

ENERGY SELF-SUFFICIENCY AND COGENERATION IN LOUISIANA CANE SUGAR FACTORIES

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ABSTRACT

Increasing energy costs (both natural gas and electricity) have made achieving energy self-sufficiency a priority at Louisiana sugar factories. Many sugar factories have been designed so that the available bagasse produced is sufficient to provide all of the energy required to operate the factory. This study was conducted to determine the fuel quality, the quantity of live steam that can be produced (boiler efficiency) and to investigate live and exhaust steam utilization in the factory in order to move Louisiana factories toward energy independence. Fuel quality and boiler efficiency were determined in over 100 bagasse boiler tests. A rigorous material and energy balance was prepared quantifying fuel usage, electrical power generation, and live and exhaust steam requirements for each of three cases presented. Results show that (1) improving bagasse quality (lower moisture and lower ash), (2) installation of economizers to reduce high average flue gas temperature and/or (3) the use of high pressure steam and more efficient evaporator schemes can make Louisiana factories energy independent.

INTRODUCTION

Sugar factories are representative of processing facilities that produce a by-product (bagasse) that can be used as fuel to operate the facility. Many sugar factories have been designed so that the available bagasse produced is sufficient to provide all of the energy required to operate the factory. In these facilities, the steam produced by burning the bagasse is sufficient to provide all of the live steam required by the prime movers, including the turbo-generators, which produce all of the electricity required by the factory and sufficient exhaust steam to operate the boiling house. In many facilities, there is sufficient excess bagasse to permit start-up and boil-off operations without the use of any supplementary fuel.

In Louisiana, the abundance and low cost of natural gas in earlier years has left a legacy of poor energy utilization that afflicts most of the Louisiana factories. Improvements in energy efficiency did not start in earnest until after the oil embargo of 1973 and the shortage of natural gas forced the industry to improve its energy utilization. During the 2005 crop, the cost of natural gas increased dramatically (to \$15/1000ft³ or \$0.53/m³) following the damage done by Hurricanes Katrina and Rita (Fig. 1). Many Louisiana factories made modifications to their 2005 crop operations to minimize gas usage. These modifications included by-passing mills to save live steam and reducing imbibition to conserve exhaust usage.

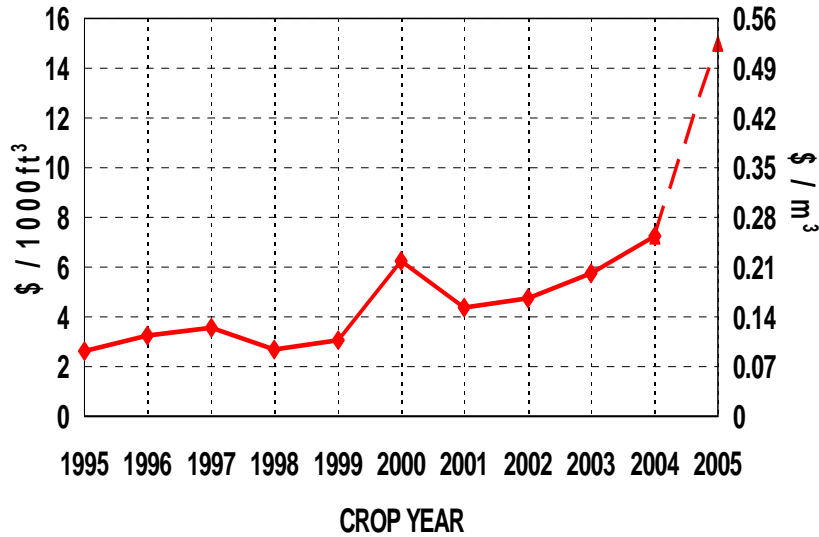


Figure 1. Cost (\$) of gas per 1000 ft³ and m³ over the past decade.

A typical Louisiana factory requiring about 450-550 kg steam/tonne cane could derive this steam by consuming about 31.2 to 40.6 m³ of gas/tonne cane. Average gas consumption in 1972 was 38.7 m³/tonne cane (1.24 MCF/short ton cane), while gas consumption for the 2005 crop was only 0.62 m³/tonne cane (0.02 MCF/short ton cane)(Fig. 2). The spike in gas usage for the 2002 crop was due to the adverse field conditions resulting from Hurricane Lili and Tropical Storm Isidore. Costs and usage of natural gas were provided by Louisiana factories (private communications).

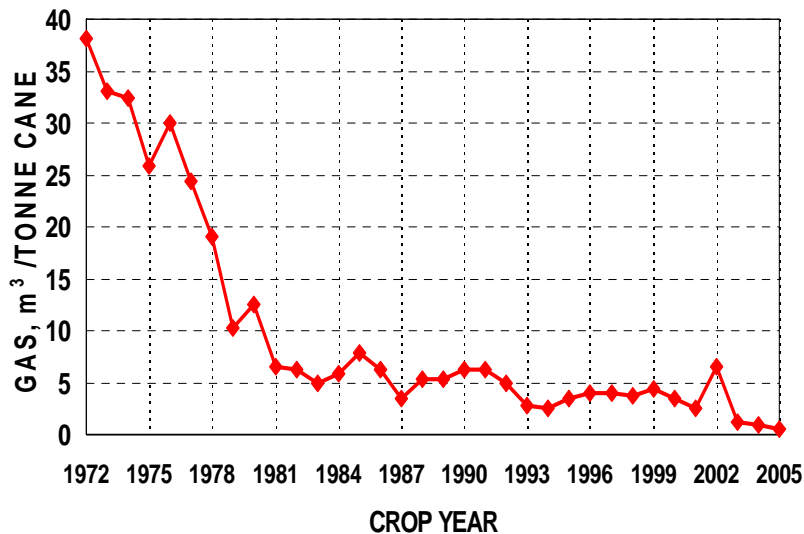


Figure 2. Historic use of gas by Louisiana sugar industry (1972-2005).

While gas consumption has shown a dramatic reduction over the last 35 years, reductions in the quantity of purchased electricity have declined very little over this period. Louisiana factories currently purchase from 3.3 to 11 kWh/tonne of cane ground. As with the cost of gas,

the cost of electricity has been rising steadily (Fig. 3). In 2005, the average cost paid for electricity was about \$0.10/kWh.

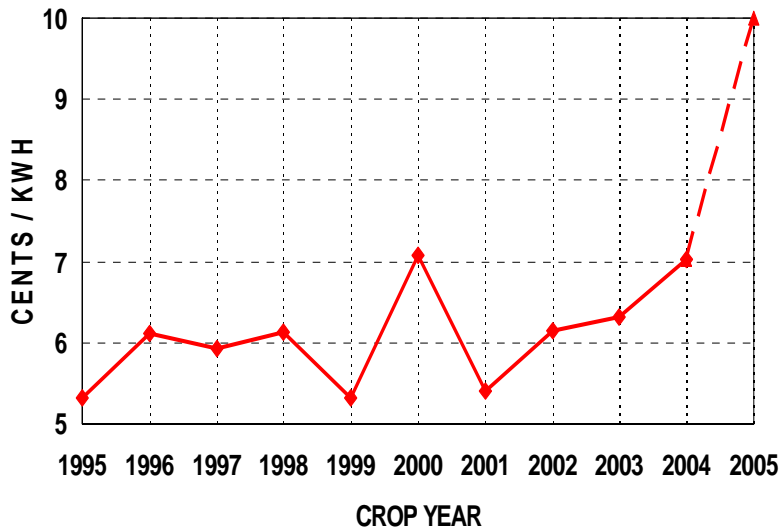


Figure 3. Electricity prices for the past decade.

