



**ADDIS ABABA UNIVERSITY**  
**SCHOOL OF GRADUATE STUDIES**  
**DEPARTMENT OF MECHANICAL ENGINEERING**

**ENHANCING POWER GENERATION CAPACITY**  
**OF**  
**METAHARA SUGAR FACTORY**

A thesis submitted to the School of Graduate Studies of Addis Ababa University (AAU) in partial fulfillment of the requirements of the degree of Master of Science (M.Sc.) in Mechanical Engineering (Specialization in Thermal Engineering).

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## Acronyms

<i>abs</i>	<i>Absolute</i>
<i>D</i>	<i>% dissolved matter in bagasse</i>
<i>EM</i>	<i>Electric motor</i>
<i>f</i>	<i>Mean fiber content of cane</i>
<i>f'</i>	<i>Fiber content of bagasse</i>
<i>GCV</i>	<i>Gross Calorific Value or Higher Calorific Value</i>
<i>GWh</i>	<i>Gigawatt (1 bln watt) hour, a typical unit to measure electricity production and use</i>
<i>ktoe</i>	<i>Kilotons of oil equivalent</i>
<i>KVA</i>	<i>Total (or apparent) power measured in kVA (Kilo Volts-Amperes)</i>
<i>KVAR</i>	<i>Reactive power measured in kVAr (Kilo Volt-Amperes Reactive)</i>
<i>KW</i>	<i>Active power measured in kW (Kilo Watts)</i>
<i>KWh</i>	<i>Kilowatt hour, unit of energy, a typical unit to measure electricity production and use</i>
<i>MCR</i>	<i>Maximum continuous rating</i>
<i>MSF</i>	<i>Metahara Sugar Factory</i>
<i>NCR</i>	<i>Nominal continuous rating</i>
<i>NCV</i>	<i>Net Calorific Value or Lower Calorific Value</i>
<i>NEMA</i>	<i>National Electrical Manufacturers Association</i>
<i>PC</i>	<i>Pressure capacity</i>
<i>PF</i>	<i>Power factor</i>
<i>RB</i>	<i>Required bagasse</i>

<i>rpm</i>	<i>Revolution per minute</i>
<i>SBA</i>	<i>Surplus bagasse amount</i>
<i>TBP</i>	<i>Total bagasse produced</i>
<i>TBR</i>	<i>Total bagasse required</i>
<i>TCD</i>	<i>Tons of cane per day</i>
<i>TCH</i>	<i>Tons of cane per hour</i>
<i>w</i>	<i>Moisture content of bagasse</i>

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## Glossary

Ash:- *is the residue remaining after incineration of bagasse or other fuel.*

Back-pressure turbine:- *is a type of steam turbine where the steam, after expanding through the turbine, exits at near atmospheric pressure.*

Bagacillo:- *is very small particles of bagasse separated either from pre-clarification juices or from the final bagasse for filtration or other purposes.*

Bagasse:- *is milling by-product remaining after extracting sugar from the stalk.*

Boiling house:- *is part of a sugar factory in which the processes of manufacture from mixed juice to sugar are carried out.*

Brix:- *is the percentage by mass of dissolved solids in a solution. It is usually measured with a refractometer.*

Captive consumption:- *is the internal processing energy need of sugar mill/factory*

CHP plant:- *Combined Heat and Power plant or cogeneration plant*

Cogeneration:- *is a process of producing both electricity and usable thermal energy from the same fuel.*

Condensing-extraction steam turbine:- *is a type of steam turbine which provides the ability to extract only the required amount of process steam at the required pressure. The rest of the steam is expanded to below atmospheric pressure for additional work.*

Imbibition water:- *is the water added to bagasse in the milling stage to mix with and dilute the juice in order to extract the most sucrose from the bagasse.*

Masseccuite:- *is the mixture of sugar crystals and syrup discharged from a vacuum pan.*

Mixed juice:- *is the mixture of juices from the extraction plant delivered into the juice scales.*

Molasses:- *is a thick, brown to deep black, honey-like substance made when cane or beet sugar is processed.*

Mud:- *is the material removed from the bottom part of the subsidiers. The mud contains the settled insoluble solids.*

Pol:- *is the apparent sucrose content of any substance expressed as a percentage by mass.*

Sucrose:- *is the pure disaccharide  $\alpha$ -D-glucopyranosyl- $\beta$ -D-fructofuranoside, commonly known as sugar.*

## ENHANCING POWER GENERATION CAPACITY OF METAHARA SUGAR FACTORY

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### Abstract

*When sugar cane is crushed and the juice separated for crystallization, the remaining dry matter - called bagasse - is burnt in furnace to provide thermal energy. The thermal energy from the combustion of bagasse is used to generate steam which is utilized to drive the power turbines, the mill turbines and for the processes in the plant. Currently, all Ethiopian sugar mills are using bagasse to generate electricity through their co-generation power plant for self sufficiency and to light the nearby villages only. But many foreign sugar mills are producing and selling electricity from excess bagasse, leaves, trashes of sugar cane in addition to self sufficiency. Metahara Sugar Factory, one of the sugar mills in Ethiopia, fortunately has the potential to use the excess bagasse, which is currently 17.2% of the total bagasse produced, to generate more electric power and earn additional money by selling the power through the national grid or using the power for its own irrigation pump stations. The above figure is determined at the current moisture % bagasse, 50.04%, and average evaporation coefficient, 1.998. But it increases to 30.23% if the moisture % bagasse is lower to 45% and the evaporation coefficient is improved on average to 2.39 by implementing different energy saving opportunities. A total annual savings of more than 14,844,094.19 Birr can be achieved through the use of the excess bagasse. This thesis has assessed the energy resource in Metahara Sugar Factory and determined the steam generation efficiency of the plant. It has also forwarded possible measures to enhance the electric power generation capacity based on measurements, collected data and foreign sugar factories experience.*

**Key words:** cogeneration power plant, electrical energy, Metahara Sugar Factory, bagasse, surplus power, excess bagasse

# CHAPTER ONE

## 1 INTRODUCTION

### 1.1 Background

Sugar as a commodity can be economically derived from either *sugar cane* or *sugar beet*. Sugar cane is cultivated in the tropical countries while sugar beet is a temperate product. Seventy per cent of the world sugar is produced from cane. The biggest world producers are Brazil (20.3 million metric tones), India (19.9 million metric tones) and the European Union (15.5 million metric tones). [1]

There are various products and by-products that can be derived from sugar cane. These are:

- a) Sugar crystals (i.e white mill or industrial sugar)
- b) Sugar syrup
- c) Molasses
- d) Bagasse, and
- e) Filter scums

The above products and by-products can be used as raw materials and foundation for various other industries. It is in these other industries that sugar becomes a strategic and multifunctional product. It has a forward and backward linkage effect in the economy.

Sugar has multifunctions in different industries beside its domestic application. It is, for instant, a key ingredient in the:

- i. Beverage industry
- ii. Confectionery industry
- iii. Pharmaceutical industry
- iv. Wine, spirit and power alcohol industry
- v. Animal feed industry
- vi. Chemical and fertilizer industry

When cane is crushed and the juice separated for crystallization, the remaining dry matter - called *bagasse* - is burnt to provide energy. The bagasse resulting from the crushing of cane can be used to generate steam for driving turbines for co-generation. This process of generating energy avoids the need to use fossil fuels to generate electricity. The net emission of greenhouse gasses, notably carbon dioxide, is less compared to the use of fossil fuel because the burning of bagasse is considered carbon neutral as it releases an amount of CO<sub>2</sub> equivalent to the amount consumed by the sugarcane during its growth period (as it was cited by [30], from Walter and Overend, 1998). But currently, in Ethiopia, the aspect of generating electric energy from bagasse is not yet exploited more.

The long-term goal of the five year development strategy, PASDEP (Plan for Accelerated and Sustained Development to End Poverty), is for Ethiopia to become a middle income country in 20-30 years. Since Ethiopia is not an oil producing country, it should achieve this target by strong industrial development.

A stable supply of enough energy is a must for industrialization. However, the access to energy in Ethiopia was relatively low, as little as 16 % (2005/06), while the average access rate of Sub-Sahara Africa was 26% [2]. The access to energy has gradually

improved to 20% in 2007/08, 35% in 2009/10 and 41% in 2010/11 by the efforts of the EEPCo (Ethiopian Electric Power Corporation) and the GoE (Government of Ethiopia) constructing new power plants and expanding the national grid, although there is still power shortage in the country. The official numbers 16%, 20%, 35% and 41% are calculated by the population living in the electrified area (which means the area the national grid reaches), but many of the poor do not have money to pay the costs for distribution lines from the national grid to their houses, and are without electricity. [2]

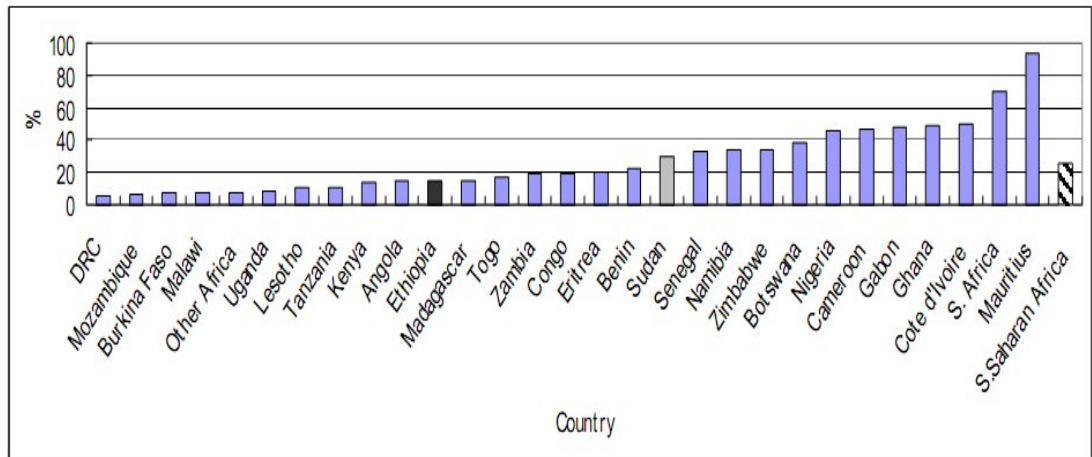


FIGURE 1.1-1: Access to Electricity, Sub-Sahara Africa (2005/06) [2]

In addition to the low access rate to electricity, another problem in the energy sector is that Ethiopia is too dependent on hydro power (85% of the total energy supply) [2], which causes brownouts during the dry season/drought. Further enhancement of the energy sector is a must in order to maintain the economic growth and become a middle-income country in 20-30 years through industrialization.

The recent oil price surge has increased the government's expenditure and worsen the account balance of the government. Therefore, export of surplus electricity is an effective countermeasure to earn foreign currency and improve the account.

There are so many opportunities locally which can reduce the oil import and increase the power generated in the country. Some of the solutions can be

- using the available energy effectively and efficiently,
- searching for other energy resources and
- substituting, whenever possible, petroleum usage by locally available fuels.

All the above suggested solutions are seen to be feasible in sugar factories as they are studied and being implemented in many sugar mills like Indian, Brazilian, Maurisius e.t.c...

## **1.2 Objective of the Thesis**

The general objective of this thesis is to assess the energy resources in Metahara Sugar Factory and to observe its energy generation and utilization efficiencies from the available resources and accordingly to identify problems in relation to energy in this sugar factory.

Currently, not all the bagasse is used and of the amount that is used, the overall conversion efficiency is relatively low. This paper makes a case for improving the efficiency of generating and using electricity from bagasse. By doing so, Metahara Sugar Factory can greatly increase its energy position in the longterm.

Finally, alternatives based on measurements, collected data and foreign sugar factories' experience will be suggested to further improve the existing power generation capacity of the factory so that it can sell the surplus power via the national grid and/or use it for its irrigation pump stations. In addition, recommendations for efficient use of energy in the factory availing for improving electricity production are forwarded.

Hence, the specific objectives of this thesis work will be to

- assess the performance of the existing co-generation in *Metahara Sugar Factory* and compare it with best practices in the World
- assess the electrical and thermal energy use at present in the plant
- identify any problem associated with the energy generation and utilization in the sugar factory and to recommend possible solutions
- identify energy conservation measures at the plant
- create excess power producing capacity by maximizing the efficiency at which the electrical and thermal energy is generated
- explore different measures used to utilize the bagasse in the factory in supplying electric power to the national electricity grid

### **1.3 Methodology**

The methods employed to achieve the above objectives are:

#### **1.3.1 Literature Survey**

Literatures are reviewed which are related to bagasse fired cogeneration power plants and the production process of sugar from sugar cane. The literatures are obtained either from electronic media, journals and/or ebooks. Secondary data are referred from previous related research studies, existing statistical data etc. that are obtained from Ethiopian Sugar Development Agency and Metahara Sugar Factory itself.

#### **1.3.2 Data Collection**

The necessary data for the thesis are collected. These data include:

- the composition of the bagasse
- amount of bagasse

- energy generating capacity
- energy consumption of the factory
- steam generating capacity of the boilers

These and the other unstated data are collected

- through interviews with the concerned personnel of the factory
- through walk through inspection of the factory
- by taking measurements onsite
- by referring previous works done by other consulting firms

### **1.3.3 Analysis and Evaluation**

The collected data is analyzed both qualitatively and quantitatively.

### **1.3.4 Conclusion and Recommendation**

Finally, conclusion is drawn based on the analysis done on the data and alternatives are forwarded to achieve the goal as a recommendation.

## **1.4 Metahara Sugar Factory**

### **1.4.1 Background and Profile of the Factory**

The establishment date of the Metahara Sugar Factory goes back as far as 1965, the time when the Dutch company, named as Hangler Vondr Amsterdam (HVA) had surveyed the area for sisal development. The increasing demand for sugar in Ethiopia and the suitability of the land and climate for sugarcane cultivation attracted HVA to extend the sugar industry to the Metahara Plains. As a result in July 1965 an agreement was signed between the Ethiopian Government and HVA under which the company acquired a concession of 11,000 hectares of land. Subsequent to the signing of the agreement, sugarcane cultivation was started in 1966. The factory started

producing plantation white sugar on November 9, 1969 with an initial crushing capacity of 1,700 tons of cane per day (TCD). Since then, the factory had undergone successive phases of expansion.

The enterprise was nationalized in 1975 and organized under the Ethiopian Sugar Corporation. Changes have been made and since 1996 it is under the management of the Ethiopian Sugar Development Agency [3].

**TABLE 1.4-1:** Profile of Metahara Sugar Factory

Year of establishment	1965
Scheme type	Government
Water source	Awash River
Diversion type	Concrete and gabion weir
Irrigated area (ha)	11,058
Crop	Sugarcane
Number of employees	Over 10,000

The factory is located about 200 km south-east of the capital city Addis Ababa, on the Addis Ababa-Adama-Dire Dawa-Djibouti road within the Upper Awash Valley. See Figure 1.4-1 below.



FIGURE 1.4-1: Geographical Location of Metahara<sup>1</sup>

## 1.4.2 Expansion Projects at MSF

### 1.4.2.1 Implemented Expansion Projects at MSF

The factory had undergone successive phases of expansion. The first expansion was made in 1973 to raise the crushing capacity of the factory from 1,700 TCD to 2,450 TCD. The second and third phases of expansion took place in 1976 and 1981, which raised the crushing capacity to 3,000 TCD and 5,000 TCD, respectively. [3]

In August 2004, PGBI Engineers & Constructors (Pty) LTD was selected by Metahara Sugar Factory to undertake a feasibility study to establish the techno-economic viability of expanding the existing factory by the addition of a back end refinery. This assignment included investigations into the existing sugar factory services to ensure that adequate steam and power was available to supply the new refinery [5]. This project has been implemented and started ethanol production.

<sup>1</sup> Retrieved on May 10, 2010, <<http://en.wikipedia.org/wiki/Metahara>>.

#### **1.4.2.2 Attempted Expansion Projects at MSF**

In line with the Government's program of expansion, Metahara Sugar Factory planned to double its crushing capacity from 5000 TCD to 10,000 TCD plus additional 10,000 hectares of sugar cane plantation area. But this expansion work could not be implemented due to problems associated with the irrigation process which are greatly being affected by the flooding of *Beseke* Lake in to *Awash* River.

In March 2006, PGBI Engineers & Constructors (Pty) LTD was selected by Metahara Sugar Factory for the second time to undertake a bankable feasibility study to establish the techno-economic viability of expanding the sugar factory from 5000 TCD to 15000 TCD and also establishing a back end refinery, an ethanol distillery, and a facility to export surplus electric power to the national electricity utility. [4] This project is terminated.

#### **1.4.2.3 Expected Expansion Projects at MSF**

Metahara Sugar Factory has currently finished the feasibility study to expand the factory with additional plantation area of 13,000 hectares in *Afar Kesem* area. The sugar cane plantation has already been started but the installation of the mills will be implemented in the next three years [2011-2013]. This project will increase the current sugar production capacity by 150,000 tons of sugar per year. [21]

# CHAPTER TWO

## 2 SUGAR PRODUCTION PROCESSES AT MSF

### 2.1 General Description

Sugarcane processing is focused on the production of cane sugar (sucrose) from sugarcane. Other products of the processing include bagasse, molasses, and filter cake. Bagasse, the residual woody fiber of the cane, is used for several purposes: fuel for the boilers and lime kilns, production of numerous paper and paperboard products and reconstituted panel board, agricultural mulch, and as a raw material for production of chemicals.

In MSF, Bagasse and bagasse-residue are primarily used as fuel sources for the boilers in the generation of steam. Thus, bagasse is a renewable energy resource. Dried filter cake is used as an animal feed supplement, fertilizer, and source of sugarcane wax. Molasses is produced in two forms: inedible for humans (blackstrap) or as edible syrup. Blackstrap molasses is used primarily as an animal feed additive but also is used to produce ethanol, compressed yeast, citric acid, and rum. Edible molasses syrups are often blends with maple syrup, invert sugars, or corn syrup.

### 2.2 Cane Sugar (Raw Sugar) Production Process

The different processes involved in sugar manufacturing are: [Refer Figure 2.2-2]

- (1) handling of cane;
- (2) cane preparation

- (3) Juice Extraction (milling);
- (4) clarification of the juice;
- (5) evaporation and concentration;
- (6) sugar crystallization;
- (7) drying, storage, and packaging, and
- (8) steam and power production from bagasse

### **2.2.1 Handling of Cane**

Handling of cane includes harvesting, transporting, weighting, dispatching, and washing of sugar cane. Harvesting of burned cane allows for harvesting and yields of cane with much less trash (dead leaves, weeds, etc). Cane should always be processed as soon as possible after harvesting to avoid quality deterioration. Cane may be further washed with water to remove clay and foreign materials.

### **2.2.2 Sugar Cane Preparation**

Cane preparation is required for good sugar extraction. This is commonly accomplished using rotary knives and/or shredders, and crushers. The goal is to achieve a very high open crusher's number in order to obtain better sugar extraction.

### **2.2.3 Juice Extraction (Milling)**

This is the process of extracting the sugar juice after crushing the mat of sugarcane in a mill tandem of multiples stages. Addition of water, imbibition water, during milling improves the efficiency of the sugar extraction. The extraction efficiency of modern mills is about 92-96%. Higher extractions will result in the extraction of more non-sugar components that will have to be removed later on.

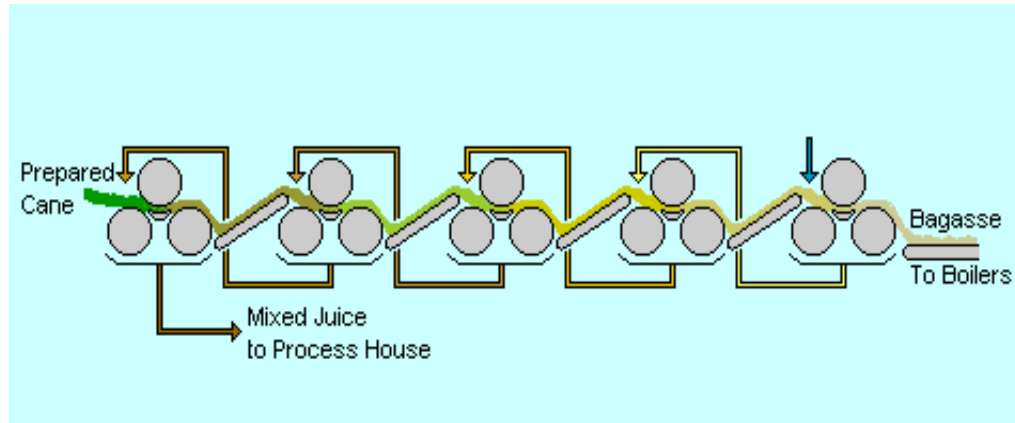


FIGURE 2.2-1: Schematics Diagram to Show the Extraction of Sugar Juice in Mills

#### 2.2.4 Juice Treatment and Clarification

The purpose of clarification is to remove the soluble and insoluble impurities from the cane juice. Lime and heat are commonly used for this purpose. Lime is used to neutralize the acidity in the juice by forming insoluble lime salts, mainly calcium phosphate. The heating above boiling temperature is used to coagulate albumina and other fats, waxes, and gums. The precipitate that is formed will entrap other particles suspended in the juice. Once the precipitate settles and forms a mud, the juice is then filtered, and the remaining mud can be compressed and used as fertilizers.

The expressed juice obtained after milling contains many impurities that have to be removed. The impurities include floating solids, colloidal matter, phenols, coloring compounds, starch, glucose, fructose, minerals, and amino acids. Then the pH of the juice is raised from about 5.6 to 7 to prevent sugar inversion. The steps involved in the juice treatment are

- (1) initial heating to 70-80°C,
- (2) addition of  $\text{Ca}(\text{OH})_2$ ,
- (3) addition of dissolved phosphates,

- (4) bubbling of sulfur dioxide or calcium dioxide through juice,
- (5) second-stage heating to  $>100^{\circ}\text{C}$ ,
- (6) addition of polyelectrolites to aid coagulation of precipitates,
- (7) sedimentation and decantation of clear juice, and
- (8) sediment filtration to separate solids and reprocessing of juice,

At the end of these processes clear juice will be produced, it is a transparent, light golden liquid.

