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**ENERGY FROM SUGARCANE BY-PRODUCTS:
ANALYSIS FOR KENYA**

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DECLARATION

I, Justus M.P. Mbithi, hereby declare that this thesis entitled “ Energy from sugarcane by-products: an analysis for Kenya’’, submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering of the University of Cape Town is my original work and that it has not been submitted in this or similar form at any other university.

Justus M.P. Mbithi

Signed -----

Date -----

University of Cape Town

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ABSTRACT

The Kenyan sugar industry continues to face the task of being competitive in a liberalized global economy that has witnessed a trend in declining sugar prices and increasing local production costs.

This dissertation attempts to investigate possible options that could assist Kenyan sugar industry to cope with the crisis. One such option is the diversification of the sugar industry's product base. Expanding their business to energy as a co-product to sugar processing, sugar companies could generate additional revenue from surplus electricity sales to the national utility. In Mauritius, gross revenue of USD 50 million, equivalent to 90% of that accruing to the miller for cane processing is generated from bagasse-based energy sales.

On the basis of the Mauritian and other experiences the research concludes that Kenya sugar industries have the potential to export 43, 258, and 306 GWh of electricity to the national grid, depending on the mode of operation of the power plant. Thus the potential for revenue expansion through power sales for the Kenyan sugar industry is substantial. Power sector reforms have seen the entry into the electricity market of independent power producers (IPPs), and so this presents a good opportunity for sugar companies to enter into power purchase agreements with the national utility for the supply of power.

Anaerobic digestion systems, used in the treatment and management of industrial effluent provide an additional benefit of generating boiler fuel in the form of biogas in sugar industries of Kenya. This technology and its application to the sugarcane industry are reviewed as part of this thesis.

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ABBREVIATIONS AND ACRONYMS

| | | |
|----------|-------|--------------------------------------------------------|
| ACFC | ----- | Agro-Chemical and Food Company |
| AFREPREN | | – African Energy Policy Research Network |
| BCATP | ----- | Bacardi Corporation Anaerobic Treatment Process |
| BIG/GTCC | --- | Biomass integrated Gasifier/Gas Turbine Combined Cycle |
| BIG/STIG | ----- | Biomass integrated Gasifier/Steam Injected Gas turbine |
| BOD | ----- | Biochemical Oxygen Demand |
| BPST | ----- | Back Pressure Steam Turbine |
| BVf | ----- | Bulk Volume fermenter |
| CEB | ----- | Central Electricity Board (Mauritius) |
| CEST | ----- | Condensing-Extraction Steam Turbine |
| CHP | ----- | Combined Heat and Power |
| COD | ----- | Chemical Oxygen Demand |
| COMESA | ----- | Common Market for Eastern and Southern Africa |
| (US)EPA | ----- | Environmental Protection Agency (US) |
| ETP | ----- | Effluent Treatment Plant |
| GATT | ----- | General Agreement on Tariffs and Trade |
| GJ | ----- | Giga Joule |
| GWh | ----- | Giga Watt hour |
| ha | ----- | Hectare |
| HRSG | ----- | Heat Recovery Steam Generator |
| IPPs | ----- | Independent Power Producers |
| JICA | ----- | Japan International Co-operation Agency |
| KAM | ----- | Kenya Association of Manufacturers |
| KenGen | ----- | Kenya electricity Generating Company |
| KPLC | ----- | Kenya Power and Lighting Company |
| KSA | ----- | Kenya Sugar Authority |
| KSB | ----- | Kenya Sugar Board |
| KWh | ----- | Kilo Watt hour |
| KV | ----- | Kilo Volt |
| LPG | ----- | Liquefied Petroleum Gas |
| m.c | ----- | moisture content |
| mg/l | ----- | milligrams per litre |
| Mpa | ----- | Mega Pascal |

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MT ----- Metric Tonne
MWh ----- Mega Watt hour
PPA ----- Power Purchase Agreement
ppm ----- parts per million
REP ----- Rural Electrification Programme
RFO ----- Residual Fuel Oil
RON ----- Research Octane Number
SONY ----- South Nyanza Sugar Company
tc ----- tonnes of cane
TCH ----- Tonnes of cane per hour
TSS ----- Total suspended solids
TWh ----- Tera Watt hours
UASB ----- Upflow Anaerobic Sludge Blanket
USD ----- United States dollars
V/V ----- Volume by Volume
WESTCO ----- West Kenya Sugar Company
ZESA ----- Zimbabwe Electricity Supply Authority

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CHAPTER 1

INTRODUCTION

Kenya, like most petroleum importing countries has over the years witnessed some economic setbacks as a consequence of erratic, and often skyrocketing oil prices. The economic problems have taken their toll on the country's overall development, impacting negatively on its balance of payments, its debts burden and social infrastructure.

Energy is widely recognized as one of the key drivers for socio-economic development and indeed, the engine for industrial development. Sessional paper no.1 of 1986 on "Economic Management for Renewed Growth" and the interim poverty reduction strategy paper (GK, 2000) emphasize the vital role of energy towards the attainment of a new industrializing status (NIC) for Kenya by the year 2020. This is a major challenge, considering that according to the 2002 "Economic Survey", 70% of the country's total energy demand is provided through the use of traditional biomass in the form of wood fuel (mainly fuel wood and charcoal). Petroleum fuel and electricity remain the major sources of commercial energy in the country, but only account for approximately 23% and 5% of total energy demand (GK, 2002) respectively.

Biomass fuel, depending on how it is used, can have far reaching negative environmental and health effects including deforestation, green house gas (GHG) emissions and respiratory ailments. Some studies have been done to improve the situation (Karekezi et al, 1995, Kammen et al, 1994), but are beyond the scope of this work and so will not be covered. There is potential however, for the utilization of biomass in combined heat and power (CHP) plants from agro-industrial waste and by-products to produce high quality energy while preserving the environment.

Some of the most promising bio-energy sources from sugarcane are: bagasse, ethanol and molasses. Bagasse can be burnt as fuel in boilers to produce process heat and generate electricity. Combined heat and power (co-generation) production results in higher energy efficiencies compared to other methods of energy production.

Ethanol and /or molasses can be used as feedstock in the production of power alcohol that can be used directly as transportation fuel or blended with gasoline.

In the past, little attention was paid to wastewater treatment and management other than the use of aerobic ponds and lagoons with effluent being drained into rivers and waterways, notwithstanding subsequent environmental and

health hazards. Legislation and strict environmental codes set for industrial effluent treatment have now been introduced in many countries, making it an expensive exercise to cope with. Anaerobic digestion (AD) systems have found widespread use in the treatment and management of high organic load industrial wastes. AD systems have the potential of providing fuel for boilers in the form of biogas and bio-fertilizer for agriculture, thus transforming an environmental and health liability to an economic asset.

An integrated system that adds value to sugarcane by-products would go along way to provide a source of income for millers and farmers alike. The extra income can also be used to modernize farming methods and milling machinery. The thrust of this research is directed towards the energy production from sugarcane by-products using Kenya as a case study.

1.1 BACKGROUND

Kenya has the potential to produce over 14 million tonnes of cane per year from 100,000 hectares (ha) under sugarcane cultivation. However, only an estimated annual average of 5 million tonnes of cane are produced from the 50,000 ha under commercial sugarcane cultivation (KSA, 1999). The commercial acreage comprises the nucleus estates and the out-grower farms. The nucleus estates are those belonging to and managed by the sugar factories, while the out-grower farms belong to large-scale farmers contracted by the sugar factories for cane deliveries. The factories also receive deliveries from non-contracted small-scale farmers depending on demand.

Sugarcane cultivation in Kenya is dependent on rainfall even though irrigation farming would guarantee increased cane supply and eliminate seasonal fluctuations caused by drought or floods. The area under sugarcane cultivation at the end of 2001 was 117,131 hectares compared to 107,985 hectares in 2000, an increase of 8.5% (KSB, 2002). From the same source, the total area harvested in commercial farms in 2001, excluding that harvested by non-contracted farmers was 47,794 hectares against 57,243 hectares in 2000, a decrease of 17% (Table 1.2). This could be attributed to a poor crop yield resulting from the 1999-2000 drought. As at the end of 2001, total cane-able area that was fallow (not under crop) was 39,709 hectares (Table 1.1).

In its annual report for 2001, the Kenya Sugar Board identified some of the factors that could have contributed to low cane yield (KSB, 2002).

- Poor land preparation.
- Little or no fertilizer use.
- Inadequate maintenance of the cane.
- Harvesting of cane at low ages

Table 1.1. Land area under sugarcane cultivation as at 31st Dec. 2001

| Sugarcane zone | Potential cane-able surface (ha) | Fallow surface (ha) |
|----------------|----------------------------------|---------------------|
| Chemelil | 18,000 | 5,325 |
| Muhoroni | 14,136 | 5,132 |
| Mumias | 48,410 | 1,920 |
| Nzoia | 21,409 | 5,595 |
| South Nyanza | 17,995 | 6,354 |
| Miwani | 16,564 | 8,818 |
| West Kenya | 15,000 | 3,083 |
| Busia | 12,000 | 3,482 |
| Overall | 163,514 | 39,709 |

Source: KSB

Table 1.2. Land area under sugarcane, area harvested, production & average yield: 1997-2001

| | 1997 | 1998 | 1999 | 2000 | 2001* |
|---------------------------|-----------|-----------|-----------|-----------|-----------|
| Area under cane (ha) | 127,560 | 117,657 | 108,793 | 107,985 | 110,666 |
| Area harvested (ha)** | 43,814 | 50,111 | 51,833 | 57,243 | 47,794 |
| Production (tonnes) | 4,278,273 | 4,661,361 | 4,415,801 | 3,941,524 | 3,550,792 |
| Average yield (tonnes/ha) | 90.81 | 85.51 | 78.42 | 60.52 | 63.71 |

*Provisional

** Does not include area harvested by non-contracted farmers.

Source: economic survey 2002.

The Sugar Act (2001) provides for the development, regulation and promotion of the sugar industry as well as the establishment, powers and functions of the Kenya sugar board. The Board is made up of thirteen members, with a chief executive and secretariat. Members are drawn from stakeholders in the industry including representatives from out-grower associations and millers.

There are six operational sugar factories in Kenya and the government has majority shares in five of them. These are: Chemelil, Muhoroni, Mumias, Nzoia, and South Nyanza. West Kenya Sugar Company is privately owned. Miwani Sugar Company, which was closed at the end of February 2001 and sold to a private investor is not yet operational.

Table 1.3. Sugarcane yields for different factories in Kenya (tc/ha) in 2000 & 2001

| Factory zone | 10-year average (1992-2001) | 2000 | 2001 | % Change 2001-2000 |
|--------------|--------------------------------|-------|-------|--------------------|
| Chemelil | 62.61 | 54.61 | 59.27 | 8.5 |
| Muhoroni | 60.27 | 48.42 | 68.16 | 40.8 |
| Mumias | 88.02 | 64.60 | 61.97 | -4.1 |
| Nzioa | 66.11 | 54.80 | 56.90 | 3.8 |
| South Nyanza | 86.30 | 69.79 | 62.23 | -10.8 |
| Miwani | 50.49 | 49.96 | 25.04 | -49.9 |
| TOTAL | 75.69 | 60.52 | 63.71 | 5.3 |

Source: KSB

Molasses, another by-product of the sugarcane industry is sold to Agro-Chemical & Food Company (ACFC) at Muhoroni, the only alcohol distillery in the country utilizing this by-product, and to farmers as feedstock for animal feed. Though most of the factories use the anaerobic sludge digestion system as one stage in their wastewater treatment, none has tapped the available biogas from this process as a fuel. The ACFC distillery has however, utilized an innovative technology of tapping this gas at a production capacity of more than 20,000m³ of methane for use in boilers as supplementary fuel and alternative to furnace oil in their operations.

1.2 RESEARCH PROBLEM.

In 2002, the six operating sugar factories in the Kenya produced 491,229 tonnes of sugar, 161,639 tonnes of molasses and 1,775, 008 tonnes of bagasse (Magero: Pers. Comm.). ACFC consumes about 65,000 tonnes of molasses per year, providing revenue to the sugar industry for a product that was previously a nuisance.

Presently, not all bagasse produced is used in the factories for the generation of heat and power. It is difficult to handle, transport and where storage facilities are lacking, the surplus is dumped in compounds around the factory posing serious environmental problems, including fire hazards.

The backpressure steam turbine co-generation cycle used in all factories in Kenya has the least thermal efficiency and so provides room for improvement. Even without upgrading the turbine systems, numerous energy efficiency measures that require little or no capital investment can result in incremental power production and subsequently, in using more bagasse. This potential will be examined in this work.

This work will also attempt to study the potential for the use of anaerobic digestion systems with methane recovery and subsequent utilization in fuel boilers. The application of anaerobic digestion systems can lead to social, economic and environmental benefits. These include:

- Cleaner air.
- Reduced public health risk.
- Fossil fuel substitution.
- Better/lower sugar prices as a result of savings in fuel costs.
- Excess power to underlying villages leading to improved standard of living.
- Cost savings to the factories.
- Improved sugarcane waste management.
- Less power demand from and export to the utility.
- Waste with higher fertilizer nutrient being available

1.3 RESEARCH OBJECTIVES AND METHODOLOGY

The overall objective of this research is to undertake an energy analysis of the Kenyan sugar industry and to search for innovative solutions to the crisis facing the industry. These include:

- Energy inefficiency in the process of sugar production.
- Product diversification (e.g. Power sales, molasses marketing, use of methane as alternative boiler fuel, use of barbojo – the cane leaves and tops or trash in co-generation)

This work will particularly explore and analyze innovative methods of:

- Increased energy efficiency in the sugar production process.
- Adding value to sugarcane by-products as feedstock for energy production.
- Transfer, adoption and application of technologies appropriate to the country

The methodology for realizing these objectives includes.

- Gathering information and data pertinent to energy use in Kenya, and in particular, resource use and potential in the sugarcane industry.
- Interviews, on-site investigations/observation and audits with all stakeholders such as millers, farmers/ farmer associations, and the Kenya sugar board, agro-chemical & Food Company, relevant government ministries and parastatals, research institutions.
- Conducting an in-depth analysis of the collected data and information

- Making appropriate recommendation for policy and decision makers based on the findings of the research.

1.4 SCOPE OF THE RESEARCH

This work will be limited to the sugar and allied industries in the sugar belt of Nyanza and western Kenya.

For more than a month, from March to April 2003, all sugar factories in Kenya went through industrial unrest, culminating in strikes and closure of most of them. This coincided with the period of data collection for this work and the opportunity for in-depth on-site investigative research was lost i.e. energy audits at the sugar industries that were initially to be carried out could not be done satisfactorily without reverting to historical data. Production data and information were however obtained from interviews, perusing through company records and other sources.

1.5. RESEARCH OUTLINE

This dissertation is organized into seven chapters as follows:

Chapter 1 is an introductory summary of the thesis touching on the background of the Kenya sugar industry, possible causes and solutions to the problem(s) bedeviling the industry, the methodology used in pin-pointing and analyzing this problem as well as the limitations encountered and the challenges faced.

Chapter 2 is a review of related research, demonstration and commercial international experiences reported in literature. These have been limited to selected country experiences relevant to the scope of this work.

Chapter 3 examines and describes the technologies available for use in both the research/demonstration and commercial phases.

Chapter 4 analyses energy production and use in the Kenyan sugar industry, using available sugarcane by-products and waste(s). The methodology used is as outlined in Section 1.3, taking into account the limitations and scope of the research. The results of this analysis indicate the nature and magnitude of the problem leading to the status quo in the sugar industry.

Chapter 5 searches for distinctly achievable, potential and innovative solutions to the problem(s) identified and discussed in Chapter 4. Potential opportunities for improvement are suggested, including those that would require little or essentially no capital investment.

Chapter 6 continues the discussions from Chapter 5 and studies the possibility of replicating successful programmes from Mauritius and elsewhere. It also touches on the importance of designing and implementing good Power Purchase Agreements (PPAs).

Chapter 7 gives a conclusion as well recommendations for achieving the objectives of this study as outlined in Sub-section 1.3

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CHAPTER 2

LITERATURE SURVEY AND COUNTRY EXPERIENCES

2.1. INTRODUCTION

This chapter reviews the latest developments in energy production and consumption from sugarcane wastes and by-products. It covers research and development activities and experiences in several countries, particularly those in Eastern and Southern Africa as well as South and Central America. Sugarcane cultivation is a major agricultural activity in Ethiopia, Kenya, Malawi, Mozambique, Madagascar, Mauritius, Swaziland, South Africa, Zambia and Zimbabwe. Other major sugarcane growing countries include Brazil, Cuba, India and the Philippines. The sequential generation of electrical power and thermal energy (steam) is referred to as the production of combined heat and power (CHP) or cogeneration.

Bagasse is the fibrous residue of sugarcane crushing and milling operations and can be used as a source for cogeneration of power and heat. In 1995, sugar mills around the world cumulatively produced over 400MW of electric power through cogeneration, of which 300MW was exported to the utility grids (Karekezi et al 2000: 10). At the beginning of the year 2000, systems installed capacity was 1,100 MW with another 450MW under construction. There is potential for electricity generation since cogeneration plant and equipment are almost uniformly an integral component of the design of sugar factories.

Ethanol and molasses are other sugar cane by-products that have been used in the production of power alcohol for blending with gasoline to give “gasohol”– a transportation fuel. Successful power alcohol programmes are reported from Brazil and Zimbabwe. Anaerobic digestion systems can be applied in industrial waste treatment to give biogas, a valuable fuel and substitute for fossil fuels in boilers. This technology is reviewed further in the chapter with respect to the Agro-Chemical and Food Company (ACFC), an alcohol distillery in western Kenya.

2.2. COGENERATION:

Co-generation using bagasse as feedstock to produce both process heat and electricity is a well-established technology in Africa. Bagasse has always been the major source of energy in the sugar cane industry. The tops and leaves of the sugarcane plant, normally referred to as trash, can also be another energy resource. Bagasse and trash each account for about one third of the above ground energy stored in sugar cane, with the remaining one-third stored as sugar. Bagasse has a gross calorific value (higher heating value) of 19,250 KJ/kg at zero moisture content and 9, 950 KJ/kg at 48% moisture content. The net calorific value (lower heating value) of bagasse at

48% moisture content is approximately 8,000 KJ/kg. Most sugar mills are capable of producing bagasse with 48% moisture content, depending on the milling process. Good milling process can produce bagasse with 45% moisture content while poor milling performance results in bagasse with approximately 52% moisture content.

The standard practice in the sugar industry is to burn bagasse to generate medium or high-pressure steam using backpressure steam turbines. The oil crises, coupled with supply and price uncertainties have shifted emphasis to the extraction of maximum power with a view to export energy to the grid. This has resulted in the preference of the condensing-extraction steam turbine (CEST) cogeneration system, which utilizes steam extracted at intermediate pressure from the turbine to provide process heat and boost efficiency.

The modern CEST cogeneration system operates at turbine inlet pressure range of 4.0 to 8.0 MPa and is capable of producing enough steam to run a typical factory and electricity in excess of on-site needs (Rabah, 2000). The excess electricity can be made available to other users by interconnection to national grid systems. The CEST system is fuelled with bagasse as it comes from the mill at 50% moisture content during the milling season. In off-season, CEST units can be operated in the condensing mode producing power only, using alternative bio-fuels e.g. barbojo (trash), wood, municipal solid waste (MSW) or heavy fuel oil. Gasification is a recent method for the production of electricity from biomass. Rather than burning the fuel, gasification involves the partial oxidation of biomass at temperatures of the order 800°C to 1200°C to produce combustible fuel gases.