No Louisiana factory generates (or has the equipment to generate) all of the factory’s electrical requirements. In fact, three of the 13 factories that operated in 2005 did not have any turbo-generators.

An achievable goal for the Louisiana sugar industry should be complete energy self-sufficiency – both for steam and for electricity.

The objectives of this study were to determine the fuel (bagasse) quality and quantity available, the quantity of live steam that can be produced (boiler efficiency) and to investigate live and exhaust steam utilization in the factory in order to move Louisiana factories toward energy independence.

MATERIALS AND METHODS

Bagasse Quality and Quantity

Seventeen mill extraction tests on 12 tandems (made up of 5-, 6- and 7-mill tandems) were conducted during the 2005 crop. Cane and bagasse samples were collected over a 30-60 minute period and analyzed for moisture, true fiber and ash (field soil) content (Birkett and Stein, 2004). Moisture % bagasse was measured by drying bagasse samples in a mechanical convection oven for 24 hours at 105°C or until constant weight. True fiber (real fiber, absolute fiber, or natural fiber) is considered the disintegrated, washed and dried, insoluble matter in the cane. Mixed juice samples were also collected during the same period. The fiber content of the mixed juice was determined by washing a known quantity of the juice through a 400-mesh sieve and drying the contents on the sieve to constant weight.

Boiler Efficiency

Also during the 2005 crop, all of the operating boilers (64 individual boilers) at all of the Louisiana factories were tested at least once and several were tested on more than one occasion (for 108 boiler tests).

The data gathered during boiler testing included:

1. Moisture and ash content of bagasse fuel.
2. Boiler steam flow, steam pressure and steam temperature.
3. Boiler feed water temperature.
4. Preheated air temperature.
5. Flue gas temperature and flue gas analysis for oxygen, carbon monoxide, nitrogen oxides and sulfur dioxide.

Flue gas temperature and gas analysis were determined using Testo 350 M/XL and Testo 300 flue gas analyzers. Preheated air temperature was determined using an Omega handheld digital thermometer and thermocouple probe.

Excess air, boiler efficiency and steam produced for every unit of bagasse burned were calculated using a computer program written for a similar study conducted in the early 1990s (Birkett and Stein, 1992). The program was based on the heat loss method and assumed undetermined heat losses of 3% (Birkett, 1966).

Factory Steam Usage

Basic assumptions for three cases are given and discussed. A rigorous material and energy balance was prepared to quantify the fuel usage, electrical power generation and the live and exhaust steam requirements for each of the three cases considered.

RESULTS AND DISCUSSION

Bagasse Quality and Quantity

The quantity of bagasse available depends primarily on the fiber content of the cane. The commercial cane varieties currently grown in Louisiana have fiber contents that average in the 11.5 to 12.5 fiber % cane range.

The true fiber in cane entering the mill was determined as part of milling tests conducted during the 1998 to 2005 period (Fig. 4). The low fiber content of the cane in 2002 was the result of very high levels of extraneous matter delivered with the cane together with the wet field conditions following the damage to the crop by Hurricane Lili and Tropical Storm Isidore.

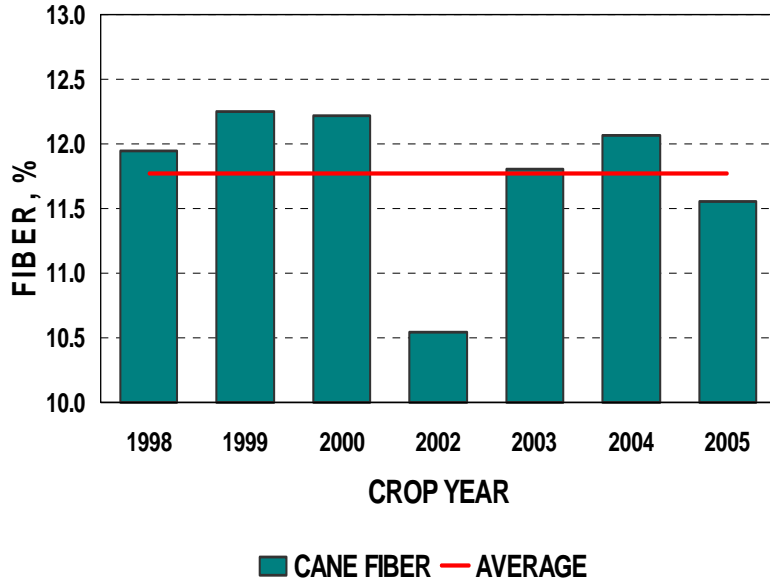


Figure 4. True fiber content of prepared cane tested (1998-2005).

Direct analysis of the cane entering the mill was performed in 2005 as part of our study on milling operations. The fiber % cane obtained for the 17 milling tests (and one diffuser test) conducted in 2005 throughout the crop varied from 9.8 to 13.2%, with an average of 11.55% (Fig. 5).

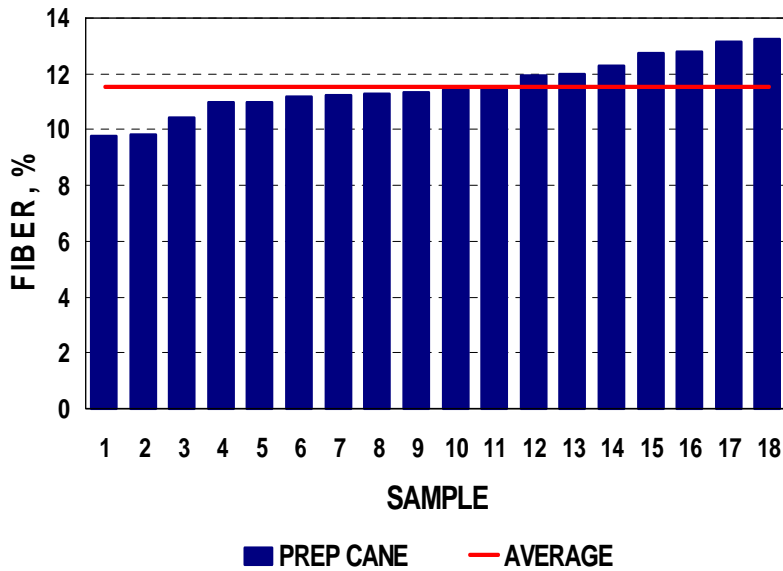


Figure 5. True fiber content of prepared cane samples during 2005 crop.

The true fiber content of bagasse was determined for each of the milling tests conducted in 2005 (Fig. 6). The true fiber content of the bagasse was also determined but on a less frequent basis in previous years (Fig. 7).