### **2.2.5 Evaporation**

The clarified juice obtained has a soluble solid content (Brix) of 13-15%, and it needs to be concentrated to syrup with 65% solids. This can be accomplished by using a multiple effect evaporator. The number of effects used is normally four (quadruple effect) or five (quintuple effect). The larger the number of effects the higher the steam economy. The lesser the number of effects, the higher the evaporation capacity of each. The first body typically maintains a steam pressure of 1-1.5 kg/cm<sup>2</sup> and a temperature of 115-125°C, while the last body has a vacuum of 650 mmHg a temperature of 55°C [6].

### **2.2.6 Pan Boiling and Sugar Crystallization**

Pan boiling and crystallization is an important operation in a sugar factory. The syrup is concentrated to a super saturated stage where sugar crystallizes. This is done in single-effect vacuum-pans (CC) and at reduced boiling temperatures. The first pure or A<sup>-</sup> solution is usually seeded with small sugar nuclei, while less pure solutions or B<sup>-</sup> and C<sup>-</sup> strikes (massecuite) are usually seeded with magma (pure juice + C<sup>-</sup> crystals). The A<sup>-</sup> strikes are centrifuged and separated into A<sup>-</sup> sugar and A<sup>-</sup> molasses. The latter is used to make a B<sup>-</sup> strike, which is allowed to undergo additional crystallization in open horizontal crystallizers at lower temperatures, or in continuous vertical crystallizers. Next it is a centrifugation step yielding B<sup>-</sup> sugar and B<sup>-</sup> molasses. The latter is used to make a C<sup>-</sup> strike, which upon crystallization and centrifugation yields

C sugar and C or blackstrap molasses. A and B sugars form the raw sugar, which is refined into white sugar at refineries. The final molasses is the chief raw material for rum production. During crystallization, it is important to obtain crystals of uniform size, shape and color. The presence of colloidal or coloring impurities trapped in the crystals should be minimized. Crystallization is carried-out in several stages because it is impossible to crystallize all sugar in syrup in one stage.

Commercial sugar is a disaccharide (sucrose) of two monosaccharides fructose and glucose. The empirical formula for sugar is  $C_{12}H_{22}O_{11}$ . It is soluble in water and ethanol.

### **2.2.7 Bagasse Use**

As mentioned before, the steam and electricity demands of the sugar factory are generally covered by the use of bagasse as fuel. Bagasse has an average calorific value of 2200 kcal/kg on wet basis [7]. Metahara Sugar factory uses bagasse to produce high-pressure steam.

### **2.2.8 Sugar Refining**

Raw sugar is priced according to the pol value, moisture content, ash, grain size, dextran content and color. The refining process of raw sugar is divided into several steps.

The first step is called affination. This process consists on the removal of a molasses film that is occluded in the raw sugar crystals. The molasses film contains most of the impurities in the sugar. The separation is carried out by using under saturated syrup at 75 Brix [8]. The mixture is centrifuged and then washed with cold water. Then the washed raw sugar is mixed with water and melted.

The next step is the defecation or clarification of washed raw liquor in which all insoluble and colloidal matters are removed. The two types of clarification systems used in refineries are phosphatation and carbonation. The phosphatation is accomplished with the use of phosphoric acid and lime.

It produces calcium phosphate floc difficult to filtrate. The common way of separating

calcium phosphate is by using air flotation. Carbonation process consists of the addition of lime and bubbling carbon dioxide to produce a calcium carbonate precipitate in the washed raw melt liquor. The calcium carbonate crystals entrap and adsorb other impurities. Clarification can be aided by the addition of quaternary ammonium compounds.

The removal of impurities that imparts color in the raw sugar is called decolorization. Such impurities include phenolic compounds, melanoidins, caramels, and invert degradation products.

The final step for white sugar production is the drying and conditioning. The obtained white sugar requires drying to remove moisture. The most commonly used dryer is the granulator. It consists of two drums in series, one for drying and the other one for cooling.

### **2.2.9 Sugar Production Process Flow Chart**

A simplified process flow diagram for the cane sugar production at Metahara Sugar Factory is shown in the next figure. The material flow, electrical energy and the thermal energy (steam) inputs are indicated with arrows.



# CHAPTER THREE

## 3 SURPLUS POWER GENERATION OPPORTUNITIES

### 3.1 Energy Sources of Sugar Factories

Nowadays, many international sugar factories produce energy for self sufficiency as well as to export surplus electric power to the national electricity utility. Countries like Brazil, USA, India and Mauritius are being benefited from energy of sugar factories highly.

There are mainly three energy sources in sugar factories namely:

- i. Bagasse
- ii. Molasses
- iii. Leaves, tops and trashes of the cane plant

Among these, the main and only energy source being used by Ethiopian sugar factories is bagasse, while efforts are being carried out to use molasses. Metahara Sugar Factory uses bagasse to produce high pressure and temperature steam for both sugar production processes and power generation (electric and motive power generation).

### 3.2 Bagasse in MSF

Bagasse is the crushed remaining of sugarcane stalks left after the extraction of juice. Normally, it is used as fuel for supplying the energy need of the sugar mills. It is a fuel of varying composition and heating value. Its characteristics depend on the climate, type of soil upon which the cane is grown, variety of cane, harvesting method, amount of cane washing, and the efficiency of the milling plant. Most bagasse has moisture content between 45 and 55% by weight which would affect the efficiency of combustion system [9]. Table 3.2-1 shows the average characteristics of a typical bagasse. The characteristics of the bagasse in MSF will be shown in the next chapter after the data obtained from the factory is analyzed. The following few pictures show the excess bagasse, belled or lumped, left over the field in MSF.



**FIGURE 3.2-1:** Partial View of Excess Bagasse Left over the Field in MSF<sup>2</sup>

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<sup>2</sup> Date picture taken: 29/10/2010 at 12:35 p.m.



**FIGURE 3.2-2:** Partial View of Excess Bagasse Left over the Field in MSF<sup>3</sup>



**FIGURE 3.2-3:** Partial View of Excess Bagasse Left over the Field in MSF<sup>4</sup>

<sup>3</sup> Date picture taken: 29/10/2010 at 12:41 p.m.

<sup>4</sup> Date picture taken: 29/10/2010 at 12:34 p.m.



**FIGURE 3.2-4:** Partial View of Belled Bagasse Left over the Field in MSF<sup>5</sup>

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<sup>5</sup> *Date picture taken: 12/05/2010 at 12:09 p.m.*

**TABLE 3.2-1:** Characteristics of Typical Bagasse [9]

<b>Analysis Methods</b>	<b>Composition</b>	<b>Value[%]</b>
<b>Proximate</b>	Fixed Carbon	11.1
	Volatile	35.9
	Moisture	50.0
	Ash	3.0
<b>Ultimate</b>	Carbon	22.9
	Hydrogen	2.8
	Sulphur	0.0
	Nitrogen	0.0
	Oxygen	21.3
	Moisture	50.0
	Ash	3.0

### 3.2.1 Bagasse's Applications

#### Fuel:

Many sugar mills burn bagasse as fuel to generate steam to power the mills and/or to produce electricity. As it was cited by [30], from Walter and Overend 1998, burning of bagasse fuel is considered carbon neutral as it releases an amount of CO<sub>2</sub> equivalent to the amount consumed by the sugarcane during its growth period. Bagasse also burns less sulfur dioxide (SO<sub>2</sub>) and nitrogen oxides (NO<sub>x</sub>) than conventional fossil fuels since it contains lower levels of both sulfur and nitrogen. [Look at Table 3.2-1 above]

**Paper and Pulp:**

An estimated 5-10% of all paper is made from agricultural crops (i.e. not from trees) and one of the most important contributors is bagasse. Bagasse contains a large amount of short fibers called 'pith'. Around 30% of these fibers are removed from the bagasse prior to pulping. Despite these efforts however a large amount of pith remains. Traditionally, there has been a perception among pulp and paper manufacturers that this remaining pith leads to poor paper production rates when compared to other forms of pulp (e.g., eucalypt pulp). This is not the case however and it has been found that bagasse can be processed just as efficiently as other forms of pulp. Bagasse fibers have been found to be well suited for tissue, corrugating medium board, newsprint, and writing paper.

**Packaging:**

Increasingly bagasse is being manufactured into packaging and food packaging products such as containers, plates, and bowls.

**3.2.2 Calorific Value of Bagasse**

The calorific value of a fuel is the quantity of heat produced by its combustion, at constant pressure and under the conditions known as "normal" of temperature and pressure (i.e. to 0°C and under a pressure of 760 mmHg).

The combustion of a product generates, inter alia, of water to the vapor state. Certain techniques make it possible to recover the quantity of heat contained in this water of combustion by condensing it.

Thus, there exist two calorific values for a fuel. The Lower Calorific Value or Net Calorific Value (NCV), if the products of combustion contain the water of combustion to the vapor state and the heat contained in this water is not recovered.

The Higher Calorific Value or Gross Calorific Value (GCV), if the water in the products of combustion is entirely condensed and the heat contained in this water is recovered.

Many formulae have been proposed to determine the calorific value of bagasse in

different country. [10]

- i. In Java the formula of Von Pritzelwitz van der Horst:

$$\text{GCV}=4550 - 10 \text{ S\%} - 45.5 \text{ W\%} \quad [\text{kcal/kg}] \quad (3-1)$$

$$\text{NCV}=4250 - 10 \text{ S\%} - 48.0 \text{ W\%} \quad [\text{kcal/kg}] \quad (3-2)$$

- ii. In Queensland the formula of Hessey:

$$\text{GCV}=4636 - 12.3 \text{ S\%} - 46.46 \text{ W\%} \quad [\text{kcal/kg}] \quad (3-3)$$

$$\text{NCV}=4324 - 12.3 \text{ S\%} - 49.04 \text{ W\%} \quad [\text{kcal/kg}] \quad (3-4)$$

- iii. In Mauritius

$$\text{NCV}=4150 - 7.5 \text{ S\%} - 47.5 \text{ W\%} \quad [\text{kcal/kg}] \quad (3-5)$$

- iv. In India

$$\text{GCV}=4600 - 8 \text{ S\%} - 53 \text{ W\%} \quad [\text{kcal/kg}] \quad (3-6)$$

- v. E. Hugot proposes

$$\text{GCV}=4600 - 12 \text{ S\%} - 46 \text{ W\%} \quad [\text{kcal/kg}] \quad (3-7)$$

$$\text{NCV}=4250 - 12 \text{ S\%} - 48.5 \text{ W\%} \quad [\text{kcal/kg}] \quad (3-8)$$

In all of the above formulae,

W% is the moisture content of bagasse in % by mass, and

S% is the soluble solids present in the bagasse expressed as % by mass.

### **3.3 Cogeneration in Metahara Sugar Factory**

Cogeneration is a process of producing both electricity and usable thermal energy at high efficiency and near the point of use. The combined generation of electricity and heat increases the total efficiency by nearly 50% as against separate production of electricity and heat [13]. Cogeneration is a well known process in the sugar industry and it is used in every single sugarcane mill.

MSF incorporates steam boilers and steam turbines for its cogeneration plant. Bagasse as a fuel is burned in the boilers' furnace producing live steam, which is supplied to the turbines. The turbines drive electrical generators and the steam leaving the turbines exhaust flow to the heating equipments for sugar manufacturing with some make-up live steam mixed with it.

The steam turbines in MSF are back pressure steam turbines. Steam exits each turbine at a pressure higher or at least equal to the atmospheric pressure, which depends on the needs of the thermal load. After the exit from the turbines, the steam is fed to the load, where it releases heat and is condensed. The condensate returns to the system.

The following schematics diagrams show the current integrated production of electricity, sugar, molasses and ethanol in the factory. [Refer Figure 2.2-2 for the sugar production processes]

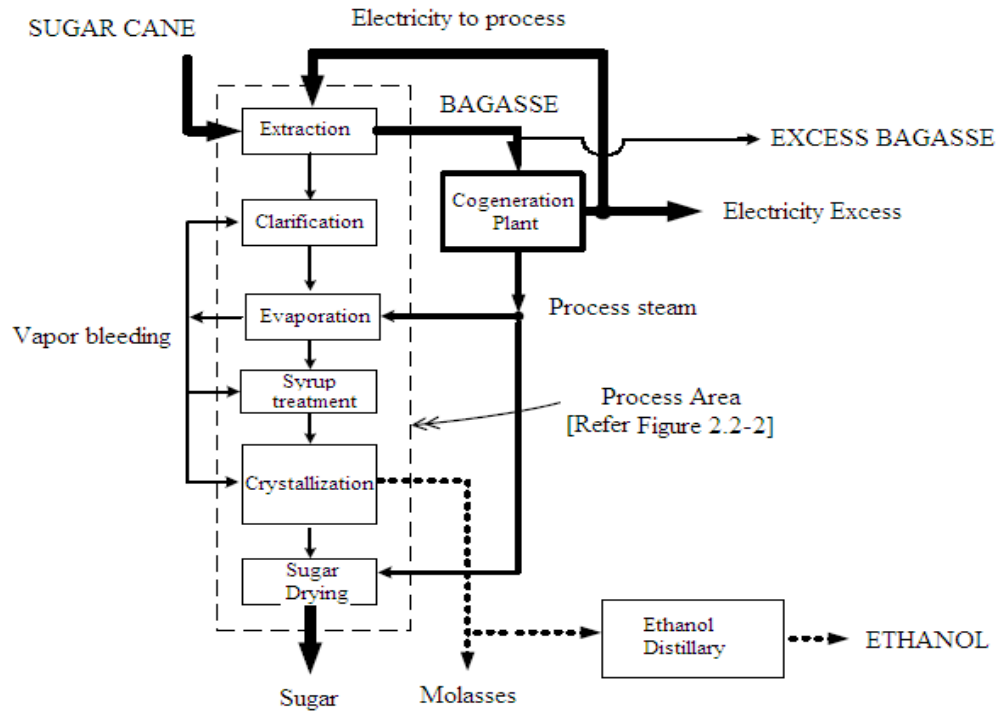


FIGURE 3.3-1: Integrated Production of Electricity, Sugar, Molasses and Ethanol in MSF

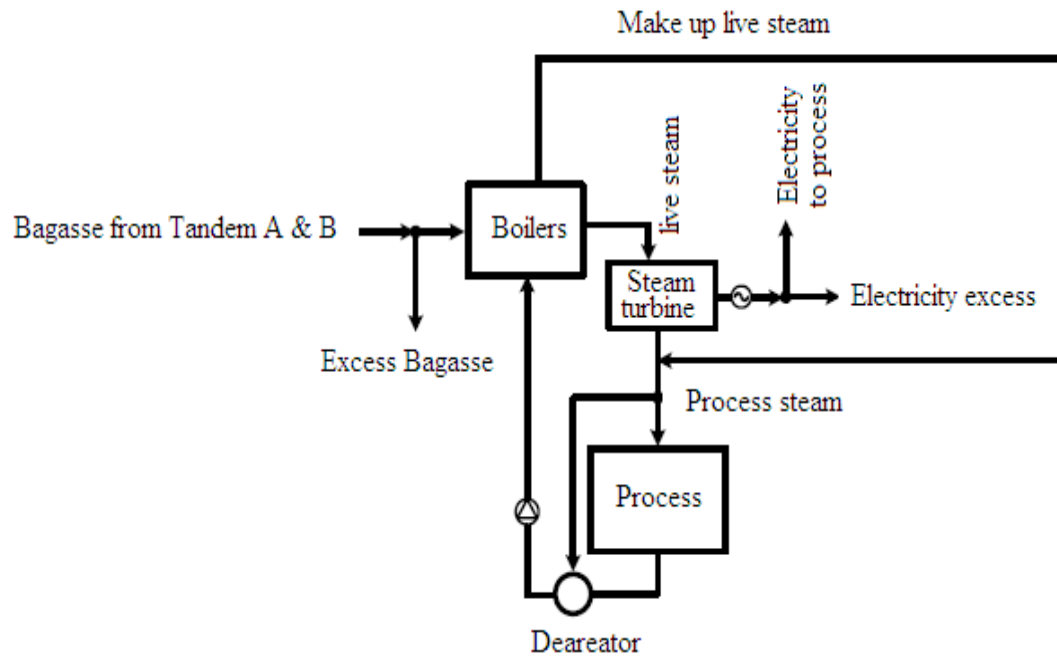


FIGURE 3.3-2: Backpressure Steam Turbines Configuration Used in MSF's Cogeneration

### 3.4 Foreign Sugar Factories' Experience in Using Bagasse for Cogeneration

#### 3.4.1 Brazil

Until the late 1990s before sugar mills were allowed to export electricity to the national grid, the costly removal of excess bagasse at the mills prompted the industry to use plants equipped with low, mostly 21-bar, pressure boilers in order to incinerate surplus bagasse. The possibility of exporting surplus energy to the grid has created a revolution in the industry. Installed capacity increased from about 100MW in 2000 to 3,081 MW in 2009 with another 460MW under construction [11].

In the first five years of the current decade the supply of electricity generated by the sugarcane processing sector to the grid grew at an annual rate of 67%. [12]

Table 3.4-1 shows in 2008/09 509 MW of actually installed capacity was used for exporting electricity to the national grid by 48 of 370 sugarcane mills.

**TABLE 3.4-1:** Surplus Power Capacity in Sugarcane Mills in Brazil

<b>States</b>	<b>Number of mills connected</b>	<b>Installed surplus power capacity during crushing season (MW)</b>
Goiás	3	52
Mato Grosso	2	16
Minas Gerais	5	32
Paraná	3	92
São Paulo	20	228
Alagoas	7	40
Bahia	1	4
Paraíba	1	9
Pernambuco	4	34
Rio Grande do Norte	2	2
<b>Total</b>	<b>48</b>	<b>509</b>

*Source:-Plinio Nastari. What can be learned from the Brazilian sugar, ethanol, cogeneration story? Presentation to the ISO/Assiut University International Seminar, Luxor, Egypt, March 2009.*

### **3.4.2 Guatemala**

Bagasse-based cogeneration has become a major activity of the sugarcane processing sector in Guatemala. Unlike Brazil, the sector is supplying energy to the national grid throughout all year.

The cogeneration program started in Guatemala in 1994 with a total amount of 160.4MW during the crushing season and 128.7MW available during the intra-crop season. [13] To guarantee firm supply of electricity operating the full year round, the sugar mills have to operate the same steam boilers, with two different types of fuel, sugarcane bagasse and bunker fuel. Since the mid-1990s the use of bunker fuel has reduced from 2.1 mln barrels per year to 350 thousand barrels. Most sugar mills use high pressure flex-fuel steam boilers. In 2008 the sector had capacity to generate 296.8MW of electricity during the harvest season and 200.3 MW during the intra-crop period. [13]

From 2006, 9 out of the total 14 sugar mills have been exporting electricity to the national grid.

**TABLE 3.4-2: Surplus Power Capacity in Guatemala: Captive Consumption by Sugar Mills (in GWh)[13]**

	<b>Pantaleon</b>	<b>Concepcion</b>	<b>Santa Ana</b>	<b>Madre Tierra</b>	<b>Magdalena</b>	<b>La Union</b>	<b>Tulula</b>	<b>San Diego</b>	<b>Trinidad</b>	<b>TOTAL</b>
2001	45.41	25.13	33.83	18.73	38.56	33.52	SD			195.17
2002	60.08	31.23	34.60	19.97	45.32	36.59	3.44			231.23
2003	61.23	31.52	33.13	22.02	56.05	44.50	12.10			260.55
2004	87.57	34.73	43.58	26.59	68.20	51.41	10.76			322.84
2005	99.94	38.90	36.85	29.19	77.08	59.14	10.32	2.84	3.96	358.21
2006	68.73	23.30	32.24	23.47	75.19	40.96	SD	7.10	12.92	283.92
2007	55.23	24.20	33.30	20.23	79.23	45.69	9.56	7.25	14.21	288.9
2008	71.10	26.45	32.25	19.58	80.24	50.47	11.47	8.36	13.25	313.17

**TABLE 3.4-3: Surplus Power Capacity in Guatemala: Exports to the Grid by Sugar Mills**  
(in GWh) [13]

	<b>Pantaleon</b>	<b>Concepcion</b>	<b>Santa Ana</b>	<b>Madre Tierra</b>	<b>Magdalena</b>	<b>La Union</b>	<b>Tulula</b>	<b>San Diego</b>	<b>Trinidad</b>	<b>TOTAL</b>
2001	125.33	136.79	98.22	67.13	52.40	90.83	6.02			576.72
2002	150.64	119.71	116.71	55.01	51.61	106.96	20.47			621.12
2003	144.30	107.72	110.52	43.88	64.51	123.22	21.88			616.04
2004	167.08	98.09	100.90	50.71	72.62	116.64	23.29			629.33
2005	193.53	105.50	99.74	63.59	87.83	129.60	25.58	0.70		706.06
2006*	185.70	102.90	99.30	70.14	158.23	117.49	35.76	1.81	15.85	787.17
2007**	58.18	30.74	36.77	25.82	56.56	39.91	13.52	0.61	9.61	271.72

\* for the first 10 months of 2006

\*\* sales till 27<sup>th</sup> February 2007

### 3.4.3 India

Until the 1970s, Indian sugar mills were using only low pressure boilers. With the growing demand for electrical power and widening gap in the demand and supply of power, the sugar mills in the mid 1990s incorporated high pressure boilers and high efficient turbines to generate additional power for supply to the grid. Most sugar factories started using 45 bar boilers, while the cogeneration units are currently using 67 to 105 bar boilers. Since the beginning of the 1990s, power cogeneration has become a major activity of India's sugar industry. About one-third of operating sugar mills (145 out of total of 492 in 2007) have installed cogeneration facilities. Some of them are still in the process of expanding their cogeneration facilities. [14]

The current capacity to co-generate and export surplus power to the national grid in

107 mills is estimated by the industry at around 2,200 MW but will increase to 3,000 MW when new cogeneration units are assembled in about 40 mills.[15]

The full potential of the sector is projected at over 10,500 MW including 3,500 MW for internal consumption and 7,000 MW for export to the national grid. [15] In Table 3-4-4 and Table 3.4-5 potentials for cogeneration by the sugar industry in different Indian states are summarized.