Energy generation through gasification involves integrating the existing Brayton (gas turbine) power generating or co-generation cycles, which have already been developed for natural gas and coal with closely, coupled biomass gasifiers. "The biomass integrated-gasifier/gas turbine combined cycle (BIG/GTCC) technology was first identified over a decade ago as an advanced technology with the potential to be cost-competitive with conventional CEST technology using biomass by-products of sugarcane processing as fuel, while drastically increasing the electricity generated per unit of sugarcane processed"(Larson et al, 2001: 54). Substantial research and demonstration activities to develop BIG/GTCC technology have been undertaken worldwide resulting in numerous system designs and commercialization efforts (Karth & Larson, 2000: 106, 119-129)

The potential energy that can be generated for export to the grid from sugarcane factories depends on the technology used. Approximately 50 million tonnes of cane are produced annually in the eastern and southern African region, and at an average 31% bagasse content in cane, this translates to about 16 million tonnes of bagasse. Depending on the option of power plant mode (continuous or firm), between 2,500 and 5,500 GWh of electricity is potentially available for export to the grid (see Table 2.1)

Table 2.1. Potential electricity export (GWh) from bagasse in the Southern and Eastern African region.

| Country | Cane-production/yr (million tonnes) | Continuous-power @ 50kWh/tc | Firm-power @ 44bars&80kWh/tc | Firm-power @ 82bars&110kWh/tc |
|--------------|-------------------------------------|-----------------------------|------------------------------|-------------------------------|
| South Africa | 22.94 | 1,146.5 | 1834.4 | 2522.3 |
| Swaziland | 8.86 | 443.0 | 708.8 | 974.6 |
| Malawi | 4.08 | 204.0 | 326.4 | 448.8 |
| Zimbabwe | 9.02 | 451.0 | 721.6 | 992.2 |
| Mozambique | 0.55 | 27.5 | 44.0 | 60.5 |
| Kenya | 4.50 | 225.0 | 360.0 | 495.0 |
| Grand Total | 49.94 | 2,497.0 | 3995.2 | 5493.4 |

Source: Deepchand (2001: 31)

Continuous power plants are those that operate only during the milling season using bagasse while firm power plants operate all year round using bagasse during crop and alternative fuels during intercrop. Following are specific country experiences in co-generation found in literature. Only selected case studies relevant to the objective of this research are reviewed from a vast collection of research information and findings available.

2.2.1. Mauritius

Mauritius produces 600,000 tonnes of sugar annually from 5.8 million tonnes of cane that yield approximately 1.8 tonnes of bagasse (Deepchand, 2000: 15). Ten power plants with installed capacities ranging between 11 to 70MW each were operational in the year 2000. (Mbohwa et al, 2002: 9). Three of these were firm power plants, fitted with condensing-extraction turbo-alternators and exhaust steam utilization mechanisms for supplying power out of the factory. The other seven were continuous power plants, providing power only for in-house consumption. Table 2.2 gives the type of bagasse-based power plants up to the year 2000.

In Reunion, the centralization process has been finalized with only two factories in operation, each processing 900,000 tonnes of cane annually. Each factory is equipped with 2x30-35 MW power plants operating at around 82 bars. Productivity of energy generation for these plants is 110 kWh/tc compared to 60 kWh/tc in Mauritius. (Deepchand 2001a: 21). Thus with further centralization of cane milling operations, improvement in exhaust steam in cane processing, upgrading the efficiency of the power plants by adopting operating pressures of 82 bars and the use of trash (cane field residues) as supplementary fuel, 800 GWh of electricity, nearly double the current quantity, can be exported to the national grid in Mauritius.

Table 2.2. Bagasse-based power plants in Mauritius up to year 2000

| Factory | Power | Boiler capacity t/hr | Pressure (bars) & temp (°C) | Turbo alternator | | Start date | Units from bagasse (GWh) | Units from coal (GWh) |
|--------------------------|-------------------|----------------------|-----------------------------|--------------------------------------------------|--------------------------------------|------------|---------------------------------|-----------------------|
| | | | | Type | Installed Capacity (MW) | | | |
| FUEL | Firm | 1x110 1x100 | 44; 430 44; 440 | Cond/Extrac Cond/Extrac | 21.7 18 | Oct.98 | 60 | 115 |
| Deep river beau champ | Firm | 1x140 | 45; 475 | Cond/extrac condensing using exhaust steam | 24.6 4 | Apr.98 | 90 | 85 |
| Belle Vue | Firm | 2x140 | 82; 525 | Cond/Extrac | 60 | Apr.2000 | 105 | 220 |
| Medine | Continuous | 1x50 2x35 | 32; 420 17; 250 | Cond/etrac Back-pressure | 10 3 | | 20 | - |
| Mon tresor Mon desert | Continuous | 1x70 | 26; 400 | Cond/extrac | 12.5 | Jul.98 | 14 | - |
| Union st- aubin | Continuous | 1x80 | 31; 440 | B/pressure | 12.2 | Jul.97 | 16 | - |
| Riche en eau | Continuous | 1x45 1x43 | 18; 310 26; 400 | Condensing B/pressure | 6 3.2 1.6 stand by | Jul.98 | 17 | - |
| Savannah | Continuous | 1x70 1x35 | 31; 410 17; 300 | Cond/extrac | 15.3 | Jul.98 | 20 | - |
| Mon lois ir | Continuous | 1x80 | 19; 325 | B/pressure | 12 | Jul. | 20 | - |
| Mon desert alma | Continuous | 1x70 1x50 | 31; 430 24.2; 343 | Con/extract | 11.2 | Nov.97 | 18 | - |
| Total | 3 firm 7 cont. | | | 7 cond/extrac 3b/pressure | 217.2 (128.2 firm, 89.0 cont.) | | 360 (235 firm, 125 cont.) | 420 |

Source: Deepchand (2001b: 10)

2.2.2 Zimbabwe

Zimbabwe has two sugar factories, Triangle Sugar Limited (TR) and Hippo Valley Estates (HV) and both are located in the lowveld. Triangle Sugar Limited has the capacity to crush about 2.5 million tonnes of sugarcane per year, producing a maximum 290,000 tonnes of raw sugar. The plant runs for 9 to 10 months per year (Mbohwa et al, 2002: 4). With an average bagasse content in the cane of 31%, 775,000 tonnes of bagasse are available annually. This bagasse is used to produce most of the plant's power requirements.

Triangle can produce 35.5 MW during the milling season and about 5 MW in the off-season. The maximum generating capacity of 140 GWh (44 kWh/tc) is very low compared to Reunion power plants, which can export 110 kWh/tc after meeting sugar-processing requirements. Some of the alternators are old and rarely used. The plant is underutilized with an output of 21 MW; just enough to satisfy in-house consumption requirements as no electricity is sold to the local utility, ZESA. Stored bagasse and coal are used during the off-crop season that lasts for three months but if more power is needed during this period it can be obtained from the utility grid. Five of the six turbines are backpressure steam turbines while the sixth is a condensing-extraction steam turbine, exhausting steam at lower pressure.

The Hippo Valley Estates Sugar Factory processes an average of 2.2 million tonnes of cane per year, producing 260,000 tonnes of raw sugar. 10,500 tonnes of cane per day (tcd) are crushed over a period of 9 to 10 months every year, yielding about 660,000 tonnes of bagasse. The plant has two diffuser lines, which can process 450 to 500 tonnes of cane per hour.

The Hippo Valley power plant typifies an embedded power generation station meaning that it is connected to a substation within a particular distribution system where the total output facility can be distributed and retailed locally by the utility, without any requirement for use of high voltage transmission lines. An embedded facility provides electricity to the distribution utility, even if the transmission grid is not close to the location of the generation plant. This has lower tariff implications since the end-user tariff will not include transmission-wheeling charges (Batidzirai, 2002: 24, Edjekumhene et al, 2001: 43-44).

The plant has five turbo alternator sets that have been in use for over twenty years. A new turbo alternator rated at 20MW has been installed giving the potential to generate up to 26 MW, 15 MW of which are used to meet factory and estate needs. The remaining 11MW is available for sale to ZESA during the crushing season. Total installed capacity at Hippo Valley estates is now 46 MW, with a 3.5 MW backpressure set recently installed.

Using the Reunion transformation rate of 110 kWh/tc would give the Zimbabwe sugar industry the capacity to generate 210 MW or 517 GWh electricity for export (Mbohwa et al, 2002: 9). Biomass-integrated gasifier/gas turbine combined cycle technology (BIG/GTCC) can raise this export potential to 1692 GWh. Both the Triangle and Hippo Valley sugar factories have a unique advantage compared to other sugar industries in that they can operate for 9 to 10 months every year. Under these circumstances, the use of coal or other alternatives in firm power plants is minimal.

The current plans are for intermittent power export to the grid at an agreed price. There is need to consider moving toward continuous power supply to the grid during the crop season by using alternative fuels (coal, barbojo, fuel oil) whenever bagasse runs out. Firm power plants should also be considered in the long term.

2.2.3. Brazil

Brazil presents a good example of utilizing sugarcane trash as a supplementary fuel to bagasse. The 330 sugar mills in the vary country widely in size, technology and age. Surplus power generation has been under consideration by the Brazilian sugar/ethanol mills for many years.

Current power sector reform programmes are paving way for use of independent power producers (IPPS) and this has created a new surge of interest among mills, resulting in the development of several projects and studies targeting small-to-medium size enterprises (SMES) for surplus power generation during the milling season. Most sugarcane factories in Brazil produce only sufficient power to satisfy their immediate energy requirements.

In countries where large systems that produce over 100 kWh/tc have been installed as in Mauritius, Reunion, Guadalupe, Guatemala and Hawaii, alternative fuel to bagasse (mostly fossil fuel) is used during off- season operations. For many years, Copersucar has been investigating the recovery and use of sugarcane trash (tops, dry and green leaves) as a supplementary fuel to increase the power generating capacity of mills. Table 2.3 shows the average energy conditions for Brazilian mills.

Table 2.3. Average conditions of the energy sector of Brazilian mills

| | |
|-----------------------------------------------|----------------------------|
| Boiler pressure/temperature | 22bar/300 ^o c |
| Electric power consumed | 12kWh/tc |
| Mechanical power consumed | 16kWh/tc |
| Process heat consumed | 330kWh/tc (500kg steam/tc) |
| Excess bagasse after supply of process energy | 7% |
| Trash used | - |
| Excess power generation | Negligible |

Source: Macedo et al (2001: 78)

In 1997 the Ministry of Science and Technology in Brazil initiated a project with funding from the United Nations Development Programme whose objective was to evaluate and develop the required technology for using bagasse and trash as fuel in advanced co-generation systems, such as the biomass-integrated gasification/gas turbine (BIG/GT), integrated with sugar/ethanol plants (Macedo et al, 2001: 77, GEF, 2002: 17). Alternatives such as those shown in table 2.4 will have to be considered when it becomes economically feasible to export electricity.

It is clear from table 2.4 that to generate power all year round, supplementary fuel is required and the alternative being considered in Copersucar is sugarcane trash. This is true for the existing CEST or the advanced BIG/GT co-generating systems. Although BIG/GT technology has not yet been commercialized, a lot of progress has been made in its development.

Table 2.4. Alternatives for generating excess electricity

| Alternative | Power generation | Process steam Consumption Kg/tc | Excess power kWh/tc |
|------------------------------|-------------------------------|---------------------------------|---------------------|
| 22 bar/300c pressure TG | Season | 500 | 0-10 |
| 82 bar/480c Back-pressure TG | All year (supplementary fuel) | 500 | 20-40 |
| 82bar/480c extrac/conden TG | All year (supplementary fuel) | 340 | 80-100 |
| BIG/GT* | | <340 | 150-300 |

Source: Macedo et al (2001:78)

*Technology not commercial

2.2.4 Cuba

Cuba's 156 sugarcane-processing factories have cane-crushing capacities ranging from about 2000 tc/day to over 10,000 tc/day, per factory. In aggregate, the sugar factories have the capacity to support 2.8 GW of CEST cogeneration capacity and 5.6 GW of BIG/ GTCC capacity (Larson et al, 2001). Given that total installed electric utility generation capacity for Cuba is 4.3 GW, this translates to 65% and 130% of the total power demand for the country, in CEST and BIG/ GTCC cogeneration options respectively. Although only about half of the factories have adequate capacity to support BIG/GTCC systems larger than 25 or 30 MW, using cane trash and bagasse from smaller factories can facilitate installation of larger capacity cogeneration systems.

In Cuba, an estimated 70% of the sugarcane crop is machine harvested without prior burning. The country has over 900 cleaning stations, used for removing trash from the cane stalks before the stalks are transported to the crushing mills. These stations are connected to mills by a low-cost cane delivery system, comprising of a dedicated rail network with more than 7000 km of track (Larson et al, 2001: 65).

Presently, most of this trash is incinerated at the cleaning stations to reduce the volume of waste transported. In the long term, Cuba can install BIG/GTCC cogeneration systems throughout its sugarcane processing industry, providing a total of 12 to 13 TWh/yr (harvest levels of 40 to 80 Mtc/yr) electricity for export. The potential with

CEST systems at 5 to 9 TWh/yr is significant considering that the 1999 level of oil-fired electricity in Cuba was about 12 TWh/yr.

2.3 POWER ALCOHOL:

Two by-products, namely: cane juice and molasses can be used as feedstock for the production of ethanol. Ethanol makes an excellent motor fuel with a research octane number (RON) of 109 and motor octane number (MON) of 98, both of which exceed those of marketed gasoline. Ethanol has lower vapour pressure than gasoline and this results in lower evaporative emissions. Ethanol's flammability in air is also much lower than that of gasoline, which means a reduction in the number, and severity of vehicle fires. The properties of ethanol as a fuel however, make it necessary (depending on blending ratios) to modify or even design dedicated motor engines (for high alcohol content blends). The main fuel properties necessitating engine modifications (with respect to the conventional gasoline engine are shown in Table 2.5

Table 2.5: Fuel Properties and characteristics

| | Gasoline | Ethanol |
|-----------------------------------|-----------------|----------------|
| Specific calorific value (KJ/Kg) | 43,900 | 26,700 |
| Octane number (RON/MON) | 91/80 | 109/98 |
| Latent heat of vaporization KJ/Kg | 376-502 | 903 |
| Ignition temperature (°c) | 220 | 420 |
| Stoichiometric A/F ratio | 14.5 | 9 |

Source: Goldemberg & Macedo (1994: 18)

In practice, ethanol fuel needs warming of the mixture because it exhibits a cooler combustion and allows a much higher compression ratio. Some kind of protection must be provided for all parts in contact with ethanol to cater for the corrosive behavior of ethanol.

Power Alcohol Programmes have successfully been implemented in several developed and developing countries (Brazil, Malawi, USA, Zimbabwe) and experiences expounded in literature (Goldemberg & Macedo, 1994, Scurlock et al 1991, Walter & Cortez, 1993).

2.4. ANAEROBIC DIGESTION

Anaerobic digestion has been used as an integral part of wastewater treatment for a long time now as an effective way of alleviating pollution problems. During anaerobic digestion, methane and carbon dioxide are produced as a result of the decomposition of complex organic compounds such as carbohydrates, proteins and lipids. This

decomposition initially yields short-chain volatile fatty acids, alcohol, ammonia and other neutral compounds, plus the formation of carbon dioxide and hydrogen. Among products generated are carbon dioxide and methane.

The use of anaerobic digestion techniques in the purification of wastewater is dependent upon atmospheric oxygen not being allowed to enter the system, since molecular oxygen is toxic to the anaerobic bacteria. There are a number of anaerobic digestion process alternatives that may be considered for wastewater treatment: anaerobic filters, fluidized bed reactors, contact digesters and the up flow anaerobic sludge blanket reactors.

Anaerobic digestion is often the most attractive solution for treatment of effluents due to the following advantages: a high BOD reduction; production of energy as biogas; production of a bio-fertilizer; small production of already stabilized biological sludge; lower capital investments and operating costs; the possibility of decentralized systems etc.

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CHAPTER 3

ENERGY CONVERSION TECHNOLOGIES IN THE SUGAR INDUSTRY

3.1. INTRODUCTION

This chapter discusses the technologies and processes available in the sugar industry. Some of these conversion technologies have already been mentioned previously in chapter 2 and can be summarized as follows:

- (a) Condensing turbines, in which the steam from the boiler is expanded in the turbine to sub-atmospheric pressures and useful power produced. From the turbine, steam is condensed and returned to the boiler.
- (b) Backpressure turbines in which steam from the boiler is expanded to the pressure required for downstream factory processes. Low to medium pressure (15-25 bars) is typical of this system, which is used where there is a large downstream demand for process steam (Williams, 1986). Useful electrical and mechanical power is also simultaneously generated.
- (c) Pass-out condensing turbines have the attributes of (a) and (b) above. Some steam is extracted at an intermediate pressure, suitable for process use, and the rest expanded to the lowest possible pressure, then condensed. Hooking the steam turbine to a generator using available shaft work generates electricity.
- (d) Biomass-integrated gasifier/combined cycle turbines, which are under continuing demonstration and commercialisation stages.
- (e) Anaerobic digestion systems, where biogas is generated from effluent treatment plants and utilized as fuel in boilers

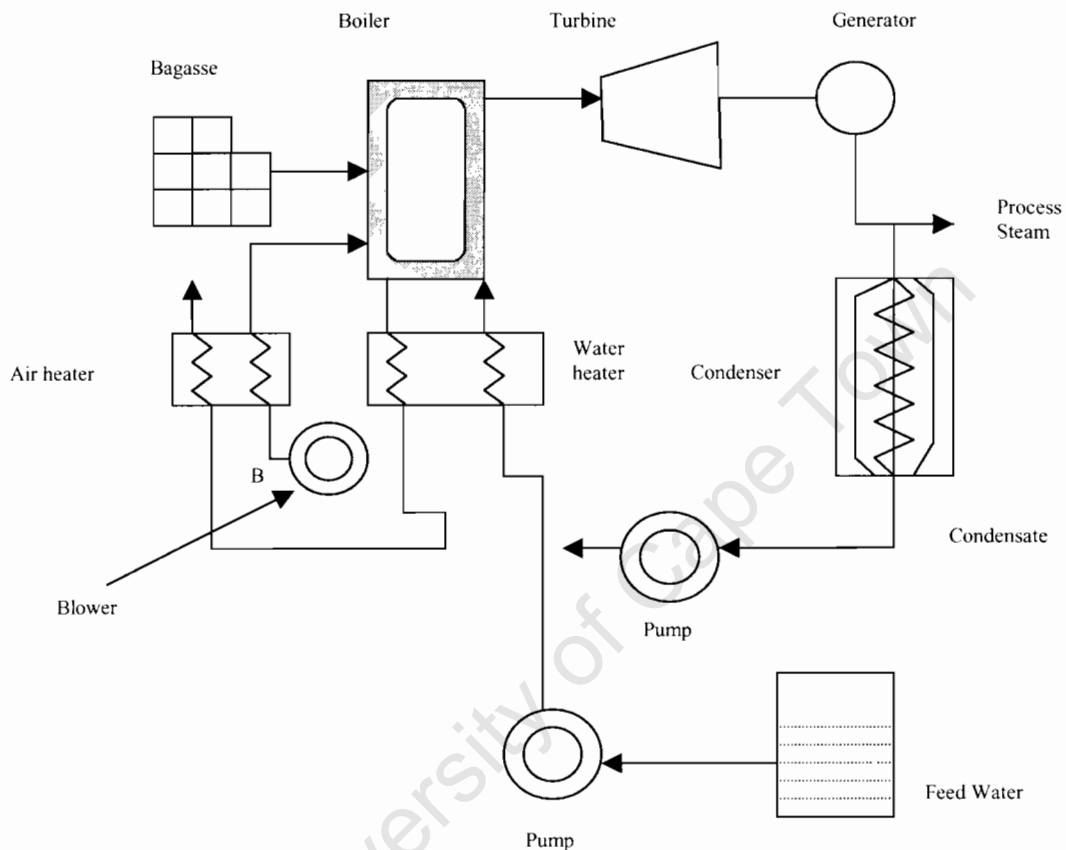
3.2 COGENERATION:

This is an energy-efficient process involving combined heat and power (CHP) production from the same energy source. The standard practice in the sugar industry is to burn bagasse to generate medium or high-pressure steam, which is used in the prime movers of the sugar factory and also for power generation (Dadhich, 1997).

Following is a brief review of the technologies and processes in sugar industry:

3.2.1. Backpressure Steam Turbine (BPST):

Fig.3.1. Bagasse-based BPST



Source: Larson et al (2001: 55)

Fig 3.1 is a schematic of the backpressure steam turbine system. It comprises an air and steam cycles. Air is introduced into the air inlet by a blower, preheated and fed into the boiler at an appropriate air-fuel ratio with bagasse. The fuel mixture is then ignited, producing a thermo- chemical reaction. This reaction in turn produces heat, which is used for raising steam (Banda, 2002). Steam from the boiler is then expanded through the backpressure turbines to the pressure required for downstream factory processes. The turbine takes the place of a reducing valve and generates useful electrical and mechanical power.