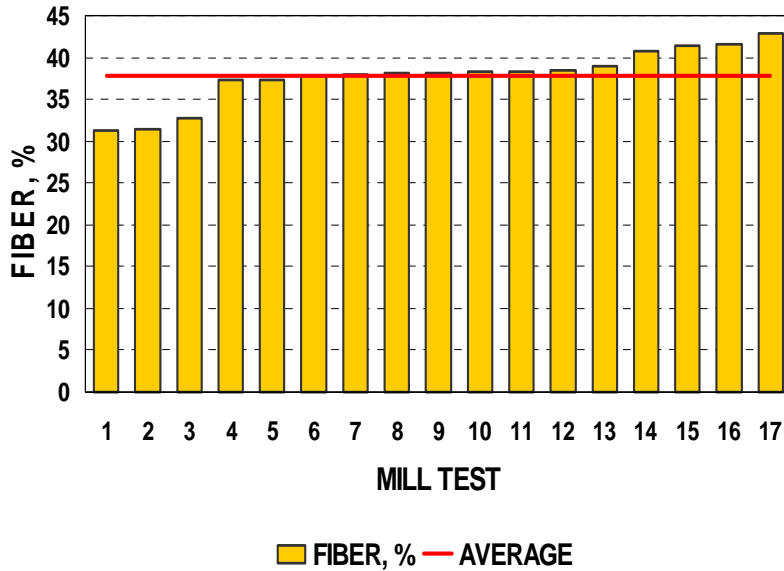


Figure 6. True fiber content of bagasse samples obtained during the 2005 crop.

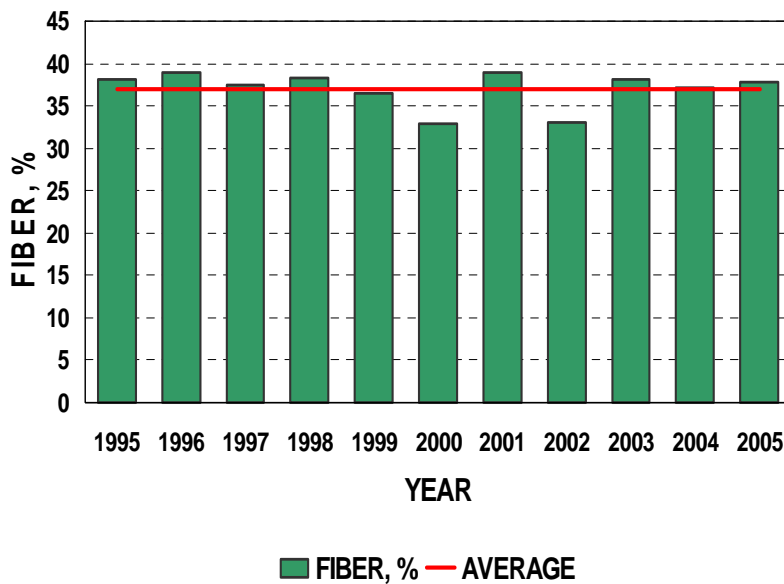


Figure 7. True fiber content in bagasse from 1995 to 2005.

The bagasse % cane can be obtained by dividing the fiber % cane by the fiber % bagasse and expressing the quotient as a percentage on the assumption that the bagasse contains all of the fiber in the cane. As part of our milling studies conducted in 2005, the fiber content of the mixed juice was determined to vary from 0.12 to 0.66% (Fig. 8). On the assumption that the mixed juice % cane is 100%, the fiber lost to the mixed juice represents from 1 to 5% of the fiber in the cane. The calculated bagasse % cane should be based on the directly determined fiber in cane less the fiber lost to the mixed juice.

At many factories, the fiber (bagacillo) in the mixed juice represented most of the bagacillo used at the filter station. However, to obtain the true quantity of bagasse

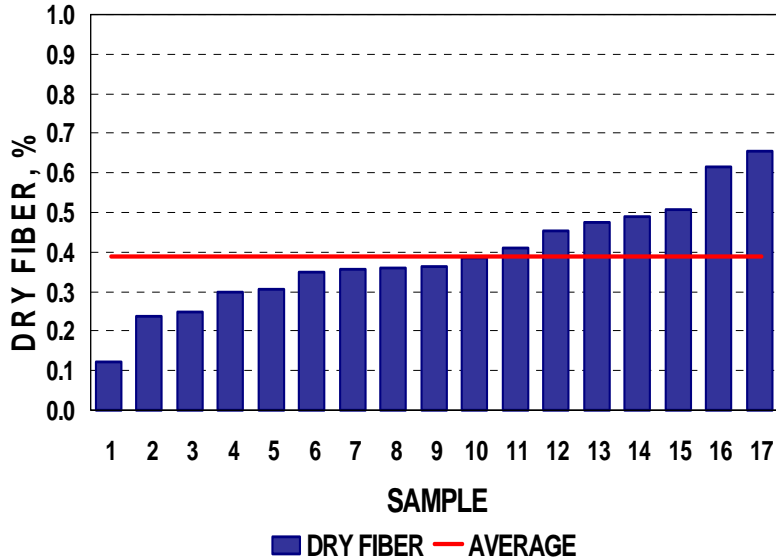


Figure 8. Dry fiber % mixed juice for 2005 crop mill test samples.

available for the boilers, the fiber in the bagacillo used at the filters should also be deducted from the measured fiber content of the cane. Based on limited filter cake analyses, the fiber in filter cake is typically less than 10 kg/tonne cane (i.e., 1% of the cane). Thus, the quantity of bagasse available for steam generation can be estimated using the measured fiber % cane less this quantity (1%).

The bagasse % cane figures for the milling tests conducted in 2005 are shown in Figure 9. Two sets of figures are shown for each test, with the higher figure being based on the total fiber in cane, and the lower figure calculated on the assumption that fiber equal to 1% of the cane is lost to the mud processing operations.

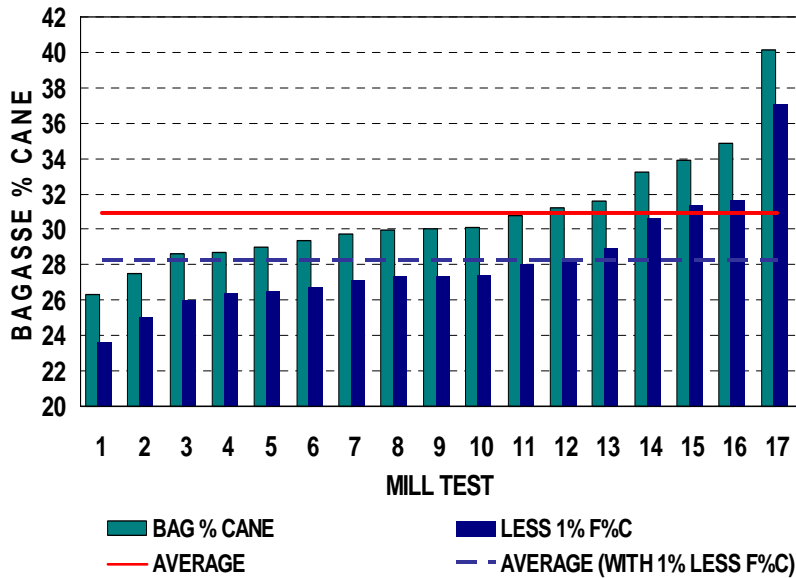


Figure 9. Bagasse % cane using measured cane fiber compared to measured cane fiber less 1%.

The higher bagasse % cane figures vary from 26.3 to 40.2% and average 30.9%. The lower (more realistic) bagasse % cane figures vary from 23.6 to 37.1% and average 28.2%. These higher bagasse % cane figures calculated by analysis agree very well with the state average bagasse % cane reported by the factories for the 1985 to 2005 crops (Fig. 10).