**TABLE 3.4-4:** Indian Potential for Cogeneration in the Sugar Industry by Individual States [14]

State	Number of mills	Total cogeneration	Captive use	Exportable Electricity
		MW		
Bihar	9	189	59	130
Uttar Pradesh	133	3350	1135	2215
Uttarakhand	10	243	72	117
Punjab	16	312	99	214
Haryana	14	215	85	130
M.P. Rajasthan, Chattisgarh	9	148	48	100
Gujarat	17	386	120	266
Maharashtra	165	3066	1080	1986
Karnataka	47	957	292	656
Andhra Pradesh	38	718	228	490
T.N. & Pondicherry	37	776	245	531
Others	7	140	37	103
<b>TOTAL</b>	<b>499</b>	<b>10500</b>	<b>3500</b>	<b>7000</b>

**TABLE 3.4-5:** Installed and Planned Cogeneration Units (as of 12th January 2008) [15]

State	Number of units	Total cogeneration MW	Proposals under implementation	
			Number of units	MW
Bihar	2	23.00	-	-
Uttar Pradesh	41	947.8	16	306.8
Punjab	3	41.0	-	-
Maharashtra	8	166.50	13	250.00
Karnataka	19	418.00	8	192.00
Andhra Pradesh	11	148.95	2	46.00
Tamil Nadu	23	503.86	1	46.00
<b>TOTAL</b>	<b>107</b>	<b>2249.44</b>	<b>40</b>	<b>817.80</b>
<b>Exports to the grid</b>	<b>107</b>	<b>1400.00</b>	<b>40</b>	<b>500.00</b>

### 3.4.4 Mauritius

Energy produced from bagasse has for decades been used in Mauritius to run the sugar mills which are self sufficient in energy requirements. Any surplus electricity is exported to the national grid as per terms negotiated with the national electricity providing company. Over time improved technologies to maximize energy output from bagasse have been inducted and the choice of a bagasse/coal based cogeneration plant operating at specific pressure levels made after a careful analysis of options to maximize energy output and return. The model is to have a cogeneration plant in tandem with the sugar mill with the mill exporting bagasse and receiving energy for its power requirements.

During the 1990s, Mauritius, an island with no domestic fossil fuels and limited resources for hydroelectric power generation (in 2007 hydro electrics contributed 7.2 ktoe out of the total output of 246 ktoe [16]), took a proactive stand on bagasse-based cogeneration to address the future challenges in the sugar industry. As a result exports of bagasse-based electricity to the national grid had nearly tripled between 1996 and 2005 and increased further in 2005 and 2008. Refer Table 3.4-6 below.

**TABLE 3.4-6: Mauritius Bagasse-Based Exports of Electricity to Grid (GWh) [17] & [18]**

<b>Season</b>	<b>Export of Electricity to Grid [GWh]</b>
1996	119.0
1997	124.6
1998	194.3
1999	188.5
2000	278.5
2001	296.5
2002	299.1
2003	296.1
2004	317.9
2005	301.6
2007	445.7
2008	467.9
2009	420.1

In 2007 there were 10 sugar mills with crushing capacities ranging from 100 to 350 tons of cane per hour, all of which generated electricity. Three of the sugar mill power plants operate throughout the year using coal during the intra-harvest periods. The advantages of bagasse cum coal source base increases stability of electricity supply by sugar mill power plant – due to specifics of island climate subject to severe tropical cyclones, cane and, hence, bagasse production varies greatly from year to year sometimes by more than 20%. Currently the total installed capacity in the sugar industry is around 240 MW (including around 140 MW from coal-based generation) [19].

### **3.4.5 South Africa**

The South African sugar industry has reiterated its readiness to contribute to the bolstering of the country's faltering electricity generation capacity. According to Tongaat Hulett, one of the leading sugar producing companies in South Africa, the country's 14 sugar mills can contribute a combined total of 400 MW to the national electricity grid by 2013, with some mills going on line as early as 2010 [20].

## **3.5 Surplus Power Generation Opportunities at MSF**

### **3.5.1 The Bagasse Fired Boilers' Efficiency**

Bagasse fired boiler efficiency ranges between 55 and 68% [31]. The factors which determine steam-bagasse ratio are excess air level, flue gas temperature, particulate in the flue gas, temperature of the feed water, fouling of the boiler tubes, fines and uniformity of the bagasse, moisture % bagasse, temperature of the bagasse, etc.

In MSF, the above factors can be given due attention so that the factory will increase its power generation potential as foreign sugar factories' experience revealed. The efficiency improvement that can be obtained by increasing the temperature of the bagasse, by reducing the moisture content of the bagasse, the excess air level, and the flue gas temperature will be seen in the next two chapters.

### **3.5.2 Working the Boilers at Rated Pressure, Flow and Temperature**

The four boilers at MSF are not working at their rated parameters. The drop in temperature and pressure of steam at the inlet of turbines leads to reduced power output and higher consumption of steam.

Enthalpy of steam is a function of temperature and pressure. At lower temperature, enthalpy will be low, work done by the turbine will be low, turbine efficiency will be low, and hence steam consumption for the required output will be higher. In other words, at higher steam inlet temperature, heat extraction by the turbine will be higher and hence for the required output, steam consumption will reduce.

If the turbines can accept it, the boilers outlet steam temperature itself can be increased because higher temperature of steam decreases the specific steam consumption of the turbines. Hence, this will save the unnecessary bagasse consumption and, hence, enhance the power generation capacity.

Steam inlet pressure to the turbines also affects the turbines performance. All the turbines are designed for a specified steam inlet pressure (22 bars for the case of MSF). For obtaining the design efficiency, steam inlet pressure shall be maintained at design level. Lowering the steam inlet pressure will hamper the turbine efficiency and steam consumption in the turbines will increase. Similarly, at higher steam inlet pressure energy available to run the turbine will be high, which in turn will reduce the steam consumption in the turbine. There are these opportunities in MSF, and hence there exists a room to enhance the power generation in this aspect.

# CHAPTER FOUR

## **4 ENERGY EFFICIENCY ASSESSMENT OF MAJOR EQUIPMENTS**

### **4.1 Data Collection and Analysis**

While doing this research work on Metahara Sugar Factory different data have been collected from many sources like documentation records from the factory's quality control laboratory, direct observations on different components, on site interviews, personal communication with phone calls and taking measurements.

The secondary as well as the primary data are presented and analyzed in the following sub sections.

#### **4.1.1 Existing Crushing Capacity**

Metahara Sugar Factory is still the largest sugar factory in Ethiopia with current installed crushing capacity of 5,000 TCD [Refer chapter one sub section 1.4.2 for the implemented expansion projects].

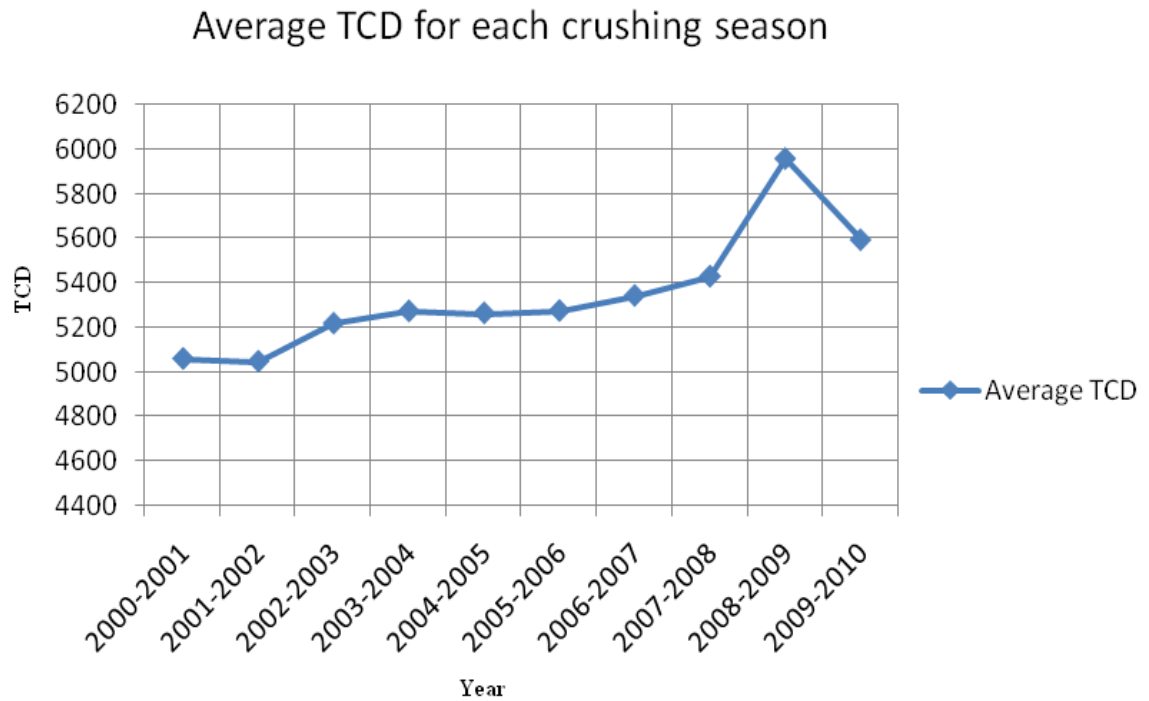
The duration of campaign (actual operation days), the season days (planned operation days), the operation days (milling days plus down time) and the milling days (actual crushing days without down time) at MSF are indicated in Table 4.1-1 for the last ten seasons. The pressure capacities (factory crushing capacities) in recent years are also shown in Table 4.1-2. In this table the average TCD is calculated as the ratio of the annual cane crushed to the respective milling days of the season.

**TABLE 4.1-1:** MSF's Campaign, Season, Operation and Milling Days (*Source: MSF*)

<b>Seasons</b>	<b>Duration of campaign [days]</b>	<b>Season days</b>	<b>Operation days</b>	<b>Milling days</b>
2000/2001	239	237.12	233.15	205.12
2001/2002	238	236.22	234.12	202.40
2002/2003	239	237.73	235.05	201.20
2003/2004	248	246.97	239.68	214.69
2004/2005	229	227.80	224.50	201.85
2005/2006	245	244.13	241.19	217.65
2006/2007	249	248.29	240.12	219.13
2007/2008	227	225.94	223.34	208.30
2008/2009	234	232.85	229.54	203.67
2009/2010	249	247.70	240.30	215.20

**TABLE 4.1-2: MSF's Annual and Daily Average Crushing Capacity**  
(Source: MSF)

<b>Season</b>	<b>Sugar cane crushed [tons]</b>	<b>Average TCD</b>
2000-2001	1,037,569.0	5058.4
2001-2002	1,021,283.0	5045.9
2002-2003	1,049,630.8	5216.9
2003-2004	1,131,770.9	5271.7
2004-2005	1,062,375.5	5263.2
2005-2006	1,147,808.7	5273.6
2006-2007	1,170,419.3	5341.2
2007-2008	1,130,541.4	5427.5
2008-2009	1,213,002.2	5955.7
2009-2010	1,203,248.9	5591.3



**FIGURE 4.1-1:** MSF’s Daily Average Crushing Capacity for the last Ten Seasons

From Table 4.1-1, the average pressure time (average milling days) is calculated to be 208.9 days. And the average TCD is found to be 5344.54 tons of cane. It is also seen that the factory’s pressure capacity always exceeded the designed capacity in the past ten years. The average TCD was also increasing for the last nine seasons due to the increase in demand of sugar in the country. The last decrease in TCD in 2009/10 is due to machine break down which increased the down time of the factory [personal communication].

### 4.1.2 Existing Sugar Production Capacity

**TABLE 4.1-3:** MSF's Annual Sugar Production for Ten Seasons

Season	Sugar for domestic use [tons]	Sugar for export/ for Bottling Company [tons]	Total Sugar production [tons]
2000/01	No data	No data	115,537.0
2001/02	No data	No data	115,642.0
2002/03	78,547.0	379,53.1	116,500.1
2003/04	103,726.1	16,608.5	120,334.6
2004/05	73,777.5	47,043.7	120,821.2
2005/06	104,708.0	20,607.6	125,315.6
2006/07	126,402.5	0.0	126,402.5
2007/08	119,359.6	5,000.0	124,359.1
2008/09	105,230.0	22,476.0	127,706.1
2009/10	98,908.9	21,126.0	120,034.9

The factory has annual average sugar production of 121,265.31 tons of sugar. The production capacity is increasing from season to season due to the above reasoning but the 2009/10 production shows a great deal of losses in sucrose due to inefficient milling caused by machine break down.

### 4.1.3 Existing Bagasse Production Capacity

The factory has no installed mechanism to weigh the bagasse produced. But recommended formulae from E. Hugot, *Hand Book of Cane Sugar Engineering*, with the help of the quality control laboratory are used to determine the quantity of bagasse produced. [10]

Bagasse contains:

- a) Moisture (water),
- b) Insoluble material, consisting mainly of cellulose, and comprising the fiber content of bagasse,
- c) Substance in solution in the water, consisting of sugar and impurities,

The fiber content of bagasse is given by

$$f' = 100 - w - D \quad (4-1)$$

where:  $f'$  is fiber content of bagasse in %

$w$  is moisture % bagasse which ranges from 45% to 50%

$D$  is % dissolved matter which ranges from 2% to 4%

$$D = pol\% + impurities\% \quad (4-2)$$

Hence, the fiber % bagasse ranges from 46 – 53%. A fairly frequent value being:  $f'=50\%$ .

The extreme values of the mean fiber content of cane are between:  $f=10\%$  and  $16\%$ ; but it generally lies in the region 12 – 15% [10]. This figure depends on the variety of sugar cane, the age of the cane in the field (below 18 months, under aged, and above 22 months, over aged), the soil type, the irrigation practice...etc.

One can obtain the quantity  $B$  of bagasse from 100 parts of cane, by equating the weight of fiber entering the mills ( $100*f$ ) to that leaving ( $B*f'$ ):

$$100 * f = B * f' \quad (4-3)$$

Hence:

$$B = 100 * \frac{f}{f'} \quad (4-4)$$

The difference between  $f$  and  $f'$  is nothing but they show the fiber content in percent of cane and bagasse, respectively, while the bagasse itself is derived from the cane.

Therefore,

$$B = 100 * \frac{12}{50} = 24\% \quad (4-5)$$

$$B = 100 * \frac{15}{50} = 30\% \quad (4-6)$$

Hence, it is seen that the quantity of bagasse varies between 24 and 30% by weight of cane, or approximately one-quarter. If the bagasse is below 24% by weight of the cane, the cane is under aged and it has more water, less sucrose, and the bagasse will be finer with less calorific value which cannot give sufficient heat to generate the required steam. This will cause a great problem for the factory since it cannot produce the required power even for self sufficiency. On the contrary, if the bagasse is above 30% by weight of the cane, then the cane is over aged and it has less water, less sucrose, and will be more fibrous. This needs more power during milling and affects the mill setting through wearing. It then has a negative impact on the struggle to enhance the power generation because more power than needed is required to extract the juice.

MSF uses the following relation from E. Hugot to obtain the bagasse amount. But the specific value from the range is determined through laboratory finding on the particular sugar cane variety.

$$BA = (0.24 \dots 0.30) * PC \quad (4-7)$$

where:  $BA$ =Bagasse amount

$PC$ =Pressure capacity

To determine the moisture content of bagasse in the tables below, the following relation is applied.

$$\text{Dry \% bagasse} = \left\{ \frac{\text{tons dry bagasse}}{\text{tons wet bagasse}} \right\} * 100\% \quad (4-8)$$

$$\text{Moisture \% bagasse} = 100 - \text{dry \% bagasse} \quad (4-9)$$

The daily cane crushed, bagasse and dry bagasse (all in tons) are obtained from the factory's archival records in the quality control laboratory for January, May and July 2009/10. The moisture % bagasse is computed using equations (4-8) and (4-9). The total bagasse is simply the sum of the bagasse produced from the two tandems in the factory (i.e there are two tandems in MSF named Tandem A, design capacity 100 TCH, and Tandem B, design capacity 140 TCH). The bagasse to cane ratio is also computed taking the ratio of the total bagasse produced to the total cane crushed per day.

**TABLE 4.1-4: The Daily Bagasse Amount for the Month of January 2009/10 Crushing Season**

Day	January, 2010								Total Bagasse [tons]	Bagasse to cane ratio
	Tandem A				Tandem B					
	Cane Crushed [tons]	Bagasse [tons]	Dry Bagasse [tons]	Moisture % bagasse	Cane Crushed [tons]	Bagasse [tons]	Dry Bagasse [tons]	Moisture % bagasse		
1	1669	451.9	226.3	49.92	3522.1	950.7	476.9	49.84	1402.6	0.27
2	1113	310.3	155.2	49.98	3726.1	1075.2	537.3	50.03	1385.5	0.29
3	1791.1	502.9	251.5	49.99	4073.7	1130.1	565.8	49.93	1633	0.28
4	1256.7	356.5	179.4	49.68	3985.9	1094.8	546.7	50.06	1451.3	0.28
5	1322.4	377.4	188.2	50.13	3600.4	985.4	491.4	50.13	1362.8	0.28
6	1607	462.7	230.8	50.12	3746.2	1054.4	526.9	50.03	1517.1	0.28
7	1259.3	357.7	179.1	49.93	3670.6	1018.3	509	50.01	1376	0.28
8	1665.8	464.2	231.9	50.04	3819.3	1072.5	537	49.93	1536.7	0.28
9	1471	412	205.8	50.05	2738	754	377.5	49.93	1166	0.28
10	1386.3	405.8	202.7	50.05	3810.9	1065.7	533.8	49.91	1471.5	0.28
11	-	-	-	-	-	-	-	-	-	
12	1585.2	470.5	234.6	50.14	3719.9	1049.4	525.4	49.93	1519.9	0.29
13	1875.1	552.5	275.6	50.12	3354.4	1002.1	502.1	49.9	1554.6	0.30
14	1815.9	507.5	253.2	50.11	3470.4	1021.9	511.1	49.99	1529.4	0.29
15	1728.4	486.4	242.8	50.08	3061.5	908	454.1	49.99	1394.4	0.29
16	1997.5	590.7	294.2	50.19	2828.8	799.9	400.2	49.97	1390.6	0.29
17	1919.5	553.2	275.9	50.13	3391.2	988.7	494.2	50.02	1541.9	0.29
18	1921.8	537.5	268.2	50.1	3666.8	1080.1	538.5	50.14	1617.6	0.29
19	1667.9	498.8	248.9	50.1	2397.6	698.2	347.9	50.17	1197	0.29
20	1926.9	563.4	281.2	50.09	3026.7	874.1	435.7	50.15	1437.5	0.29
21	1657.2	475.3	237.2	50.09	3921.7	1097.3	548.1	50.05	1572.6	0.28
22	1874.2	561.5	280	50.13	3120.4	892	445.6	50.04	1453.5	0.29
23	1522.4	439	218.8	50.16	3672.7	1006.6	503.4	49.99	1445.6	0.28
24	1308.4	380.9	190	50.12	2764	819.5	409.9	49.98	1200.4	0.29
25	1000.6	294.2	146.3	50.27	3552.6	1026.8	514.6	49.88	1321	0.29
26	1371.3	402.3	200	50.29	3405.5	985.4	491.9	50.08	1387.7	0.29
27	1660.5	492.3	245.2	50.19	2972.5	835.9	416.8	50.14	1328.2	0.29
28	1511.3	414.3	206.6	50.13	3646.9	1027	511.5	50.19	1441.3	0.28
29	1834.9	548.2	273.1	50.18	3929.5	1094.9	544.5	50.27	1643.1	0.29
30	1532.5	452.4	225.4	50.18	3652.6	1050.5	524.1	50.11	1502.9	0.29
31	1671.2	488.6	243.7	50.12	3139.8	887.5	492.4	44.52	1376.1	0.29

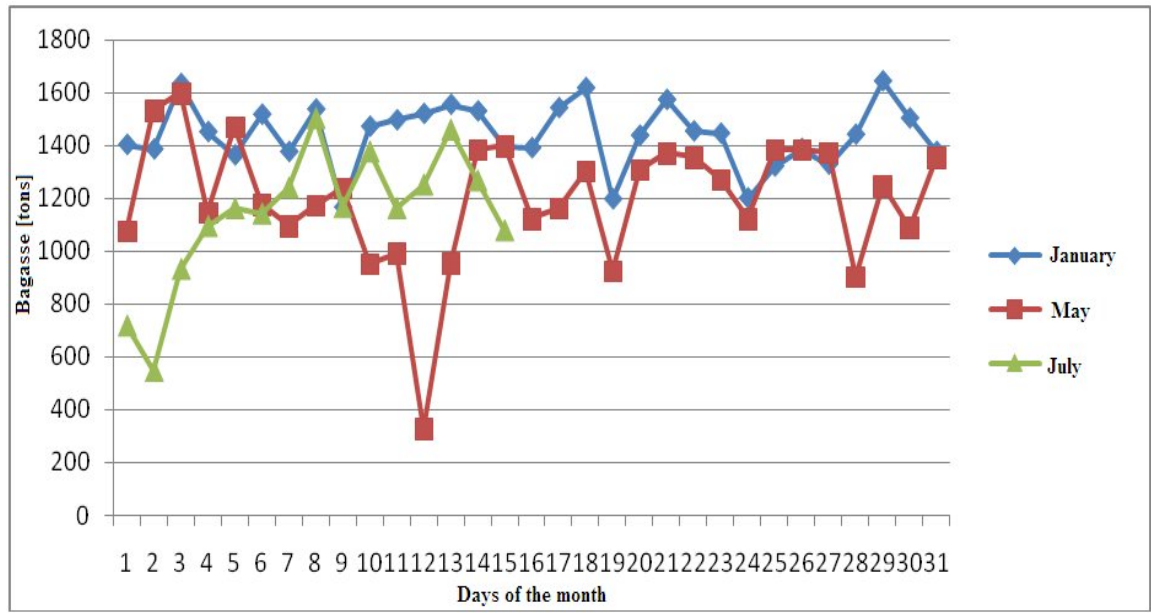
**TABLE 4.1-5:** The Daily Bagasse Amount for the Month of May 2009/10 Crushing Season