Process steam and electrical energy consumption at the factory will in practice determine cogenerator output and the power available for export. Fluctuations in factory steam consumption significantly disturb the export levels. Attempts to regulate the flow of electricity exports are likely to create an imbalance in fuel or factory steam availability and a reduction in electrical energy generating efficiency.

In the condenser the exhaust steam comes into contact with the cold surface of the water tubes to form condensate. Extraction of the heat from the condenser may be through a cooling tower or water-spray open to the atmosphere. Some water is lost in the process and is replaced with de-aerated and de-mineralized make-up water. De-aeration and de-mineralization of the water is important to avoid fouling of the boiler pipes (Banda, 2002). The condensate is then returned to the boiler after pumping through the heaters.

The backpressure steam turbine cycle technology is the least thermodynamically efficient system in the industry. Typically, BPST systems operate at pressures in the range 15-25 bars.

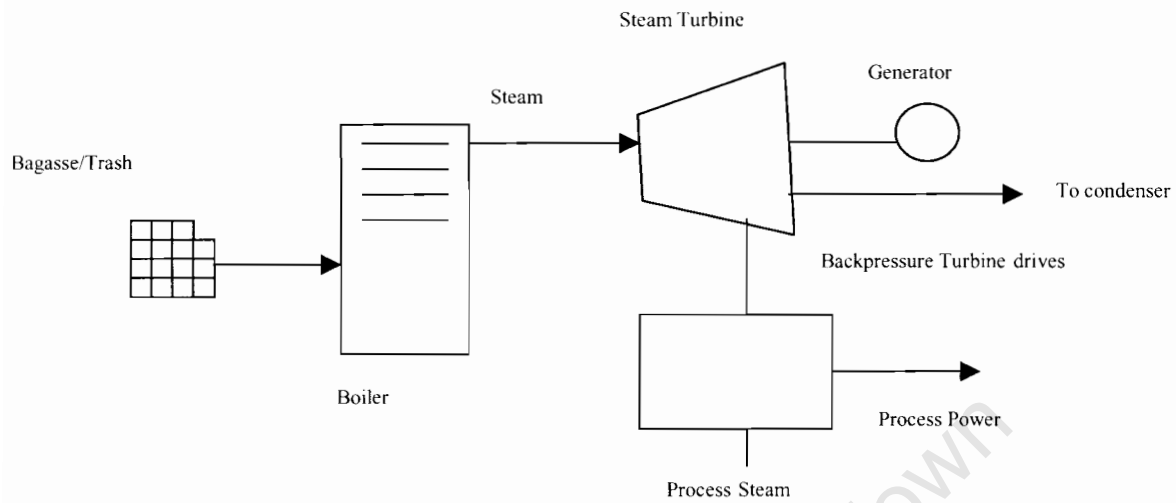
3.2.2. Condensing-extraction steam turbine (CEST)

The addition of straight condensing turbo-alternators to the backpressure turbine will facilitate stable electric energy heat rate. The trend worldwide has been to consider using the condensing-extraction steam turbine cogeneration system with the objective of large-scale electricity export to the grid. It follows that the higher the primary steam pressure and temperature and the lower the steam pressures for motive purposes, evaporation and condensing, the greater the export energy for a fixed input of fuel to the steam generators.

At turbine inlet pressure range between 4.0 and 8.0 MPa, the modern CEST cogeneration system is capable of producing enough steam to run a typical factory and electricity in excess of on-site needs. Surplus electricity can be made available to other users by using the factory as an embedded generation facility or transmitting it by interconnecting the co-generator with national grid systems.

The CEST system is fuelled with bagasse as it comes from the mill at 50% moisture content during the milling season. In off-season, CEST units can be operated in the condensing mode producing power only, using stored bagasse, trash or other alternative fuels. The exhaust steam of the backpressure turbine drives provides all process steam demand. Steam is sometimes tapped off at two points: the high-pressure and the low-pressure lines to the process. The CEST systems operate at 40-85 bars (Banda, 2002)

Fig. 3.2. Bagasse/trash-based CEST system



Source: Larson et al (2001: 60)

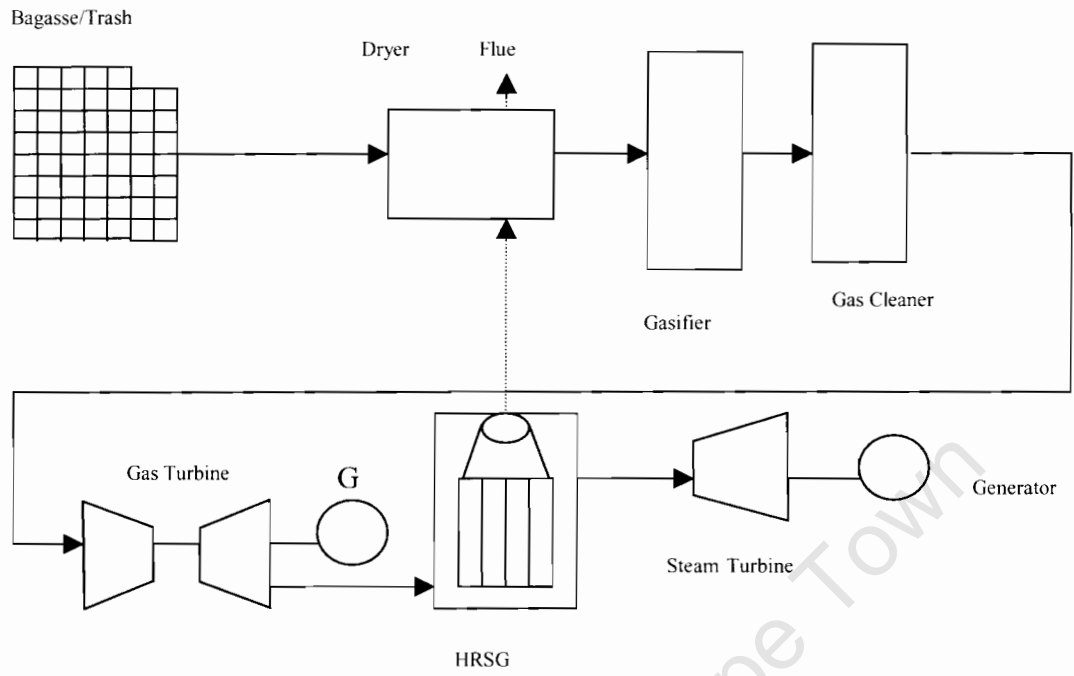
3.2.3. Biomass-integrated-gasifier/gas turbine combined cycle (BIG/GTCC)

Gasification is a new method that can be used to produce electricity from biomass. It involves the partial oxidation of biomass at temperatures of the order 800⁰C to 1200⁰C to produce combustible fuel gases. Energy generation is achieved by marrying existing Brayton (gas turbine) power generating or cogeneration cycles, which have already been developed for natural gas to closely, coupled biomass gasifiers.

This technology was first identified more than ten years ago as an advanced technology with the potential of being cost-competitive with conventional CEST technology using biomass by-products of sugarcane processing as fuel, while dramatically increasing the electricity generated per unit of sugarcane processed (Larson et al, 2001). Substantial efforts have since been undertaken worldwide to develop BIG/GTCC systems and carry out pilot, demonstration and commercial projects.

The biomass (bagasse / trash) is passed through a dryer (ideally fueled by waste heat) before being converted into a combustible fuel gas in the gasifier. The product (gas) requires to be cleaned before entering the gas turbine-generator. A heat recovery steam generator (HRSG) is then used to raise steam from the hot exhaust of the gas turbine and a steam turbine-generator used to produce additional electricity. Three variations of this basic configuration have been identified and are under commercial development. Table 3.1. is a summary of their relative advantages and disadvantages.

Fig3.3. Simplified schematic of BIG/GTCC system



Source Larson et al (2001: 62)

Variant 1 is characterized by the use of a fluidized-bed reactor operating at atmospheric pressure followed by a second gasification stage in which a catalyst (dolomite) is used to reduce the content of heavy hydrocarbon product (‘tars’) that are part of the gas produced in the first reactor.

In variant 2, the gasifier is operated at atmospheric pressure and rather than partial combustion, the biomass is indirectly heated. Product gas passes through a tar-cracking unit before being cooled, cleaned and compressed to fuel the gas turbine.

Variant 3 involves operating a fluidized-bed gasifier under elevated pressure using air for the partial oxidation. Product gas is cooled only modestly, cleaned at elevated temperature before passing to the gas turbine combustor.

Steam cycle design and operation within a sugar factory are dictated by both theoretical and practical considerations, key elements of which include (Dadhich, 1997, Deepchand, 2001a,b)

- kWh price of electricity for export;
- Magnitude of energy and power export;
- Export energy and power scheduling;
- Cane crushing capacity, process efficiency and bagasse/supplementary fuel availability;

- Factory layout-existing or new proposed equipment;
- Operation and maintenance expertise and existence
- Duration of power purchase agreement (PPA)

Table 3.1. Advantages and disadvantages of BIG/GTCC designs

| Gasifier design | Advantages | Disadvantages |
|------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Low pressure Air blown (Variant 1) | -Easy fuel feed to gasifier -Conventional gas cleaning equipment -Economically suited for modest size | -Waste water from gas cleaning -Fuel gas compressor adds cost, reduces efficiency -Limited economically |
| Low-pressure, indirectly heated (Variant 2) | -Easy fuel feed to gasifier -Conventional gas cleaning equipment -Economically suited for modest size -High energy content fuel gas | -Waste water from gas cleaning -Need for fuel gas compressor, but smaller than variant 1. -Limited economically to modest size -Operation more challenging than variant 2. |
| High-pressure Air blown (Variant 3) | -Higher efficiency due to lack of gas compressor -Dry hot-gas clean up -Economically suited to larger scale than others | -Difficult fuel feed to gasifier -More challenging gas cleaning -High NO _x emissions -Limited economically to larger scale |

Source: Larson et al (2001: 56)

3.3 ANAEROBIC DIGESTION SYSTEMS

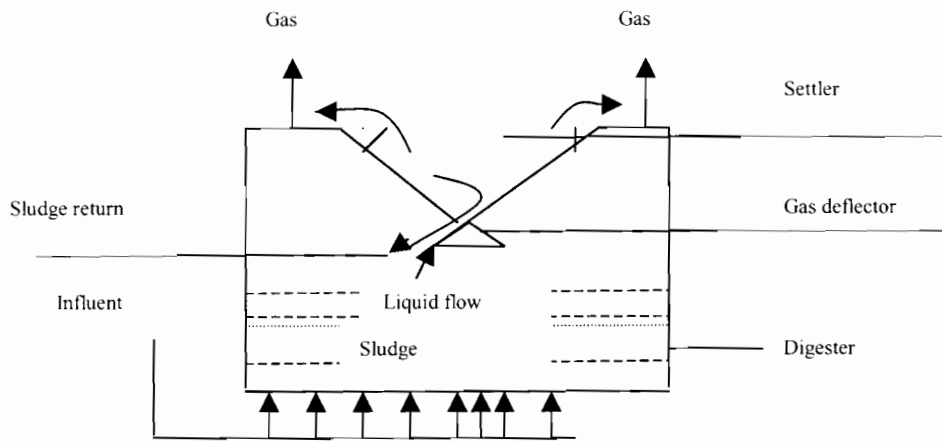
3.3.1. Anaerobic treatment

The process has been well known for a long time in connection with the treatment of wastewater sludge. Long-term technical development has produced different processes and reactors but only three of these: the up flow anaerobic sludge blanket (UASB), the Bacardi Corporation anaerobic treatment process (BCATP), and the bulk volume fermenter (BVf) will be discussed in this chapter.

3.3.2 Up flow Anaerobic Sludge Blanket (UASB)

The UASB reactor consists of a tank at the bottom of which the digester itself is located and at the top of which a settler preceded by a gas system is located. Wastewater, uniformly distributed at the bottom of the reactor passes through a biological sludge layer, which transforms the organic material into biogas. Deflectors prevent the gas from entering into the settlers other than certain areas of the reactor

Fig. 3.4. A schematic diagram of the UASB reactor *



*Source: Adopted from Souza (Undated)

The portion of the sludge that reaches the settler is separated, returning to the bottom of the reactor. Effluent is uniformly withdrawn from the surface of settler

3.3.3 BCATP:

The Bacardi Corporation Anaerobic Treatment process (BCATP) plant has been in operation for twenty-one years since its startup at San Juan, United States in January 1982. Confronted with the challenge of finding an environmentally acceptable yet cost-effective means of disposing of its strong distillery wastewater, Bacardi Corporation carefully evaluated numerous conventional and advanced treatment technologies. After nearly ten years of studies in which such factors as the high organic content in wastewater, the degree of biochemical oxygen demand (BOD) removal required by the US. Environmental protection agency (EPA), the capital cost of the system and the value of the methane generated by the process were considered, Bacardi Corporation came to the conclusion, with the concurrence of (US) EPA that anaerobic treatment was the preferred process for protecting the environment and complying with its discharge requirements.

The BCATP utilizes acetogenic (facultative), and methanogenic bacteria, immobilized on fixed rigid plastic media, to convert the soluble organic waste into a methane-rich gas, thereby reducing the BOD of the wastewater treated. Since startup, BCATP plant has met or exceeded all design performance criteria and the biogas generated is currently substituting a significant portion of the fuel consumed by the distillery steam boilers.

According to Szendrey et al (undated) the patented Bacardi Corporation anaerobic system is applicable to a wide variety of wastewaters and substrates. Pilot and laboratory scale studies have confirmed that the following streams are readily and cost effectively treatable using the system:

- Pharmaceutical fermentation wastewater.
- Citric acid fermentation wastewater.
- Pulp paper mill wastewater.
- Cheese whey.
- Yeast production wastewater.
- Molasses distillery slops.
- Brewery wastewater.
- Organic chemical manufacturing water.
- Winery wastewater.
- Vegetable processing waste.

In general, most wastewaters having a BOD greater than 500mg/l and a total suspended solids (TSS) content below 15,000mg/l can be successfully treated by the Bacardi Corporation anaerobic treatment process.

3.3.4 BVf Plant:

The Bulk Volume fermenter (BVf) plant at the Agro-Chemical & Food Company's (ACFC) Muhoroni plant was commissioned in 1997 as the first phase (anaerobic digestion) of the effluent treatment plant (ETP) of the Kenyan distillery. The digester walls are constructed of reinforced concrete and covered with a special membrane, resistant to rain and heat.

Anaerobic digestion is achieved through subsequent stages of hydrolysis, acetogenesis and methanogenesis, with the biogas produced composed of 55-60% methane. Production of biogas ranges between 23,000 to 30,000m³/day (calorific value of methane 8822 Kcal/m³). The biogas is used to fuel boilers, which produce process heat. The daily production is capable of substituting 12.5 tonnes of furnace thereby generating an equivalent Ksh. 3million/month (us 437,500/month exch. Rate 2002: 1 US\$= Ksh 80) in savings. Effluent treatment is completed in three stages (phases) to reduce the Biochemical Oxygen Demand (BOD) and the Chemical Oxygen Demand (COD) of the effluent by 90% and 70% respectively.

Stage I: Primary Treatment

- Cooling of the effluent.
- Anaerobic digestion with biogas generation

Stage II Secondary Treatment

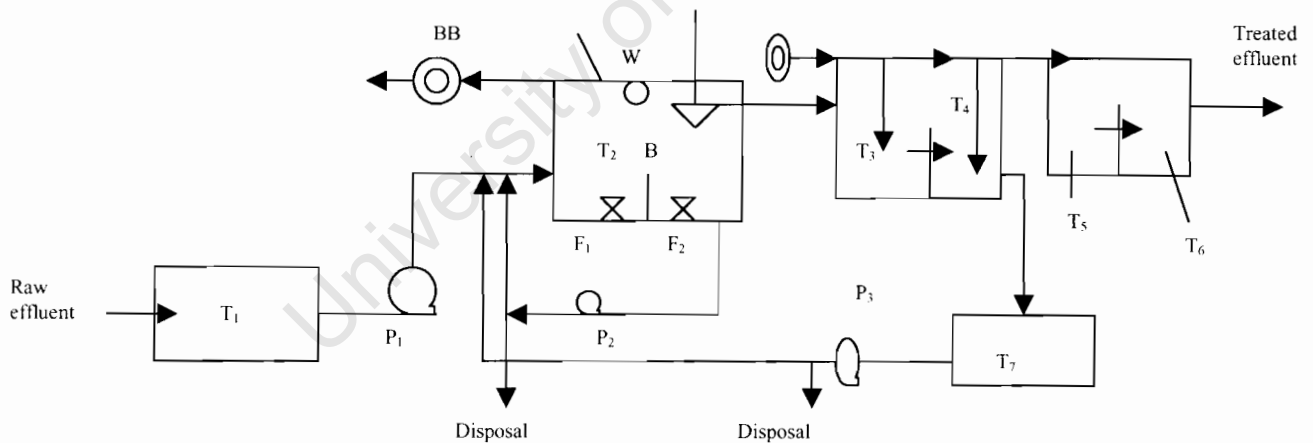
- Aeration of effluent (aerobic biodegradation).
- Sedimentation, recirculation and removal of sludge thickener.
- Thickening of excess sludge and sending it to the aerobic digester.

Stage III Tertiary Treatment

- Short time aeration (aerobic biodegradation).

The second phase of the ETP was completed in 1999 and comprises the aerobic digestion plant. This is a system of lagoons comprising secondary and tertiary aerated ponds (working volume 12.8 million and 1.2 million litres respectively) and air blowers. Retention times are nine days and half-day respectively for the secondary and tertiary stages. The BVf is a unique installation of its kind in Sub-Saharan Africa. Previously, the ACFC had contemplated the use of a vinasse boiler but this was shelved in place of the BVf. Fig. 3.5 is schematic diagram of an effluent treatment system incorporating the BVf facility.

Fig 3.5 BVf Effluent Treatment System



Source: Kshetry (1992: 8)

Key

T₁-----Cooling & settling tank

T₂-----Anaerobic digester

T₃-----Aeration tank

T₄-----Clarifier tank

F₁&F₂-----Mixers

P₁-----Transfer pump

P₂-----Sludge circulation pump

P₃-----Sludge pump

T₅-----Tertiary aeration tank

T₆-----Treated effluent tank

T₇-----Sludge thickener

FM-----Floating membrane

B-----Baffle

BB-----Biogas blower

AB-----Air blower

GLSS-----Gas/liquid/solid separator

W-----Weight

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CHAPTER 4

ENERGY ANALYSIS OF SUGARCANE BY-PRODUCTS IN KENYA

4.1. INTRODUCTION

In this Chapter, an analysis will be made of the energy use in three of the six operating sugar factories in Kenya, namely Mumias Sugar Company, Nzoia Sugar Company and West Kenya Sugar Company using data collected from fieldwork. An overall energy performance for the industry will also be briefly reviewed. Lastly an energy balance for the effluent treatment plant (ETP) at the Agro-Chemical & Food Company will be undertaken.

4.2 FIELD WORK

The methodology used for data collection was outlined in Chapter 1, Section 1.3. By studying and perusing production records in all the sugar companies during field visits to the factories, pertinent data and information were collected. At the production facilities, observations were made and discussions held with the technical and management staff. Historical energy data, used for estimating the energy balance of a sample boiler were authenticated by direct measurements, rapid energy audits and consultations with quality control, boiler room, production floor and power house chemists, engineers, technologists and other technical, management and support staff. Data and further information were gathered from relevant organizations (Ministries of Energy, Industry, Agriculture, Environment, Kenya Power & Lighting Company, Kenya Electricity Generating Company, Electricity Regulatory Board, Kenya Sugar Board, Kenya Industrial Research & Development Institute, Kenya Association of Manufacturers, National Council for Science & Technology, National Environment Management Agency, Universities & Research Institutes and the Internet) and individuals.

All sugar companies were visited but reliable data and information for the last five years could only be obtained from Mumias, Nzoia and West Kenya Sugar Companies.

The Sugar Companies

Most of the companies do not keep records systematically, particularly information relating to energy use. Table 4.1 is a summary of selected production and performance parameters for the whole industry. Part of the data was directly extracted from company records or provided from Kenya Sugar Board statistics and the remaining derived from empirical findings and physical measurements during fieldwork.