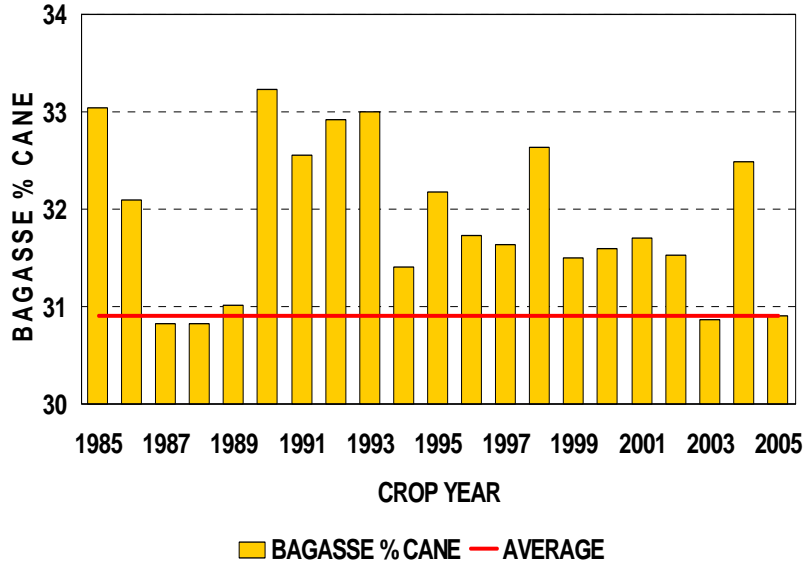


Figure 10. Bagasse % cane as reported by factories.

Apart from the quantity of bagasse available, the quality of the bagasse, as measured by its ash and moisture content, is also important. The moisture content of the bagasse affects the furnace temperature and the rate of combustion, while the ash (field soil) increases the effective moisture (moisture content of the ash-free bagasse) and additionally increases the need to clean the furnaces. The effect ash has on bagasse quality and its subsequent effect on heating value have been discussed by Wright (2003). Problems related to ash in bagasse, such as clinker formation and reduced heat transfer, are pointed out by Wienese (2001).

The ash content of the bagasse samples obtained from the milling tests, as well as those obtained during the boiler tests, varied from 1.7 to 10%, with an average of 4.2% in 2005 (Fig. 11).

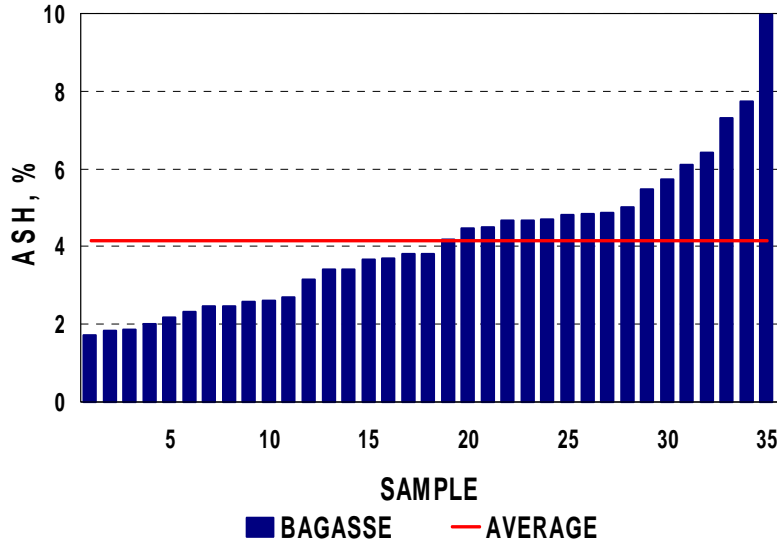


Figure 11. Ash content of bagasse samples from milling and boiler tests.

Weather conditions during the 2005 crop were unusually dry yet the ash content of the bagasse was higher than usual in Louisiana (Fig. 12). The higher ash content in recent years may be due to a combination of hurricane damage and/or the reduced degree of cane washing being practiced in recent years.

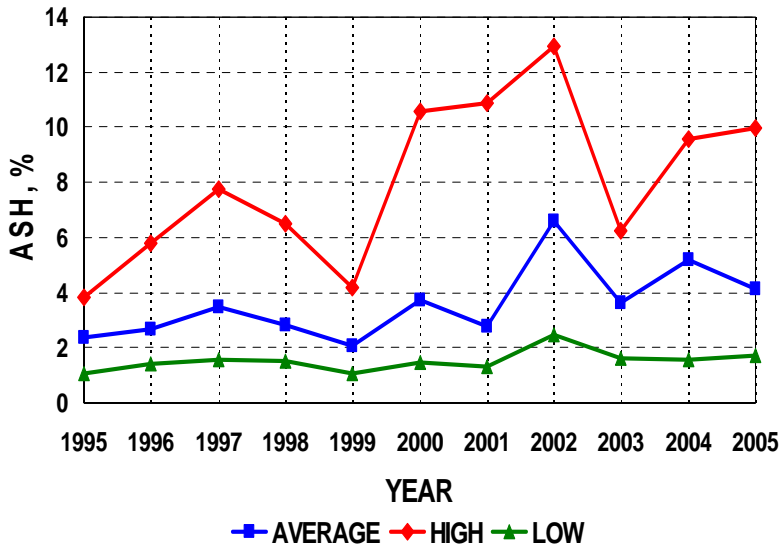


Figure 12. Ash % bagasse for samples from 1995-2005.

The moisture content of the bagasse samples obtained from the milling tests, as well as those obtained during the boiler tests varied from 50.25 to 61.68%, with an average of 54.46% (Fig. 13).

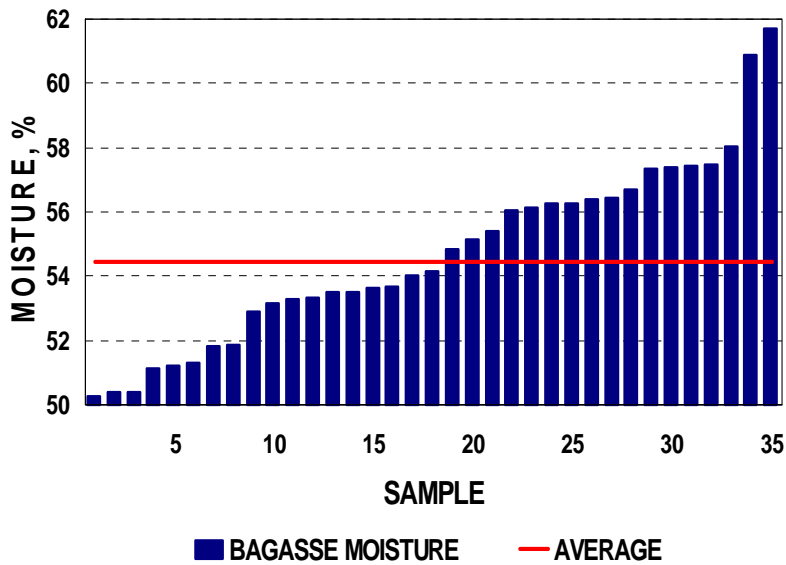


Figure 13. Moisture content of bagasse from milling and boiler tests.