Day	May, 2010								Total Bagasse [tons]	Bagasse to cane ratio
	Tandem A				Tandem B					
	Cane Crushed [tons]	Bagasse [tons]	Dry Bagasse [tons]	Moisture % bagasse	Cane Crushed [tons]	Bagasse [tons]	Dry Bagasse [tons]	Moisture % bagasse		
1	864.9	280.3	139.7	50.16	2701.3	795.7	397.4	50.06	1076	0.30
2	1841.9	558	277.7	50.23	3308.4	973.2	482.1	50.46	1531.2	0.30
3	1215.2	356	177.3	50.2	4124.8	1242.3	619.4	50.14	1598.3	0.30
4	396.3	115.7	57.7	50.13	3457.4	1029.5	513.8	50.09	1145.2	0.30
5	1632.8	472.5	235.7	50.12	3369.2	998.7	488.6	51.08	1471.2	0.29
6	404.2	118.6	59.2	50.08	3611.2	1057.1	527.3	50.12	1175.7	0.29
7	877.9	273.1	136.1	50.16	2835.1	821.3	409.6	50.13	1094.4	0.29
8	1125.8	321.8	160.5	50.12	2967.8	851.7	425.3	50.06	1173.5	0.29
9	940.7	273.3	136.2	50.16	3330.8	965.3	482.2	50.05	1238.6	0.29
10	906.7	282	140.4	50.21	2336.6	669.3	331.2	50.52	951.3	0.29
11	642.5	207.5	103.3	50.22	2784.8	784	390.5	50.19	991.5	0.29
12	558.4	180.1	89.8	50.14	519.6	145.4	72.4	50.21	325.5	0.30
13	764.2	255.2	127.2	50.16	2501.2	698.2	348.3	50.11	953.4	0.29
14	1063.8	414	206.4	50.14	3354.5	970.3	483	50.22	1384.3	0.31
15	1373.1	446.6	222.5	50.18	3233.2	951.9	475.1	50.09	1398.5	0.30
16	993.5	286.5	142.8	50.16	2954.1	836.1	416.9	50.14	1122.6	0.28
17	578	166.4	82.9	50.18	3504.2	995.5	497	50.08	1161.9	0.28
18	788.1	246.5	122.7	50.22	3654.4	1057	527.2	50.12	1303.5	0.29
19	756.5	240	119.4	50.25	2365.3	685	342.5	50.00	925	0.30
20	730.1	233.1	116.2	50.15	3661.2	1074.9	536.2	50.12	1308	0.30
21	833.9	274.5	136.9	50.13	3838.6	1096.1	547.3	50.07	1370.6	0.29
22	1160	381.2	190.2	50.1	3393	973.9	485.7	50.13	1355.1	0.30
23	850.5	245.1	122.2	50.14	3044	1024.3	511.5	50.06	1269.4	0.33
24	887.4	252.9	126.1	50.14	3647.7	869.1	433.3	50.14	1122	0.25
25	1197.1	358.5	178.7	50.15	4061.8	1024.3	516.1	49.61	1382.8	0.26
26	948.6	288.3	143.7	50.16	3443.1	1096.1	593.9	45.82	1384.4	0.32
27	1103.1	314.2	156.5	50.19	3256	1058.6	526	50.31	1372.8	0.31
28	728.5	212.4	105.9	50.14	2438.5	689.5	344.1	50.09	901.9	0.28
29	888.5	256.3	127.7	50.18	3312	990.3	486.7	50.85	1246.6	0.30
30	831.2	235.5	117.5	50.11	2336	852	429	49.65	1087.5	0.34
31	1077.1	309	154.1	50.13	2874.6	1045	531.3	49.16	1354	0.34

**TABLE 4.1-6: The Daily Bagasse Amount for the Month of July 2009/10 Crushing Season for 15 Crushing Days <sup>6</sup>**

Day	July, 2010								Total Bagasse [tons]	Bagasse to cane ratio
	Tandem A				Tandem B					
	Cane Crushed [tons]	Bagasse [tons]	Dry Bagasse [tons]	Moisture % bagasse	Cane Crushed [tons]	Bagasse [tons]	Dry Bagasse [tons]	Moisture % bagasse		
1	1130.5	324.1	161.6	50.14	1075.6	396	199.3	49.67	720.1	0.33
2	252.2	73.2	36.5	50.14	1621.7	475.4	237.2	50.11	548.6	0.29
3	849.8	244.8	122.1	50.12	2438.5	689.5	344.1	50.09	934.3	0.28
4	1519.5	437.8	218.4	50.11	2548	658.9	330.6	49.83	1096.7	0.27
5	1152.6	369.8	184.5	50.11	2709	793.3	396.3	50.04	1163.1	0.30
6	1392.5	441.5	220.2	50.12	2663.4	702.5	350.1	50.16	1144	0.28
7	1443.6	442.8	226	48.96	3361.2	798.8	399.8	49.95	1241.6	0.26
8	1519.5	475.2	236.7	50.19	3675.9	1029.2	513.4	50.12	1504.4	0.29
9	1469.4	465.8	231.6	50.28	2542.6	701.6	350.5	50.04	1167.4	0.29
10	1126.4	354.3	176.4	50.21	3745.9	1023.8	511.8	50.01	1378.1	0.28
11	859.2	246.5	122.8	50.18	3358.2	917.7	460	49.87	1164.2	0.28
12	1261.9	362.5	171	52.83	3068.4	890.5	445.3	49.99	1253	0.29
13	1384.3	398	198.6	50.1	3709.8	1062	530.6	50.04	1460	0.29
14	1028	297.5	148.4	50.12	3346	970.5	483.4	50.19	1268	0.29
15	1260.2	355.9	177.3	50.18	2484	724.4	362	50.03	1080.3	0.29

<sup>6</sup> Data was not available for the remaining days of the month because the factory was shut down for overhaul maintenance.



**FIGURE 4.1-2:** MSF's Daily Bagasse Produced in January, May and July 2009/10 Crushing Season

The two extra ordinary reductions in bagasse production in May and July are due to machine break down which affected the milling plant.

The wet bagasse from the mills is directly transported by using chain conveyors, and distributed to all the furnaces and fed through holes on the top of the furnaces called chutes.

The average pol % bagasse (s%) and average moisture % bagasse (w%) of MSF are 2.485 and 50.04 respectively as obtained from the collected data.

Hence, the average higher calorific value and lower calorific value of the bagasse in MSF are:

$$HCV = 4600 - 12 * S\% - 46 * W\% \quad (4-10)$$

$$= 4600 - 12 * 2.485 - 46 * 50.04$$

$$= 2268.34 \text{ kcal/kg}$$

$$= 9497.54 \text{ kJ/kg}$$

$$LCV = 4250 - 12 * S\% - 48.5 * W\% \quad (4-11)$$

$$= 4250 - 12 * 2.485 - 48.5 * 50.04$$

$$= 1793.24 \text{ kcal/kg}$$

$$= 7508.3 \text{ kJ/kg}$$

But as the literature survey indicates on average the higher calorific value and lower calorific value of bagasse in different mills reach 9769.2 kJ/kg and 8027.7 kJ/kg, respectively. These values can be obtained by properly drying the bagasse before it is charged into the boilers. It is most sugar mills' experience that the bagasse can be dried up to 45% moisture % bagasse although there is a report stating that 38% moisture % bagasse was observed in Hawaii and Formosa.

“Poor work at the mills will give a bagasse of 50% moisture, while very good work will give a bagasse of 45% moisture. Certain factories in Hawaii and Formosa have reported moistures of the order of 38%, but these are exceptional figures. It is difficult, even in a modern mill, to obtain figures as low as 44%.” [24]

According to the data collected on average 29.07% of the sugarcane crushed is bagasse (average value of the bagasse to cane ratios in the above three tables); which is almost the same as other countries' bagasse to cane ratio.

The average tons of cane crushed per day at MSF is calculated from the three tables and is found to be 5344.54 tons/day. Hence, the quantity of bagasse produced per day

is estimated to be 1553.66 tons/day (29.07% \*5344.54 tons/day). The average furnace fuel consumption is 5427.94 liters/day (see Table 4.1-7). The furnace fuel replacement value of bagasse is 0.18 tons of furnace fuel per ton of bagasse. [28]

The equivalent bagasse amount corresponding to this value of furnace fuel is

$$\text{Equivalent bagasse amount} = \{ \text{average furnace fuel} * \text{density of furnace fuel} / \text{furnace fuel bagasse equivalent} \}$$

$$\begin{aligned} \text{Equivalent bagasse amount} &= \{ 5427.94 \text{ liters/day} * 950 \text{ kg/m}^3 * 0.001 \text{ m}^3/\text{lit} / \\ &0.18 \text{ ton of furnace fuel per ton of bagasse} \} \\ &= 28.65 \text{ tons/day} \end{aligned}$$

Therefore, the total bagasse available, on average, is

$$TBA = 1553.66 + 28.65 \quad (4-12)$$

$$TBA = 1582.31 \text{ tons/day or } 66 \text{ tons/hr.}$$

**TABLE 4.1-7: Annual Furnace Fuel Consumption at MSF***(Source: MSF)*

<b>Season</b>	<b>Furnace fuel Liters/Qt. Sugar</b>	<b>Furnace fuel consumed [liters]</b>
2000/01	2.06	2380062.20
2001/02	2.17	2509431.40
2002/03	2.08	2423202.08
2003/04	0.54	649806.84
2004/05	0.17	205396.04
2005/06	0.47	588983.32
2006/07	0.91	1150262.75
2007/08	0.23	299612.03
2008/09	0.52	664071.72
2009/10	0.39	468136.11

## 4.1.4 Main Equipment of Interest for the Research

### 4.1.4.1 Steam Generators

There are four bi-drum bagasse fired, water tube boilers in Metahara Sugar Factory with a design generating capacity and other technical specifications listed in *Appendix A*. These boilers are named as Boiler #1, Boiler #2, Boiler #3, and Boiler #4. Boilers #1, 2, & 4 have auxiliary furnace fuel burners but not boiler # 3.

Generally, boilers can be classified according to: intended service, location of fire and water spaces, type of circulation, arrangement of steam and water spaces, number and type of furnaces, burner location, furnace pressure, type of super-heaters, control of superheat, and operating pressure. Hence, the boilers at Metahara Sugar Factory can be classified according to the type of furnaces as:

- Boilers # 1, 2, & 3      ward furnace boilers
- Boiler # 4              inclined grate furnace boiler



**FIGURE 4.1-3:** The Four Boilers' Chimney at MSF<sup>7</sup>

<sup>7</sup> Date picture taken: 12/05/2010 at 12:09 p.m.

#### **4.1.4.1.1 Components of Each Boiler Unit**

Each boiler unit comprises of: -

- i) feed water system,
- ii) steam system, and
- iii) fuel system

##### **i) The Feed Water System**

This provides water to the boiler and regulates it automatically to meet the steam demand. Various valves provide access for maintenance and repair.

The feed water system consists of: -

- hot well tank (common to all, quantity one),
- reserve feed water tanks (common to all, quantity one),
- deaerators (quantity 2, 1 common to boiler I, II, and III and the other for boiler IV),
- economizer (one for each),
- feed water pumps (quantity 3 but 1 standby, 1 for boiler I,II, and III and 1 for boiler IV),
- make up pumps (one common to all), and
- deaerator lift pumps (quantity 2, 1 for boiler I,II, and III and 1 for boiler IV).

The deaerators are used for removing non-condensing gases like O<sub>2</sub>, CO<sub>2</sub> from the feed water system before entering the boilers. If these gases enter the boilers, they cause corrosion of boiler tubes. To remove these gases steam is blown inside the

deaerator tanks and the condensate is flashed so that the gases will be removed up the tanks.

The economizers are heat exchangers which are used to heat the feed water before entering the boiler-drums by the flue gases leaving the boilers. Water passes through the inside of the tubes and flue gases in the outside. Economizers can be installed before or after air heaters. But it is recommended before the air heater in high pressure boilers and after the air heater in low pressure boilers [10]. In Metahara Sugar Factory the economizers are installed after the air heaters although the boilers are high pressure boilers. This is because the boilers were not equipped with economizers initially and these have been added to increase the efficiency of the boilers later on after the air heaters.

## **ii) The steam system**

The steam system collects and controls the steam produced in the boilers. The steam is directed through a piping system to the point of use. Throughout the system, the steam pressure is regulated using valves and checked with steam pressure gauges.

The steam system also consists of: -

- steam separators at the upper drum,
- steam headers, and
- piping system to power turbines, mill turbines and make up steam fitted with different manual and automatic valves

## **iii) The fuel system**

This system includes all equipments used to provide fuel to generate the necessary heat. The equipment required in the fuel system depends on the type of fuel used in the system. It is known that the fuel in sugar factories is bagasse even though furnace fuel oil is sometimes used for emergency case. i.e. in case of mill stops, carrier failure, peak load time etc...

The fuel system of each boiler unit includes: -

- bagasse metric conveyors and rotary bagasse feeders
- forced draft fans (FD fans)
- induced draft fans (ID fans)
- bagasse spreaders and cinder recovery fans
- air heaters (quantity 4, one for each)
- furnace fuel oil burners (standby)
- chimney

The Forced Draft (FD) Fans are used to force air from the atmosphere or surrounding through each air heater in to the furnace which is used for combustion. When the air passes through the air heaters, it absorbs heat from the flue gases and is heated. This increases the combustion efficiency of the boilers.

The Induced Draft (ID) Fans are used to transport the flue gases from the furnaces through the boilers path up each of the chimney to the atmosphere.

The Air heaters are also heat exchangers like the economizers installed in the path of the flue gases and they are used to heat the air used for combustion before entering the furnaces. These also improved the efficiency of the boilers. In MSF, the flue gases pass inside the tubes of the air heaters and air in the outside. And the air heaters and economizers are misplaced because the economizers were installed later on to improve the efficiency of the boilers.

Partial view of the boilers control panel at MSF is shown in the following photograph. The properties of the feed water, superheated steam, air and flue gases as they are obtained from the boiler control panels are also shown in Table 4.1-8.



FIGURE 4.1-4: The Boilers' Control Panel at MSF<sup>8</sup>

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<sup>8</sup> Date picture taken: 03/05/2010 at 03:36 p.m.

TABLE 4.1-8: Average Operating Parameters of the Four Boilers as Obtained from the Boilers Control Panel (*read on 01/07/2010*)

Descriptions	Boiler 1	Boiler 2	Boiler 3	Boiler 4
Steam generation (tons/hr)	20	20	20	50
Superheated steam temperature (°C)	370	376	372.5	378
Superheated steam pressure (kg/cm <sup>2</sup> )	22	22	22	23
Feed water temperature to deaerator (°C)	88	88	88	89
Feed water temperature to economizer (°C)	105	105	104	104
Feed water temperature after economizer (°C)	125	129	120	130
Feed water pressure pump discharge (kg/cm <sup>2</sup> )	25	25.5	25.8	30
Feed water pressure to economizer (kg/cm <sup>2</sup> )	24	23.5	24	23.5
Inlet air temperature (°C)	190	195	194	240
Flue gas temperature before air heater (°C)	280	290	290	300
Flue gas temperature after air heater (°C)	184	170	175	185
Flue gas temperature at economizer outlet(°C)	159	148	152	147
Flue gas temperature to the atmosphere (°C)	158	146.5	151	145

The flue gas properties of the boilers as obtained from the combustion analyzer and the ambient temperature are indicated in the following tables.

**TABLE 4.1-9: Flue Gas and Ambient Conditions of the Boilers**

Boilers	Measured	Trial 1	Trial 2	Trial 3	Average
Boiler I	Oxygen	12%	11%	11.5%	11.5%
	Carbon dioxide	9.2%	8.4%	8.5%	8.7%
	Carbon monoxide	0.86%	0.95%	0.98%	0.93%
	Ambient temperature	33 °C	35 °C	34.8 °C	34.5 °C
Boiler II	Oxygen	10%	11.9%	11.5%	11%
	Carbon dioxide	8.3%	9.4%	10.5%	9.4%
	Carbon monoxide	0.3%	0.65%	0.45%	0.47%
	Ambient temperature	31 °C	34.2 °C	30.8 °C	32 °C
Boiler III	Oxygen	11.6%	12.1%	12.5%	12.06%
	Carbon dioxide	8.1%	9.2%	8.8%	8.7%
	Carbon monoxide	0.46%	0.65%	0.48%	0.53%
	Ambient temperature	34.5 °C	35 °C	35.5 °C	35 °C
Boiler IV	Oxygen	7.8%	9.23%	8.47%	8.5%
	Carbon dioxide	11.9%	12.6%	13%	12.5%
	Carbon monoxide	1.6%	0.78%	1.22%	1.2%
	Ambient temperature	35.5 °C	37.4 °C	35.7 °C	36.2 °C

#### 4.1.4.2 Power Turbines

The factory currently generates about 5.4 MW [see equation (4-13)] of electricity from its three steam-driven power turbines (3.3 MW capacity each, one on standby) and consumes all of it. And it has two standby diesel units of 400 kW each. The factory imports power from the national grid only during the low season.

The two turbines work at a time and the third one is a stand-by. But due to load increase in the factory and age of the turbines, all the three turbines usually work at a time.

The advantage of these steam turbines is that they are back pressure turbines with exhaust steam pressure of  $2.25 \text{ kg / cm}^2$  (abs). The exhaust steam together with live make-up steam from the boilers is used for the evaporation of water from the juice in the evaporation plant.



FIGURE 4.1-5: Partial View of the Three Turbo-alternators (Power Turbines)<sup>9</sup>

<sup>9</sup> Date picture taken: 29/10/2010 at 01:10 p.m.

**TABLE 4.1-10: Average Operating Parameters of the Turbines**

No.	Descriptions	Turbine I	Turbine II	Turbine III (Standby)
1.	Rated live steam pressure (abs)	22 bars	22 bars	22 bars
2.	Operating live steam pressure (abs)	20 bars	20 bars	-
3.	Rated steam consumption	25 tons/hr	25 tons/hr	25 tons/hr
4.	Operating steam consumption	28 tons/hr	28 tons/hr	-
5.	Back pressure (abs)	2.25 bars	2.25 bars	2.25 bars
6.	Rated live steam temperature	370 <sup>0</sup> C	370 <sup>0</sup> C	370 <sup>0</sup> C
7.	Operating live steam temperature	365 <sup>0</sup> C	365 <sup>0</sup> C	-

**The three-phase generators**

Speed	1500 rpm
Power factor (cos( $\phi$ ))	0.75
Rated voltage	3000 V
Rated current	815 A
Generated current	700A
Efficiency (full load)	95.7%

The current generator output is

$$P = \frac{V * I * pf * \sqrt{3}}{1000} \text{ kW} \quad (4-13)$$

where:  $V$  is the voltage output

$I$  is the current

$Pf$  is the power factor

$$P = \frac{3000 * 700 * 0.75 * \sqrt{3}}{1000} = 2727.98 \text{ kW}$$

$$\dot{W}_{turbine} = (h_i - h_e) * \dot{m}_1 \quad (4-14)$$

where:  $h_i$  is the enthalpy at inlet to the turbine

$h_e$  is the enthalpy at exit of the turbine

$\dot{m}_1$  is the mass flow rate of steam to the turbine

$$\dot{W}_{turbine} = \frac{P}{\eta_{gb} * \eta_{gen}} \quad (4-15)$$

where:  $P$  is the generator output, from equation

$\eta_{gb}$  is the double helical gear box efficiency

$\eta_{gen}$  is the generator efficiency

$$\dot{W}_{turbine} = \frac{2727.98}{0.98 * 0.957} = 2908.73 \text{ kW}$$

$$\eta_{turbine} = \frac{\dot{m}_1 * (h_i - h_e)}{\dot{m}_1 * (h_i - h_{es})} \quad (4-16)$$

where:  $\dot{m}_1$  is the mass flow rate of steam to the turbine

$\eta_{turbine}$  is the efficiency of the turbine

$h_i$  is the enthalpy at inlet to the turbine

$h_e$  is the enthalpy at exit of the turbine

$h_{es}$  is the enthalpy at exit of the turbine, for isentropic line

$$\eta_{turbine} = \frac{\dot{W}_{turbine}}{\dot{m}_1 * (h_i - h_{es})} = \frac{2908.73 * 1000}{28000 * \frac{1}{3600} * (3170.987 - 2681.298) * 1000}$$

$$\eta_{turbine} = 76.4\%$$

The current efficiency of the turbines is 76.4%. The design rated output, pressure and temperature of the turbo-alternator are 3180 kW, 22 bars (abs), 370 °C, respectively. The design efficiency of the turbines is

$$\dot{W}_{turbine} = \frac{3180}{0.98 * 0.957} = 3390.7 \text{ kW}$$

$$\eta_{turbine} = \frac{\dot{W}_{turbine}}{\dot{m}_1 * (h_i - h_{es})} = \frac{3390.7 * 1000}{32000 * \frac{1}{3600} * (3182.06 - 2688.16) * 1000}$$

$$\eta_{turbine} = 77.2\%$$

There is a discrepancy between the design and actual efficiencies of the turbines. The current operating parameters, therefore, need to be regulated accordingly to enhance the efficiencies of the turbine.