The turbine system used by these factories was found to be the backpressure steam turbine (BPST). It was observed that nearly all six-sugar factories under-utilize their capacities in power generation. Only Mumias Sugar

Company has generated extra power for export to the Kenya Power and Lighting Company (KPLC). Muhoroni Sugar Company can generate 10MW if one of the boilers (no. 4) is operated while South Nyanza Sugar Company and Chemelil have 3.2 MW and 3.5 MW turbo-alternators respectively lying idle (Magero 2003: pers.comm.). Nzoia Sugar Company, which is not connected to the national electricity grid, is capable of generating in excess for sale. A good number of these factories still rely on national grid power to supplement self-generated capacity for their energy requirements. This has resulted in increased production costs, and consequently to reduced competitiveness.

Table 4.1 Energy performance parameters of all sugar companies – 1997 – 2001.

| Item | 1997 | 1998 | 1999 | 2000 | 2001 |
|--------------------------------|------------------|------------------|------------------|------------------|------------------|
| 1. Production | | | | | |
| Cane crushed (tc) | 4,393,153 | 4,840,080 | 4,673,247 | 3,907,835 | 3,689,571 |
| Molasses (t) | 170,633 | 160,093 | 163,928 | 141,735 | 126,605 |
| Molasses % cane | 3.88 | 3.31 | 3.51 | 3.63 | 3.43 |
| 2 Cane quality | | | | | |
| Pol % | 11.92 | 12.23 | 12.70 | 12.45 | 12.11 |
| Fibre % | 17.52 | 17.95 | 17.95 | 17.4 | 16.95 |
| Item | 1997 | 1998 | 1999 | 2000 | 2001 |
| 3. Milling data | | | | | |
| Pol extraction % | 86.8 | 86.64 | 90.15 | 87.1 | 87.64 |
| Milling losses % | 8.08 | 8.16 | 10.13 | - | - |
| 4. Time account | | | | | |
| Gross grinding (hrs) | 70,080 | 63,356 | 59,166 | 51,748 | 37,944 |
| Actual grinding (hr) | 37,481 | 36,123 | 33,024 | 24,268 | 20,817 |
| Overall time eff. | 53.5 | 57.2 | 55.82 | 49.9 | 60.19 |
| Factory time eff. hrs | 75.5 | 73.44 | 67.2 | 55.33 | 80.21 |
| 5. Bagasse (t) | 1,672,473 | 1,964,104 | 1,901,077 | 1,560,399 | 1,435,243 |
| % Cane | 38.07 | 40.58 | 40.68 | 39.93 | 38.39 |
| % Pol | 3.63 | 3.83 | 3.64 | 3.95 | 3.77 |
| % Moisture | 50.91 | 51.34 | 51.38 | 51.71 | 51.81 |
| % Fibre | 45.0 | 44.99 | 46.31 | 43.62 | - |
| 6. Consumables | | | | | |
| Furnace oil (m ³) | 4,705 | 3,915 | 3,927 | 2,086 | 1,629 |
| Firewood (t) | 24,867 | 29,164 | 37,466 | 27,663 | 3,334 |
| Lime (kg/tc) | 1.1 | 1.1 | 1.05 | 1.12 | 0.98 |
| Sulphur (t) | 395.7 | 419.5 | 360 | 358 | 221 |
| 7. Capacity utilization | | | | | |
| % | 63.1 | 66.5 | 67.1 | - | 45.71 |

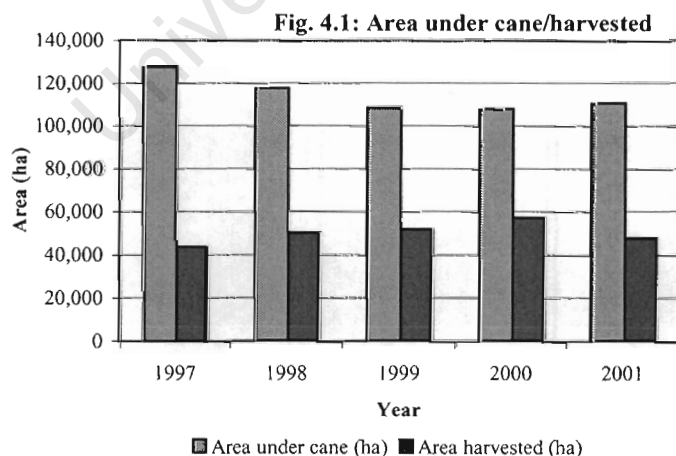
The Muhoroni Distillery

The only alcohol distillery in the country to produce power alcohol (45,000litres / day) was the Agro-chemical and food company (ACFC) at Muhoroni in Nyanza province. This distillery, annexed to the Muhoroni sugar company is the only known enterprise to utilize Anaerobic Digestion system technology in a large scale for waste treatment while generating energy in the form of biogas (23,000m³ / day) as a substitute for fossil fuel in boilers. Three weeks were dedicated to the collection of data and information from this facility. During this period the operations of the effluent treatment plant were studied and recorded, samples of influent and effluent taken and tested in the quality control laboratories, visits made to the boiler room and the distillery and observations made on biogas consumption, electricity and steam utilization, operational data collected and extracted from personnel and company records, and interviews and discussions held with technical operations staff and management. The information and data collected was used to work out material and energy balances for the effluent treatment plant.

Cane Production

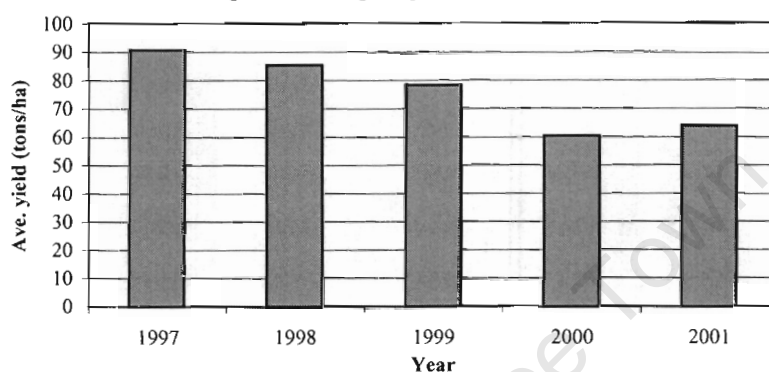
Most of the data and information on cane and bagasse production were obtained from the Kenya Sugar Board and Sugar Companies' inventories and records. Some data and information were also obtained from interviews and personal communication with individuals from Government, Non-Governmental organizations and the Private Sector.

Area under cane decreased drastically from 127,560 hectares (ha) in 1997 to 107,985 ha in 2000, increasing only marginally to 110,666 ha in 2001 (Table 1.2, Fig. 4.1)



This is in contrast to an increase in area harvested (excluding area harvested by non-contracted farmers) from 43,814 to 57,243 ha. between 1997 and 2000. Except an increase in 1998, sugar production decreased over the five year period as did the average yield (tonnes/ha) which showed only a marginal increase in 2001 over 2000 (fig.4.2). This can be mainly attributed to drought.

Fig. 4.2: Average sugarcane yield 1997 - 2001



Bagasse

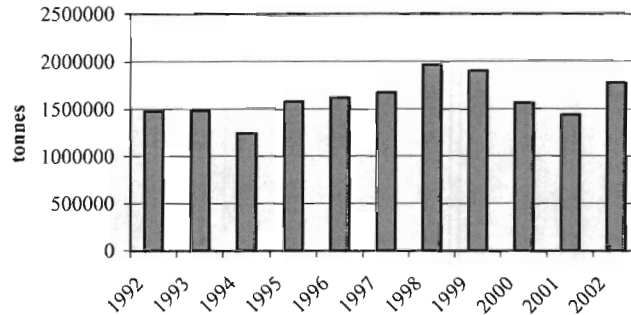
Bagasse has conveniently been used as fuel in combined heat and power (CHP) production to provide the sugarcane processing facility with its process heat and captive power requirements. In Kenya, bagasse (51% moisture content) typically accounts for 30-40% of the total weight of cane crushed (Table 4.1)

Table 4.2. Bagasse availability (tonnes) in Kenya: 1992-2002

| Year | Bagasse | m.c. % |
|------|---------|--------|
| 1992 | 1470820 | 50.48 |
| 1993 | 1481417 | 50.48 |
| 1994 | 1241828 | 50.96 |
| 1995 | 1573562 | 50.36 |
| 1996 | 1618427 | 50.79 |
| 1997 | 1672473 | 50.9 |
| 1998 | 1964104 | 51.34 |
| 1999 | 1901077 | 51.38 |
| 2000 | 1560399 | 51.71 |
| 2001 | 1435243 | 51.81 |
| 2002 | 1775007 | - |

Source: computation from KSB statistics

Fig 4.3. Bagasse availability (tonnes) in Kenya: 1992-2002.



Bagasse production is characterized by fluctuations over the ten-year period from 1993 to 2002. The main cause behind these fluctuations is changing rainfall patterns. Mumias, the largest of the sugar companies accounted for 52% of total production in 2002, while the smallest, West Kenya Sugar Company accounted for a mere 4% of total production.

4.3 ENERGY ANALYSIS

Energy performance is obtained from the computation of records of energy data and information gathered in the field and records extracted from sugar companies, for the years 1998 to 2000. Reasonably reliable production and energy data for the years 1998-2000 were available from three companies namely: Mumias, Nzoia and West Kenya. All three are located in the western belt of the sugar zone and in relatively close proximity to one another. For the purpose of this Study, energy performance analysis is carried out on these three companies. Performance analysis for the whole industry based on estimated energy potential will also be undertaken.

The energy audit system is based on the "Energy Accounting Manual" guidelines produced by the Ministry of Energy in conjunction with the Kenya Association of Manufacturers (KAM). A glossary of terms and energy performance computations can be found in appendices A and B.

Energy intensity (I_e) is the average amount of energy required to produce a product or group of products expressed in energy per unit of production

$$I_e = \frac{E_t}{P_t} \text{-----(4.1)}$$

Where I_e is energy intensity

E_t is total energy

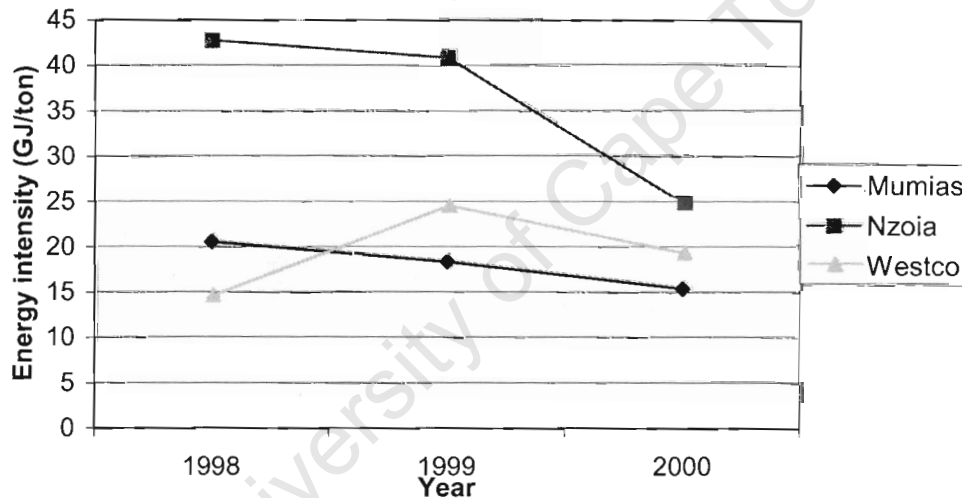
P_t is total production

Table 4.3 and Fig. 4.4 illustrate energy intensities for three sugar companies, calculated using equation (4.1).

Table 4.3. Energy intensity for three sugar companies in Kenya

| Company | Total Production (tonnes sugar) | | | Total energy use (GJ) | | | Energy Intensity | | |
|---------|---------------------------------|---------|---------|-----------------------|-----------|-----------|------------------|------|------|
| | 1998 | 1999 | 2000 | 1998 | 1999 | 2000 | 1998 | 1999 | 2000 |
| Mumias | 229,098 | 251,243 | 217,243 | 4,722,760 | 4,609,360 | 3,354,909 | 20.6 | 18.4 | 15.4 |
| Nzoia | 37,769 | 49,996 | 41,484 | 1,616,869 | 2,045,856 | 1,034,454 | 42.8 | 40.9 | 24.9 |
| Westco | 17,273 | 16,859 | 7,920 | 252,872 | 412,370 | 152,948 | 14.6 | 24.5 | 19.3 |

Fig. 4.4. Energy intensity of three sugar companies: 1998 - 2000



Results for Mumias and Nzoia sugar companies show successive improvements (decreasing energy intensity) in terms of energy consumption per unit of production in the period the three-year period. West Kenya Sugar Company recorded deteriorating (increase in energy intensity) energy use between 1998 and 1999. The reason could be as result of poorly maintained equipment, leading to low capacity utilization. The trend however, improved between 1999 and 2000 with a recorded decrease in energy intensity.

Energy performance is derived using energy intensity data:

$$E.P(Y_b, c) = \frac{I_1 - I_2}{I_1} \text{-----(4.2)}$$

Where

E.P is the energy performance between the base (Y_b) year and the current (Y_c) year;

I_1 is the energy intensity in the base year

I_2 is the energy intensity in the current year

Energy performance is similarly derived using base year and current year total energy results: -

$$EP(Y_b, c) = \frac{E_2 - E_1}{E_2} = \frac{I_1 - I_2}{I_1} \quad \text{----- (4.3)}$$

Where,

E.P ($Y_b - Y_c$) is the energy performance between base and current year,

E_1 , the current year energy is the total amount of energy used to manufacture a product or group of products in the current year.

E_2 , the base year equivalent energy is the total energy that would have been required in the base year at the original energy intensity, to produce the current year production output.

$$E_2 = E_0 * PF \quad \text{----- (4.4)}$$

Where,

E_0 , the base year energy is the energy required to operate the plant, which is essentially independent of production;

P.F, the production factor is the ratio of current year production output to base year production output.

Table 4.4. Energy performance of three companies in the sugar industry

| Company | Energy Intensity | | | Energy performance (% improvement) | |
|---------|------------------|------|------|------------------------------------|-------------|
| | 1998 | 1999 | 2000 | 1998 -1999 | 1999 - 2000 |
| Mumias | 20.6 | 18.4 | 15.4 | +11 | +16 |
| Nzoia | 42.8 | 40.9 | 24.9 | +4 | +39 |
| Westco | 14.6 | 24.5 | 19.3 | -67 | +21 |

Rearranging equation (4.2) gives

$$EP(Y_b, c) = \frac{I_1 - I_2}{I_1} = 1 - \frac{I_2}{I_1},$$

which bears similarity to the thermal efficiency definition for a thermodynamic cycle.

$$\eta = 1 - \frac{T_2}{T_1} \quad \text{----- (4.5)}$$

Where,

η , is the thermal cycle efficiency representing the highest thermodynamic efficiency possible when operating between two temperature levels,

T_1 , is the temperature at which heat addition to the cycle takes place,

T_2 , is the temperature at which heat rejection from the cycle takes

In this context, energy performance as calculated using equation (4.2) is an expression of efficiency of the entire energy system (factory) between the base and current years. It captures both thermal and captive power generation systems. For a cogeneration system according to equation (4.5), the higher the temperature at turbine inlet (T_1) and the lower the temperature the exhaust (T_2) the higher the efficiency. A system designer would therefore look for higher parameters, costs permitting. For the lower temperature T_2 , limitations occur due to the ambient conditions available at given site. The lower the ambient temperature, the lower the cooling water temperature considered for the design and therefore lower vacuum in the condenser.

Energy performance in captive power generation can also be expressed in terms of the ratio of the quantum of self-generated electricity to the tonnage of cane crushed over a given period

$$I_p = \frac{kWh}{tc} \text{-----(4.6)}$$

Table 4.5. Electricity production per tonne of cane crushed, kWh/tc

| Company | Electricity generation (kWh) | | | Tonnes of cane (tc) | | | I _p (kWh/tc) | | |
|---------|------------------------------|------------|-------------------|---------------------|-----------|-----------|-------------------------|------|------|
| | 1998 | 1999 | 2000 ¹ | 1998 | 1999 | 2000 | 1998 | 1999 | 2000 |
| Mumias | 59,138,000 | 59,845,000 | 57,298,000 | 2,197,224 | 2,200,191 | 1,908,806 | 27.0 | 27.0 | 30.0 |
| Nzoia | 10,614,000 | 11,794,000 | 13,104,000 | 440,428 | 521,095 | 417,705 | 24.0 | 23.0 | 31.0 |
| Westco | 3,460,000 | 1,002,000 | 2,112,000 | 212,867 | 207,600 | 106,581 | 16.0 | 5.0 | 20.0 |

¹ Includes 2,385 MWh export to the national grid.

The year 2000 recorded an increase in electricity generation per tonne of cane crushed for all three factories. This could be attributed to the 1999 – 2000 countrywide power crisis that witnessed electric power rationing including unscheduled outages and therefore the need to increase captive power generation in industries. All computed figures are however, still far below the average 40 to 60 kWh/tc reported for Brazil and Mauritius and 110 kWh/tc achieved in Reunion. As mentioned earlier all Kenyan sugar factories use the backpressure steam turbine cogeneration cycle, which is the least efficient for power production.

Table 4.6. Heat to Power ratio for three companies in Kenya

| Company | Total energy (GJ) | | | Electricity (GJ) | | | Heat (GJ) | | | Heat/power | | |
|---------|-------------------|-----------|-----------|------------------|---------|---------|-----------|-----------|-----------|------------|------|------|
| | 1998 | 1999 | 2000 | 1998 | 1999 | 2000 | 1998 | 1999 | 2000 | 1998 | 1999 | 2000 |
| Mumias | 4,722,760 | 4,609,360 | 3,354,909 | 223,922 | 223,016 | 215,917 | 4,498,838 | 4,386,344 | 3,181,992 | 20 | 20 | 15 |
| Nzoia | 1,616,869 | 2,045,856 | 1,034,454 | 46,935 | 51,642 | 56,844 | 159,934 | 1,994,214 | 977,610 | 33 | 39 | 17 |
| Westco | 252,872 | 412,370 | 152,948 | 14,566 | 15,696 | 9,961 | 238,306 | 396,674 | 142,987 | 16 | 25 | 14 |

The heat to power ratio is the energy ratio of recoverable electricity and heat. Though the ratio is expected to vary significantly with the amount of process steam produced, the typical value for a backpressure steam turbine is 5 (Kantha & Larson 2000: 103). The ratio as shown in table 4.6 is high, particularly for 1998 and 1999. This implies that too much goes towards thermal energy production at the expense of power production. The typical value for a condensing extraction steam turbine with a capacity factor of 0.9 (operation 90% of the time at full capacity) is reportedly also 5:1 (Kantha & Larson 2000:105). The values are however, reasonably fair and will come down when energy losses in the boilers (steam production) and turbines (power production) are considered.

Table 4.1 gives the energy performance of all sugar companies in Kenya, using various parameters. From this Table, the following observations can be made: -

- i) Bagasse content of cane is very high at nearly 40% compared to the international average of 31%.
- ii) The moisture content of bagasse is high, at an average 51% which is a pointer to poor milling performance.
- iii) Furnace oil and firewood have been used over the years in varying quantities to supplement bagasse.
- iv) Factory Time Efficiency (FTE) is low in contrast to the international average of 91.7%.
- v) Industry performance in the year 2000 was lowest as a result of drought.

Table 4.7 shows the aggregate energy inputs per fuel type for the sugar industry in Kenya.

Table 4.7. Total industry energy inputs per fuel type:

| | 1997 | 1998 | 1999 | 2000 | 2001 |
|----------------------------|---------|---------|---------|---------|--------|
| Bagasse (10 ³) | 13,380 | 15,713 | 15,209 | 12,483 | 11,482 |
| F. Oil | 189,517 | 157,696 | 158,180 | 84,024 | 65,616 |
| Wood | 201,423 | 236,228 | 303,475 | 224,070 | 27,005 |

Source: computed using data from table 4.1

It is evident from table 4.7 that bagasse has always been the predominant fuel in the sugar industry, accounting for more than 96% of total fuel consumption in all the five years between 1997-2001. Wood and fuel oil mostly only used for start-up operations, particularly after maintenance.

