure = 0.035 bar (3.5 kPa), h2 = 2037.80 kJ/kg

The pump work has been neglected as it is very low compare to the turbine work.

Work done by turbine, ηTh (h1-h2) = 0.85× (3440.11 - 2037.80) = 1191.96 kJ/kg

η_{mech} 95% & efficiency of alternator η_{alt} 90% then

Alternator output = WT× η_{mech} × η_{alt} = 1191.96×0.9×0.95 = 1019.12 kJ/kg



Cogeneration flowsheet

m_1 rate of steam consumption/kWh, m_1 = 3600/ 1019.12 = 3.53 kg/kWh

Heat consumption = m1 (h1-hfg) =3.53(3440.11 – 111.23) = 11750.94 kJ/kWh

As efficiency of boiler is 80% = 11750.94/0.80

Heat consumption = 14688.67 kJ/kWh

Amount of fuel × Calorific value = Heat consumption

Amount of fuel = Heat Consumption/ Calorific Value

= 14688.67 KJ * kg/7733 KJ * kWh

=1.89 kg/kWh =1.9 kg/kWh

Description	Value
Turbine inlet temperature	510 ℃
Turbine inlet pressure	65 bar
Condenser pressure	0.035 bar
Mechanical efficiency of turbine	95%
Efficiency of alternator	90%
Efficiency of boiler	80%
Calorific value of fuel	7733 kJ/kg

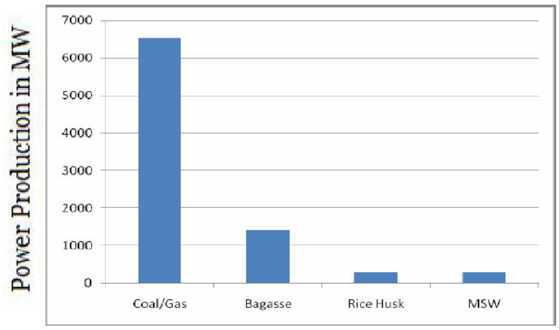
Now if we want to produce 1400MW power for 350 days & 24 hours then amount of fuel required = 1400×8400×1.9×1000 = 2.23×1010 kg = 22.3 MT. Therefore, the potential of power generation by bagasse in Uttar Pradesh is 1400 MW which can replace approximately 560 tonne of coal otherwise. The green house emissions are also lower in the burning of bagasse reducing the environmental pollution. Total power saved by Bagasse, Rice Husk and MSW = 1400+257.07+258.98 = 1916.05 MW .Power produced by one tonne of coal = 2.5 MW approx. Amount of coal required to produce 1916.05 MW = 1916.05 ÷ 2.5= 766.42 tonnes

Price of coal per tonne = Rs 4500-5000

Then total amount of money saved = 5000 × 766.42= Rs 38, 32,100

Future Scope [7]

India is the second largest producer of sugarcane in the world after the Brazil which produces approximately 340 million metric tons/year with the production rate of 78.44 tones/ha from an area of 4,300,000 ha yielding nearly 50 million metric tons of bagasse, which is mostly used as a captive boiler fuel and as a raw material in paper industry. India has potential for producing electricity of 3,000GWh/year using bagasse. India placed at top position in Asia for producing sugarcane then after China which produces approximately 100 MT in 1200 Hectares. Thailand produced 75 MT in 1000 Hectares. Other countries Australia, Colombia, Cuba, Pakistan and Mexico etc. also produced sugarcane at low level. Uttar Pradesh produces 38.78% of the total production of India.



Power production by different Fuels

Indian Sugar mills both in the private and cooperative / joint sector have accepted the importance of implementing high efficiency grid connected cogeneration power plant for generating exportable surplus. Gujarat, being one of the leading sugarcane producer and processor states, has the potential to set up Bagasse base co-generation power plants. The proposed project envisages setting up of a Bagasse based co-generation power plant, either to be added in an existing Sugar Mill or as a standalone unit for power generation. Cogeneration in sugar industry to produce excess power and exported to the State Electricity Board grid has gained momentum and is the order of the day.

Type of Fuel	Power Potential (MW)
Coal/Gas	6532
Bagasse	1400
Rice Husk	257.07
MSW	258.98

Power production by different fuels in Uttar Pradesh

The successful operation of four full fledged cogeneration plants in Uttar Pradesh and a few more in other states have given the required confidence for the sugar industry to implement cogeneration plants. The state wise potential of bagasse cogeneration in India is tabulated below:

State wise potential of Bagasse base cogeneration in India

Sr. No.	State	Potential (MW)
1	Maharashtra	1250
2	Uttar Pradesh	1250
3	Tamil Nadu	500
4	Karnataka	500
5	Andhra Pradesh	300
6	Bihar	300
7	Gujarat	250
8	Punjab	150
9	Other	500
10	Total	5000

SUMMARY

As the conventional fuels such as coal, petroleum etc. are limited in the nature therefore alternate source of the energy for the fulfillment of the future demand is required. Also, the power production by the conventional fuels is not environment friendly. Today the focus is concentrated on the renewable energy sources such as solar power, wind power, geothermal energy, ocean tidal power, hydropower, electricity by biomasses and municipal solid waste. These all are the environment friendly. The electricity production through bagasse, rice husk and municipal solid waste is more easily adoptable and can be easily applicable to most of the part of the country. Electricity through these sources is cheaper than the electricity produced by the conventional fuels and also the emission is very low and this small amount of the emission can be easily controlled compare to the emission of the conventional fuels. Also, the sugar cane plant is an agricultural crop that is known to have a high bioconversion efficiency to capture sunlight as a result of which a high amount of atmospheric carbon is fixed into biomass. The main interest until recently was to recover only sugar from this biomass. It can now be considered as a major renewable energy resource in cane sugar producing countries. Bagasse and other biomass, which are renewable, can play a major role in substituting fossil fuel for future power generation. The case study of Uttar Pradesh by JP Yadav and BR Singh reveals the feasibility and extensive application of bagasse for electricity production. There is a potential of 3500 MW bagasse based cogeneration potential and 16500 MW other biomass power potential in the country. [7] Therefore, the use of bagasse as a fuel for power generation can be an option to supplement the growing power demand as the conventional power source i.e. fossil fuel is diminishing day by day.

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