BAGASSE GASIFICATION TECHNOLOGIES FOR ELECTRICITY PRODUCTION IN THE SUGAR INDUSTRY

KTKF KONG WIN CHANG, AF LAU AH WING AND L WONG SAK HOI

Mauritius Sugar Industry Research Institute, Réduit, Mauritius

Abstract

The energy potential of the cane sugar industry using the conventional steam cycle is considered in comparison to that using bagasse gasification technology. The conventional steam cycle using condensing turbo-generator sets has a potential of producing annual exportable electricity of only 115 kWh/t cane compared with 275 kWh/t cane with the biomass integrated gasification – gas turbine technology (BIG-GT). With the latter, if all the bagasse were gasified, Mauritius and South Africa have the potential of exporting respectively 1 600 GWh and 5 900 GWh of electricity annually, over and above meeting energy needs of the sugar factories. In addition, if the trash is also gasified, it is estimated that the Mauritian sugar industry could export a total of 2 050 GWh of electricity annually. The technical problems involved in integrating gasification technologies into the cane sugar factories are being addressed in Brazil. Reference is hence made to the Brazilian project on the Biomass Power Generation: Sugar Cane Bagasse and Trash. Flow diagrams show the two modes of operation being considered for the BIG-GT integration with a typical mill.

Introduction

The cane sugar industry has long recognised the enormous potential in the use of bagasse for the production of energy. Many sugar factories are presently producing considerable amounts of electricity for export to the utility grid while at the same time meeting on-site energy needs by installing modern condensing-extraction steam turbines for cogeneration. However, biomass gasification technology applied to bagasse gasification in conjunction with gas fired turbines, which could become commercially available in the near future, offer higher thermodynamic efficiencies. A case study of the Mauritian condition will illustrate the potential of biomass gasification technology compared to the conventional steam cycle using condensing turbo-generator sets.

After having satisfied its own steam and electrical energy requirements, the Mauritian sugar industry, while adopting the conventional steam cycle, supplied on an average 15 kWh/t cane (Anon, 1992-95) electrical energy to the national grid (based on total cane production), totalling 70-85 GWh annually. In 1997, 125 GWh of electricity, i.e. 21,5 kWh/t cane was exported to the national grid. With biomass gasification technology, efficiencies in the range of 40-45% based on net plant output and lower heating value of the fuel are reported (Elliot and Booth, 1995) to be feasible even with first generation plants. Further, it appears that plant size will have little effect on the economic and technical viability of BIG-GT. This is therefore an interesting feature for both small and large mills.

Energy potential with condensing turbo-generator sets in Mauritius

In the present industry, the excess bagasse available for production of electricity to be exported to the national grid is estimated to be 300 000 tons per year. The surplus electrical energy exported by the Mauritian sugar industry to the national power utility, the Central Electricity Board (CEB), for the years 1993-97 is shown in Table 1.

Studies by Kong and Lau (1996) and Noël (1996), updated for conditions prevailing in 1997, found that more energy can be generated in the existing small (100 tch) or medium sized (150 tch) factories, as shown in Table 2. Major improvements would be centered on process steam saving in the manufacturing process, and by maximising the use of vapour bleeding.

Under optimum operating conditions, Noël (1996), found that a factory should be able to generate at least 100 kWh/t cane after satisfying its own steam and energy requirements assuming a fibre per cent cane of 13,5%, 5% bagasse wastage, a process steam consumption of 340 kg/t cane and

Table 1. Electrical energy exported by sugar factories.

Year	Electricity export from bagasse (GWh)	kWh/t cane
1993	70,5	13,0
1994	76,6	15,9
1995	84,1	16,3
1996	119,0	22,6
1997	124,6	21,5

Table 2. Surplus energy potential for small and medium-sized factories.

Size	Boiler pressure (bar)	Prime movers back pressure	Process steam (kg/t cane)	Surplus electricity (kWh/t cane)
Small	20	Single-stage	420	18
Medium	>30	Multi-stage	400	25

Table 3. Annual Electricity Production Potential.