4.4. ENERGY BALANCE AT THE ETP FACILITY AT ACFC, MUHORONI.

Evaluation of the quality and quantity of wastewaters is done through stringent quality control in the effluent treatment plant (ETP) laboratory, where performance parameters are reported on a daily basis and the records analysed on a monthly basis. Performance reported on a daily basis include, among others:

- Spent-wash flow
- Average COD in effluent
- COD load per day
- Loading rate
- Substrate temperature
- pH
- Acidity
- Alkalinity
- Total suspended solids (TSS)
- Total volatile solids

From the laboratory test analyses, the percent COD and BOD are computed and the quantity of biogas produced is calculated. This biogas is used as a substitute for fuel oil in dual-fuel fired boilers. Energy produced is calculated from the quantity of biogas and its fuel oil equivalent determined. The results are then compared with the actual amount of fuel oil consumed in the boiler.

The Biochemical Oxygen Demand (BOD) is the quantity used to evaluate the concentration of substances dissolved in water and can be defined as the amount of oxygen required to biologically (aerobically) degrade the organic matter in a waste stream. Its magnitude is determined by the aerobic metabolism of heterotrophic micro-

organisms (1st stage BOD, or Carbon BOD), and also by the metabolism of autotrophic micro-organisms (2nd stage BOD). Thus BOD in the two stages is: $BOD = 2.67C + 4.54N$

Chemical Oxygen Demand (COD) of a wastewater is measured in terms of potassium dichromate ($K_2Cr_2O_7$) reduced by the sample in 2 hours of reflux in a medium of boiling 50% sulphuric acid (H_2SO_4) and in the presence of a silver sulphate (Ag_2SO_4) catalyst. It is defined as the amount of oxygen required to chemically oxidize the organic matter in a waste stream. BOD and COD influent and effluent values are important performance parameters that are continuously reported in the laboratory. BOD_5 (5 days at 20°C) require five days to yield analytical results and that is why COD values are preferred for process control.

Results obtained from laboratory records at the ACFC facility give an average COD reduction of 70%, BOD_5 reduction of 90% and biogas composition of 60% methane, 30% CO_2 with trace amounts of other compounds such as hydrogen sulphide and water vapour making the rest. These results were used to compute energy and material balances for the ETP facility:

Biogas generation:

1 kg of COD digested releases 0.53 m³ biogas

COD of effluent = 100,000;

Total spent wash = 750 m³/day

Total COD loading = 75 tonnes/day

COD reduction = 70%

COD digested = 52.5 tonnes

Biogas generated = 52,500 * 0.53 = 27,825 m³/day

Calorific value of biogas = 18 MJ/m³

Energy production per day = 500,850 MJ ≈ 500 GJ.

Calorific value of furnace oil = 42.28 GJ/t

Mass of furnace oil equivalent to biogas generated = $\frac{500GJ / day}{40.28GJ / t} = 12.4 \text{ tonnes/day.}$

Sludge generation:

a) ANAEROBIC DIGESTER

3% of COD = 2.25 tonnes is converted into biomass. The level of biomass in the digester builds up to the optimum in two years. After this period the biomass/sludge will have to be disposed of. This is a very nutrient-rich bio-fertilizer and ACFC is exploring the possibility of exporting it to EU countries where organic fertilizer is in high demand.

b) AERATION TANK

30% of the COD = 22.5 tonnes is converted into biomass. The biomass/sludge from the aeration tank is concentrated in another tank and fed to the anaerobic digester or disposed of.

University of Cape Town

CHAPTER 5

5. POTENTIAL IMPROVEMENTS

5.1. INTRODUCTION

The sugar industry and sugarcane farmers periodically experience periods of economic difficulties, primarily due to price volatilities resulting from agro-climatic conditions and an unstable world market. Controls and restrictions imposed by the General Agreement on Tariffs and Trade and the World Trade Organization (GATT/WTO) as well as the Common Market for Eastern and Southern Africa (COMESA) have continued to impact negatively on the price of sugar in Kenya. Liberalization of the market has resulted in an influx of imports and rising production costs in the country. Stabilization of the sugar industry can be maintained by reducing dependence on revenue from sugar. At present, the revenue from by-products for almost all sugar factories in Kenya is negligible. The only product being sold is molasses. The revenue situation can be improved by diversifying products from the industry in the form of exportable surplus electricity and biogas.

This chapter will attempt to identify potential innovative schemes for improving operational efficiency and expanding revenue from the Kenyan sugar industry.

Power Sector Reforms

Electricity is the second most important commercial energy in Kenya after petroleum. Electricity is governed by the Electric Power Act 1997, which directly regulates the generation, transmission, distribution and supply of electric power. The transmission, distribution and supply functions are vested in the Kenya Power and Lighting Company (KPLC) while the major generating entity remains the Kenya electricity Generating Company (KenGen). Present installed capacity in September 2002 was 1,048 MW. The commissioning of the Tsavo Power Company later that year added a further 75 MW to the national grid (GK, 2003).

The power sector is assuming increasing importance with on-going sectoral reforms that have led to changes in electricity generation with four independent power producers (IPPs) namely: Iber-Africa, Westmont, Orpower4 and Tsavo Power with a total generation capacity of 187MW. Aggreko, Deutz and Cummins, contracted as Emergency Power Producers (EPPs) at the height of the 1999-2001-power crisis to supply electricity as a short-gap measure but left in June 2001 (Kamfor, 2002: 43). Private participation in electricity generation as result of liberalization provides an opportunity to the sugar companies to enter the electricity market and diversify their revenue base. Mumias Sugar Company took that initiative between 2000 and 2001 and is presently negotiating a

Power Purchase Agreement (PPA) with KPLC. The other sugar companies only co-generate to satisfy their captive demand. All have now applied for licensing to export excess power.

The energy analysis of Kenyan sugar industries gives a picture of gross energy inefficiency in power production (Chapter 4). There is however, significant potential for efficiency improvement in the sector to guarantee more electricity generation.

Electricity generation

The low efficiencies of the backpressure steam turbine can be compensated for through simple energy conservation measures but the current predominant option is to utilize the condensing-extraction steam turbine (CEST) to derive maximum power for export. The biomass-integrated gasifier /gas turbine combined cycle is the latest innovative technology for electricity production from biomass. Though not commercially operational at present, intense worldwide efforts on the commercialization of this technology is likely to lead to it being available within few years.

Biogas

Anaerobic digestion (AD) systems present another opportunity for the sugar industry with double benefits of resolving an effluent disposal problem while providing a useful by-product fuel (biogas) for use in boilers. Already in Kenya, the ACFC effluent treatment plant at Muhoroni, generating over 20,000m³/day of biogas is a showpiece that can be replicated in the sugar industry.

5.2 COMBINED HEAT AND POWER PRODUCTION

The low-pressure (20 bar or less) boilers feeding backpressure steam turbines were designed to be inefficient, so that they could consume all available bagasse while generating enough power and steam to operate the mills. System efficiency could substantially be improved by adopting any one or all of the following measures:

- Boiler efficiency improvements
- Steam efficiency improvements
- Change-over to CEST in the short- to medium term
- Using BIG/GTCC technology in the medium- to long term.

5.2.1.Boiler efficiency improvements

Boiler efficiency η_1 can be calculated by using the Input –Output Method:

$$\eta_1 = \frac{\text{effective heat output}}{\text{total heat input}} \times 100\% = \frac{Q_s}{H_i \times F} \times 100\%$$

Where,

$Q_s = m(h_2 - h_1)$ is the effective heat output in MJ/Kg, or the heat absorbed by generated steam (or hot water) per Kg or m³ of fuel,

H_i = the lower calorific value of fuel, MJ/Kg,

F = the fuel consumption, Kg/hr, or m³/hr,

m = quantity of generated steam (or hot water), Kg/hr,

h_1 = enthalpy of feed water, MJ/Kg,

h_2 = enthalpy of generated steam (or hot water), MJ/Kg,

$$\eta_1 = \frac{m(h_2 - h_1)}{H_i \times F}$$

Boiler efficiency can also be calculated using the Heat Loss method:

$$\eta_2 = \frac{\text{Total heat loss}}{\text{Total heat input}} \times 100\%$$

Heat loss in the boiler can occur through:

- Exhaust gas
- Radiation
- Blow-down and,
- Others

In small boilers, loss is somewhat difficult to determine accurately, therefore it is not desirable to apply the Heat Loss Method (JICA, 1999). Heat loss through exhaust gases is given by the following equation:

$$L_e = G \cdot C_g(t_g - t_0), \text{ MJ/m}^3$$

Where,

L_e = heat loss due to exhaust gas (including water- vapour),

C_g = average specific heat of exhaust gas, MJ/m³°C

t_g = exhaust gas temperature, °C

t_0 = ambient temperature, °C

G = quantity of exhaust gas (including water vapour) = $G_0 + G_w + (r - 1)A_0$, m³

G_0 = theoretical quantity of dry exhaust gas, m³

G_w = quantity of water vapour generated by combustion and quantity of water vapour due to moisture in fuel, m³

A_0 = theoretical quantity of combustion air,

r = air ratio ($r \geq 1$)

$$r = \frac{21}{[21 - (O_2)]} = \frac{(CO_2)_{\max}}{CO_2}$$

Where, (O_2) and (CO_2) are the quantities of oxygen and carbon dioxide in dry exhaust gas, and $(CO_2)_{\max}$ is the maximum value of (CO_2) , at $r=1$,

$(G_0 + G_w)$ and A_0 are calculated from the composition of fuel.

Following now is the energy balance of a sample boiler, feeding a backpressure steam turbine and typically used in Kenya sugar factories. The information and data used were obtained from the fieldwork and literature (JICA 1999):

1. Present boiler efficiency

Feed water

| | |
|-------------|----------------------------|
| Quantity | = 10.5×10^3 kg/hr |
| Temperature | = 20°C |
| Enthalpy* | = 83.9 KJ/kg |

Generated steam

| | |
|------------------------------|-----------------------------------------------------------|
| Pressure | = 20 bar |
| Dryness | = 98% |
| Quantity | = $10.5 \times 10^3 \times 0.9 = 9.5 \times 10^3$ kg/hr |
| Enthalpy of saturated water* | = 909 KJ/kg |
| Enthalpy of saturated steam* | = 2799 KJ/kg |
| Enthalpy of generated steam | = $909 + (2799 - 909) \times 0.98 = 2761$ KJ/kg |
| Heat of generated steam | = $9.5 \times 10^3 \times 2761 = 26230 \times 10^3$ kg/hr |

Fuel

| | |
|----------------------------------|---------------------------------------------------------------------|
| Lower calorific value of bagasse | = 8000 KJ/kg |
| Fuel consumption | = 4.5×10^3 kg/hr |
| Input heat | = $4.5 \times 10^3 \times 8000 = 36000 \times 10^3$ KJ/hr |
| Effective heat output | = $26230 \times 10^3 - (9.5 \times 10^3) \times 83.9 = 25433$ kg/hr |

Boiler efficiency = $\frac{25433}{36000} \times 100 = 70.6\%$

* From steam tables (Roger 1988)

2. Heat losses

Exhaust gases:

$$G_o + G_w = 36 \text{ kg}$$

$$r = \frac{21}{21-8} = 1.62 \text{ (8\% oxygen)}$$

$$c_g = 0.079 \text{ KJ/kg}$$

$$t_g = 375^\circ\text{C}$$

$$t_o = 33^\circ\text{C}$$

$$A_o = 11.09 \text{ kg}$$

$$G = 36 + (1.62-1) \times 11.09 = 42.9 \text{ kg}$$

$$L_e = 42.9 \times 0.079 (375-33) \times 4.5 \times 10^3 = 5216 \times 10^3 \text{ KJ/hr}$$

$$\% \text{ heat loss through exhaust gases} = \frac{5216}{36000} \times 100 = 14.5\%$$

Blowdown:

$$\text{Blowdown rate} = 10\%$$

$$\text{Quantity of blowdown water} = 10.5 \times 10^3 \times 0.1 = 1050 \text{ kg/hr}$$

$$\text{Heat held by blowdown water} = 1050 (909-83.9) = 866.4 \times 10^3 \text{ KJ/hr}$$

$$\% \text{ heat loss} = \frac{866.4}{36000} \times 100 = 2.4\%$$

3. Heat Balance

Input:

$$\text{Heat of combustion} = 36000 \times 10^3 \text{ KJ/hr}$$

Output

$$\text{Heat of generated steam} = 26230 \times 10^3 \text{ KJ/hr}$$

$$\text{Heat loss through exhaust gas} = 5216 \times 10^3 \text{ KJ/hr}$$

$$\text{Heat held by blow water} = 866.4 \times 10^3 \text{ KJ/hr}$$

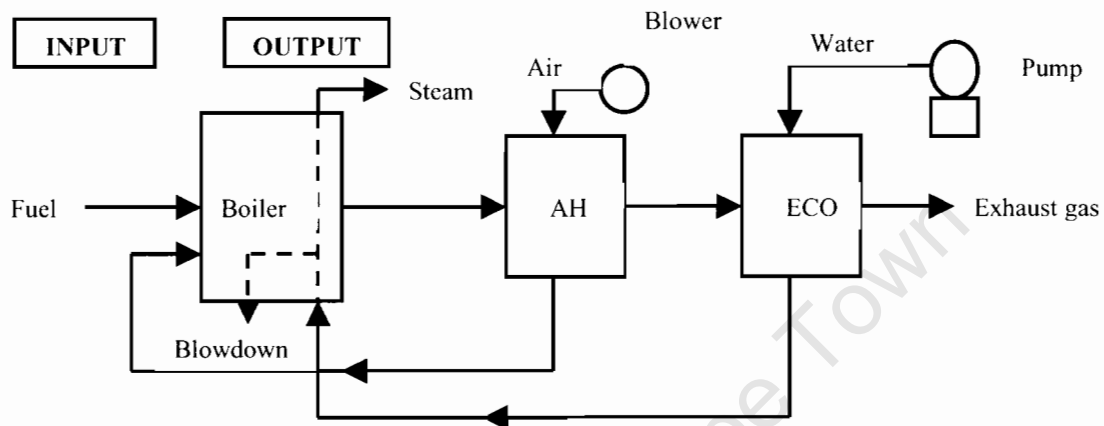
$$\text{Other heat losses} = 3687.6 \times 10^3 \text{ KJ/hr}$$

Boiler efficiency improvements can be achieved by minimizing boiler heat losses. Among the energy conservation measures used are:

- Optimum air to fuel ratio
- Exhaust heat recovery, using an air heater and economizer

- Condensate recovery
- Continuously controlled blow-down
- Insulation to minimize conductive, convective and radiative heat losses.

Fig.5.1. Using an air heater and economizer



$$\text{Boiler efficiency (\%)} = \frac{\text{Output heat}}{\text{Input heat}} \times 100\% = \frac{\text{Heat output of generated} - \text{heat of feed water}}{(\text{Fuel consumption}) \times (\text{lower calorific value of fuel})} \times 100\%$$

$$\begin{aligned} \text{Heat recovery rate at air preheater (AH) \%} &= \frac{\text{Recovery heat at AH}}{\text{Input heat}} \times 100\% \\ &= \frac{(\text{heat of exhaust gas at AH inlet}) - (\text{heat of exhaust gas at AH outlet})}{(\text{fuel consumption}) \times (\text{lower calorific value of fuel})} \times 100\% \end{aligned}$$

$$\begin{aligned} \text{Heat recovery} &= \frac{\text{Recovery heat at ECO}}{\text{Input heat}} \times 100\% \\ &= \frac{(\text{heat of feedwater at ECO outlet}) - (\text{heat of feedwater at ECO inlet})}{(\text{fuel consumption}) \times (\text{lower calorific value of fuel})} \times 100\% \end{aligned}$$

Heat Recovery:

Exhaust gases:

(a) Reduction of %Oxygen from 8 to 4%

$$R = \frac{21}{21 - 4} = 1.24$$

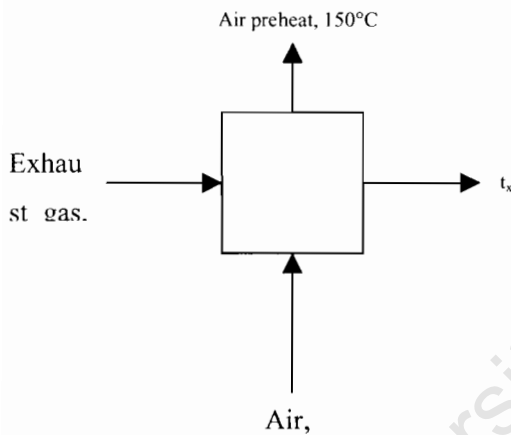
$$G = 36 + (1.24 - 1) \times 11.09 = 38.7 \text{ kg}$$

$$L_e = 38.7 \times 0.079 (375 - 33) \times 4.5 \times 10^3 = 4705 \times 10^3 \text{ kg/hr}$$

$$\% \text{ Heat loss} = \frac{4705}{36000} \times 100 = 13.1\%$$

$$\text{Heat recovery} = 14.5 - 13.1 = 1.4\%$$

(b) Using air preheater



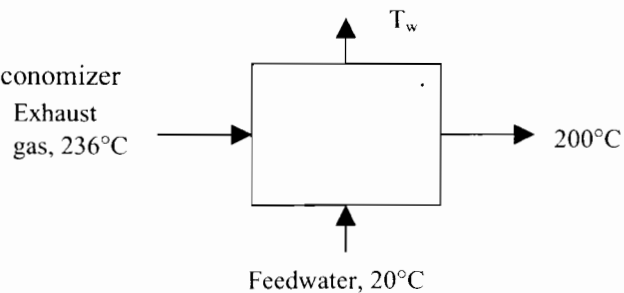
$$38.7 \times 0.079 (375 - t_x) = 38.7 \times 1.24 \times 0.079 (150 - 33) = 426.7 \text{ KJ/kg}_{\text{fuel}}$$

$$t_x = 236^\circ\text{C}$$

$$\text{Heat recovered by air preheater} = 426.7 \times 4.5 \times 10^3 = 1920 \times 10^3 \text{ KJ/hr}$$

$$= \frac{1920}{36000} \times 100 = 5.3\%$$

(b) Using an economizer



$$10.5 \times 10^3 \times 1.0 (T_w - 20^\circ\text{C}) = 38.7 \times 0.079 (236-200) \times 4.5 \times 10^3 \times (1-0.014-0.053)$$

$$T_w - 20 = \frac{462000}{10500} = 44$$

$$T_w = 64^\circ\text{C}$$

Heat collected by economizer = $10.5 \times 10^3 \times 1.0 (64-20) = 462 \times 10^3 \text{ KJ/hr}$

$$\text{Heat recovery by economizer} = \frac{462}{36000} \times 100 = 1.3\%$$

Total heat recovery from exhaust gases = $(1.4+5.3+1.3) = 8\%$

Blowdown

Reduce blowdown rate from 10 to 6%

Quantity of blowdown water = $10.5 \times 10^3 \times 0.06 = 630 \text{ kg/hr}$

Heat held by blowdown water = $630 (909-83.9) = 519.8 \times 10^3 \text{ KJ/hr}$

$$\% \text{ heat recovery from blowdown} = \frac{866.4 - 519.8}{36000} \times 100 = 1\%$$

Other heat losses

Good lagging can reduce these by close to 10% (JICA, 1999)

Table 5.1 is a summary of the energy balances of our sample boiler before and after energy efficiency improvements.