The steam consumption per kWh is, currently, 10.264 kg/kWh. The increase in steam inlet temperature by 10 °C in back pressure type turbine reduces the steam consumption in the turbine by about 1.5 % and improves the turbine efficiency by about 0.12 % [33].

If the steam temperature can be maintained at 370 °C and the pressure at 22 bars and the mass flow rate at 28 tons/hr, it will be possible to generate 2779.5 kW of power assuming the power generation efficiency of the turbines increases by 0.75% as per the above justification (i.e. 77.15%). Hence, there will be an increase in 103 kW power output and an improved steam consumption of 10.07 kg/kWh.

#### 4.1.4.3 Mill Turbines



**FIGURE 4.1-6:** The Three Mill Turbines for Tandem A<sup>10</sup>

<sup>10</sup> Date picture taken: 29/10/2010 at 01:09 p.m.



**FIGURE 4.1-7:** One of the Five Mill Turbines for Tandem B<sup>11</sup>



**FIGURE 4.1-8:** Partial View of the Five Mill Turbines for Tandem B<sup>12</sup>

<sup>11</sup> Date picture taken: 29/10/2010 at 12:55 p.m.

<sup>12</sup> Date picture taken: 29/10/2010 at 12:56 p.m.

### Tandem A Mill Turbines

Quantity: three (3)

Mill No.1 450 kW at 1750 rpm secondary shaft speed

Mill No.2 375 kW at 1750 rpm secondary shaft speed

Mill No.3 337.5 kW at 1750 rpm secondary shaft speed

Live steam pressure 21 kg/cm<sup>2</sup> (gauge)

Live steam temperature 365 °C

Back pressure 1.25 kg/cm<sup>2</sup> (gauge)

#### Steam consumption

Mill No.1 6273 kg/hr (max)

Mill No.2 5227 kg/hr (max)

Mill No.3 4770 kg/hr (max)

### Tandem B Mill Turbines

Quantity: five (5)

Live steam pressure 21 kg/cm<sup>2</sup> (gauge)

Live steam temp 365 °C

Back pressure 1.25 kg/cm<sup>2</sup> (gauge)

#### Steam consumption

Mill # 1	Steam consumption at full load	7102 kg/hr
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Mill (# 2-5)	Steam consumption at full load	5300 kg/hr each
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#### 4.1.4.4 Electric Motors in MSF



**FIGURE 4.1-9:** One of the Biggest Electric Motors in MSF, the Coupling is Dismantled for Maintenance<sup>13</sup>

The two parameters of importance in a motor are efficiency and power factor. The efficiencies of induction motors remain almost constant between 50 - 100% loadings (see Figure 4.1-10). [22] When a motor has a higher rating than that required by the equipment, motor operates at part load. In this state, the efficiency of the motor is reduced. Replacement of under loaded motors with smaller motors will allow a fully loaded smaller motor to operate at a higher efficiency.

<sup>13</sup> Date picture taken: 29/10/2010 at 12:37 p.m.

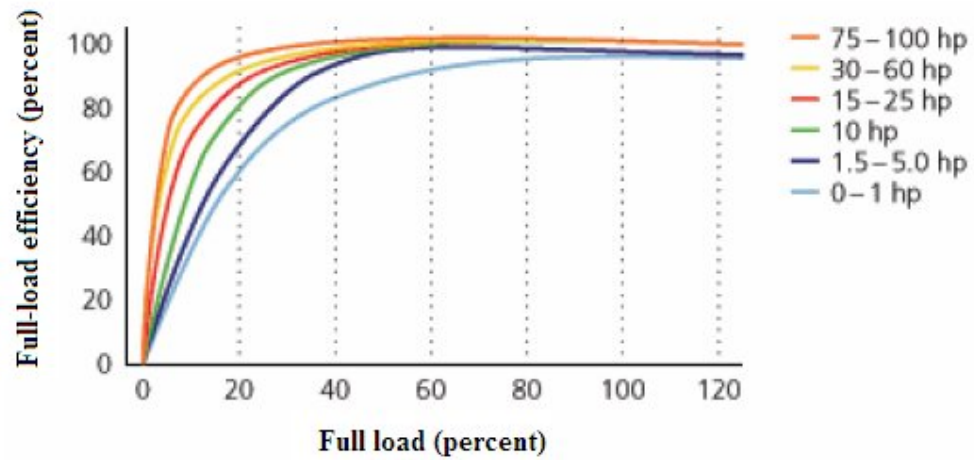


FIGURE 4.1-10: Efficiency vs. Loading [35]

To determine the Motor Loading by input power measurements, first the input power  $P_i$  is measured with a hand held power meter or can be determined if the power factor, voltage, and current are measured using equation (4-17).  $P_i$  is the three-phase power in kW.

$$P_i = \frac{V * I * PF * \sqrt{3}}{1000} \quad (4-17)$$

where:

$P_i$  = Three-phase power in kW

V= RMS voltage, mean line-to-line of 3 phases

I = RMS current, mean of 3 phases

PF = Power factor as a decimal

The rated kW and efficiency from the motor name plate is recorded, in case the nameplate is removed or damaged the rated kW is obtained from the manual. Since the figures of kW mentioned in the name plate is for output conditions, the input power at full-rated load is obtained by

$$P_{ir} = \frac{\text{Nameplate full rated load}}{\eta_{fl}} \quad (4-18)$$

where:

$P_{ir}$  = Input power at full-rated load in kW

$\eta_{fl}$  = Efficiency at full-rated load

The percentage loading can now be calculated as follows

$$\text{Load} = \frac{P_i}{P_{ir}} * 100\% \quad (4-19)$$

where:

Load = Output power as a % of rated power

$P_i$  = Measured three-phase power in kW

$P_{ir}$  = Input power at full-rated load in kW

For example, for Tandem A Cane Un-loader (the first row in Table 4.1-11), the nameplate details of the first motor (EM1) are given as power = 15 kW, efficiency  $\eta$  = 0.93. Using a clamp on power meter the actual three phase power drawn is found to be 12.632 kW.

The Input power at full-rated power in kW is, therefore,

$$P_{ir} = 15 / 0.93$$

$$P_{ir} = 16.13 \text{ kW}$$

The percentage loading will be

$$\text{Load} = 12.632/16.13$$

$$\text{Load} = 77.5 \%$$

The data collected using 3Φ/1Φ Power Clamp-on Meter regarding electric motors at MSF are presented in Table 4.1-11. With measured parameters taken from hand-held instruments, the above equations are used to calculate the three-phase input power to the loaded motor. Each motor's part-load is quantified by comparing the measured input power under load to the power required when the motor operates at rated capacity.

The NEMA definition of motor energy efficiency is the ratio of its useful power output to its total power input and is usually expressed in percentage, as shown in the following equation.

$$\eta = \frac{0.7457 * hp * Load}{P_i} \quad (4-20)$$

where:

$\eta$  = Efficiency as operated in %

hp= Nameplate rated horsepower

Load = Output power as a % of rated power

$P_i$  = Three-phase power in kW

It was more difficult to determine the full load efficiency of the motors that have been in service for a long time. And most of the nameplates on the motors in MSF are lost or painted over. In this case, it is almost impossible to locate efficiency information. Also, since some of the motors have been rewound, there is a probability that the motor efficiency has been reduced. The data in Table 4.1-11 have been collected to estimate the total power consumed by the motors in MSF.

**TABLE 4.1-11: Power Consumption of the Electric Motors**

Plant Sections and Electric Motors		Rated power [kW]	Power factor PF	KVAR [kVar]	KVA [kVA]	Input power Pi [kW]	Load %
Tandem A Cane Unloader	EM1	15	0.87	7.159	14.519	12.632	77.5
	EM2	15	0.71	12.937	18.371	13.043	80.0
Tandem B Cane Unloader	EM1	22	0.78	15.689	25.071	19.556	81.8
	EM2	22	0.83	12.193	21.861	18.144	75.9
Tandem A Cane Feeding Tables	EM1	12.25	0.79	8.358	13.632	10.769	80.9
	EM2	12.25	0.81	7.629	13.009	10.538	79.1
Tandem B Cane Feeding Tables	EM1	30	0.89	13.815	30.299	27.0	82.8
	EM2	30	0.9	12.773	29.304	26.0	79.7
Tandem A Teasers	EM1	7.5	0.91	2.878	6.940	6.316	77.5
	EM2	7.5	0.89	3.270	7.172	6.383	78.3
Tandem B Teasers	EM1	22	0.93	7.246	19.713	18.333	76.7
	EM2	22	0.9	9.166	21.027	18.925	79.1
Tandem A Horizontal Cane Carrier	EM1	12.25	0.93	4.304	11.708	10.889	81.8
Tandem A Cane Kicker	EM2	12.25	0.92	4.691	11.969	11.011	82.7
Tandem A Anvil Cane Carrier	EM3	12.25	0.89	5.517	12.100	10.769	80.9
Tandem A Inclined Cane Carrier	EM4	17.25	0.9	7.187	16.487	14.839	79.1
Tandem B Auxiliary Cane Carrier	EM1	30	0.78	20.057	32.051	25.000	76.7
Tandem B Elevator Cane Carrier	EM2	30	0.8	19.149	31.915	25.532	78.3
Tandem B Band Cane Carrier	EM3	22	0.84	12.357	22.774	19.130	80.0
Tandem A First Cane Cutter	EM1	225	0.87	106.261	215.51	187.50	76.7
Tandem A Second Cane Cutter	EM2	480	0.85	247.898	470.58	400.00	76.7
Tandem B Roughing cane cutter	EM1	300	0.86	146.812	287.70	247.42	75.9
Tandem B First finishing cane cutter	EM2	300	0.8	189.474	315.78	252.63	77.5
Tandem B Second finishing cane cutter	EM3	480	0.8	309.677	516.12	412.90	79.1
Tandem A Juice pumps	EM1	15	0.9	6.249	14.337	12.903	79.1
	EM2	15	0.92	5.497	14.025	12.903	79.1
	EM3	15	0.93	5.100	13.874	12.903	79.1

Table Cont'd

Tandem B Juice pumps	EM1	15	0.76	11.034	16.978	12.903	78.3
	EM2	15	0.86	7.656	15.004	12.903	78.3
	EM3	15	0.93	5.100	13.874	12.903	78.3
	EM4	15	0.92	5.497	14.025	12.903	78.3
	EM5	15	0.89	6.611	14.498	12.903	78.3
Dorr Rotating Mud Filters	EM1	1.125	0.87	0.548	1.112	0.968	78.3
Dorr Rotating Mud Filters Agitator	EM1	0.75	0.7	0.680	0.952	0.667	80.9
Lime Slaker rotary drum	EM1	2.25	0.73	1.893	2.771	2.022	81.8
Lime Classifier's rack	EM1	1.5	0.86	0.782	1.533	1.1	66.7
Transport trough under pans	EM1	7.5	0.8	4.839	8.065	6.452	78.3
	EM2	7.5	0.86	3.709	7.267	6.250	75.8
	EM3	7.5	0.74	5.802	8.626	6.383	77.4
	EM4	7.5	0.89	3.341	7.328	6.522	79.1
5 Crystallizers for A massecuite stirrer drive	EM1	5.625	0.9	2.270	5.208	4.6	74.4
	EM2	5.625	0.87	2.657	5.388	4.6	74.4
	EM3	5.625	0.84	2.997	5.523	4.639	75.0
	EM4	5.625	0.76	4.051	6.233	4.7	76.0
	EM5	5.625	0.7	4.936	6.912	4.839	78.3
Crystallizer for A/C massecuite stirrer drive	EM1	5.625	0.74	4.446	6.610	4.891	79.1
Crystallizer for C massecuite stirrer drive	EM1	5.625	0.8	3.553	5.921	4.737	76.6
Vacuum Crystallizer stirrer drive	EM1	5.625	0.76	4.051	6.233	4.737	76.6
A/B fore Worker feed mixer stirrer	EM1	5.625	0.72	4.471	6.443	4.639	75.0
A/B fore worker Centrifugals	EM1	31	0.8	20.667	34.444	27.556	80.9
	EM2	31	0.76	22.207	34.169	25.969	76.2
	EM3	31	0.75	23.268	35.177	26.383	77.4
	EM4	31	0.78	22.356	35.725	27.865	81.8
	EM5	31	0.89	13.810	30.288	26.957	79.1
	EM6	31	0.87	16.535	33.536	29.176	85.6

Table Cont'd

A/B fore worker Centrifugals Ventilating fans	EM1	1.5	0.76	1.080	1.662	1.263	78.3
	EM2	1.5	0.74	1.186	1.763	1.304	80.8
	EM3	1.5	0.8	1.000	1.667	1.333	82.6
	EM4	1.5	0.81	0.896	1.527	1.237	76.7
	EM5	1.5	0.71	1.308	1.857	1.319	81.8
	EM6	1.5	0.78	1.035	1.654	1.290	80.0
A/B After worker Centrifugals	EM1	31	0.9	13.496	30.961	27.865	83.6
	EM2	31	0.81	19.731	33.645	27.253	81.8
	EM3	31	0.86	15.490	30.355	26.105	78.3
	EM4	31	0.83	17.729	31.787	26.383	79.1
	EM5	31	0.94	9.376	27.482	25.833	77.5
A/B After worker Centrifugals Ventilating fans	EM1	1.5	0.87	0.731	1.483	1.290	80.0
	EM2	1.5	0.72	1.285	1.852	1.333	82.6
	EM3	1.5	0.87	0.764	1.550	1.348	83.6
A/B After worker Centrifugals Ventilating fans	EM4	1.5	0.83	0.886	1.589	1.319	81.8
	EM5	1.5	0.79	1.001	1.633	1.290	80.0
Continuous Centrifugals for C Massecuite	EM1	30	0.83	16.800	30.120	25.000	77.5
	EM2	30	0.76	21.834	33.595	25.532	79.1
	EM3	30	0.85	16.167	30.691	26.087	80.9
	EM4	45	0.83	25.688	45.455	37.500	77.5
Continuous Centrifugals for D Massecuite D After worker Continuous Centrifugals	EM1	30	0.77	20.716	32.468	25.000	77.5
	EM2	30	0.77	20.502	32.133	24.742	76.7
	EM3	30	0.76	21.604	33.241	25.263	78.3
Continuous Centrifugals for D Massecuite D Fore Worker continuous Centrifugals	EM1	75	0.83	44.194	78.201	64.516	80.0
	EM2	75	0.71	64.901	91.512	64.516	80.0
	EM3	45	0.83	26.516	46.921	38.710	80.0
Vacuum Crystallizer's stirrer	EM1	5.625	0.80	3.629	6.048	4.839	80.0

Continuous Crystallizers	EM1	11.25	0.77	8.019	12.568	9.677	77.4
	EM2	11.25	0.86	5.742	11.253	9.677	80.0
	EM3	11.25	0.82	6.881	11.874	9.677	80.0
	EM4	11.25	0.90	4.687	10.753	9.677	80.0
	EM5	11.25	0.81	7.132	12.022	9.677	80.0
	EM6	11.25	0.81	7.132	12.022	9.677	80.0
A/B fore worker conveyor	EM1	11.25	0.89	4.984	10.705	9.474	75.8
A/B After worker Conveyor	EM1	11.25	0.85	5.750	10.916	9.278	74.2
Screw Conveyors Under C/D Continuous Centrifugals	EM1	11.25	0.82	6.666	11.503	9.375	75.0
	EM2	11.25	0.80	7.306	12.043	9.574	76.6
	EM3	11.25	0.73	9.159	13.401	9.783	78.3
	EM4	11.25	0.80	7.630	12.579	10.000	80.0
A Magma Minglers	EM1	11.25	0.85	5.996	11.211	9.474	75.8
	EM2	11.25	0.83	6.366	11.414	9.474	75.8
C Magma Minglers	EM1	4.125	0.80	2.596	4.279	3.402	74.2
	EM2	4.125	0.82	2.559	4.472	3.667	80.0
D Fore worker Magma Minglers	EM1	11	0.76	7.880	12.125	9.215	75.4
D After worker Magma Mingler	EM1	4.125	0.73	3.335	4.842	3.511	76.6
	EM2	4.125	0.76	3.171	4.879	3.708	80.9
Remelters	EM1	3.75	0.85	2.064	3.859	3.261	78.3
Melt Sugar Screw Conveyor	EM1	4.125	0.85	2.457	4.595	3.882	84.7
Dump Sugar Bucket Elevator	EM1	5.625	0.80	3.449	5.781	4.639	74.2
Dried/Cooled sugar Bucket elevator	EM1	5.625	0.78	3.863	6.112	4.737	75.8
Sugar Dryer	EM1	11.25	0.79	7.476	12.068	9.474	75.8
	EM2	11.25	0.74	8.892	13.220	9.783	78.3
Fluidized bed Dryer/Cooler blowers	EM1	11	0.83	6.507	11.745	9.778	80.0
	EM2	11	0.70	9.191	12.914	9.072	74.2
	EM3	11	0.85	6.057	11.410	9.670	79.1
	EM4	11	0.75	8.345	12.616	9.462	77.4
	EM5	11	0.75	8.720	13.184	9.888	80.9
	EM6	11	0.86	5.738	11.245	9.670	79.1
	EM7	11	0.81	6.767	11.471	9.263	75.8

Table Cont'd

Fluidized bed Dryer/Cooler Drive Unit	EM1	11	0.88	5.053	10.638	9.362	76.6
Vibrating Screen Theme Vibrator # 1	EM1	4.124	0.77	2.825	4.449	3.437	75.0
Vibrating Screen Theme Vibrator # 2	EM1	5.625	0.85	3.031	5.709	4.839	77.4
Belt Conveyor Under Weigher # 1	EM1	1.1	0.89	0.494	1.096	0.978	80.0
Belt Conveyor on Tacho Scale # 1	EM1	0.55	0.86	0.293	0.575	0.494	80.8
Belt Conveyor After Weigher Scale #1	EM1	1.1	0.83	0.656	1.169	0.967	79.1
Belt Conveyor Under Weigher # 2	EM1	1.1	0.78	0.765	1.217	0.946	77.4
Belt Conveyor on Check Scale # 2	EM1	0.55	0.72	0.448	0.641	0.458	74.9
Conveyor After Weigher Scale # 2	EM1	0.375	0.77	0.267	0.416	0.319	76.6
Induced Draught Fan BI	EM1	93.75	0.82	56.373	99.115	81.522	78.3
Induced Draught Fan BII	EM1	93.75	0.80	59.612	98.270	78.125	75.0
Induced Draught Fan BIII	EM1	93.75	0.76	67.330	103.13	78.125	75.0
Induced Draught Fan BIV	EM1	431.25	0.81	257.501	439.09	355.67	74.2
Forced Draught Fan BI	EM1	52.5	0.76	37.807	58.172	44.211	75.8
Forced Draught Fan BII	EM1	52.5	0.74	41.355	61.236	45.161	77.4
Forced Draught Fan BIII	EM1	52.5	0.77	37.829	59.289	45.652	78.3
Forced Draught Fan BIV	EM1	161.25	0.87	77.864	156.53	135.78	75.8
Bagasse Spreader Fan BI	EM1	13.125	0.89	5.739	12.454	11.053	75.8
Bagasse Spreader Fan BII	EM1	13.125	0.79	8.366	13.681	10.825	74.2
Bagasse Spreader Fan BIII	EM1	13.125	0.78	9.437	15.005	11.667	80.0
Bagasse Spreader Fan BIV	EM1	18.75	0.79	12.087	19.819	15.707	75.4
Deaerator Lift Pump for BI, BII and BIII	EM1	11.25	0.73	8.964	13.116	9.574	76.6
Deaerator Lift Pump for BIV	EM1	11.25	0.86	6.318	12.330	10.588	84.7

Table Cont'd

Feed water pump for BI, BII and BIII	EM1	53	0.73	45.341	65.831	47.727	81.9
Feed water pump BIV	EM1	161.25	0.80	100.517	168.94	135.78	76.6
Make up pump	EM1	6	0.78	3.863	6.112	4.737	71.8
Inclined bagasse carrier (from Tandem A to boiler)	EM1	26	0.87	13.078	26.525	23.077	80.8
Elevated bagasse belt conveyor (from Tandem B to boiler)	EM1	11	0.76	7.849	11.996	9.072	75.1
Horizontal bagasse carrier (feeding boilers)	EM1	38	0.87	17.815	35.971	31.250	74.8
Surplus bagasse carrier (Slat conveyor)	EM1	30	0.90	12.372	27.894	25.000	75.8
Return bagasse carrier (Slat conveyor)	EM1	30	0.87	14.353	28.604	24.742	75.1

The total power consumption of the electric motors in MSF, considering the major power consuming motors, is 4172.8 kW. The total electric power production is around 5456 kW from the two power turbines. The difference in electric power production and the captive consumption of the plant which includes the power consumption of air conditioning equipments and lighting systems in the factory as well as the offices is 1283.2 kW. This power is consumed in the nearby village for lighting, cooking equipments, air conditioning and refrigeration equipments and the likes.

The electric motors are loaded from 66% to 87 % of the full load as seen in the above table. The less loaded electric motors should be replaced by smaller motors so that the overall electric energy utilization efficiency of the motors will be improved.

The power factors of the electric motors can further be improved through proper application of the power factor correction capacitors. If the lower power factors can be improved to at least 0.9, 346.73 kW power can be saved.

#### **4.1.5 Factory Steam Consumption**

The annual average steam to cane ratios of the factory for the last ten seasons are obtained from the production department and presented in Table 4.1-12 below. The annual average steam generated can, therefore, be computed from the annual average cane crushed (Table 4.1-2) and these steam to cane ratios. The result is shown in the second column of the next table. The annual average total steam generated is found to be 612,122.9 tons/year as computed from Table 4.1-12.