	Conventional steam cycle		BIG-GT technology	
	(kWh/t cane)	(GWh)	(kWh/t cane)	(GWh)
All bagasse for electricity production	143	825	303	1751
Less electricity for factory	28	162	28	162
Annual exportable electricity	115	663	275	1589
CTL* @ 72% moisture	45	258	88	509
Less electricity for CTL processing	8	47	8	47
Annual exportable electricity	37	211	80	462
Total annual exportable electricity	151	874	355	2051

*CTL = cane tops and leaves

a power consumption of 28 kW/tch. Further, it was shown (Rivière, 1992), that a surplus of 100 kWh/t cane could be generated with the present technology, i.e. high pressure boilers (up to 45 bar), condensing extraction turbo-generator sets, a steam to bagasse ratio of 2,4 and using 340 kg/t cane of steam for juice processing.

Energy potential with BIG-GT technology

Assuming an overall efficiency of the BIG-GT system of around 45%, it can be shown that an electricity output of 0,97 kWh/kg bagasse (NCV 7,8 MJ/kg, 49% moisture content) is achievable. Using the cane production potential of the Mauritian sugar industry, Table 3 shows the electricity production potential of the cane sugar industry with the BIG-GT technology compared with the condensing extraction turbo-generator sets technology as utilised in Reunion island. An annual cane production of 5,5 million tons, bagasse production of 1,65 million tons, and cane tops and leaves totalling 20% of the millable cane at 76% moisture (Deepchand, 1986) were assumed. Calculation shows that the scenario depicted in Table 3 is achievable if it is assumed that 85% of the NCV of the bagasse is converted to heat and electricity. Steam at the rate of 340 kg/t cane would be available for processing.

For an estimated bagasse surplus of 300 000 tons, some 291 GWh electricity (0,97 kWh/kg bagasse) can be potentially generated with the BIG-GT technology compared with 145 GWh for the condensing extraction turbo-generator sets technology. Calculations done previously (Kong and Lau, 1996) indicated that, with the BIG-GT technology, Mauritius has the potential of exporting 1 600 GWh of electricity utilising all its bagasse and 2 000 GWh where, in addition, all the trash is gasified. However, Wong Sak Hoi and Autrey (1997) reported a dramatic increase in fibre % cane in recent years. Table 3 takes into consideration the increase in fibre content of the cane and the resulting effect on the electricity production potential of the Mauritian sugar industry with the updated figures.

At a bagasse % cane of 32,0, an estimated 6 500 GWh of electricity would have been produced for the 1996-97 crop if all the bagasse produced from the 20 950 835 tons of cane of the South African sugar industry had been gasified and the BIG-GT technology used. If it is assumed that the factory has a power requirement of 28 kWh/t cane, then South Africa would have had a potential of exporting around 5 900 GWh of electricity annually after meeting all its energy needs.

Thermoelectric cycles

The standard size for a biomass plant is 15-50 MW. With the conventional thermal electric power plant based on the Rankine cycle, in which steam raised in boilers propels condensing turbines which drive alternators to generate electricity, a plant sized at 15-50 MW has a conversion efficiency of only around 30%. Biomass power plants of 15-50 MW based on the BIG-GT technology reach efficiencies greater than 40% and could in the future be greater than 50%. Table 4 gives a list of the cycles in the family of BIG-GT systems.

Table 4. BIG-GT systems.

Available technologies	Future technologies
BIG-OC - Open cycle	BIG-ISTIG - Steam injection with intercooler
BIG-CC - Combined cycle	BIG-ICR - Cycle with intercooler and regeneration
BIG-STIG - Steam injection	

Of the available systems, the most promising for maximising electricity production in the sugar industry is the BIG-CC system (Biomass Integrated Gasification - Combined cycle) (De Queiroz and Nascimento, 1994). This system has an efficiency 50% higher than the open cycle and requires only a slightly larger investment to increase its economic performance significantly. Figure 1 illustrates the main elements of a BIG-CC system. In this system the exhaust gases from the gas turbines are used to raise steam in a waste heat boiler, which powers another condensing extraction generator set.