Table 5.1 Efficiency improvements in boiler (sample)

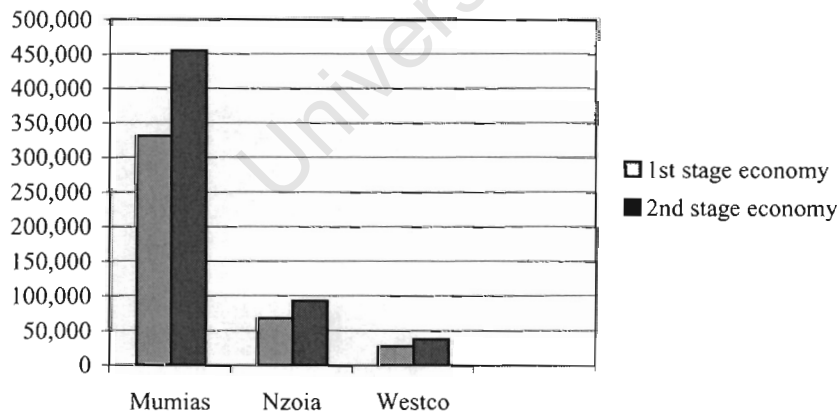
| Parameter | Present boiler | % | After improvement | % |
|--------------------------|----------------------|------|---------------------|------|
| Input | | | | |
| Heat of combustion | 36000×10^3 | 100 | 36000×10^3 | 100 |
| Output | | | | |
| Heat of generated steam | 26230×10^3 | 72.9 | 31340×10^3 | 87.1 |
| Heat loss by exhaust gas | 5216×10^3 | 14.5 | 2340×10^3 | 6.5 |
| Heat held by blow water | 866.4×10^3 | 2.4 | 519.8×10^3 | 1.4 |
| Other heat losses | 3687.6×10^3 | 10.2 | 1800×10^3 | 5 |
| Efficiency | | 70.6 | | 84.8 |

5.2.2. Steam efficiency improvements

The ratio of process steam consumption ranges between 50 and 55% of cane crushed. This can be reduced to 42-45% by the incorporation of modifications in the juice heating and evaporation systems. Table 5.1 shows potential steam savings during sugarcane processing for three sugar companies using 2001 statistics.

| Table 5.2.Reduction in sugarcane processing steam consumption | | | |
|----------------------------------------------------------------------|--------------------------|--------------------------|--------------------------|
| | Business as usual | 1st stage economy | 2nd stage economy |
| Steam consumption | 500Kg/tc | 340Kg/tc | 280Kg/tc |
| Steam used, tons | | | |
| Mumias | 1,033,810 | 702,990 | 578,933 |
| Nzoia | 210,961 | 143,453 | 118,138 |
| Westco | 84,536 | 57,484 | 47,340 |
| Steam saved (tons/yr) | | | |
| Mumias | | 330,820 | 454,877 |
| Nzoia | | 67,508 | 92,823 |
| Westco | | 27,052 | 37,196 |

Fig.5.2.Steam savings



A lot of process steam in the sugar production process is used in juice heating and evaporation. Energy efficiency improvements should therefore be encouraged in this area. Juice concentration is done in multiple-effect evaporators. The underlying principle in multiple-effect evaporation is that direct steam

is added only once and the vapour produced by the boiling juice is repeatedly used for boiling in successive vessels. The result is that great savings in steam are achieved.

RILLEUX’S PRINCIPLES

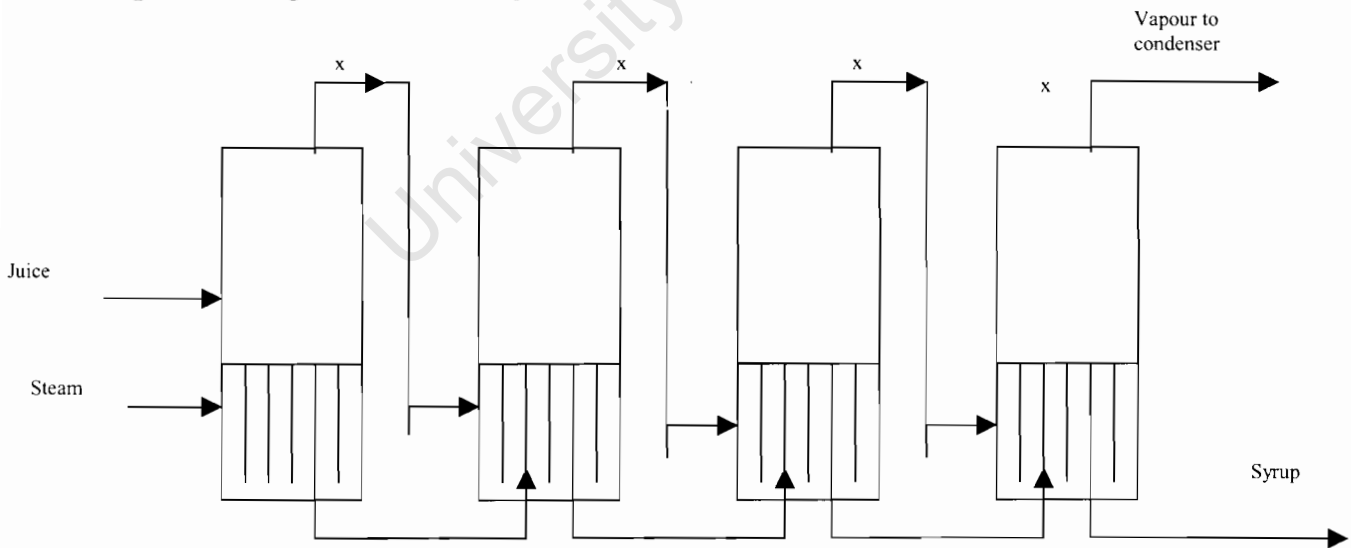
There are three important principles used in multiple-effect evaporation:

First Principle: In a multiple-effect evaporator, each tonne of steam supplied to the first body will evaporate one tonne of water in each body in series. With “N” effects, one tonne of steam evaporates “N” tones of water.

Second Principle : If a weight of vapour “W” is bled from effect “M” of “N” effects and used in place of steam for a given duty, the saving in steam is equal to $\frac{M}{N} \times W$. For example, if bleeding is done for the first body of a quadruple set, the saving is $\frac{1}{4}$ th the weight of the vapour used.

Third Principle: In any apparatus in which steam or vapour is condensed, it is necessary to withdraw continuously the non-condensable gases, which are unavoidably left in the heating surface compartment.

Fig 5. 3. Arrangement without vapour bleeding:

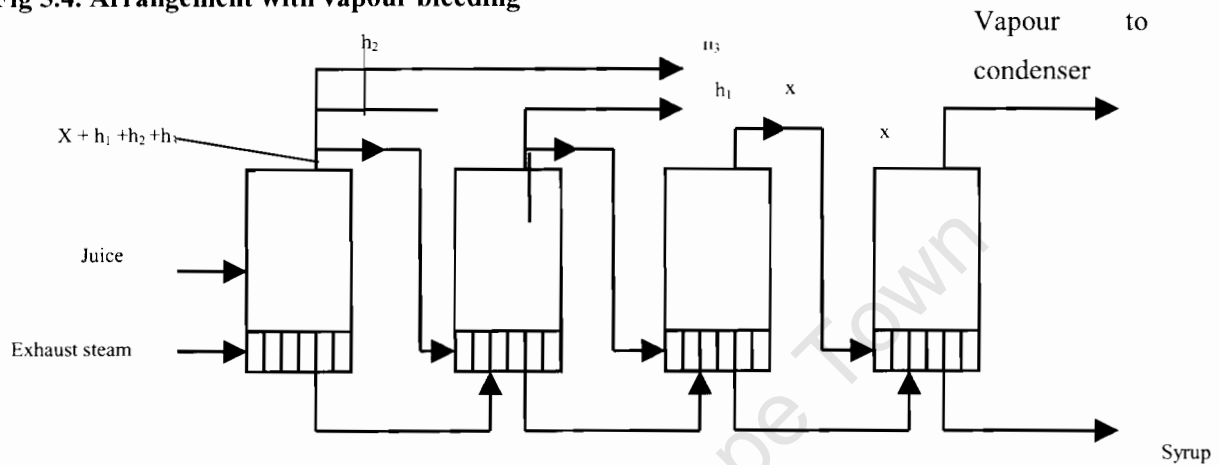


Taking evaporation from last effect = X

Evaporation from 1st body = X

Evaporation from 2nd body = X
 Evaporation from 3rd body = X
 Evaporation from 4th body = X
 TOTAL EVAPORATION = 4X

Fig 5.4. Arrangement with vapour bleeding



If evaporation from last vessel = X
 Evaporation from 1st body = X + h₁ + h₂ + h₃
 Evaporation from 2nd body = X + h₁
 Evaporation from 3rd body = X
 Evaporation from 4th body = X
 TOTAL EVAPORATION = 4X + 2h₁ + h₂ + h₃

These concepts are now applied below to data and information collected in the fieldwork and from literature:

Data

| | |
|--------------------------------------------|----------------------|
| Brix of juice | = 15° |
| Brix of syrup | = 60° |
| Mixed juice % of cane | = 100 |
| Exhaust steam temperature | = 124° |
| Temperature of 1 st body vapour | = 104°C |
| Temperature of 2 nd body vapour | = 80°C |
| Exhaust steam pressure | = 1.5 bar |
| 1 st body vapour pressure | = 0.5 bar |
| 2 nd body vapour pressure | = 0.3 bar |
| Heating surface of each evaporator | = 670 m ² |

Calculations

Basis----- 100Kg

Cane + added water = mixed juice + bagasse

Clear juice % of cane = 100

Total evaporation on clear juice = $\frac{60 - 15}{60} \times 100 = 75$

Specific heat of the juice (brix of juice = 15° = $1 - (0.006 \times 15) = 0.91$

Steam/vapour required for primary juice heating

Juice enters primary juice heater at 35°C and leaves at 70°C. The temperature of vapour bled for this juice heating = 80°C (2nd body vapour temperature). At 80°C, latent heat of vapourization of water = 551.4Kcal/Kg (from steam tables), therefore

$$\text{Weight of vapour required} = \frac{\text{wt. of juice} \times \text{sp. ht.} \times (t_1 - t_0)}{\text{latent ht.} \times \text{efficiency}}$$

$$\text{Assuming 5\% losses, } h_1 = \frac{75 \times 0.91(70 - 35)}{551.3 \times 0.95} = 4.56 \text{ tonnes}$$

Hence vapour required for primary juice heating, $h_1 = 4.56$ tonnes/hr.

Usually, when steam generation and crushing are steady, we are able to get enough vapour for secondary juice heating. However, for pan boiling, the vapour is supplemented by exhaust steam.

Steam/vapour required for secondary juice heating

Juice enters secondary juice heater at 70°C and leaves at 102°C. The temperature of vapour bled from this juice heating = 104°C (1st body vapour temperature).

At 104°C, the latent heat of vapourization of water = 534.6Kcal/Kg,

$$h_2 = \frac{75 \times 0.91(102 - 70)}{534.6 \times 0.95} = 4.3 \text{ tonnes/hr}$$

Steam/vapour required for pan station

With five pans from average operating results, we estimate that steam requirements at pan flow is approximately

15% of crushing rate = $\frac{15 \times 125}{100} = 18.75$ tonnes/hr. The crushing rate of 125 tonnes of cane per hour (tch) is the

average for SONY. It should be noted that due to frequent additions of water in pans, it is not possible to determine the exact amount of steam required. Out of this, it has further been established that 3.3 tonnes of the total pan station steam required is exhaust steam. Therefore,

Vapour bled from pan station = $18.75 - 3.5 = 15.25$ tonnes/hr

$$h_3 = 15.25 \text{ tonnes/hr}$$

Arrangement with vapour bleeding

Let x = evaporation from last vessel,

$$\begin{aligned} 1^{\text{st}} \text{ body evaporation} &= x + h_1 + h_2 + h_3 \\ 2^{\text{nd}} \text{ body evaporation} &= x + h_1 \\ 3^{\text{rd}} \text{ body evaporation} &= x \\ 4^{\text{th}} \text{ body evaporation} &= x \\ \text{Total evaporation} &= 4x + 2h_1 + h_2 + h_3 \end{aligned}$$

Substituting in the calculated values:

$$\begin{aligned} 4x + 2(4.56) + 4.3 + 15.25 &= \frac{75(60 - 15)}{60} = 56.25 \\ 4x + 28.67 &= 56.25 \\ x &= 6.9 \text{ tonnes/hr.} \end{aligned}$$

Vapour bled from 1st vessel = $6.9 + 4.56 + 4.3 + 15.25 = 31.0$ tonnes/hr

For a well-maintained system with adequate lagging, 1.17 tonnes of steam are required to evaporate 1 tonne of water. Therefore,

Steam required in 1st body = $31.0 \times 1.17 = 36.3$ tonnes/hr.

Arrangement without vapour bleeding

Again, taking evaporation from last effect = x

$$\begin{aligned} \text{Evaporation from 1}^{\text{st}} \text{ body} &= x \\ \text{Evaporation from 2}^{\text{nd}} \text{ body} &= x \\ \text{Evaporation from 3}^{\text{rd}} \text{ body} &= x \\ \text{Total Evaporation} &= 4x \end{aligned}$$

$$\begin{aligned} \text{Substituting calculated values, } 4x &= 56.25 \\ x &= 14.06 \text{ tonnes/hr.} \end{aligned}$$

Hence, exhaust steam requirement for the above = $1.17 \times 14.06 = 16.45$ tonnes/hr.

In this case exhaust steam will be required for both juice heating and pan boiling. There is no vapour bleeding.

Exhaust steam requirement for primary juice heating

At 124°C, latent heat of vapourization of water = 523.43Kcal/Kg,

$$\text{Exhaust steam required} = \frac{75 \times 0.91(70 - 35)}{523.43 \times 0.95} = 4.8 \text{ tonnes/hr}$$

Exhaust steam requirement for secondary juice heating

Latent heat of vapourization at 124°C = 523.43

$$\text{Exhaust steam required} = \frac{75 \times 0.91(102 - 70)}{523.43 \times 0.95} = 4.4 \text{ tonnes/hr}$$

Steam requirement for pan boiling

As before, steam required = 15% × 125 = 18.75 tonnes/hr

Total exhaust steam requirement = 16.45 + 4.8 + 4.4 + 18.75 = 44.4 tonnes/hr.

Total exhaust steam requirement with vapour bleeding was previously found to be 36.3 tonnes/hr.

Exhaust steam saving = 44.4 - 36.3 = 8.1

By vapour bleeding for juice heating and partly for pans, 8.1 tonnes/hr (20%) in steam savings, were obtained. Using a 5-effect evaporator instead of the quadruple-effects would result in further savings. Other energy conservation measures for system efficiency improvement include proper lagging of steam distribution lines and steam trapping.

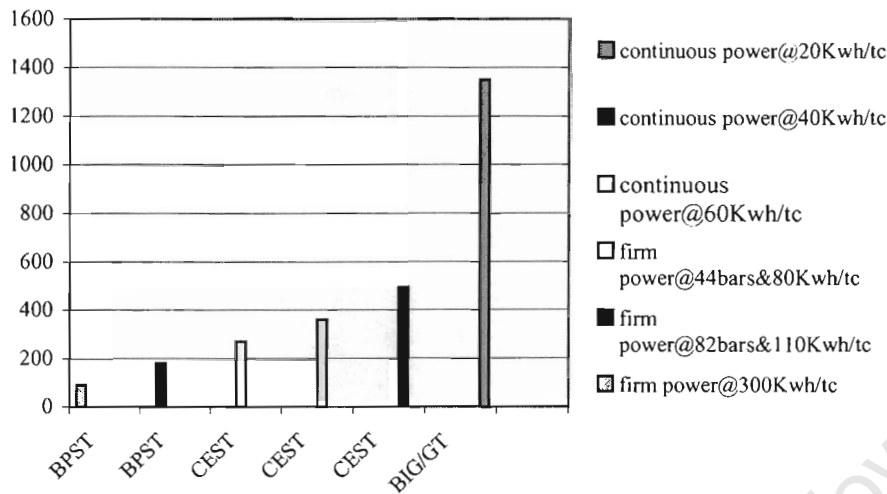
5.2.3 CEST and BIG/GTCC systems

By reducing the amount of steam required in the production process from 500 to 340 or to 280 Kg per tonne of sugarcane, additional electricity in the range of 24-33 kWh per tonne of cane (assuming 20% efficiency for the conversion of steam to electricity or 6.7 Kg of steam for one kWh generation (Moreira, 2000: 49). Using high-pressure boilers (40 to 60 bar or more) and condensing-extraction steam turbine would yield yet higher efficiencies and additional power (80 to 100 kWh/tc) for export from the mill.

Potential electricity export to the grid from sugarcane factories will depend not only on the technology adopted but also on whether the mode of power generation is intermittent (partial operation during the milling season using bagasse), continuous (consistent operation during the milling season using bagasse) or firm (all-year operation using bagasse during crop and alternative fuels during inter-crop). In Mauritius, steam power plants at pressures between 25 to 31 bars operate at around 50 kWh/tc. At 44 and 82 bars, the efficiency increases to 80 and 110 kWh/tc respectively.

Since the early 1990s, considerable technology development and demonstration efforts relating to BIG/GTCC commercialization have been undertaken (Kartha et al, 2000:106,124). Advanced demonstration projects have been carried out in Sweden, the United Kingdom and Brazil. Fig 5.5 gives an illustration of the potential electricity export (GWh) from bagasse for the Kenya sugar industry with an average cane crushing capacity of 4.50 million tonnes per year.

Fig 5.5 Potential electricity export (GWh) from bagasse in Kenya



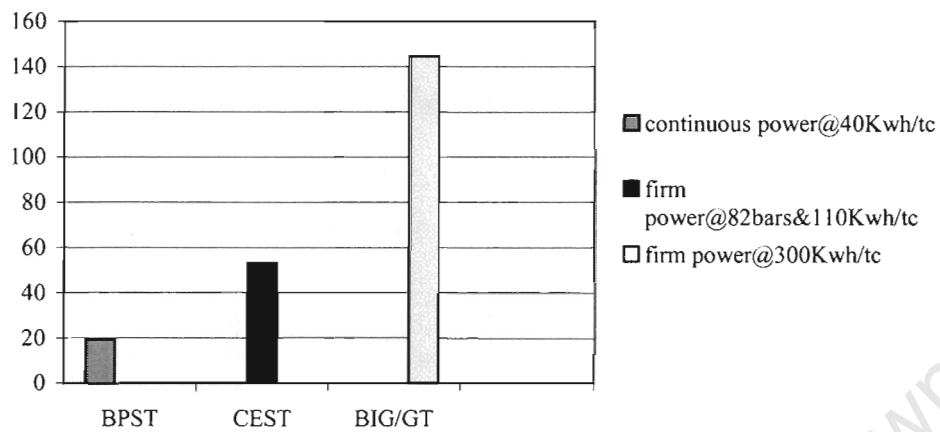
Taking the highest capacity factor of 0.9 for Mumias sugar company and 350 days/year operation (the Kenya sugar industry has the advantage of long crop seasons, lasting up to eleven months), the electricity contribution to the national grid from the sugar industry would be 5% and 15% of today's total generation capacity of slightly over 1000 MW from all sources using CEST and BIG/GTCC technologies, respectively. (Fig 5.6)

The Biomass- Integrated Gasifier/Steam Injected Gas turbine (BIG/STIG) provides for the production in a steam injected gas turbine cycle from the gas turbine exhaust heat using a heat recovery steam generator. Whenever the steam is not needed for on-site processing, it is injected back into the gas turbine combustion and passed through for power generation. BIG/STIG systems have the capacity to produce over 600 kWh/tc if operated all year round. The BIG/ISTIG cogeneration system is an advanced version of BIG/STIG achieved by adding an inter-cooler to the compressor, with a capacity to produce over 700 kWh/tc if operated all year round (Rabah, 2000:7).

Karekezi & Ranja (1997:22) have estimated net electricity production potential for Kenya at 2.63 TWh/yr in 2027 using BIG/STIG technology, representing more than three times actual electricity production from all sources in 1987. An even more optimistic figure of 3.56TWh/yr present generation potential is given by Rabah (2002:8) from the combined sugar-milling industries and alcohol distilleries, equivalent to more than 90% total energy generated in the country from all other sources in 1996.

Using compacted and/or pre-dried bagasse and trash can also enhance cogeneration system efficiency.

Fig 5.6 Potential electricity export capacity (MW) from bagasse in Kenya.