**TABLE 4.1-12: Annual Average Steam to Cane Ratio and Total Steam Generated**

<b>Season</b>	<b>Steam to cane ratio</b>	<b>Total steam generated [tons]</b>
2000/01	0.56	581038.64
2001/02	0.56	571918.48
2002/03	0.57	598289.67
2003/04	0.529	598706.86
2004/05	0.53	563059.28
2005/06	0.565	648512.09
2006/07	0.56	655434.81
2007/08	0.541	611623.22
2008/09	0.53	642891.17
2009/10	0.54	649754.46

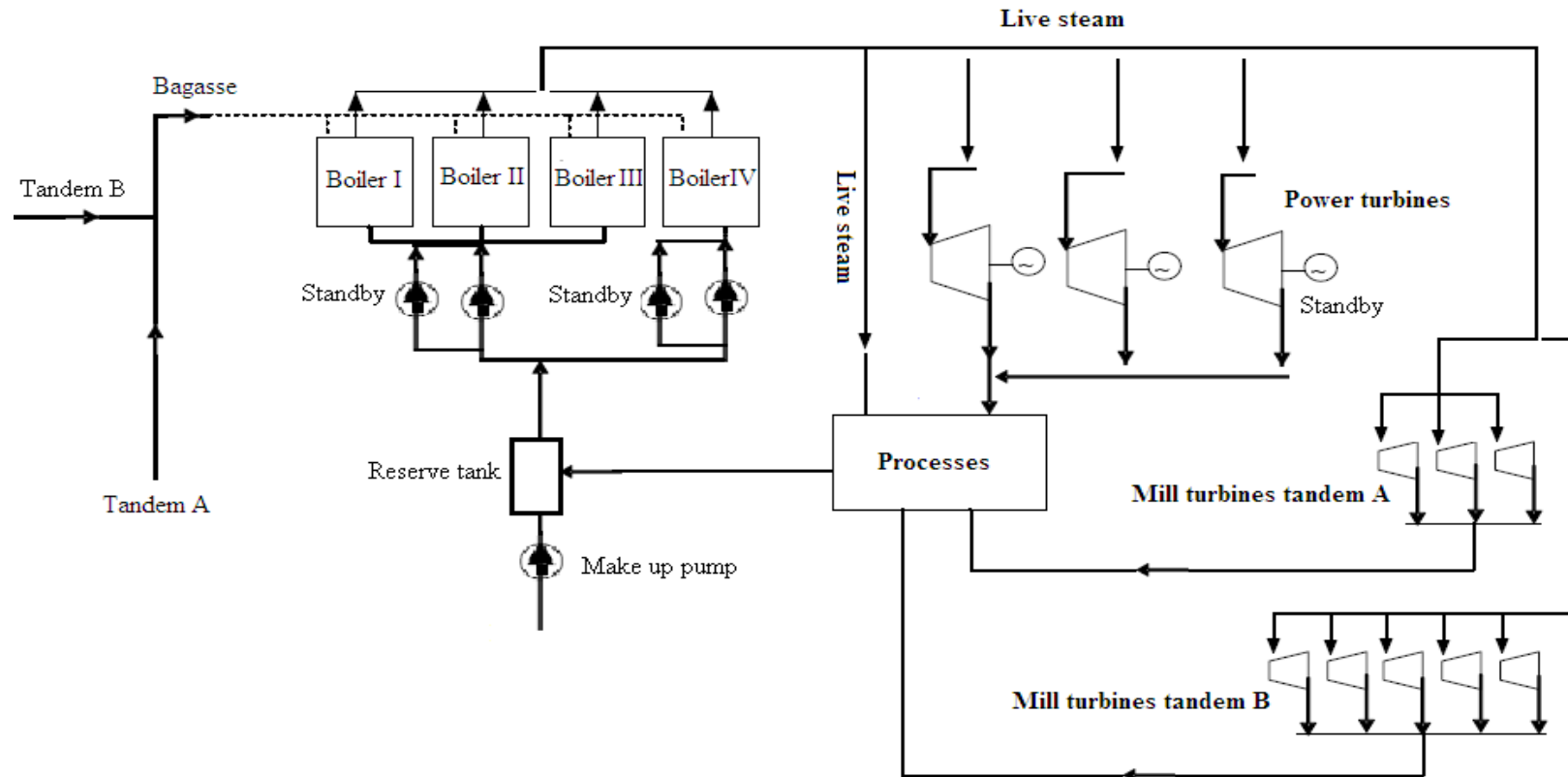


FIGURE 4.1-11: Schematic Layout of the Bagasse Flow, Steam Generators and Steam Consuming Units in the Factory

The actual average steam consumption rates in the factory by the different units are indicated below.

Tandem A Mill Turbines

Mill No.1	5 tons/hr
Mill No.2	3.5 tons/hr
Mill No.3	3.5 tons/hr

Tandem B Mill Turbines

Mill No. 1	6 tons/hr
Mill (No. 2-5)	4.25 tons/hr each

Live steam to Power Turbine 1                      28 tons/hr

Live steam to Power Turbine 2                      28 tons/hr

The total steam consumption of prime movers                      91 tons/hr

Exhaust steam demand of boiling house                      105.7 tons/hr

Centrifugal and drier house                      5.3 tons/hr

Boiler blow off and leakages                      2.1 tons/hr

Live steam make-up to exhaust for boiling house                      11.6 tons/hr

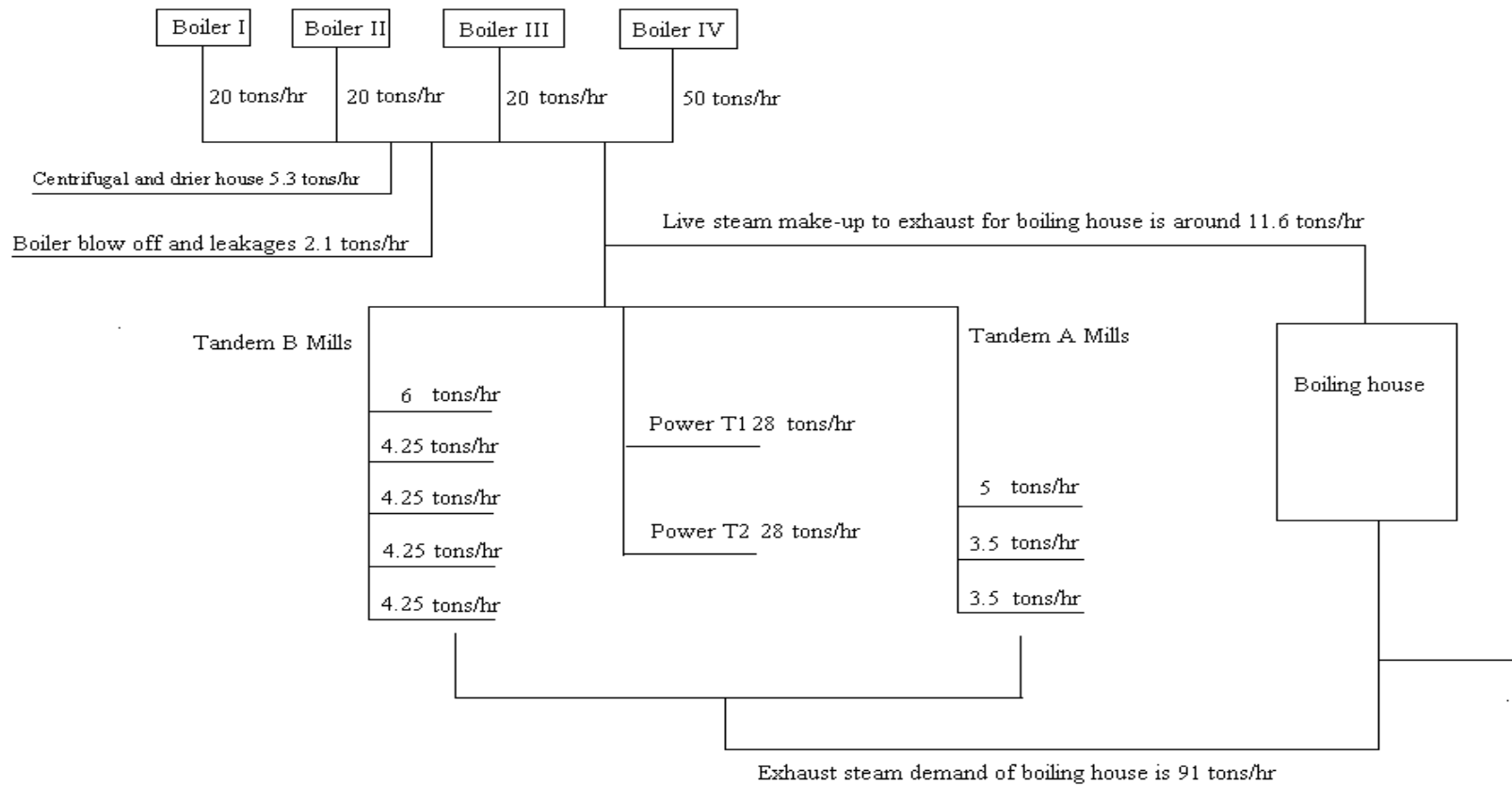


FIGURE 4.1-12: Average Steam Generation and Consumption Rates

#### **4.1.6 The Efficiency of the Boilers and their Bagasse Consumption**

The current steam production rates of the boilers are 20 tons/hr from Boilers I, II, and III and 50 tons/hr from Boiler IV as shown in Table 4.1-8.

There are basically two methods to calculate efficiency of the boiler: Input-Output method and Heat Loss method. In Input-Output method, boiler must be in steady running condition and the data of heat input in the form of fuel and air and heat output in the form of steam and other losses is taken. Here the Heat Loss method is applied to determine the efficiency and the Input-Output method is then used to find the bagasse consumption of each boiler.

The heat input was calculated above in equation (4-11). Then, all the heat losses are estimated. The effective heat output is, therefore, heat input less the heat losses. The output to input ratio gives the efficiency.

The heat losses in the furnace and at the boiler consist of the following:

- a) Latent heat of the water formed by combustion of hydrogen in the bagasse
- b) Latent heat of the water contained in the bagasse
- c) Sensible heat of the flue gas leaving the boiler
- d) Losses in unburnt solids
- e) Losses by radiation from the furnace and specially from the boiler
- f) Losses due to bad combustion of carbon giving CO instead of CO<sub>2</sub>



FIGURE 4.1-13: Typical Loss Area in one of the Furnaces<sup>14</sup>

The efficiencies of the boilers and their bagasse requirement will be calculated as follows:

### Boiler I

The equation of the net calorific value (4-11) has already taken in to account losses (a) and (b).

The loss (c) is given by

$$q = [(1 - w)(1.4m - 0.13) + 0.5] * 4.187 * T \quad [kJ / kg] \quad (4-21)$$

<sup>14</sup> Date picture taken: 03/05/2010 at 03:44 p.m.

where:

$q$  = sensible heat lost in flue gases

$T$  = temperature of the flue gases, in  $^{\circ}\text{C}$

$w$  = moisture per unit bagasse

$m$  = ratio of weight of air used for combustion to weight  
theoretically necessary

Excess air is determined by measuring the concentration of non-reacted  $\text{O}_2$  in the flue gases. A good approximation for excess air, expressed as a percent, can be calculated from the following equation. [Refer Table 4.1-9 for the values]

$$\%Excess\ Air = \frac{\%O_2 - \frac{\%CO}{2}}{20.9 - \left(\%O_2 - \frac{\%CO}{2}\right)} \times 100 \quad (4-22)$$

$$\%Excess\ Air = \frac{11.5 - \frac{0.93}{2}}{20.9 - \left(11.5 - \frac{0.93}{2}\right)} \times 100$$

$$\%Excess\ Air = 111.86\ \%$$

Hence, the excess air coefficient,  $m$ , is

$$m = \frac{\%Exces\ Air}{100} + 1 \quad (4-23)$$

$$m = \frac{111.86}{100} + 1 = 2.1186$$

Therefore, the sensible heat of the flue gas leaving Boiler I is

$$q = [(1 - 0.5004)(1.4 * 2.1186 - 0.13) + 0.5] * 4.187 * 158$$

$$q = 1268.11 \text{ kJ / kg}$$

The three other losses are taken in to account by means of coefficients applied to the total quantity of heat which is still available after the first three losses: [26]

$\alpha$ =coefficient taking into account losses by unburnt solids

$\beta$ = coefficient taking into account losses due to radiation

$\eta$ = coefficient taking into account losses due to incomplete combustion

The quantity of heat remaining to be transferred to the steam is, therefore, given by the expression:

$$M_v = (4250 - 1200 * s - 4850 * w - q[\text{kcal / kg}])\alpha\beta\eta * 4.187 \text{ [kJ / kg]} \quad (4-24)$$

where:

$M_v$ = heat transferred to the steam per kg of bagasse burnt

w = moisture of bagasse

s = sucrose per unit bagasse

q = sensible heat of the flue gases

$\alpha = 0.94$  for Ward furnaces [26]

$\beta = 0.97$  based on [26] and Figure 4.1-12

$\eta = 0.98$  [26]

$$M_v = (4250 - 1200 * 0.02485 - 4850 * 0.5004 - 302.87) * 0.94 * 0.97 * 0.98 * 4.187$$

$$M_v = 5575.99 \text{ kJ / kg}$$

The overall efficiency of Boiler I is, therefore,

$$\eta_1 = \frac{M_v}{GCV \text{ of bagasse}} * 100\% = \frac{5575.99}{9497.54} * 100\% = 58.7\% \quad (4-25)$$

The average amount of bagasse consumed per day by this boiler is calculated with the help of software. The inputs to and outputs from the software are shown below. [27]

**Cane**

Fibre%Cane

Milling

Diffusion

---

**Bagasse**

Moisture%Bagasse

Ash%Bagasse

Brix%Bagasse

---

**Steam and Water**

Steam Pressure  bar abs

Steam Temp  °C

Feed Water Temp  °C

---

**Boiler Efficiency**

Boiler Efficiency  %

FIGURE 4.1-14: Inputs to the Software for Boiler I

**TABLE 4.1-13:** Outputs from the Software for Boiler I

Bagasse Moisture	50.04 %
Ash in Bagasse	2.5 %
Brix in Bagasse	3.57 %
Fibre in Cane	13.66 %
Fibre Lost in Juice	2 kg/100kg cane
Boiler Efficiency	58.7 %
Bagasse HCV	9193 kJ/kg
Evaporation Coefficient	1.97 ton steam/ton bagasse
Steam% Cane	0.52 ton steam/ton cane

Table 4.1-13 gives the quantity of bagasse that is sufficient to produce a unit mass of steam.

The quantity of steam that is required is determined by the design of the juice heating, evaporation and pan boiling parts of the factory, and the average rate is 20 tons/hr as shown in Table 4.1-8.

The Required Bagasse amount for Boiler I [ $RB_1$ ] is:

$$RB_1 = \frac{m_{steam1}(h_{st} - h_{fw})}{\eta_1 * HCV} \quad (4-26)$$

where:

$RB_1$  is the bagasse required by the 1<sup>st</sup> boiler

$x_1$  is the boiler evaporation coefficient from Table 4.1-13

$h_{st}$  is enthalpy of the steam at boiler outlet

$h_{fw}$  is enthalpy of the feed water

$m_{steam1}$  is the mass flow rate of the steam from Boiler I

$$\text{The boiler evaporation coefficient, } x_1 = \frac{\eta_1 * HCV}{(h_{st} - h_{fw})} \quad (4-27)$$

$$RB_1 = \frac{m_{steam1}}{x_1} \quad (4-28)$$

$$RB_1 = \frac{20}{1.97} = 10.15 \text{ tons / hr}$$

### Boiler II:

The explanation is the same as Boiler I but the different figures are shown below.

The excess air is [Refer Table 4.1-9 for the values]

$$\%Excess \text{ Air} = \frac{\%O_2 - \frac{\%CO}{2}}{20.9 - \left(\%O_2 - \frac{\%CO}{2}\right)} \times 100 \quad (4-29)$$

$$\%Excess \text{ Air} = \frac{11 - \frac{0.47}{2}}{20.9 - \left(11 - \frac{0.47}{2}\right)} \times 100$$

$$\%Excess \text{ Air} = 106.21 \%$$

Hence, the excess air coefficient,  $m$ , is

$$m = \frac{\%Exces \text{ Air}}{100} + 1 \quad (4-30)$$

$$m = \frac{111.86}{100} + 1 = 2.0622$$

Therefore, the sensible heat of the flue gas leaving the boiler is

$$q = [(1 - w)(1.4m - 0.13) + 0.5] * 4.187 * T \quad [kJ / kg] \quad (4-31)$$

$$q = [(1 - 0.5004)(1.4 * 2.0622 - 0.13) + 0.5] * 4.187 * 146.5$$

$$q = 1151.6 \text{ kJ / kg}$$

The heat transferred to the steam per kg of bagasse burnt

$$M_v = (4250 - 1200 * s - 4850 * w - q[kcal / kg])\alpha\beta\eta * 4.187 \quad [kJ / kg] \quad (4-32)$$

$$M_v = (4250 - 1200 * 0.02485 - 4850 * 0.5004 - 275.04) * 0.94 * 0.97 * 0.98 * 4.187$$

$$M_v = 5680.1 \text{ kJ / kg}$$

The overall efficiency of Boiler II is

$$\eta_2 = \frac{M_v}{GCV \text{ of bagasse}} * 100\% = \frac{5680.1}{9497.54} * 100\% = 59.8\% \quad (4-33)$$

The inputs to and outputs from the software are shown below.

**Cane**

Fibre%Cane

Milling  
 Diffusion

---

**Bagasse**

Moisture%Bagasse

Ash%Bagasse

Brix%Bagasse

---

**Steam and Water**

Steam Pressure  bar abs

Steam Temp  °C

Feed Water Temp  °C

---

**Boiler Efficiency**

Boiler Efficiency  %

FIGURE 4.1-15: Inputs to the Software for Boiler II

TABLE 4.1-14: Outputs from the Software for Boiler II

Bagasse Moisture	50.04 %
Ash in Bagasse	2.5 %
Brix in Bagasse	3.57 %
Fibre in Cane	13.66 %
Fibre Lost in Juice	2 kg/100kg cane
Boiler Efficiency	59.8 %
Bagasse HCV	9193 kJ/kg
Evaporation Coefficient	2.00 ton steam/ton bagasse
Steam%Cane	0.53 ton steam/ton cane

Table 4.1-14 gives the quantity of bagasse that is sufficient to produce a unit mass of steam. The average steam generation of Boiler II is 20 tons/hr as shown in Table 4.1-8.

The Required Bagasse amount for Boiler II [ $RB_2$ ] is:

$$RB_2 = \frac{m_{steam2}(h_{st} - h_{fw})}{\eta_2 * HCV} \quad (4-34)$$

where:

$RB_2$  is the bagasse required by the 2<sup>nd</sup> boiler

$x_2$  is the boiler evaporation coefficient from Table 4.1-14

$h_{st}$  is enthalpy of the steam at boiler outlet

$h_{fw}$  is enthalpy of the feed water

$m_{steam2}$  is the mass flow rate of the steam from Boiler II

The boiler evaporation coefficient,  $x_2 = \frac{\eta_2 * HCV}{(h_{st} - h_{fw})}$  (4-35)

$$RB_2 = \frac{m_{steam2}}{x_2} \quad (4-36)$$

$$RB_2 = \frac{20}{2} = 10 \text{ tons / hr}$$

**Boiler III:**

The explanation is the same as Boiler I but the different figures are shown below.

The excess air is [Refer Table 4.1-9 for the values]

$$\%Excess\ Air = \frac{\%O_2 - \frac{\%CO}{2}}{20.9 - \left(\%O_2 - \frac{\%CO}{2}\right)} \times 100 \quad (4-37)$$

$$\%Excess\ Air = \frac{12.06 - \frac{0.53}{2}}{20.9 - \left(12.06 - \frac{0.53}{2}\right)} \times 100$$

$$\%Excess\ Air = 129.5\%$$

Hence, the excess air coefficient,  $m$ , is

$$m = \frac{\%Exces\ Air}{100} + 1 \quad (4-38)$$

$$m = \frac{111.86}{100} + 1 = 2.295$$

Therefore, the sensible heat of the flue gas leaving the boiler is

$$q = [(1 - w)(1.4m - 0.13) + 0.5] * 4.187 * T \quad [kJ / kg] \quad (4-39)$$

$$q = [(1 - 0.5004)(1.4 * 2.295 - 0.13) + 0.5] * 4.187 * 151$$

$$q = 1289.93 \text{ kJ/kg}$$

The heat transferred to the steam per kg of bagasse burnt

$$M_v = (4250 - 1200 * s - 4850 * w - q[\text{kcal/kg}])\alpha\beta\eta * 4.187 \text{ [kJ/kg]} \quad (4-40)$$

$$M_v = (4250 - 1200 * 0.02485 - 4850 * 0.5004 - 308.08) * 0.94 * 0.97 * 0.98 * 4.187$$

$$M_v = 5556.51 \text{ kJ/kg}$$

The overall efficiency of Boiler III is

$$\eta_3 = \frac{M_v}{GCV \text{ of bagasse}} * 100\% = \frac{5556.51}{9497.54} * 100\% = 58.5\% \quad (4-41)$$

The inputs to and outputs from the software are shown below.

<b>Cane</b>	
Fibre%Cane	<input type="text" value="13.66"/>
<input checked="" type="radio"/> Milling	
<input type="radio"/> Diffusion	
<b>Bagasse</b>	
Moisture%Bagasse	<input type="text" value="50.04"/>
Ash%Bagasse	<input type="text" value="2.5"/>
Brix%Bagasse	<input type="text" value="3.57"/>
<b>Steam and Water</b>	
Steam Pressure	<input type="text" value="22"/> bar abs
Steam Temp	<input type="text" value="372.5"/> °C
Feed Water Temp	<input type="text" value="104"/> °C
<b>Boiler Efficiency</b>	
Boiler Efficiency	<input type="text" value="58.5"/> %
<input type="button" value="go"/>	

FIGURE 4.1-16: Inputs to the Software for Boiler III

TABLE 4.1-15: Outputs from the Software for Boiler III

Bagasse Moisture	50.04 %
Ash in Bagasse	2.5 %
Brix in Bagasse	3.57 %
Fibre in Cane	13.66 %
Fibre Lost in Juice	2 kg/100kg cane
Boiler Efficiency	58.5 %
Bagasse HCV	9193 kJ/kg
Evaporation Coefficient	1.96 ton steam/ton bagasse
Steam%Cane	0.52 ton steam/ton cane

Table 4.1-15 gives the quantity of bagasse that is sufficient to produce a unit mass of steam. The average steam generation rate is 20 tons/hr from Boiler III as shown in Table 4.1-8.