There are several formulas for calculating the gross calorific value (GCV) or gross heating value (GHV) of bagasse (Paturau, 1989; Hugot, 1986). One of the simpler formulas (Chen and Chou, 1993) for calculating the GCV of bagasse is:

$$GCV = 8350 \times \frac{(100 - \text{Moisture \% Bagasse} - \text{Ash \% Bagasse})}{100} \text{ Btu/lb}$$

or

$$GCV = 19,410 \times \frac{(100 - \text{Moisture \% Bagasse} - \text{Ash \% Bagasse})}{100} \text{ kJ/kg}$$

Boiler Efficiency

The efficiency of the boiler station plays a major role in the quantity of steam that can be generated. The primary factors that affect the boiler efficiency are:

1. The quality of the fuel (bagasse).
2. The quantity of excess air used for combustion.
3. The temperature of the flue gases.
4. The completeness of the combustion.

The quality of bagasse available has been discussed in the previous section.

The oxygen and carbon monoxide content of the flue gases can be used to calculate the level of excess air used for combustion. The oxygen % dry flue gases varied from 0.7 to 16.1% and averaged 7.5% (Fig. 14). As would be expected, at the very low oxygen levels, carbon monoxide concentrations measured were high.

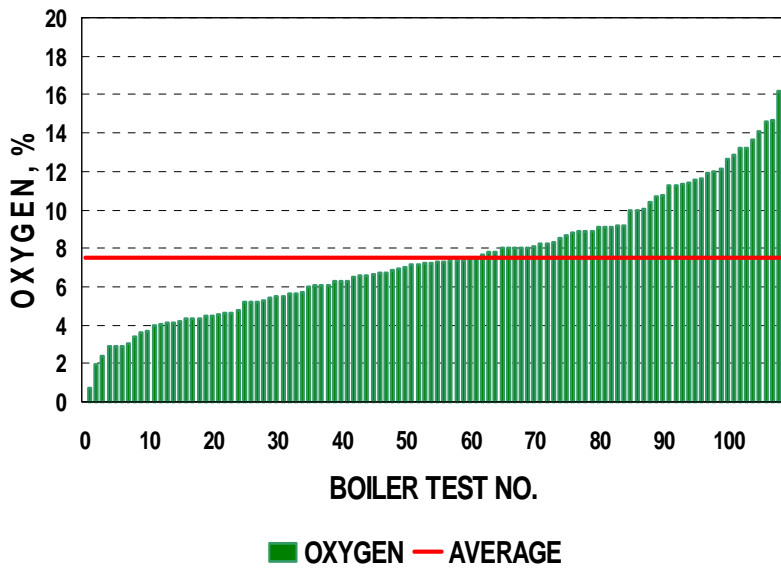


Figure 14. Percentage oxygen in dry flue gases.

The calculated excess air used for combustion is shown in Fig. 15. The excess air levels varied from 0.8 to 319% and averaged 64.7%.

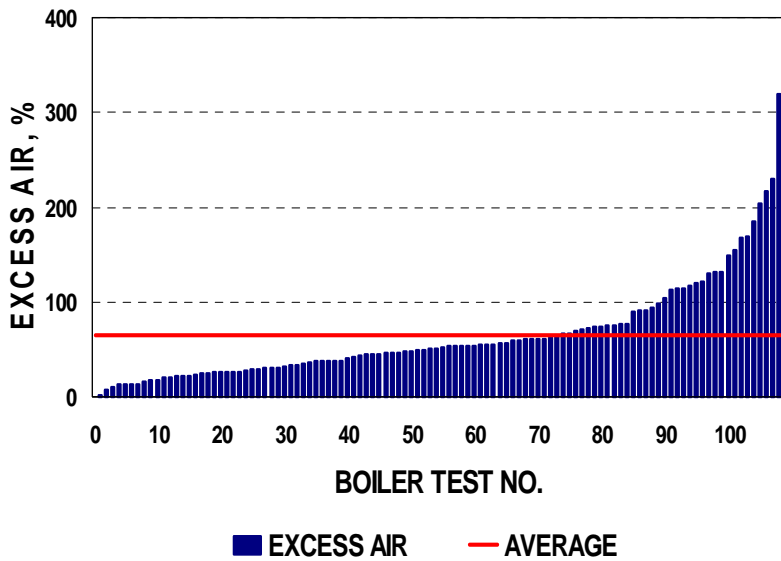


Figure 15. Calculated excess air levels.

The flue gas temperatures after the air preheater (but before the scrubbers) varied from 168 to 333°C (334 to 631°F) and averaged 236°C (457°F) (Fig. 16).

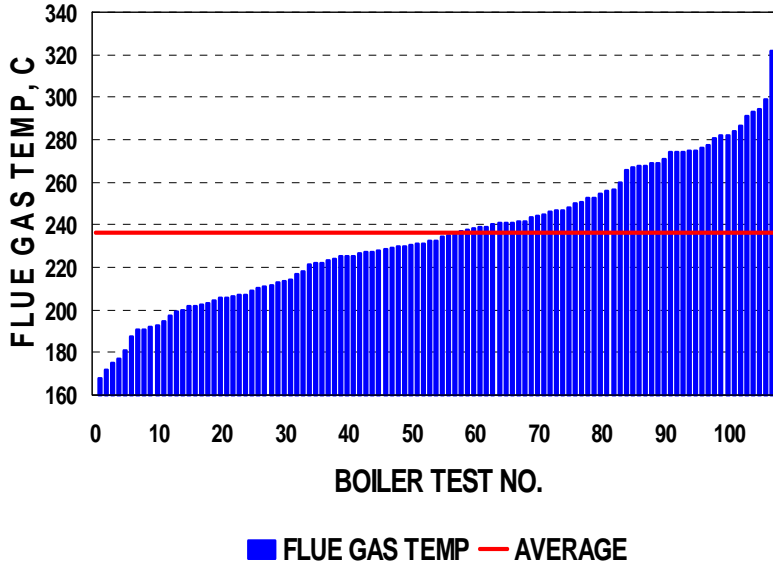


Figure 16. Flue gas temperatures measured during the 2005 crop.

The preheated air temperature leaving the air preheaters used for combustion varied from a low of 155.6 (312°F) to a high of 312.8°C (595°F), with an average of 236.5°C (458°F) (Fig. 17).

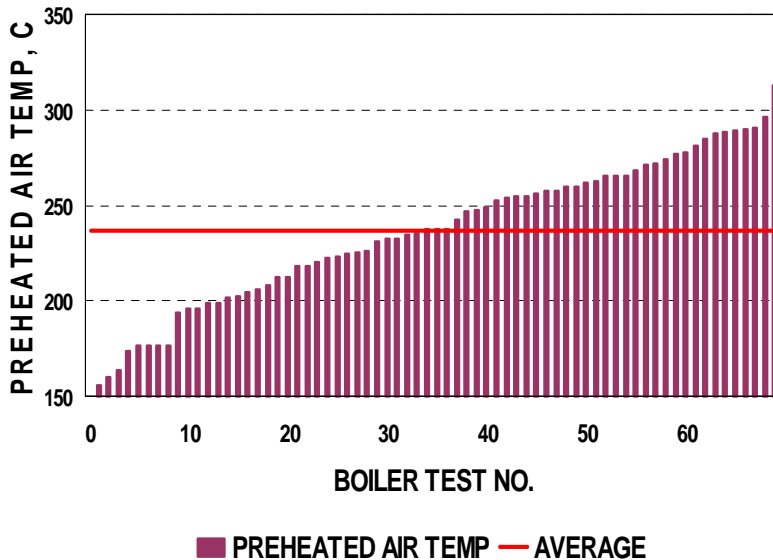


Figure 17. Preheated air temperatures measured during the 2005 crop.