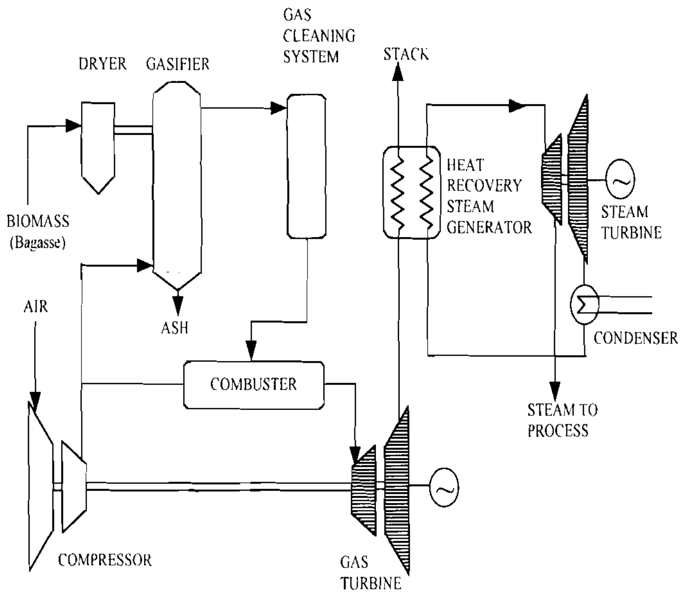

Figure 1. Main elements of a Biomass Integrated Gasification - Combined Cycle (BIG-CC).

Technical problems being resolved

Under the project BRA/96/G31-Biomass Power Generation: Sugar Cane Bagasse and Trash, the Centro de Technologia Copersucar has as their main objective the evaluation and development of the technology required in the complete cycle of electric power generation with the advanced system (BIG-GT) using the biomass of sugarcane as fuel (Anon, 1997). The project work plan includes:

- evaluation of sugarcane trash availability and quality
- evaluation of agronomic routes to green cane harvesting with trash recovery
- bagasse and trash atmospheric fluidised bed gasification tests
- integration of the BIG/GT system with a typical mill
- identification and evaluation of environmental impacts.

BIG-GT integration with typical mill

Based on preliminary BIG-GT data provided by Termiska Processor AB of Sweden (TPS) for wood chips and the laboratory gasification tests of sugarcane bagasse and trash, two alternative modes of operation are presently being considered (Anon, 1998). These are the independent thermal power plant and cogeneration, full or partial. Figures 2 and 3 give simplified flow diagrams for the two alternative modes of operation. In order to facilitate the evaluation of the project, the following basic assumptions were made:

- BIG-GT plant: based on GE LM 2500 gas turbines
- Heat recovery steam generator (HRSG) pressure/temperature (bar/°C): 82/480, 22/300 and 2,5/saturated
- Mill process steam consumption levels (kg steam/t cane): 500, 340, 280.

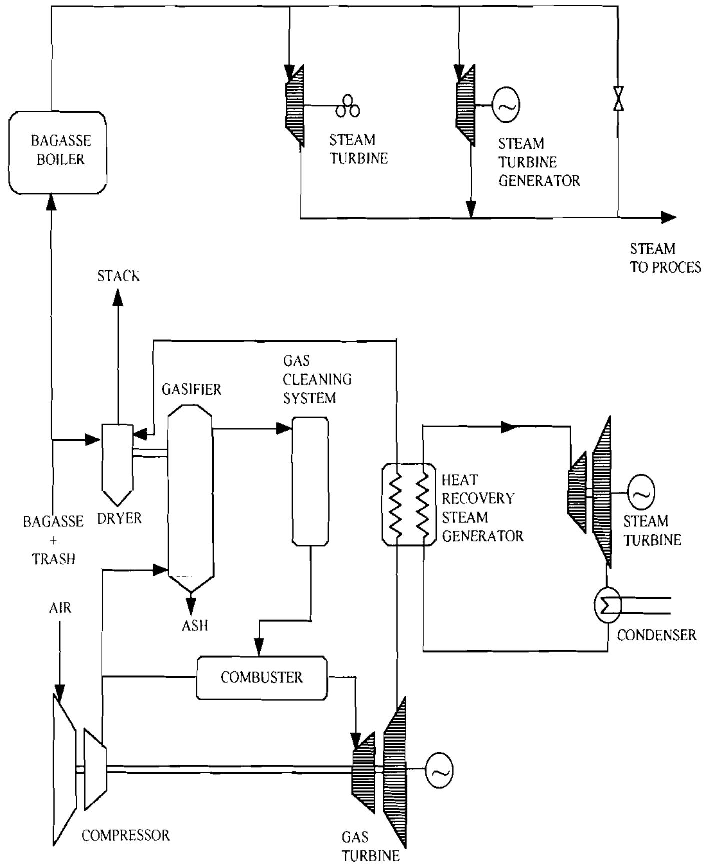

Figure 2. BIG-CC - mill basic integration modes (independent mode).