The Required Bagasse amount for Boiler III [ $RB_3$ ] is:

$$RB_3 = \frac{m_{steam3}(h_{st} - h_{fw})}{\eta_3 * HCV} \quad (4-42)$$

where:

$RB_3$  is the bagasse required by the 3<sup>rd</sup> boiler

$x_3$  is the boiler evaporation coefficient from Table 4.1-15

$h_{st}$  is enthalpy of the steam at boiler outlet

$h_{fw}$  is enthalpy of the feed water

$m_{steam3}$  is the mass flow rate of the steam

The boiler evaporation coefficient,  $x_3 = \frac{\eta_3 * HCV}{(h_{st} - h_{fw})}$  (4-43)

$$RB_3 = \frac{m_{steam3}}{x_3} \quad (4-44)$$

$$RB_3 = \frac{20}{1.96} = 10.2 \text{ tons / hr}$$

### Boiler IV:

The explanation is the same as Boiler I but the different figures are shown below.

The excess air is [Refer Table 4.1-9 for the values]

$$\%Excess\ Air = \frac{\%O_2 - \frac{\%CO}{2}}{20.9 - \left(\%O_2 - \frac{\%CO}{2}\right)} \times 100 \quad (4-45)$$

$$\%Excess\ Air = \frac{8.5 - \frac{1.2}{2}}{20.9 - \left(8.5 - \frac{1.2}{2}\right)} \times 100$$

$$\%Excess\ Air = 60.77\%$$

Hence, the excess air coefficient,  $m$ , is

$$m = \frac{\%Exces\ Air}{100} + 1 \quad (4-46)$$

$$m = \frac{111.86}{100} + 1 = 1.608$$

Therefore, the sensible heat of the flue gas leaving the boiler is

$$q = [(1 - w)(1.4m - 0.13) + 0.5] * 4.187 * T \quad [kJ / kg] \quad (4-47)$$

$$q = [(1 - 0.5004)(1.4 * 1.608 - 0.13) + 0.5] * 4.187 * 145$$

$$q = 946.95 \text{ kJ/kg}$$

The heat transferred to the steam per kg of bagasse burnt

$$M_v = (4250 - 1200 * s - 4850 * w - q[\text{kcal/kg}])\alpha\beta\eta * 4.187 \text{ [kJ/kg]} \quad (4-48)$$

$$M_v = (4250 - 1200 * 0.02456 - 4850 * 0.5004 - 226.16) * 0.94 * 0.97 * 0.98 * 4.187$$

$$M_v = 5864.3 \text{ kJ/kg}$$

The overall efficiency of Boiler IV is

$$\eta_4 = \frac{M_v}{GCV \text{ of bagasse}} * 100\% = \frac{5864.3}{9497.54} * 100\% = 61.75\% \quad (4-49)$$

The inputs to and outputs from the software are shown below.

<b>Cane</b>	
Fibre%Cane	<input type="text" value="13.66"/>
<input checked="" type="radio"/> Milling	
<input type="radio"/> Diffusion	
<b>Bagasse</b>	
Moisture%Bagasse	<input type="text" value="50.04"/>
Ash%Bagasse	<input type="text" value="2.5"/>
Brix%Bagasse	<input type="text" value="3.57"/>
<b>Steam and Water</b>	
Steam Pressure	<input type="text" value="23"/> bar abs
Steam Temp	<input type="text" value="378"/> °C
Feed Water Temp	<input type="text" value="104"/> °C
<b>Boiler Efficiency</b>	
Boiler Efficiency	<input type="text" value="61.75"/> %
<input type="button" value="go"/>	

FIGURE 4.1-17: Inputs to the Software for Boiler IV

TABLE 4.1-16: Outputs from the Software for Boiler IV

Bagasse Moisture	50.04 %
Ash in Bagasse	2.5 %
Brix in Bagasse	3.57 %
Fibre in Cane	13.66 %
Fibre Lost in Juice	2 kg/100kg cane
Boiler Efficiency	61.75 %
Bagasse HCV	9193 kJ/kg
Evaporation Coefficient	2.06 ton steam/ton bagasse
Steam%Cane	0.55 ton steam/ton cane

Table 4.1-16 gives the quantity of bagasse that is sufficient to produce a unit mass of steam. The average steam generation is 50 tons/hr from Boiler IV as shown in Table 4.1-8.

The Required Bagasse amount for Boiler IV [ $RB_4$ ] is:

$$RB_4 = \frac{m_{steam4}(h_{st} - h_{fw})}{\eta_4 * HCV} \quad (4-50)$$

where:

$RB_4$  is the bagasse required by the 4<sup>th</sup> boiler

$x_4$  is the boiler evaporation coefficient from Table 4.1-16

$h_{st}$  is enthalpy of the steam at boiler outlet

$h_{fw}$  is enthalpy of the feed water

$m_{steam4}$  is the mass flow rate of the steam

The boiler evaporation coefficient,  $x_4 = \frac{\eta_4 * HCV}{(h_{st} - h_{fw})}$  (4-51)

$$RB_4 = \frac{m_{steam4}}{x_4} \quad (4-52)$$

$$RB_4 = \frac{50}{2.06} = 24.3 \text{ tons / hr}$$

#### 4.1.7 The Current Excess Bagasse in MSF

The total bagasse requirement (*TBR*) of the power plant per hour is computed as the sum of the bagasse consumption of the four boilers.

$$TBR = RB_1 + RB_2 + RB_3 + RB_4 \quad (4-53)$$

$$TBR = 10.15 + 10 + 10.2 + 24.3$$

$$TBR = 54.65 \text{ tons / hr}$$

The surplus bagasse (*SBA*) is, therefore,

$$SBA = TBP - TBR \quad (4-54)$$

*TBP* (total bagasse produced) is from equation (4-12)

$$SBA = 66 - 54.65 = 11.35 \text{ tons / hr}$$

On daily basis, the average bagasse production is 1582.31 tons per day, the total bagasse requirement of the power plant currently is 1311.6 tons per day and the surplus bagasse of the plant is 272.4 tons per day which is 17.2% of the bagasse produced.

Annually, the average bagasse production is 330,544.56 tons, the total bagasse requirement of the power plant is 273,993.24 tons and the excess bagasse in the plant is 56,611.32 tons which is 17.2% of the bagasse produced. These figures are determined at the current situation of the plant where the average evaporation coefficient of the boilers and the moisture % bagasse are 1.998 tons of steam per ton of bagasse and 50.04 %, respectively.

### 4.1.8 The Current Cogeneration Efficiency

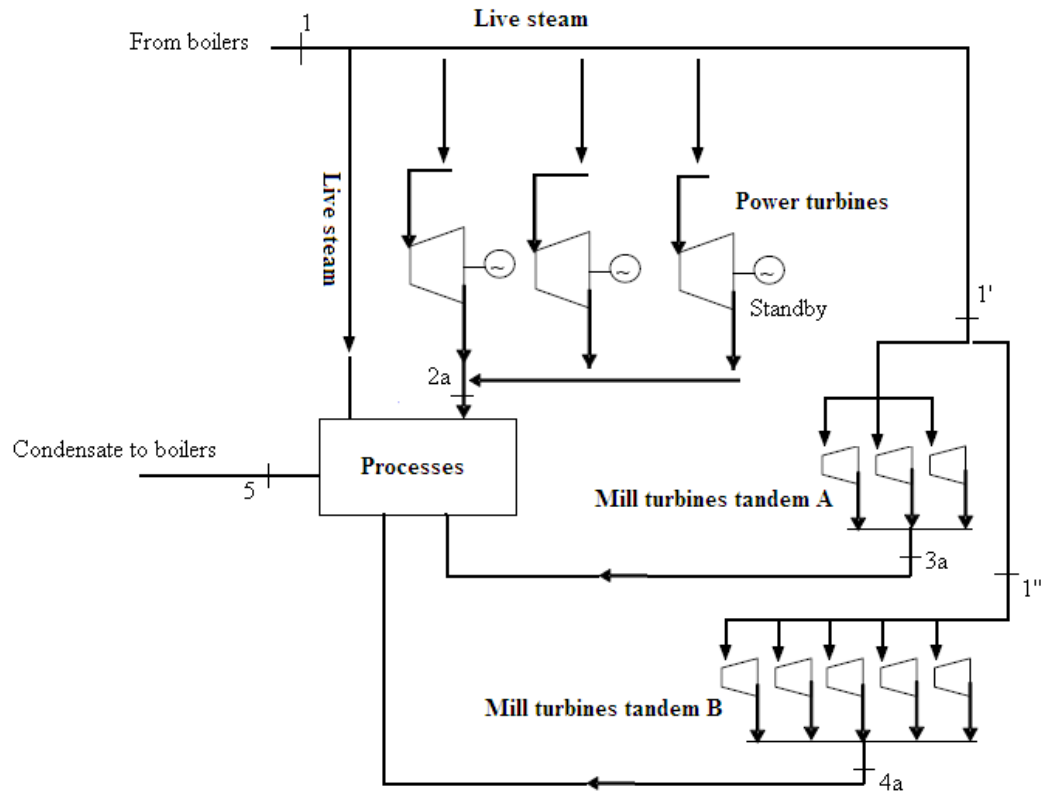


FIGURE 4.1-18: Schematic Layout of the Steam Distribution and Consuming Units

The electrical power generated from the power turbines is

$$P_{elect} = 5455.96 \text{ kW}$$

The mechanical power output from the mill turbines are

From Tandem A mill turbines

Mill No.1 450 kW

Mill No.2 375 kW

Mill No.3 337.5 kW

From Tandem B mill turbines

Mill No.1 493 kW

Mill No.2-5 370 kW

Therefore,  $P_{\text{mech}}=450+375+337.5+493+4*370=3135.5$  kW

The process heat flow is:

$$\dot{Q}_{\text{process}} = m_{\text{makeuplivesteam}}(h_1 - h_5) + m_{\text{exhaust1}}(h_{2a} - h_5) + m_{\text{exhaust2}}(h_{3a} - h_5) + m_{\text{exhaust3}}(h_{4a} - h_5)$$

$m_{\text{makeuplivesteam}} = 4.69$  kg / sec Make up live steam to processes

$m_{\text{exhaust1}} = 15.56$  kg / sec Exhaust from power turbines

$m_{\text{exhaust2}} = 3.33$  kg / sec Exhaust from tandem A mill turbines

$m_{\text{exhaust3}} = 6.39$  kg / sec Exhaust from tandem B mill turbines

$h_1 = 3170.99$  kJ/kg,  $h_{2a} = 2796.86$  kJ/kg,  $h_{3a} = 2788.96$  kJ/kg,

$h_{4a} = 2780.97$  kJ/kg,  $h_5 = 368.58$  kJ/kg

Hence,  $\dot{Q}_{\text{process}} = 74402.38$  kW

The total useful power is

$$P_{\text{output}} = P_{\text{elect}} + P_{\text{mech}} + \dot{Q}_{\text{process}}$$

$$P_{\text{output}} = 5455.96 + 3135.5 + 74402.38$$

$$P_{output} = 82993.84 \text{ kW}$$

Heating power in bagasse,

$$\dot{Q}_{bagasse} = m_{bagasse} * LCV_{bagasse}$$

$$\dot{Q}_{bagasse} = (54.65 / 3.6) * 7508.3$$

$$\dot{Q}_{bagasse} = 113980.17 \text{ kW}$$

The power generation efficiency is

$$\eta_{pgen} = \frac{P_{elect} + P_{mech}}{\dot{Q}_{bagasse}} * 100\% = \frac{5455.96 + 3135.5}{113980.17} * 100\% = 7.54\%$$

The cogeneration plant efficiency is

$$\eta_{cog} = \frac{P_{output}}{\dot{Q}_{bagasse}} * 100\% = \frac{82993.84}{113980.17} * 100\% = 72.8\%$$

## CHAPTER FIVE

### 5 PROPOSED SOLUTIONS FOR ENHANCING POWER GENERATION

#### 5.1 Using Bagasse Dryer

Drying generally refers to the removal of moisture from a solid by evaporation. Based on the mode of heat transfer, bagasse dryers can be classified into two types.

- i. Indirect or non-contact dryers, and
- ii. Direct or contact dryers.

Both indirect drying and direct drying can be attempted for drying of bagasse. By reducing the moisture content of bagasse, boiler efficiency can be greatly improved resulting in excess bagasse being available for generating additional steam. Moreover, this process can result in enhanced level of electricity exported to the grid or used for field pump stations. Bagasse drying by using flue gas is widely applicable in countries like Cuba, Australia, India, Brazil and USA. [29]

The most widely applicable bagasse drying method in many countries is by using the flue gas in pneumatic bagasse dryer. For instance, Santo Antonio Sugar Factory in Brazil increases steam production by 16% by drying the bagasse from 52% to 40% moisture. Salerno & Santana (1986) developed pneumatic dryer that reduced the moisture content from 47% to 35% with an inlet gas temperature of 250 °C.

##### 5.1.1 Indirect Bagasse Dryers

They are also called as non-adiabatic units, where the heat transfer medium is separated from the product to be dried by a metal wall. In the case of drying of bagasse, the heat transfer is only through conduction and forced convection. No

radiative heat transfer takes place because of lower temperature levels of operation.

As literatures prove, even after discounting for the energy of steam used and the electrical power required for the drive of dryer motor, there can be significant energy economy because of increased boiler efficiency and increased boiler steam output. The increase in boiler efficiency and steam to bagasse ratio because of lower moisture content in bagasse used is shown in Table 5.1-1.

A typical indirect dryer for bagasse application can be a bin dryer. The large bin is kept vertical with large diameter (100 or 150 mm) pipes passing along the vertical axis at a pitch of 450 to 600 mm and the bin circumference is also lined with vertical steam pipes. The pipes are fed at the top with low pressure steam with radial outlets from a common feed header, reaching to individual pipes. The pipes are again connected together at the bottom end and the condensate removed out of the system. The bagasse is charged to the dryer at the top from belt conveyors. The bagasse descends vertically down to the bottom where it is extracted by a bagasse extractor. During its travel down the container bin, the bagasse gets dried by physical contact with the steam pipes and the liberated water vapor travels up and out of the container bin. This can easily be tried in MSF which is a promising feature.

### **5.1.2 Direct Bagasse Dryers**

Direct dryers or adiabatic or contact type dryers transfer heat by direct contact of the product with the hot gases. The gas transfers sensible heat to provide the heat of vaporization of the moisture present in the solid. It is possible to obtain some non luminous radiation heat transfer benefit also in this case, since the moisture content in bagasse is quite high. Direct heating is preferred wherever feasible, for the following reasons:

- i) Rate of heat transfer is high due to direct contact between the flue gas and the raw material.
- ii) Short residence time
- iii) Uniform drying

Drum type rotary dryers can be selected for direct drying bagasse. The waste flue gases at boiler outlet or other suitable temperature level can be used for this purpose. Generally, rotary dryers operate in concurrent mode to avoid possibility of ignition. However, since bagasse contains very high moisture and the waste gases contain significantly low quantities (less than 8% by weight, if the excess air level in MSF is rectified) of oxygen, a counter current dryer can be advantageously adopted to save on cost and space for dryer installation.

The main component of this dryer is a steel shell set up on rollers by means of bandages (hoops) located in the shell. The cylindrical chamber is usually inclined with a slope to the horizontal so that the solids slowly progress through the dryer under gravity, but the characteristic action of the dryer is provided by the longitudinal lifting baffles which collect the material and subsequently shower it through the flue gas stream as the barrel rotates. These lifting baffles are fastened to the inner surface of the drum.

Bagasse drying is a concept which deserves additional attention and developmental efforts. Two arrangements, sequence arrangement and parallel arrangement are proposed, Figure 5.1-1 and Figure 5.1-2.

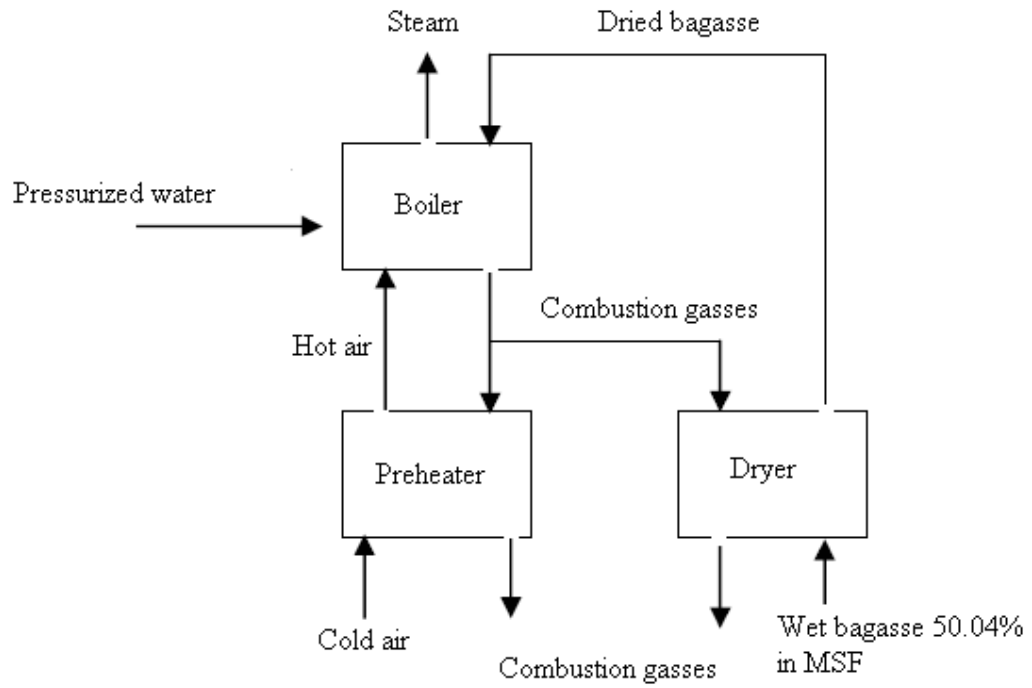
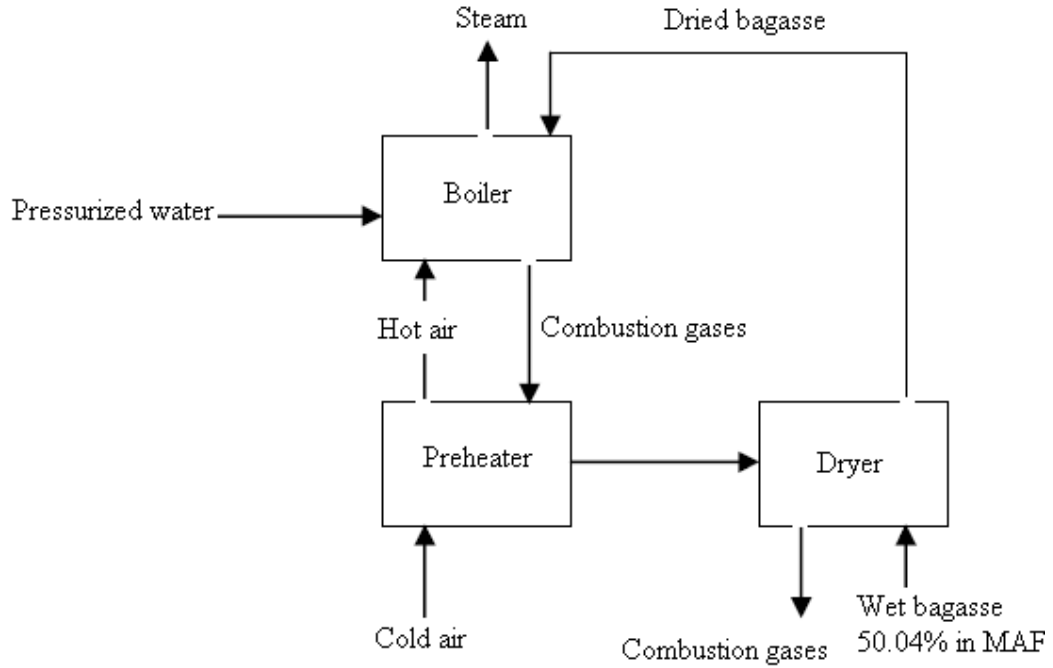


FIGURE 5.1-1: Parallel Arrangement Flowchart



**FIGURE 5.1-2:** Sequence Arrangement Flowchart

The following table shows different values of LCV, HCV, Boiler Efficiency, and Steam to Bagasse ratio corresponding to possible values of moisture % bagasse which can be obtained by drying the bagasse in MSF.