As previously stated, the boiler efficiency was calculated using the heat loss method and assuming undetermined heat losses of 3%. In this method, the boiler efficiency is calculated using the bagasse analysis (moisture and ash content), the flue gas analysis (oxygen and carbon monoxide) together with the flue gas temperature. The boiler efficiencies varied from 38 to 62%, with an average of 55.15% (Fig. 18).

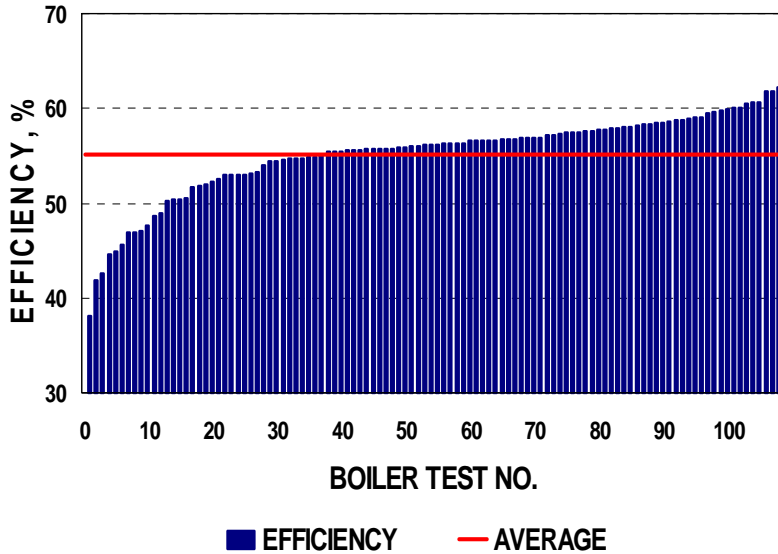


Figure 18. Boiler efficiencies based on GCV for all boilers tested during the 2005 crop.

An extensive study on Louisiana bagasse boilers was conducted in 1990-92 (Birkett and Stein, 1992). In this study even though 15 years have passed, the average flue gas temperature and boiler efficiency were virtually identical to those obtained in 2005.

Also of interest is the quantity of steam produced from bagasse. This is shown in Figure 19. Kilograms steam produced per kg bagasse varied from 1.1 to 2.3 and averaged 1.9.

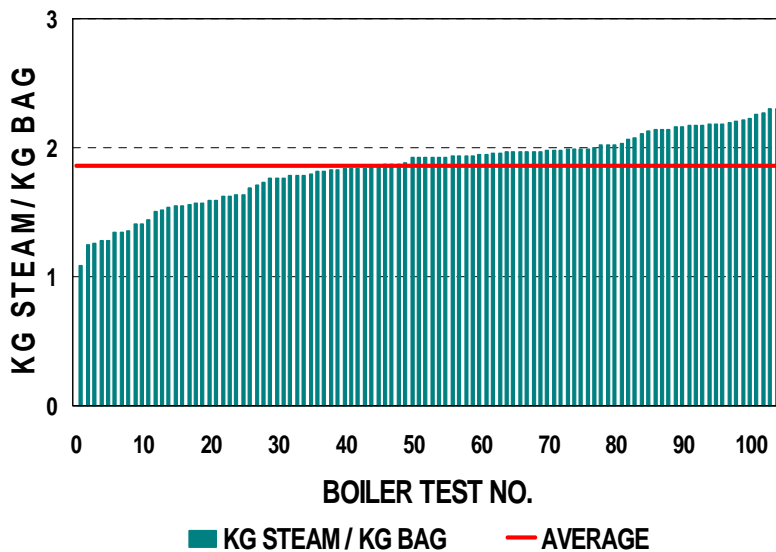


Figure 19. Kilograms steam produced per kilogram bagasse burned.

Methods to Improve Boiler Efficiency. There are essentially three methods that can be used to improve the boiler efficiency:

1. Improve the bagasse quality.
2. Reduce the level of excess air.
3. Reduce the temperature of the flue gases.

Bagasse Quality. The quality of Louisiana bagasse is poor. In 2005 the average moisture content was 54.47% and the ash content 4.15%. The effective moisture content of the bagasse was 56.37% (Fig. 20). Effective moisture is the moisture % ash-free bagasse.

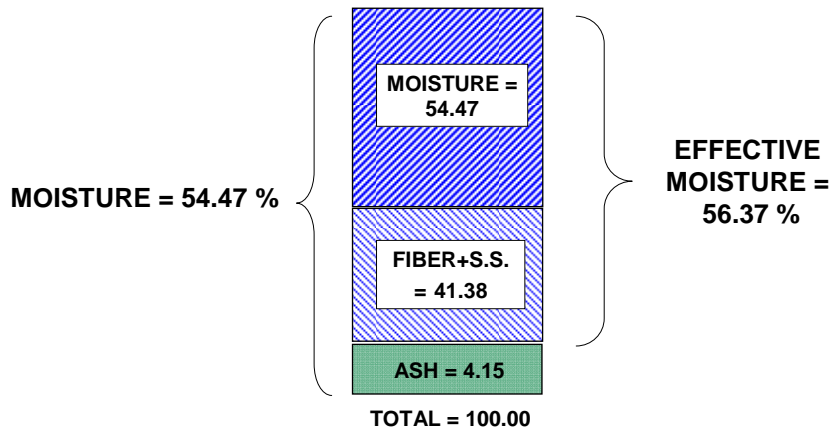


Figure 20. Effective moisture content of average bagasse.

The recent installation of larger mills at some factories and the greater emphasis on improved extraction should result in an improvement in the quality of the bagasse.

The calculated effect of lowering the moisture % bagasse by 1% is an increase in the boiler efficiency of 0.82%. Similarly, the effect of lowering the ash % bagasse by 1% is an increase in the boiler efficiency of 0.47%.

The role that effective bagasse moisture has on boiler efficiency can be observed from the following plot of boiler efficiency versus effective bagasse moisture (Fig. 21). This data indicates that each one point reduction in the effective moisture content of the bagasse yields a 0.9% increase in the boiler efficiency, which agrees fairly well with the calculated increase of 0.82%.

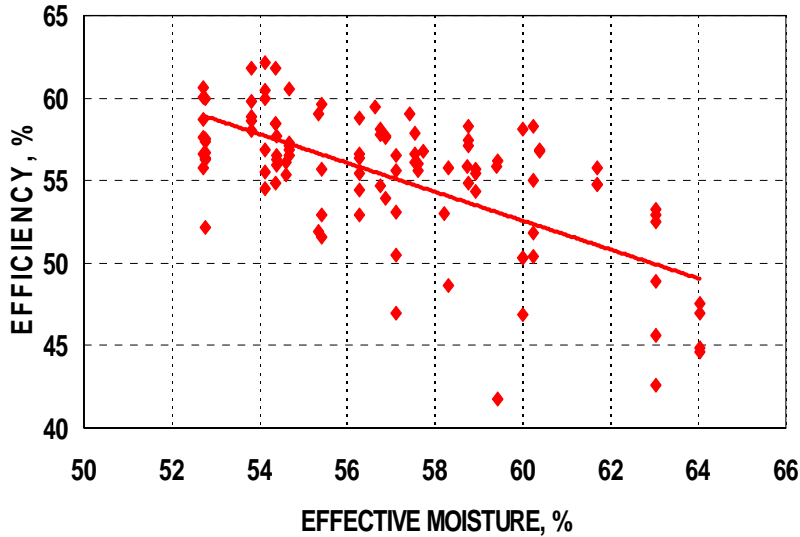


Figure 21. Boiler efficiency versus effective bagasse moisture.