Discussion

Current findings indicate that BIG-GT systems offer more scope for optimising the use of the energy potential of sugarcane world-wide. A preliminary evaluation made by TPS for HRSG (Heat Recovery Steam Generator) operating at 60 bar/500°C in a combined cycle revealed that the net power output of a module with one LM-2500 has been estimated to be 33 MWe. When the technical problems have been resolved, it will be possible to generate electricity in many small blocks with relatively low investment and high conversion efficiencies.

Once the technology has been adapted to the burning of bagasse, BIG-GT systems will not only have an important

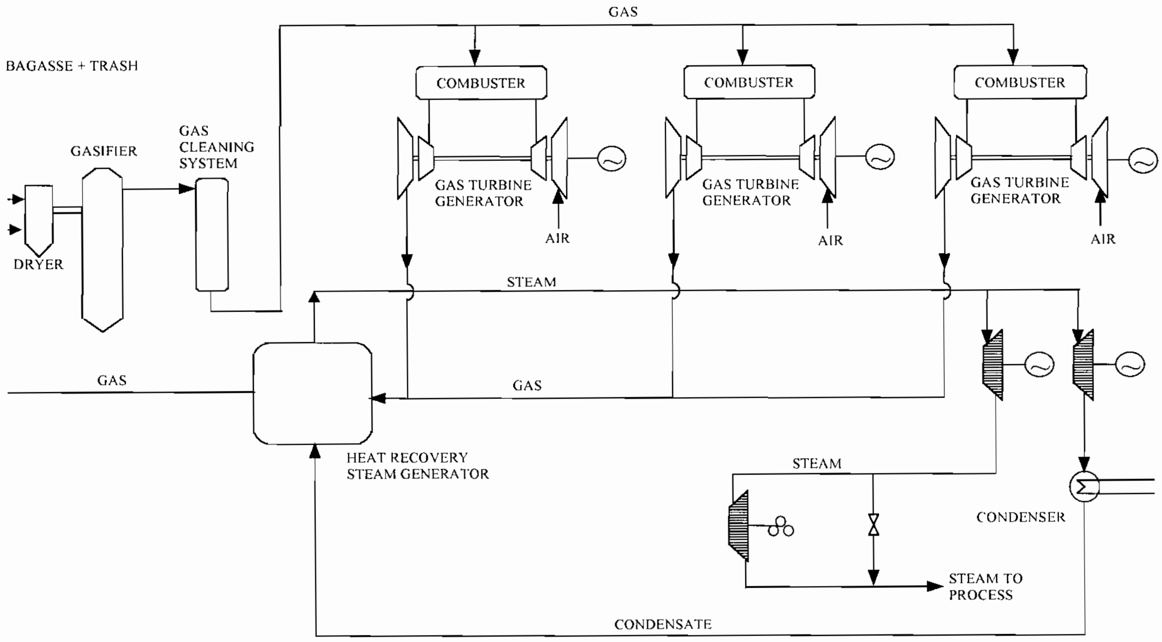

Figure 3. BIG-GT – mill basic integration mode (cogeneration mode).

economic implication for the sugarcane industry but will also have an impact on the environment. Results obtained so far have shown the extraordinary contribution that the new technology may have in reducing greenhouse gas emissions, as well as particulate emission. More biomass would be used for power production and, in addition, because of the higher efficiencies in conversion, less fossil fuel would need to be burnt.

A major advantage with the development of the utilisation of gas turbines is that they benefit from R&D work carried out in the jet engine industry. If it is assumed that the overall conversion efficiency on NCV of bagasse to useful heat and electrical energy is 85% and, if this energy can be converted into electrical energy at an efficiency of 45%, it would be possible to have sufficient energy for 340 kg process steam/t cane. Consequently, if the sugar industry is to benefit from this technology, efforts should be made to reduce the process steam to 340 kg/t cane in the long term. This should present no technical problems as simulations carried out with sextuple effect evaporators have shown that process steam could theoretically be reduced to less than 300 kg/t cane (Kong *et al.*, 1999).

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