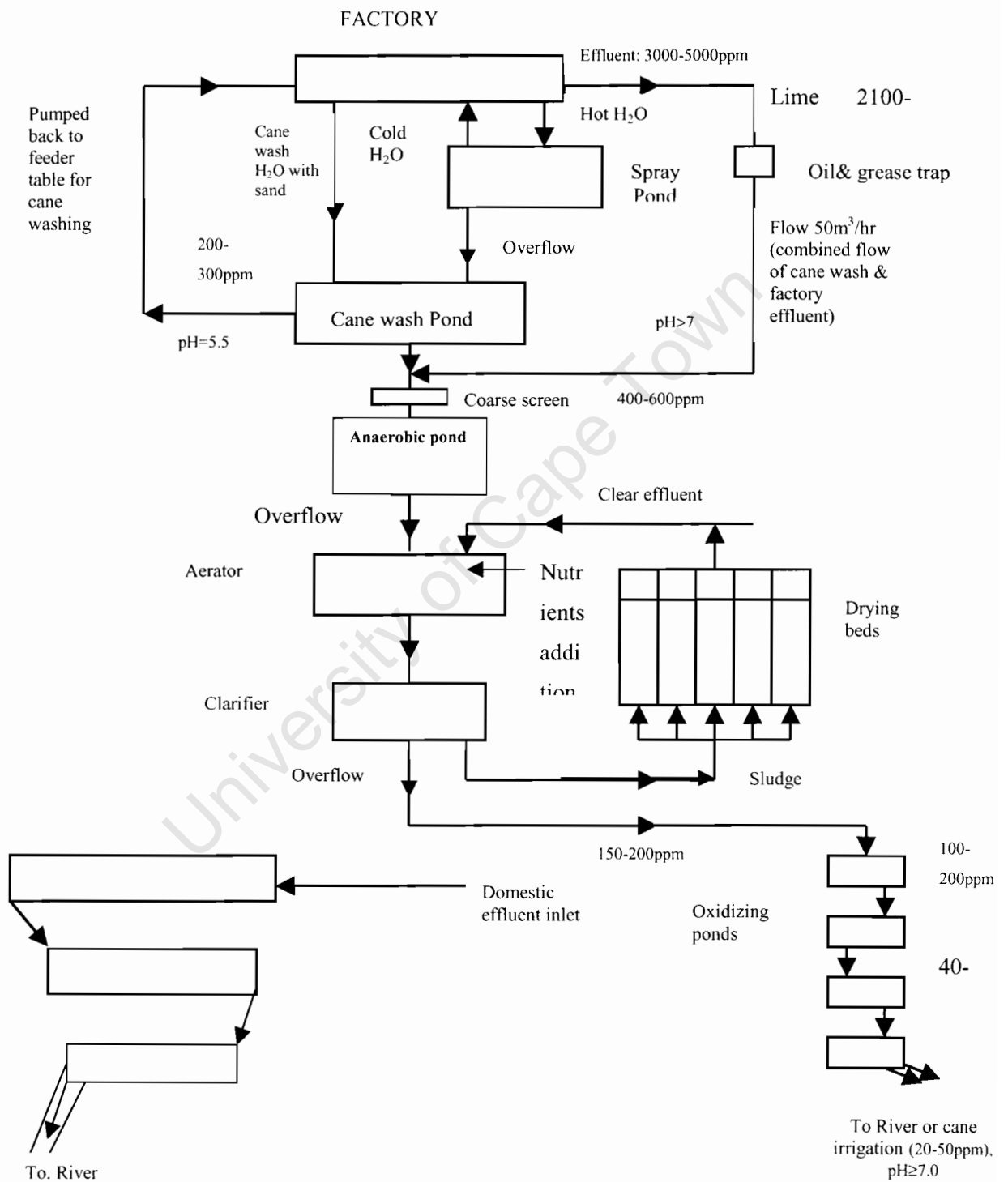


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5.3 BIOGAS PRODUCTION FROM EFFLUENT TREATMENT

The effluent treatment system in the sugar companies is as illustrated in fig. 5.7 below:

Fig. 5.7 Effluent treatment in the sugar factories *(Mbithi: 1984)



The open pond anaerobic treatment process is not very effective, removing at best 60% of COD (Oyuya & Odhiambo, 2003: Pers.comm.). The post-treatment method of using an anaerobic lagoon followed by a facultative lagoon can and does lower the COD, but no provision is made in any of the sugar factories to tap and utilize the biogas from the system.

Several technologies are available, as listed earlier in Chapter 3, for generating and using biogas as a co-product of the sugarcane industry. These include the Upflow Anaerobic Sludge Blanket (UASB), the Bacardi Anaerobic Treatment Process (BCATP), and the Bulk Volume fermenter (BVf). They can be incorporated at existing effluent treatment plants at the anaerobic pond level.

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CHAPTER SIX

6.APPLICATION AND POLICY OPTIONS FOR KENYA

6.1.INTRODUCTION

This Chapter will review successful technology experiences for generating energy from sugarcane by-products and their possible application and policy implications in Kenya.

As incomes rise, energy users prefer more high-grade energy carriers including modern biomass. If biomass energy were “modernized”, it might be more widely used and play a much more significant role in overall energy service provision, particularly in developing countries (Kartha & Larson, 2000: 31). Combined Heat and Power (CHP) and Anaerobic Digestion (AD) systems are examples of sustainable modernized biomass systems based on existing commercial technologies.

The successful replication of a modernized bio-energy system will spread accrued benefits to more people than would an isolated project if the following key elements are conceptualized (Kartha & Larson 2000: 116-118):

- Sound technology
- Sufficient scale of demand for the technology
- Access to the electricity grid
- Involvement of the private sector

6.2. TECHNOLOGY

Cogeneration and anaerobic digestion systems are proven technologies that have widely been used in commercial applications, particularly in the sugarcane and distillery industries (Batidzirai, 2002, Craveiro et al, 1986, Dadhich, 1997, Deepchand, 2001a, Kartha & Larson, 2000). The important role of continued research and demonstration activities was discussed in Chapter 5. Boiler, process and steam efficiency improvements and other energy conservation activities were emphasized and recommended as important for enhancing the competitiveness of the sugar industry, in that they would make it possible to generate surplus electricity for export to the grid.

6.2.1. The Mauritian and other experiences:

One of the principal means of cutting production costs in cane milling is the consolidation of milling activities through centralization. In 1997, the government of Mauritius came up with a Blue Print on Centralization of Cane Milling Activities (Deepchand, 2001b: 8). Prior to this, several requests from factories for closures and centralization, with the objective of rationalizing milling operations, had been received. The Blue Print set guidelines and conditions for closures and emphasized the need to link such closures with energy generation from bagasse. This led to the phasing out of intermittent power plants and the setting up of continuous and firm power plants.

In the year 2000, Mauritius had three firm power plants, each one associated with specific peculiarities such as installed capacities, operating pressures and temperatures, the condensing-extraction turbo alternator and use of exhaust steam for additional electricity generation. There were seven continuous power plants with specificities compared to each other. The firm power plants were (Deepchand, 2001b: 10-16):

1. Deep River Beau Champ with a crushing capacity of 270 TCH (tonnes of cane per hour) and total power export of 26.5 MW
2. Flacq United Estate Ltd (FUEL) with a TCH of 260 and installed capacity of 40.5 MW
3. Belle Vue with a TCH of 310 and a net power export to the grid of 52 MW during crop period and 62 MW during the intercrop

Medine and Union St. Aubin factories have made requests for the implementation of two additional firm power plants in the medium term

In the Reunion Island, the centralization process is over with only two factories in operation. Each of these factories processes around 900,000 tonnes of cane per year. Equipped with 2×30-35 MW power plants each, and operating at 82 bars, these units export 110 kWh of electricity per tonne of cane. This is well above the 60 kWh/tc obtained in Mauritius (Deepchand, 2001b: 21, Mbohwa & Fukuda, 2002: 5). Deepchand suggests (2001a: 21-22) “further centralization of cane-milling activities, improvement in exhaust steam processing, upgrading the efficiency of the power plants by adopting pressures of 82bars and the use of cane field residues as supplementary boiler fuel” as measures that could be used to achieve and, even exceed the Reunion Island efficiency. The experiences of other countries were discussed in Chapter 2.

6.2.2. Application options in cogeneration for Kenya:

Table 6.1 gives selected factory performance indicators for Kenyan sugar industry in the year 2002.

Table 6.1 Selected parameters of factory performance for Kenya sugar companies: 2002

| Company | Rated Capacity (TCH) | Cane crushed (MT)** | Sugar made (MT) | Bagasse produced (MT) |
|--------------|----------------------|---------------------|-----------------|-----------------------|
| Chemelil | 135 | 688,738 | 60,503 | 270,674 |
| Muhoroni | 100 | 459,230 | 37,413 | 180,477 |
| Mumias | 350 | 2,033,500 | 253,224 | 799,166 |
| Nzoia | 125 | 595,540 | 57,012 | 234,046 |
| South Nyanza | 125 | 523,018 | 63,098 | 205,546 |
| West Kenya | 63 | 216,540 | 19,979 | 85,099 |

Source: KSB (Magero: Pers. Comm.)

** Computed on the basis of data for bagasse produced and the ten-year average of bagasse % of cane for Kenyan factories (Table 4.1)

In the context of the Mauritian experience, Baguant (1992: 162-164) makes the following observations on factory characteristics and equipment for the generation of exportable electricity:

Intermittent Power:

Almost 10kWh of exportable electricity per tonne of cane can be produced as long as the power plant conforms to the following:

- Crushing rate of above 80 TCH
- Total boiler capacity of above 40 tonnes per, hour producing steam at 10 to 15 bar pressure (150 to 200 psig)
- Steam to bagasse ratio of 1.8 to 2.2
- Specific steam consumption (SSC) of 500 Kg to 600 Kg steam per tonne of cane.
- Self- consumption of electricity not exceeding 20 kWh/tc
- Equipped with an additional turbo alternator of around 0.5 to 1.5 MW

All Kenyan sugar factories apart from West Kenya Sugar Company (rated capacity = 63 TCH) satisfy the conditions for intermittent power export and their potential is illustrated in Table 6.2.

Table 6.2. Intermittent electricity export potential for Kenya sugar companies in 2002

| Company | Cane crushed (tc) | Electricity export (GWh) |
|--------------|-------------------|--------------------------|
| Chemelil | 688,738 | 6.89 |
| Muhoroni | 459,230 | 4.59 |
| Mumias | 2,033,500 | 20.34 |
| Nzoia | 595,540 | 5.96 |
| South Nyanza | 523,018 | 5.24 |
| TOTAL | | 43.02 |

Continuous Power Plants:

These power plants can export up to 60 KWh/tc electricity provided:

- The minimum size of the power plant is 15 MW allowing a total production of around 40 GWh at 90% load factor (10 GWh for self-consumption and 30 GWh for exportation).
- Total supply of cane per year is above 400,000 tonnes and crushing rate 150 TCH for 3000 hours
- Steam to bagasse ratio is at least 2.5
- Specific steam consumption is brought down to at least 400 Kg of steam per tonne of cane through modification of juice heating, evaporation and sugar boiling systems
- Total boiler capacity is 120 tonnes per hour and pressure of 30 to 40 bar
- A condensing turbine, which is more efficient than the backpressure turbine is used.

Five of the Kenyan sugar factories qualify for the continuous power production option on the basis of annual cane supply. The low capacity rates of some of the factories are compensated by the long harvest period in Kenya (11 months or more than 6000 hours). The other conditions are achievable with minor modifications. Table 6.3 shows the electricity export potential for these companies, using the continuous power plant option.

Table 6.3. 2002 continuous power plant electricity export potential for Kenyan sugar Companies

| Company | Cane crushed (tc) | Electricity export (GWh) |
|--------------|-------------------|--------------------------|
| Chemelil | 688,738 | 41.3 |
| Muhoroni | 459,230 | 27.6 |
| Mumias | 2,033,500 | 122.0 |
| Nzoia | 595,540 | 35.7 |
| South Nyanza | 523,018 | 31.4 |
| TOTAL | | 258.0 |

Firm Power Plants:

The Reunion Island efficiency of 110 kWh/tc is achievable, provided:

- The plant is operational all year round, which means 300 days (7200hours) with 65 or 66 days allowed for maintenance. Bagasse is available for most of the year and can be supplemented by fuel oil, cane trash or wood, whenever the needed.
- Total supply of cane per year is above 700,000 tonnes
- Steam to bagasse ratio is at least 2.5
- Specific steam consumption is below 400 kg of steam per tonne of cane
- Total boiler capacity is 140-150 tonnes per hour, and pressure at 82 bars
- A condensing turbine is used

Of the six operating companies, only Mumias Sugar Company meets the conditions for firm power production with modification. Chemelil Sugar Company would also qualify if it could source the surplus bagasse from neighbouring Muhoroni. Some capital investment would also be required to install high-pressure boilers in the two factories. The potential exportable electricity from the two companies would then be as reflected in Table 6.4 using the firm power plant option.

Table 6.4. 2002 Firm power electricity export potential for two Kenyan companies

| Company | Available cane (tc) | Electricity export (GWh) |
|----------|---------------------|--------------------------|
| Chemelil | 750,000 | 82.5 |
| Mumias | 2,033,500 | 223.7 |
| TOTAL | | 306.2 |

6.3 DEMAND FOR TECHNOLOGY

The Electric Power Act (1997) liberalized power production by allowing small IPPs to participate in electricity generation, previously the preserve of KPLC. Whereas the Act allows individuals and institutions to generate power for their own use, the permissible outputs are limited. Section 4 of the Act should be amended to allow small-scale producers generate without restriction and sell the surplus electricity to the market. Sugar companies currently generate a total of 17.3 MW of electricity (Kamfor, 2002: 60) above their requirements. To enhance power production, section 4 of the Act could be amended to make ministerial licensing powers less restrictive on levels of production and allow higher outputs.

While section 128 of the Act seems aimed at creating a regulatory mechanism for the use of any natural resources for power production, all such resources are vested in the government. Resources such as bagasse in cogeneration and “waste” for making biogas could attract licensing according to this section. This could be delimiting, rigid

and could discourage individuals or institutions from venturing into power generation. A more flexible provision should be introduced to ease access to natural resources for small-scale power production.

Establishing cost competitiveness for small-scale bio-energy projects presents a challenge due to limited economy of scale, associated with small systems. For the sugar industry, the solution seems to lie in the centralization of milling activities (Deepchand 2001a, 2001b).

6.3.1 Rural Electrification

The Rural Electrification Programme (REP), administered by the KPLC until July 1998 is part of the strategy to implement the government policy of providing electricity to the rural populace. According to the interim Poverty Reduction Strategy Paper (I-PRSP), the basic objective since the 1980s was to balance rural-urban development, support the development of agro-industries and encourage growth of “urban centers” in rural areas (GK, 2000). Since 1998, REP has been financed through external grants, soft loans and exchequer revenue (5% levy on retail electricity sales) and the fund administered through the Ministry of Energy.

A decentralized approach to rural electrification is desirable to reduce the high costs associated with distribution networks. This approach is based on the supported introduction of small-scale generation technologies, strategically established in areas where grid extension would be too expensive or inaccessible in the long term.

Embedded generation:

Small power plants supplying outlying distribution areas not only benefit the rural consumers but the utility because, one of the factors determining the maximum size of any particular power station is the total capacity of all stations supplying the grid. Ideally, no particular station should provide more than 5-10% of the total power. This implies that, when switched in or out of service, the overall effect on the supply will be minimal. Conversely, if a station were to provide 50% of the total supply, there would be a massive surge in power when it is switched in and an equally massive drop when it is switched out (Batidzirai, 2002: 27). Diversification in electricity supply is also important in avoiding over-reliance on any particular technology. Hydropower for instance, is susceptible to vagaries of weather, while fossil fuel-based stations are susceptible to fuel availability and price volatility.

A network of 33 KV and 11 KV rural overhead lines serves Chemelil, Muhoroni, Mumias and West Kenya Sugar Companies. This network feeds the nearby towns of Muhoroni, Mumias/Butere, Kakamega and the surrounding farms and businesses. The introduction of embedded generation facilities (at 11 KV or 33 KV) would significantly improve the power flow in these areas. Nzoia and South Nyanza Sugar Companies are yet to be

connected to the national grid and would require the authority and distribution facilities of KPLC to supply surrounding areas.

The concession approach

A concession approach might work well for installing and operating small-scale, biomass-based electricity generating systems in a region. In countries such as Kenya, where electricity generation capacity expansion is not keeping pace with growing demand, granting concessions similar to those granted for oil and gas exploration and production would be a prudent approach to rural electrification, based on renewable energy systems. The key elements in developing the concession approach include (Kartha & Larson, 2000: 117):

1. Conducting a regional survey to identify prospective areas to be developed
2. Delineating the resource area into concession areas
3. Soliciting bids under published terms and conditions
4. Licensing successful bidders

In Mauritius, the Concession Projects Act (1997) provides for the creation of a Concession Projects Division, sets out the rules and regulations for project implementation and the establishment of a one-stop shop to deal with applications within four weeks.

6.4. ACCESS TO ELECTRICITY GRID

Grid access is important because the economics of any biopower system is largely dependent on capacity utilization. Low capacity factors mean that the capital investment in a project must be amortized over a smaller number of kWh generated, leading to higher cost per unit (cost/kWh). Local demand for electricity in the rural areas may not be high or sustained enough to yield economically viable capacity factors. The utility grid provides the means for electricity supply to urban demand centers and the attendant capacity factor build-up.

In the context of on-going power sector reforms, it should be noted that the most direct form of expanding access under a privatized, restructured model is to introduce a mandate for grid expansion under the terms of privatization (Dubash, 2001: 12). Regulatory measures are often required, and have been employed elsewhere to overcome electric utility inertia to purchase power from independent generators. In the United States, the 1998 Public Utilities Regulatory policy Act (PURPA) obliged utilities to purchase at fair prices. Bagasse-derived electricity at sugarcane processing facilities in Brazil is similarly expected to benefit and expand significantly with the intended regulation requiring and mandating utilities to buy biomass-generated electricity at an attractive price to sellers (Kartha & Larson, 2000: 117)

In Kenya where the KPLC is the sole entity responsible for electricity transmission and distribution, a regulatory mechanism is needed to allow proper and reasonable access to the grid. The Electricity Regulatory Board, the Ministry of Energy, KPLC and all stakeholders in electric power generation should be involved in the formulation and implementation of the institutional and legal frameworks necessary for and conducive to both public and private sector participation in electric power development. The Electric Power Act needs further review to accommodate fair and unrestricted access to the national grid system.

6.5. PRIVATE SECTOR INVOLVEMENT

With proper policy mechanisms, appropriate public-sector oversight and competitive bidding for projects or concession areas, the private sector could be the necessary vehicle to drive technology replication initiatives (Kartha & Larson, 2000: 118). It should be noted from the outset however, that privatized utilities have little or no commitment in achieving social or environmental public benefits, unless they are explicitly required to or are given incentives to do so through regulatory structures (Dubash, 2001: 10). Thus despite the important opportunities of involving the private sector, its role of delivering energy services to the rural areas is limited to effective demand. Energy services will only reach this population if there is public sector involvement, either directly or through incentives.

The most important mechanism for grid-connected bio-energy systems is the establishment of standard, reliable, long-term power purchase/power supply agreements (PPAs/PSAs). Power purchase/supply agreements are the contractual relationships between the generator/supplier and the utility/buyer that binds the two parties (Dadhich 1997: 82). Appendix D is an outline of PPAs in Mauritius.

In Kenya, PPAs were signed between the KPLC and four independent power producers (IPPs). All the contracts had the following common features (*Daily Nation, 25th Feb 2003*):

1. Capacity charge as a fixed payment to the companies by KPLC, regardless of whether or not the power is consumed
2. Energy rate charged to KPLC, depending on the amount of power consumed
3. Fuel costs, which were fixed depending on fuel used by the IPP

Most of these PPAs were signed at time when the country had an imminent power crisis and the KPLC, which doubled as the sole transmission and distribution company as well as a major generator could hardly cope with generation capacity expansion demands. They were therefore hurriedly negotiated and without scrutiny from an

independent body. The contracts were not only inflexible but provided no incentive for the independent producers to be efficient.

In signing the PPAs, the highest capacity charge of 395 USD per month per kWh, exclusive of taxes and calculated on the basis of the US consumer price index (CPI) went to IberAfrica. At the time of signing the seven-year contract in August 1996, the CPI was 156.7. It has since risen to about 180, with the implication that power prices have had to be raised by the difference. Westmont, another of the IPPs signed its PPA with KPLC in the same year, settling for a capacity charge of 212 USD per kWh per month. OrPower4 and Tsavo Power both signed 20-year contracts with KPLC in 1998 and 1999, respectively. The government-owned Kenya Electricity Generating Company (KenGen) is the dominant generator, and does not charge any capacity charge to KPLC. Its power is mainly hydro-based.

According to the interim Poverty Reduction Strategy Paper, “the current restructuring of the power sector will be completed rapidly and attention focused on bringing in a strategic partner to improve the performance of KPLC” (GK, 2000: I-PRSP) prior to privatization as the optimum way to increase competition within the sector. In the same document, rationalization of the sugar industry as a prelude to privatization is also given a high priority.