Level of Excess Air. The average level of excess air currently employed of 65% is often associated with high levels of carbon monoxide. It would seem that achieving complete combustion with lower levels of excess air will require improvements in bagasse quality and furnace design.

Flue Gas Temperature. The high average temperature of the flue gases leaving the air heater of 236°C (457°F) is a major cause of low boiler efficiency (Fig. 22). This plot of flue gas temperature versus calculated boiler efficiency is based on the average bagasse analysis and the average flue gas analysis for the 2005 crop.

Reducing the flue gas temperature from 232°C (450°F) to 149°C (300°F), with all other conditions remaining constant, will increase the boiler efficiency from 56 to 62%. This increase in boiler efficiency will result in the production of 10.7% more steam from a given quantity of bagasse.

The flue gas temperature can be reduced from 232°C to 149°C by employing an economizer placed in the flue gas path to heat the boiler feed water leaving the deaerator prior to it entering the boiler. Currently, there are no economizers installed on any of the boilers in Louisiana.

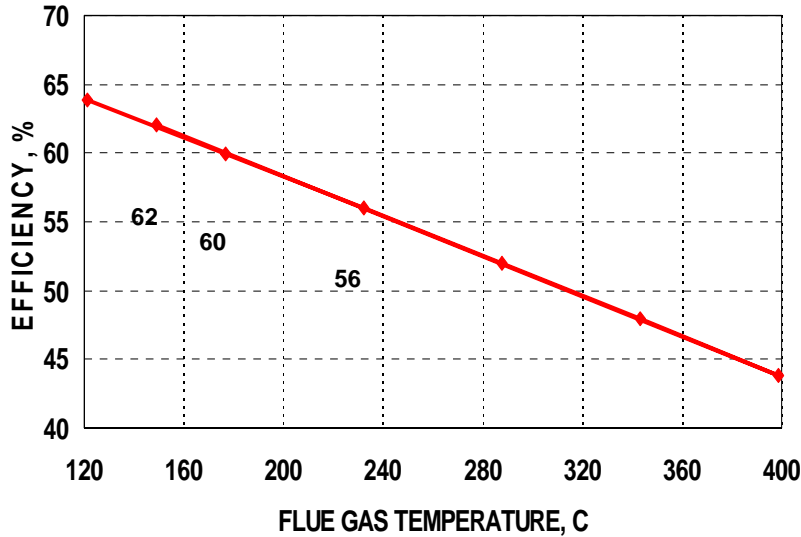


Figure 22. Flue gas temperature versus calculated boiler efficiency on GCV.

For the average boiler, the use of an economizer to lower the flue gas temperature by 83.3°C (150°F) will result in a temperature rise of 54.4°C (98°F) in the boiler feed water. This level of heating of the boiler feed water should not be a problem at most installations as the heated boiler feed water will be below the drum water temperature even for low pressure boilers.

Factory Steam Usage

Improvements in bagasse quality and in boiler efficiency will result in increased steam production from the available fuel. However, these improvements alone may not be sufficient to achieve total energy self-sufficiency.

The factory's live steam usage can readily be reduced by use of higher pressure steam. Similarly, the factory's exhaust steam requirement can be substantially reduced by employing more steam efficient evaporator schemes.

Three cases are considered. The first case (Fig. 23) represents a typical Louisiana factory, while the second case (Fig. 24) is representative of a factory with a higher live steam pressure and a more energy efficient evaporator configuration but no change in the boiler efficiency or factory operating conditions. The third case (Fig. 25) is similar to the high pressure case but utilizes a topping turbine to reduce the live steam pressure to that of the first case for use in existing factory turbines.

Case 1 – Typical Louisiana Sugar Factory

Basic Assumptions:

Grinding Rate, TCD	9,072	
Cane, % Pol	13.0	
% Fiber (True)	11.24	
Pol Extraction, %	94.0	
Bagasse, % Moisture	54.0	
% Ash	3.0	
Imbibition % Cane	30.0	
Syrup Purity	85.0	
Boiler Efficiency, %	55.0	
Boiler Feed Water Temperature, °C	121.1	
Power Required, kW/TCH	20.56 (7,768 kW at 9,072 TCD)	
Electricity Required, kW/TCH	<u>10.58</u> (4,000 kW at 9,072 TCD)	
Total Power	31.14 KW/TCH	
Turbine Efficiency, %	50.0	
Turbo-Generator Efficiency, %	68.0	
Miscellaneous Steam Usage, kg/h		
Live Steam	9,072	
Exhaust Steam	4,536	
Analyses:		
	<u>Brix</u>	<u>Purity</u>
Syrup	65.0	85.0
A Massecuite	92.0	85.0
B Massecuite	93.0	74.0
C Massecuite	96.0	55.0
A Molasses (Diluted)	65.0	69.0
B Molasses (Diluted)	65.0	52.0
Final Molasses	86.0	32.0
A & B Sugar	99.75	98.8
C Magma		85.0
Steam Generating Conditions	14.5 bar gauge, saturated	
Evaporator Scheme	Quadruple Effect Evaporator with First Vapor to High Grade Pans and Raw Juice Heaters	
Sugar Boiling Scheme	Conventional Three Boiling	

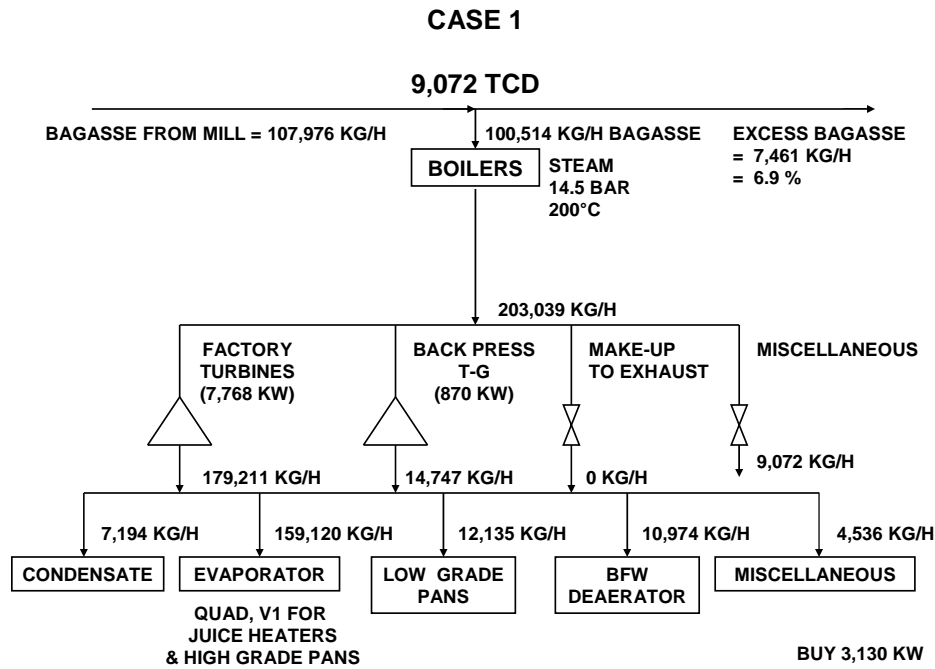


Figure 23. Typical Louisiana factory (low steam pressure, quadruple effect) steam flows and power generated.

Case 2 – Higher Pressure Steam & Quintuple Case

The assumptions for this case are identical to those for Case 1 with the exceptions that:

Steam is generated at 44.8 bar gauge, 399°C

A quintuple effect evaporator is employed with first vapor bled for all vacuum pans and third (final) stage juice heating, second vapor is used for the second stage juice heaters and third vapor is used for the primary juice heating.

The available bagasse is sufficient to produce all of the steam required by the factory turbines and the production of 870 kW while meeting the factory’s exhaust steam needs and producing an excess of bagasse of 6.9%. This quantity of “excess” bagasse is necessary to permit operations during lost time stops without the need to burn supplementary fuel. Note that the factory requires 4000 kW but that only 870 kW is generated, necessitating the purchase of about 3000 kW from the utility.

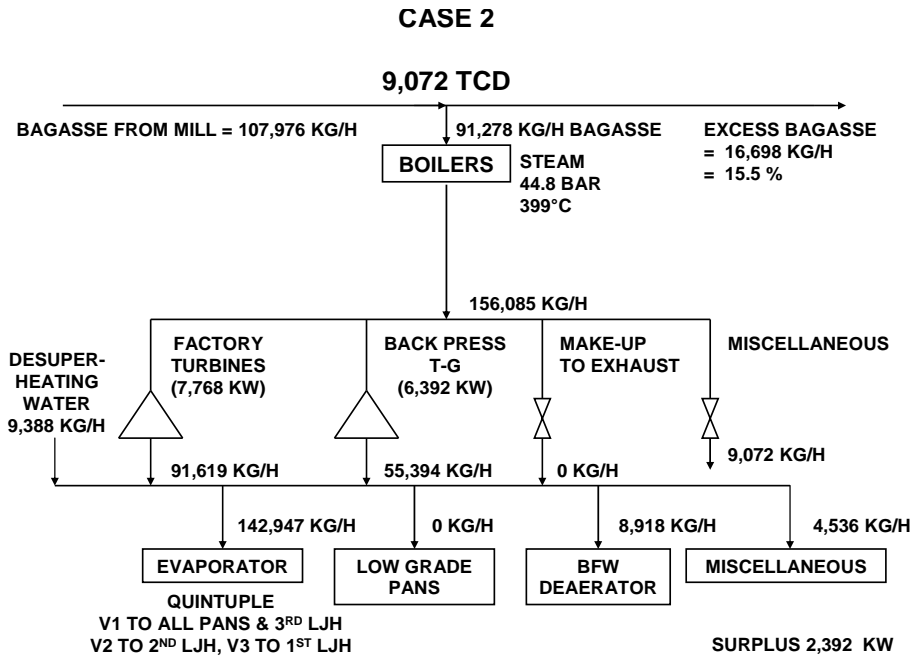


Figure 24. High pressure steam and quintuple effect evaporator steam flows and power generated.

The corresponding summary for the high steam pressure/quintuple effect evaporator case (Case 2) is shown in Figure 24. In this case, the factory can meet all of its power requirements, its exhaust steam requirements and generate 2392 kW of surplus power while producing an increased surplus of bagasse equivalent to 15.5% of production. The increased surplus of bagasse can be used to provide additional steam that could be used for increased electricity generation, more imbibition, or simply sold as a by-product if a market exists for its sale.

Case 3 – Topping Turbine

Two Louisiana factories have installed large new boilers that can operate at 44.8 bar gauge/399°C (650 psig/750°F). To derive the benefits of high pressure steam in a factory with low pressure turbines, a topping turbine can be installed to reduce the high pressure steam to supply the existing factory turbines while providing electricity. This case is summarized as Case 3 (Fig. 25). This case is very similar to Case 2 in that excess power is cogenerated (3498 kW) and surplus bagasse (15%) is produced.

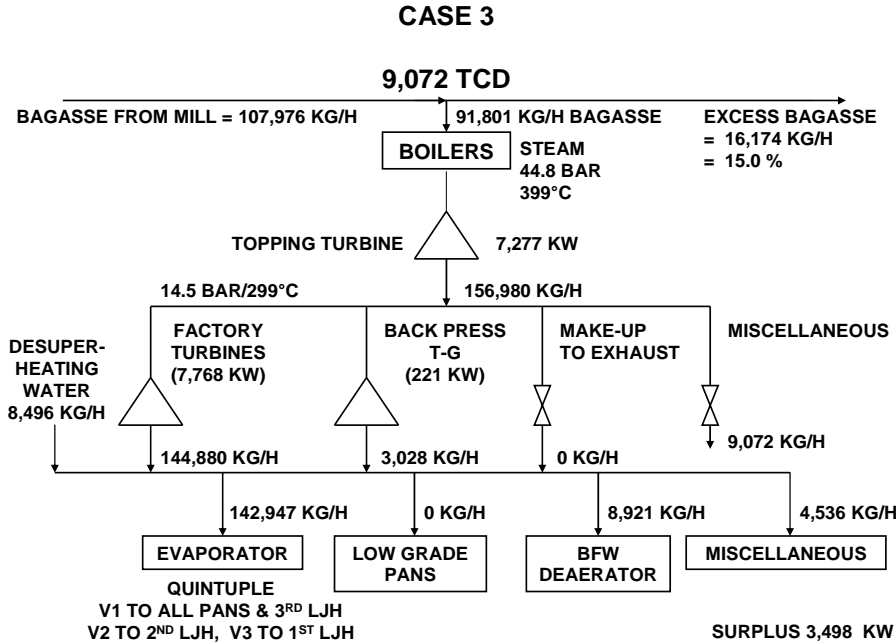


Figure 25. High pressure steam, topping turbine and quintuple effect evaporator steam flows and power generated.

Note that in retrofitting low pressure factories, the new high pressure boilers may only provide a portion of the total steam needs of the factory, so that only the high pressure steam will be sent through the topping turbine. This arrangement will reduce the quantity of electricity generated but, depending on the size of the high pressure boiler, the topping turbine could provide all or most of the factory’s electrical requirements.

CONCLUSIONS

In summary, in implementing a plan to ensure a sugar factory’s energy independence the following should be considered:

1. Improving the quality of the bagasse (lower moisture and lower ash) can improve boiler efficiency and increase steam production.
2. Boiler efficiency can be improved. In the case of Louisiana sugar factories, the primary area of improvement can be expected to come from the installation of economizers to reduce the high average flue gas temperature.
3. Even without any improvements in bagasse quality or boiler efficiency, the use of high pressure steam and more efficient evaporator schemes can make Louisiana factories energy independent or exporters of electricity.

The most economic solution to energy independence will likely be some combination of all of the above.

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