This Chapter has largely dwelt on the replication potential in cogeneration for electricity production using bagasse. The replication concepts and principles outlined can be applied to other technologies, such as, biogas production from wastewater treatment in the sugar industry. Candidate technologies for replication in this regard include:

- The Bacardi Corporation Anaerobic Treatment Process (BCATP)
- The Up flow Anaerobic Sludge Blanket (UASB) system
- The bulk volume fermenter

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

The first task in preparing this thesis was the identification of the problem(s) besetting the Kenyan sugar industry. It was noted that the sector faced daunting challenges in the context of increasing local production costs and decreasing sugar prices, locally as well as internationally. The decision to embrace liberalization without adequate preparation of its consequences exacerbated the crisis. It was further observed that most of the sugar companies underutilized their capacities, with Chemelil operating at 50.3% level of efficiency in 2002 as opposed to its 85% potential, Mumias at 82.5 and the others with efficiency levels between these two (Magero, 2003: pers.comm.).

An energy analysis of the industry was conducted from which it was concluded that the current production processes were unsustainably inefficient. Subsequently, measures were recommended to realize optimum utility and potential of sugarcane by-products. Among the options is bagasse-based electricity export to the national grid. It was found that the sugar industry in Kenya has the potential to contribute between 5 to 15% of the total electric power generation capacity from all sources. The potential contribution will depend on the transformation technology employed (BPST, CEST, etc) and the mode of operation (intermittent, continuous or firm power production). Another option that was studied is the utilization of the anaerobic digestion process not only as method for the treatment of sugar processing wastewater, but also to generate biogas, a fuel that is used in boilers.

Several policies and measures that are considered necessary to achieve long-term viability and sustainability of the industry were discussed and recommended in chapters 5 and 6. These include but are not limited to: factory modernization, adoption/replication of successful technology experiences as reported from Mauritius, Reunion, India and elsewhere, the rational use of energy co-products to sugar processing and other energy conservation measures. Other policies and measures that are recommended:

- Regulatory and institutional structures that favour and encourage investment by IPPs. Currently, the Electricity Regulatory Board (ERB) is the entity charged with the responsibility of regulating the power sector, while the Ministry of Energy is the licensing authority for IPPs.
- A bagasse energy development programme should be contemplated, drawing from the similar experiences in Mauritius, Reunion, India and elsewhere but taking into consideration the local situation. This could be done through the formulation of a comprehensive renewable energy policy blueprint.

- Taking advantage of “ green finance” available through the Global Environmental Facility (GEF), the Clean Development Mechanism (CDM), bilateral and multilateral partners and other investments to develop and implement environmentally benign energy projects such as cogeneration and other renewable energy initiatives.

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APPENDIX A

GLOSSARY OF TERMS

Base Energy is the energy required to operate the plant, which is essentially independent of production.

Base Year is the reference year in the past to which the Current Year performance is being compared. The selected reference year should have data available and be representative of a typical year.

Base Year Equivalent Energy is the total amount of energy that would have been required in the Base Year at the original energy intensity, to produce the Current Year production output.

Company is the aggregate of all the plants that make up one industrial enterprise.

Current Year is the year currently being accounted for.

Current Year Energy is the total amount of energy used to manufacture a product or group of products in the Current Year.

Energy is the capacity for doing work: taking a number of forms that may be transformed from one into another, such as thermal (heat), mechanical (work), electrical, and chemical, in customary units, measured in kilowatt hours (KWh) or megajoules (MJ).

Energy Accounting is the process of accurately gathering all pertinent information on production and energy usage and the subsequent analysis for reporting and control purposes.

Energy Input is the total (in MJ) of all energy types used for the specific purpose of manufacturing a product or group of products during the year. (oil, L.P.G, Purchased electricity, coal, wood, etc;).

Energy Intensity is the amount of energy required to produce a product or group of products expressed in energy used per unit of production.

Energy Performance is the measure of the energy per unit of production increase or decrease in the Current Year versus the Base Year expressed as a percentage.

Energy type is a specific fuel or energy form used by the plant. (Oil, Electricity, wood, etc;).

Heating Value is the gross (Higher Heating Value) energy content of a fuel in MJ.

Joule is a unit of work or energy, the amount of energy expended in one second by an electric current of one ampere in a resistance of one ohm.

Production Factor is the production output of the Current Year divided by the production output of the Base Year.

Production output is the number of saleable production units produced, in a given period of time.

Production unit is a measure of the quantity of saleable production that closely relates to energy demand, such as the number of items produced. Other measures of production units may be weight, length, volume, hours of machine operation, shifts worked, etc;

Reporting Centres are the areas at which production and energy consumption are measured and reported. They can be a single process, combination of processes, department, plant or company.

Total Energy is all the energy used by a Reporting Centre in a reporting period.

Transportation Fuel is the fuel used by company cars and trucks operated off company property. This fuel is not usually recorded as part of the plant energy input since transportation is not a direct part of the manufacturing process. Companies that wish to determine their vehicle energy performance usually do so separately from plant performance. In-plant vehicle fuel could be included in the plant energy accounting data.

Variable Energy is the energy associated with production, which varies with production output.

Waste Energy is the energy, which is lost without being fully utilized. It may include the energy in a fluid or stream, exhaust gases, discharge waters or even refuse.

APPENDIX B: ENERGY PERFORMANCE COMPUTING

Mumias Sugar Company

REPORTING CENTRE TOTAL ENERGY USE (GJ)

CompanyMumias Sugar Co.....

Reporting centre.....factory.....

ProductSugar.....

Reporting Period.....1998.....

Total production output..... 229,098 tonnes

| Energy type (1) | Quantity used (2) | Energy conversion factor (GJ/unit) (3) | Gigajoules (GJ) per energy type (4) = (2) x (3) |
|------------------------------|----------------------|-------------------------------------------|----------------------------------------------------|
| Fuel oil (RFO) | 3,621 litres | 0.04028 | 145.9 |
| Fuel wood (60% m.c) | 350 tonnes | 8.1 | 2,835 |
| Electricity (grid) | 3,063 MWh | 3.6 | 11,026.8 |
| Electricity (self generated) | 59,138 MWh | 3.6 | 212,896 |
| Bagasse | 561,982 tonnes | 8.0 | 4,495,856 |
| TOTAL: | | | 4,722,759.7 |

Reporting centreFactory...

Total production output..251,243 t...

Reporting period1999...

| Energy type (1) | Quantity used (2) | Energy conversion GJ /unit (3) | Gigajoules (GJ) per energy type (4) = (2) x (3) |
|------------------------|----------------------|-----------------------------------|----------------------------------------------------|
| Fuel oil | 2,380 litres | 0.04028 | 95.9 |
| Fuel wood | 400 tonnes | 8.1 | 3240 |
| Electricity (grid) | 2,104 MWh | 3.6 | 7574.4 |
| Electricity (self gen) | 59,845 MWh | 3.6 | 215,442 |
| Bagasse | 547,876 tonnes | 8.0 | 4,383,008 |
| TOTAL: | | | 4,609,360.3 |

Reporting centre*Factory*.....

Total production output.217,772.....

Reporting period2000.....

| Energy type (1) | Quantity used (2) | Energy conversion GJ /unit (3) | Gigajoules (GJ) per energy type (4) = (2) x (3) |
|------------------------|----------------------|-----------------------------------|-------------------------------------------------------|
| Fuel oil | 2419litres | 0.04028 | 97.4 |
| Fuel wood | 400 tonnes | 8.1 | 3240 |
| Electricity (grid) | 2679 MWh | 3.6 | 9,644.4 |
| Electricity (self gen) | 54,913 MWh | 3.6 | 197,686.8 |
| Bagasse | 393,030 tonnes | 8.0 | 3,144,240 |
| TOTAL: | | | 3,354,908.6 |

$$1998 \text{ Energy intensity} = \frac{\text{total energy}}{\text{total production}} = \frac{4,722,759.7}{229,098} = 20.6 \text{ GJ/t}$$

$$1999 \text{ Energy intensity} = \frac{\text{total energy}}{\text{total production}} = \frac{4,609,360.3}{251,243} = 18.4 \text{ GJ/t}$$

$$2000 \text{ Energy intensity} = \frac{\text{total energy}}{\text{total production}} = \frac{3,354,905.6}{217,772} = 15.4 \text{ GJ/t}$$

The results show that there has been successive improvement in energy consumption per unit of production in the years 1998 – 2000

1998 – 1999 Energy performance

Company:*Mumias Sugar Co*..... Reporting*Factory*.....
 Reporting year.....1999.....
 Reporting year ... 1998.....

$$P.F = \frac{Y_c \text{ Production}}{Y_b \text{ Production}} = \frac{251,243}{229,098} = 1.1$$

(1999 production output was 10% higher than in 1998)

$$E_2 = E_0 \times P.F = 4,722,759.7 \times 1.1 = 5,195,035.6 \text{ GJ}$$

$$\text{Energy performance \%} = \frac{E_2 - E_1}{E_2} \times 100 = \frac{5196035.6 - 4609360.3}{5195035.6} \times 100 = 11.3\%$$

$$\text{E.P (1998 – 1999)} = 11.3\%$$

This implies that energy utilization in 1999 was 11.3% better than 1998. The factory used 11.3% less energy to produce a unit of production.

1999 – 2000 Energy performance

Company... *Mumias Sugar Co.* Reporting centre.....*Factory*.....
 Reporting period.....*2000*.....
 Base Year..... *1999*...

$$\text{P.F} = \frac{Y_c \text{ Production}}{Y_b \text{ Production}} = \frac{217,772}{251,243} = 0.87$$

(Production output was 13% lower in 2000 compared to 1999)

$$E_2 = E_0 \times \text{P.F} = 4,609,360.3 \times 0.87 = 4,010,143.4 \text{ GJ}$$

$$\text{Energy performance \%} = \frac{E_2 - E_1}{E_2} \times 100 = \frac{(4010143.4 - 3354908.6)}{4010143.4} \times 100 = 16.3\%$$

$$\text{E.P (1999- 2000)} = 16.3\%$$

The plant used 16.3% less energy in the year 2000 to produce a unit of production than in 1999.

Nzoia Sugar Company

REPORTING CENTRE TOTAL ENERGY USE (GJ)

Company *Nzoia Sugar Co...* **Reporting centre** *Factory*...
Product *sugar* **Reporting period***1998*
Total production output.....*37,769 t...*

| Energy type (1) | Quantity used (2) | Energy conversion GJ/unit (3) | Gigajoules (GJ) per energy type (4) = (2) x (3) |
|------------------------|----------------------|----------------------------------|-------------------------------------------------------|
| Fuel oil | 43,000litres | 0.04028 | 1732 |
| Fuel wood | 2000tonnes | 8.1 | 16,200 |
| Electricity (grid) | 2424 MWh | 3.6 | 8,724.4 |
| Electricity (self gen) | 10,614 MWh | 3.6 | 38,210.4 |
| Bagasse | 194,000 tonnes | 8.0 | 1,552,000 |
| TOTAL: | | | 1,616,868.8 |

Reporting Centre *Factory...*

Total production output... *49,996...*

Reporting period1999...

| Energy type (1) | Quantity used (2) | Energy conversion GJ/unit (3) | Giga joules (GJ) per energy type (4) = (2) x (3) |
|------------------------|----------------------|----------------------------------|--------------------------------------------------------|
| Fuel oil | 50,000litres | 0.04028 | 2014 |
| Fuel wood | 2000tonnes | 8.1 | 16,200 |
| Electricity (grid) | 2551 MWh | 3.6 | 9183.4 |
| Electricity (self gen) | 11,794 MWh | 3.6 | 42,458.4 |
| Bagasse | 247,000 tonnes | 8.0 | 1,976,000 |
| TOTAL: | | | 2,045,856 |

Reporting centre..... *Factory.....*

Total production output*41484* Reporting period.*2000*.....

| Energy type (1) | Quantity used (2) | Energy conversion GJ/unit (3) | Gigajoules (GJ) per energy type (4) = (2) x (3) |
|------------------------|----------------------|----------------------------------|----------------------------------------------------|
| Fuel oil | 35,000litres | 0.04028 | 1409.8 |
| Fuel wood | 2,000tonnes | 8.1 | 16,200 |
| Electricity (grid) | 2686 MWh | 3.6 | 9669.6 |
| Electricity (self gen) | 13,104 MWh | 3.6 | 47,174.4 |
| Bagasse | 120,000 tonnes | 8.0 | 960,000 |
| TOTAL: | | | 1,034,453.8 |

$$1998 \text{ Energy intensity} = \frac{\text{total energy}}{\text{total production}} = \frac{1616868.8}{37769} = 42.8 \text{ GJ/t}$$

$$1999 \text{ Energy intensity} = \frac{\text{total energy}}{\text{total production}} = \frac{2045856}{49996} = 40.9 \text{ GJ/t}$$

$$2000 \text{ Energy intensity} = \frac{\text{total energy}}{\text{total production}} = \frac{1034453.8}{41484} = 24.9 \text{ GJ/t}$$

Though energy consumption per unit of production has improved in successive years, Nzoia's energy efficiency is far below that of Mumias.

1998 – 1999 Energy Performance

Company *Nzoia Sugar Co.....* Reporting centre..... *Factory*
 Reporting period.....*1999...*
 Base year.....*1998...*

$$P.F = \frac{Y_c \text{ Production}}{Y_b \text{ Production}} = \frac{49,996}{37,769} = 1.3$$

(Production was 30% higher in 1999 compared to 1998)

$$E_2 = E_0 \times P.F = 1,616,868 \times 1.3 = 2,101,929.4 \text{ GJ}$$

$$\text{Energy performance \%} = \frac{E_2 - E_1}{E_2} \times 100 = \frac{2101929.4 - 2045856}{2101929.4} \times 100 = 2.7\%$$

$$E.P (1998 - 1999) = 2.7\%$$

There was only a slight improvement of 2.7 % in energy performance between 1998 and 1999.

1999 – 2000 Energy performance

Company *.Nzoia Sugar Co.....* Reporting Centre *Factory...*
 Reporting period..... *2000.....*
 Base year *.1999.....*

$$P.F = \frac{Y_c \text{ Production}}{Y_b \text{ Production}} = 0.83$$

$$E_2 = E_0 \times P.F = 2,045,856 \times 0.83 = 1,698,060.4 \text{ GJ}$$

$$\text{Energy performance \%} = \frac{E_2 - E_1}{E_2} \times 100 = \frac{1698060.4 - 1034453.8}{1698060.4} \times 100 = 39\%$$

$$E.P (1999 - 2000) = 39\%$$

The factory used 39% less energy in 2000 than in 1999

West Kenya Sugar Company

REPORTING CENTRE TOTAL ENERGY USE (GJ)

Company..... *Westco*..... Reporting Centre.....*Factory*...
 Product*Sugar*..... Reporting period*1998*.....

Total production output *17,273*.....

| Energy type (1) | Quantity used (2) | Energy conversion GJ/unit (3) | Gigajoules (GJ) per energy type (4) = (2) x (3) |
|------------------------|----------------------|----------------------------------|----------------------------------------------------|
| Fuel oil | 8000 litres | 0.04028 | 322.2 |
| Fuel wood | 0 | 8.1 | 0 |
| Electricity (grid) | 586 MWh | 3.6 | 2,109.6 |
| Electricity (self gen) | 3460 MWh | 3.6 | 12,456 |
| Bagasse | 29,748 tonnes | 8.0 | 237,984 |
| TOTAL: | | | 252,871.8 |

Reporting centre.....*Factory*...

Reporting period.....*1999*.....

Total production output..... *16,859*...

| Energy type (1) | Quality used (2) | Energy conversion GJ/unit (3) | Gigajoules (GJ) per energy type (4) = (2) x (3) |
|------------------------|---------------------|----------------------------------|----------------------------------------------------|
| Fuel oil | 6,000 litres | 0.04028 | 241.7 |
| Fuel wood | 0 | 8.1 | 0 |
| Electricity (grid) | 3358 MWh | 3.6 | 12,088.8 |
| Electricity (self gen) | 1002 MWh | 3.6 | 3,607.2 |
| Bagasse | 49,554 tonnes | 8.0 | 396,432 |
| TOTAL: | | | 412,369.7 |

Total production output.....7920..... Reporting period.....2000.....

| Energy type (1) | Quantity used (2) | Energy conversion GJ /unit (3) | Gigajoules (GJ) per energy type (4) = (2) x (3) |
|------------------------|----------------------|-----------------------------------|----------------------------------------------------|
| Fuel oil | 10,200litres | 0.04028 | 410.9 |
| Fuel wood | 0 | 8.1 | 0 |
| Electricity (grid) | 655 MWh | 3.6 | 2358 |
| Electricity (self gen) | 2112 MWh | 3.6 | 7603.2 |
| Bagasse | 17,822 tonnes | 8.0 | 142,576 |
| TOTAL: | | | 152,948.1 |

$$1998 \text{ Energy intensity} = \frac{\text{total energy}}{\text{total production}} = \frac{252871.8}{17273} = 14.6 \text{ GJ/t}$$

$$1999 \text{ Energy intensity} = \frac{\text{total energy}}{\text{total production}} = \frac{412369.7}{16859} = 24.5 \text{ GJ/t}$$

$$2000 \text{ Energy intensity} = \frac{\text{total energy}}{\text{total production}} = \frac{152948.1}{7920} = 19.3 \text{ GJ / t}$$

(Energy consumption per unit of production increased drastically in 1999 and then improved slightly in 2000)

1998 – 1999 Energy performance

Company ... *Westco*..... Reporting centre.....*Factory*...
 Reporting period.....*1999*.....
 Base year.....*1998*.....

$$P.F. = \frac{Y_c \text{ Production}}{Y_b \text{ Production}} = \frac{16,859}{17,273} = 0.98$$

(There was a slight decline of 2% in production in 1999 compared to 1998)

$$E_2 = E_0 \times P.F. = 252,871.8 \times 0.98 = 246,810.9 \text{ GJ}$$

$$\text{Energy performance \%} = \frac{E_2 - E_1}{E_2} \times 100 = \frac{246810.9 - 412369.7}{246810.9} \times 100 = - 67.1\%$$

APPENDIX C

POWER PURCHASE AGREEMENTS (PPAs): MAURITIUS

(a) Continuous Power Plants:

- (1) Contract duration of 15 years with provision for additional 5-year extension periods upon mutual agreement
- (2) Bagasse to be the sole combustible for energy supply with a minimum of 16 GWh energy supplied/purchased every year
- (3) Minimum continuous power export to the grid of 4.5 MW during the crop season and 10.5 MW for 20 days after the end of crop
- (4) A set price set and indexed as from starting date of contract, taking into consideration the c.i.f. price of fuel oil in the two preceding years and a bagasse transfer price is in addition, paid by the Central Electricity Board (CEB)
- (5) Provision for *Force Majeure* or an event year like cyclone or drought when cane (hence bagasse production) is decreased
- (6) Power intake during the daily off-peak period (01.00 to 05.00 hours) is set at 3.5 MW and 5 MW thereafter
- (7) Specifics for mode of payment, compensation for energy imported by the sugar factory during stoppages, metering of energy exported as well as power output, interruption of supply due to breakdowns and methods of resolution of disputes
- (8) Payment of a bonus for minimum power guaranteed by the power company and as a counterpart, payment of penalty in case of default, like power output reduction.

(b) Firm Power Plants

Most of the features outlined in (a) above have been taken on board with the following modifications:

- (1) Contract duration of 18 years with the same provision for renewal
- (2) 80 GWh of energy is purchased by CEB out of which 45 GWh as a minimum originates from bagasse
- (3) Minimum power of 11 MW as semi-base load, 17 MW as peaking power for two hours during evening peak (18.00 to 20.00 hours) in October and November. During intercrops, Sundays and public holidays, 13 MW is on semi-base load and 18 MW peaking power

- (4) The KWh prices are indexed taking into account the coal (alternative fuel) price, the exchange rate and finally, the consumer price index (CPI) in Mauritius
- (5) Provisions for mode of payment, purchase of coal (alternative fuel) by open international tendering, separate metering of the energy from the two combustibles- coal (alternative fuel) and bagasse, catering for a *Force Majeure* situation, interruptions of supply, environmental compliance and handling contract disputes
- (6) Allowance of 45 days per year for scheduled maintenance, and, in addition, scheduled stoppages- 2 per month each of 24 hours duration upon mutual consent
- (7) Penalties applicable for outages and output reductions

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