**TABLE 5.1-1: LCV, HCV, Boiler Efficiency, and Steam to Bagasse Ratio Corresponding to Possible Values of Moisture % Bagasse without Affecting the Current Excess Air Level of each Boiler<sup>15</sup>**

Moisture % bagasse	LCV [kJ/kg]	HCV [kJ/kg]	Boiler Efficiency [%]				Steam to Bagasse Ratio (Boiler evaporation coefficient)			
			B1	B2	B3	B4	B1	B2	B3	B4
<b>50.04</b>	<b>7508.3</b>	<b>9497.5</b>	<b>58.7</b>	<b>59.8</b>	<b>58.5</b>	<b>61.7</b>	<b>1.97</b>	<b>2.00</b>	<b>1.96</b>	<b>2.06</b>
49.50	7618.0	9601.5	59.0	60.1	58.8	62.0	2.00	2.03	1.99	2.09
49.00	7719.5	9697.8	59.3	60.4	59.1	62.3	2.04	2.06	2.02	2.12
48.50	7821.0	9794.1	59.5	60.6	59.3	62.5	2.06	2.09	2.05	2.15
48.00	7922.6	9890.4	59.8	60.9	59.6	62.8	2.10	2.12	2.08	2.19
47.50	8024.1	9986.7	60.0	61.1	59.8	63.0	2.12	2.15	2.11	2.21
47.00	8125.6	10083.0	60.3	61.3	60.1	63.3	2.16	2.18	2.14	2.25
46.50	8227.2	10179.4	60.5	61.6	60.3	63.5	2.19	2.21	2.17	2.28
46.00	8328.7	10275.7	60.7	61.8	60.5	63.7	2.21	2.24	2.20	2.31
45.50	8430.2	10372.0	61.0	62.0	60.8	64.0	2.25	2.27	2.23	2.34
<b>45.00</b>	<b>8531.8</b>	<b>10468.3</b>	<b>61.2</b>	<b>62.3</b>	<b>61.0</b>	<b>64.2</b>	<b>2.28</b>	<b>2.31</b>	<b>2.26</b>	<b>2.37</b>

<sup>15</sup> In the table B1, B2, B3, and B4 refer to the four boilers at MSF

Currently, the moisture % bagasse in MSF is 50.04% as obtained from the collected data in section 4.1.3. If bagasse dryers are used to lower the moisture content, the boilers efficiencies can be improved as shown in the above table. If we can reduce the moisture percent up to 45%, as most foreign sugar factories achieve it, the boilers at MSF will have better efficiencies as shown in the last row. The steam to bagasse ratios will also be improved.

## **5.2 Reducing the Excess Air Level**

Excess air is an expression of how much more air is used for the combustion than strictly necessary. The calculation is based on the measured level of oxygen in the flue gases and the known concentration of oxygen in the air. In practice, a certain level of excess air is needed in all cases to ensure complete combustion. This excess air is around 3-5 % for liquid and gaseous fuels and approximately 11% for solid fuels, depending on the preparation of the fuel. Unnecessary excess air is basically a factor to be avoided. The unneeded air simply carries heat up the stack away from the burner and is wasted. A fine line must always be drawn between too much excess air and incomplete combustion, which will manifest in high levels of carbon monoxide.

By reducing the excess air level of operation in the boilers at MSF, the efficiencies of the boilers will be improved. From foreign sugar mills experience, the excess air levels can be rectified up to 50%. Although, there are evidences that the excess air level can go as low as 30 to 35% [32].

**TABLE 5.2-1:** Recommended Values of Excess Air Coefficients [32]

Sl. No.	Types of fuel/firing systems	Excess air coefficient, $m$
1.	Bagasse/wood/bark on grates/stokers	1.30-1.40
2.	Coal/Lignite on grates/stokers	1.30-1.40
3.	Pulverized coal firing/dry bottom	1.18-1.25
4.	Pulverized coal firing/wet bottom	1.12-1.20
5.	Fluidized bed combustion	1.10-1.20
6.	Oil firing	1.02-1.10
7.	Natural gas firing	1.05-1.10

By reducing the excess air level below 50% (at most 50%) which is practiced by some foreign sugar mills, Metahara Sugar Factory can save bagasse which can be used to produce additional steam. These are depicted in the following tables for the four boilers.

**TABLE 5.2-2: Boiler Efficiency and Steam to Bagasse Ratio of the Boilers at 50 % Excess Air Level and Different Moisture % Bagasse**

Moisture % bagasse	Boiler Efficiency [%]				Steam to Bagasse Ratio (Boiler evaporation coefficient)			
	B1	B2	B3	B4	B1	B2	B3	B4
<b>50.04</b>	<b>61.4</b>	<b>62.1</b>	<b>61.8</b>	<b>62.2</b>	<b>2.06</b>	<b>2.08</b>	<b>2.07</b>	<b>2.07</b>
49.50	61.7	62.4	62.1	62.5	2.1	2.11	2.10	2.11
49.00	62.0	62.6	62.4	62.7	2.13	2.14	2.13	2.14
48.50	62.2	62.9	62.6	63.0	2.16	2.17	2.16	2.17
48.00	62.5	63.1	62.9	63.2	2.19	2.20	2.20	2.20
47.50	62.7	63.4	63.1	63.5	2.22	2.23	2.23	2.23
47.00	63.0	63.6	63.4	63.7	2.25	2.26	2.26	2.26
46.50	63.2	63.9	63.6	63.9	2.28	2.30	2.30	2.29
46.00	63.4	64.1	63.8	64.2	2.31	2.33	2.32	2.33
45.50	63.7	64.3	64.1	64.4	2.35	2.36	2.35	2.36
<b>45.00</b>	<b>63.9</b>	<b>64.5</b>	<b>64.3</b>	<b>64.6</b>	<b>2.38</b>	<b>2.39</b>	<b>2.38</b>	<b>2.39</b>

In addition to the moisture content of the bagasse, if the excess air levels are corrected to 50%, the boilers will have better efficiencies as shown in the table above. The steam to bagasse ratios will also be improved greatly.

Hence, taking 45% bagasse moisture content and 50% excess air, the bagasse consumption of the boilers will be forecasted to be:

$$RB_i = \frac{m_{steami}}{x_i} \quad (5-1)$$

where:  $RB_i$  is the bagasse required by the  $i^{\text{th}}$  boiler

$x_i$  is the boiler evaporation coefficient from Table 5.2-2

$m_{steami}$  is the mass flow rate of steam from  $i^{\text{th}}$  boiler

$$RB_1 = \frac{20}{2.38} = 8.40 \text{ tons / hr} \quad (5-2)$$

$$RB_2 = \frac{20}{2.39} = 8.37 \text{ tons / hr} \quad (5-3)$$

$$RB_3 = \frac{20}{2.38} = 8.40 \text{ tons / hr} \quad (5-4)$$

$$RB_4 = \frac{50}{2.39} = 20.9 \text{ tons / hr} \quad (5-5)$$

The total bagasse required ( $TBR$ ) will be:

$$TBR = RB_1 + RB_2 + RB_3 + RB_4 \quad (5-6)$$

$$TBR = 8.4 + 8.37 + 8.4 + 20.9$$

$$TBR = 46.07 \text{ tons / hr}$$

The forecasted surplus bagasse is, therefore,

$$SBA = TBP - TBR \quad (5-7)$$

$TBP$  (total bagasse produced) is from equation (4-12)

$$SBA = 66 - 46.07 = 19.93 \text{ tons / hr}$$

Therefore, on daily basis, the average bagasse produced is 1582.31 tons per day (from equation (4-12)), the total bagasse requirement of the power plant, as forecast above, will be 1105.68 tons per day and the surplus bagasse of the plant will be 478.32 tons per day which is 30.23% of the bagasse produced. These measures will increase the current excess bagasse from 272.4 to 478.32 tons per day, i.e. from 17.2% to 30.23% of the bagasse produced.

### **5.3 Operating Parameters of the Turbines**

Currently, the turbines are operating below the rated live steam pressure and temperature. If corrective measures are taken to increase the live steam pressure to 22 bars (abs) and the live steam temperature to 370 °C, there will be an increase in the efficiency of the turbines. The power output from the generators will increase by 103 kW (refer section 4.1.4.2).

### **5.4 Improving the Power Factors of the Electric Motors**

The power factors of the electric motors (see Table 4.1-11) can further be improved through proper application of the power factor correction capacitors. If the lower power factors can be improved to at least 0.9, 346.73 kW power (3,037,354.8 kWh per year) can be saved.

### **5.5 Cumulative Effects towards Additional Power Generation**

Additional electric power generated, if the turbines operate at improved efficiency, is 51.5 kW. And if the power factors of the electric motors are corrected at least to 0.9, 346.73 kW power can be saved. Therefore, the kWh per year will be

$$(51.5 + 346.73) \times 365 \times 24 = 6,967,090.8 \text{ kWh per year} \quad (5-8)$$

The amount of surplus bagasse is 99,921.05 tons per year.

The amount of steam to be generated by using this surplus bagasse is

$$99,921.05 \times 2.39 = 238,811.31 \text{ tons/year. (2.39 is the average evaporation coefficient)}$$

The generated steam is equivalent to  $238,811.31 / (365 \times 24) = 27$  tons of steam per hour, throughout the year.

The boilers are capable of generating this steam because they are currently generating less than their capacity, refer *Appendix A*.

**TABLE 5.5-1:** Current and Proposed Capacity of the Boilers

Boilers	Current Capacity [tons/hr]	Proposed Capacity [tons/hr]
Boiler I	20	25
Boiler II	20	26
Boiler III	20	26
Boiler IV	50	60
TOTAL	110	137

**TABLE 5.5-2:** Current and Proposed Specific Steam Consumptions

Power Turbines	Current Specific Steam Consumption [kg/kWh]	Proposed Specific Steam Consumption [kg/kWh]
Turbine I	10.264	10.07
Turbine II	10.264	10.07
Turbine III <sup>16</sup>	-	10.07

The additionally generated steam has the capacity to produce:

$$27 \text{ tons/steam per hr} \times 99.31 \text{ kWh/ton of steam} = 2681.4 \text{ kWh of energy per hour.}$$

The kWh energy throughout the year is:

$$2681.4 \times 365 \times 24 = 23,489,064.0 \text{ kWh per year} \quad (5-9)$$

The total kWh per year will be the sum of (5-8) and (5-9), i.e. 30,456,154.8 kWh per year, or 3476.73 kW of electricity.

Hence, additional 3476.73 kW of electricity can be generated if all the proposed energy saving opportunities are implemented. This can be achieved with the new proposed facilities like the bagasse dryers added to the existing energy facilities of the factory and taking energy efficiency corrective measures.

<sup>16</sup> It is a standby turbine but now it is proposed to be included in the system.

## 5.6 Cogeneration Efficiency after Improvement

The electrical power generation from the power turbines will be

$$P_{elect} = 5455.96 + 103 + 3476.73 = 9035.69 \text{ kW}$$

The mechanical power output will be

$$P_{mech} = 450 + 375 + 337.5 + 493 + 4 \times 370 = 3135.5 \text{ kW}$$

The process heat flow is (referring Figure 4.1-18):

$$\dot{Q}_{process} = m_{makeuplivesteam} (h_1 - h_5) + m_{exhaust1} (h_{2a} - h_5) + m_{exhaust2} (h_{3a} - h_5) + m_{exhaust3} (h_{4a} - h_5)$$

$$m_{makeuplivesteam} = 4.69 \text{ kg/sec} \quad \text{Make up live steam to processes}$$

$$m_{exhaust1} = 23.06 \text{ kg/sec} \quad \text{Exhaust from power turbines}$$

$$m_{exhaust2} = 3.33 \text{ kg/sec} \quad \text{Exhaust from tandem A mill turbines}$$

$$m_{exhaust3} = 6.39 \text{ kg/sec} \quad \text{Exhaust from tandem B mill turbines}$$

$$h_1 = 3178.26 \text{ kJ/kg}, \quad h_{2a} = 2785.28 \text{ kJ/kg}, \quad h_{3a} = 2788.96 \text{ kJ/kg},$$

$$h_{4a} = 2780.97 \text{ kJ/kg}, \quad h_5 = 368.6 \text{ kJ/kg}$$

$$\text{Hence, } \dot{Q}_{process} = 92381.54 \text{ kW}$$

The total useful power is

$$P_{output} = P_{elect} + P_{mech} + \dot{Q}_{process}$$

$$P_{output} = 9035.69 + 3135.5 + 92381.54$$

$$P_{output} = 104552.73 \text{ kW}$$

The heating power in bagasse will be,

$$\dot{Q}_{bagasse} = m_{bagasse} * LCV_{bagasse}$$

$$\dot{Q}_{bagasse} = (57.48 / 3.6) * 8531.8$$

$$\dot{Q}_{bagasse} = 136224.41 \text{ kW}$$

The power generation efficiency will be

$$\eta_{pgen} = \frac{P_{elect} + P_{mech}}{\dot{Q}_{bagasse}} * 100\% = \frac{9035.69 + 3135.5}{136224.41} * 100\% = 8.93\%$$

The cogeneration plant efficiency will be

$$\eta_{cog} = \frac{P_{output}}{\dot{Q}_{bagasse}} * 100\% = \frac{104552.73}{136224.41} * 100\% = 76.75\%$$

# CHAPTER SIX

## 6 FINANCIAL AND ECONOMIC ANALYSIS

Although it is possible to implement many energy efficiency strategies at little cost to the energy consumer, some efficiency strategies may require large amounts of capital. Such capital intensive investments in energy efficiency should be evaluated on the same basis as any other investment such as capacity expansion, modernization of process equipment, or new buildings. In many cases energy efficiency investments will be more attractive than other competing investment opportunities. If they are not, then the alternative investment should be made.

While some energy efficiency investments may be attractive at current energy prices, one should identify these potential investments in advance in order to facilitate timely implementation if energy prices increase in the future.

It is important that the cost and benefits of the energy economy measures identified in this paper be appraised using the most appropriate values and on a common basis. From the point of view of the factory, the appropriate values are financial i.e. the costs and benefits that would be recorded in the books of accounts but from broader view of the national economy as a whole the costs and benefits must be presented as economic or opportunity values (shadow prices). Explanation of financial values, shadow values and the technique of economic appraisal are given below. This chapter presents the economic and financial feasibility for the alternative energy efficiency improvement measures discussed in the previous chapter.

Financial values: In investment terms, financial values are based on quotations obtained from potential suppliers and modified to account for the cost of engineering and site supervision. A contingency sum is included to allow for any uncertainty in

the cost of procurement and installation.

Shadow values: The foreign exchange portion of material and transport costs is converted to local currency by applying a premium 30% relating to an official exchange rate of \$1=16.56 Birr (as on January 23, 2011).

Discount rate: A discount rate of 10% per year has been employed in the calculation of net present values and of internal rate of return.

Useful life: In general a useful life of 15 years has been assumed for energy economy measures.

Customs duty: It is believed that the equipment identified in the energy economy measures be imported duty free, because the sugar factory is owned by the government.

## **6.1 Economic Evaluation Methodology**

Two basic techniques have been employed in the analysis to drive indicators of financial and economic performance for the measures. The two techniques are the simple pay back method and the discounted cash flow analysis. These techniques are explained below.

### **I. Simple Payback Period**

The payback is defined as the period of time for the benefits following an investment to accumulate sufficiently to receive original investment. It is used in industry to provide an easy to understand indicator for short to medium term investments.

### **II. Discounted cash flow (DCF)**

Capital investment projects typically generates a serious of cash flows over an extensive period of time and given that money has a time value, the future sums arising have to be discounted at a compound rate to a present value before they can be compared with the investment cost. This form of analysis is more commonly applied

to long term investments and is generally preferred by international funding agencies. There are three principal variants of the DCF technique i.e.

- net present value (NPV)
- internal rate of return (IRR), and
- benefit to cost ratio (BCR)

The net present value (NPV) gives a quantity of money equal to the difference between the total benefits over the life time of the investment discounted to a reference date and the total disbursement discounted to the same date. Positive NPV indicates worthwhile investment.

The internal rate of return (IRR) represents the maximum effective percentage return on investment, where the investment will remain viable and therefore the decision regarding the viability of the investment can be made by comparing the IRR with the opportunity cost of capital.

The benefit to cost ratio (BCR) is the ratio of discounted benefits to discounted costs. The calculation of both NPV and BCR requires prior assumption to be made regarding the opportunity cost of capital i.e. discount rate. If the BCR value is greater than unity it implies that the investment is viable.

## **6.2 Investment Cost**

The total capital investment for retrofit measures is the sum of the direct cost (which is the purchased equipment costs and direct installation costs), indirect installation cost, contingency costs, sales taxes and freight. The purchased equipment costs (PEC's) used in this paper are based on the information found from machinery manufacturers on the internet.

Capital investment cost elements

Direct cost (DC)

Purchased equipment cost (PEC)

Direct installation cost (DIC)-15% of PEC

- Foundation & support
- Handling & erection
- Electrical, piping, painting

Indirect installation costs (IIC)-5% of PEC

- Engineering works
- Contractor fees
- Startup
- Performance test

Contingencies (C)-5% of PEC

- Equipment redesign & modification
- Cost escalation
- Delay in startup

Freight (2% of PEC)

The following table provides a list of various cost elements included in the capital costs.

**TABLE 6.2-1: Total Investment Cost for the Energy Efficiency Measures**

No.	Item	Cost in Birr
1	Direct costs	
	Purchased equipment cost (PEC)	16,600,000.00
	Direct installation cost (DIC)-15% of PEC	2,490,000.00
2	Indirect installation costs (IIC)-5% of PEC	830,000.00
3	Contingencies (C)-5% of PEC	830,000.00
4	Freight (2% of PEC)	332,000.00
	Total	21,082,000.00

### 6.3 Operating Cost

Direct annual costs (DC)

Utilities:

- Electricity: 0.4805 Birr/kWh

Operating labor

- Supervising labor: 40 Birr/day
- Operating labor: 20 Birr/day

Maintenance

- Maintenance labor: 15 Birr/day
- Maintenance materials: 100% of maintenance labor

Indirect annual costs (IC)

Overhead: 60% of operating labor

Insurance: 1% of capital cost

Depreciation: 15 years equipment life

Total annual operating cost=DC+IC

**TABLE 6.3-1: Annual Operating Cost for the Energy Efficiency Measures**

No.	Item	Unit	Quantity	Annual cost in Birr
1	Direct annual costs (DC)			
1.1	Utilities			
	Electricity: 0.4805 Birr/kWh	kWh	100,000	48,050.00
1.2	Operating labor			
	Supervising labor: 40 Birr/day	person	3	43,800.00
	Operating labor: 20 Birr/day	person	6	43,800.00
1.3	Maintenance			
	Maintenance labor: 15 Birr/day	person	3	16,425.00
	Maintenance materials: 100% of maintenance labor	-	-	16,425.00
2	Indirect annual costs (IC)			
	Overhead: 60% of operating labor	-	-	62,415.00
	Insurance: 1% of capital cost	-	-	210,820.00
	Depreciation: 15 years equipment life	-	-	1,405,466.67
<b>TOTAL</b>				<b>1,847,201.67</b>

## 6.4 Profitability Analysis

To see the profitability of the project analysis can be made by discounted cash flow methods such as NPV, IRR, and BCR methods. If all benefits and costs can be assigned monetary values, one can calculate the ratio of present value of net benefits to costs.

$$\text{Benefits to cost ratio} = \frac{\text{present worth of gross profit}}{\text{present worth of gross cost}}$$

If the ratio of B/C is  $>1$ , the project is profitable.

If the ratio of B/C is  $<1$ , the project is not profitable.

**TABLE 6.4-1: Discounted Cash Flow Analysis of the Investment (‘000)**

Item	Year										Total	
	0	1	2	3	4	5	6	7	8	9		10
Capital investment	21,082.00											
Operating cost		1,847.20	1,847.20	1,847.20	1,847.20	1,847.20	1,847.20	1,847.20	1,847.20	1,847.20	1,847.20	
salvage value											7,027.33	
Revenue (saving)	0.00	14,844.0	14,844.0	14,844.0	14,844.0	14,844.09	14,844.09	14,844.09	14,844.09	14,844.09	14,844.09	
Gross cost	21,082.0	1,847.20	1,847.20	1,847.20	1,847.20	1,847.20	1,847.20	1,847.20	1,847.20	1,847.20	1,847.20	39,554.01
Gross revenue	0.00	14,844.0	14,844.0	14,844.0	14,844.0	14,844.09	14,844.09	14,844.09	14,844.09	14,844.09	21,871.42	155,468.27
Net cash flow	-21,082.0	12,996.8	12,996.8	12,996.8	12,996.8	12,996.89	12,996.89	12,996.89	12,996.89	12,996.89	20,024.22	115,914.25
Discount factor	1.000	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	
Discounted cash flow	-21,082.0	11,814.1	10,735.4	9,760.66	8,876.87	8,071.07	7,330.24	6,667.40	6,069.54	5,510.68	7,729.35	61,483.45
P.W Gross cost	21,082.00	1,679.10	1,525.78	1,387.24	1,261.63	1,147.11	1,041.82	947.61	862.64	783.21	713.02	32,431.20
P.W Gross profit	0.00	13,493.2	12,261.2	11,147.9	10,138.5	9,218.18	8,372.06	7,615.02	6,932.19	6,293.89	8,442.37	93,914.66

The net present value, NPV, of the project = 61,483,458.31Birr

$$\text{Benefits to cost ratio} = \frac{\sum P.W \text{ of gross profit}}{\sum P.W \text{ of gross cost}}$$

$$\text{Benefits to cost ratio} = \frac{93,914.66}{32,431.20}$$

$$\text{Benefits to cost ratio} = 2.89$$

Since the net present value and the benefit to cost ratio is >1, this project will be profitable.

## 6.5 Payback Period

Here, the payback analysis is made for all energy economy measures i.e. the house keeping measures, the low cost measures and for the retrofit measures.

$$\text{payback (all measures)} = \frac{\text{total cost of all measures}}{\text{annual savings from the measures}}$$

$$\text{payback (all measures)} = \frac{22,929,201.67}{14,844,094.19}$$

$$\text{payback (all measures)} = 1.54 \text{ years}$$

# CHAPTER SEVEN

## **7 CONCLUSIONS, RECOMMENDATIONS AND FUTURE OUTLOOK**

Nowadays, sugar mills in many countries are contributing remarkable amount of electric energy to the nations in addition to sugar manufacturing and ethanol production. Moreover, for the factories to be competitive in the international market, they are giving due attention to utilize each by-product effectively and efficiently.

This paper has assessed the energy generation efficiency of Metahara Sugar Factory. Based on the data collected from the factory and the lesson learnt from the experiences of foreign sugar factories, analysis is done. While analyzing the data, problems are identified and possible solutions are proposed to enhance the power generation capacity of this factory.

The researcher has come up with the following conclusions and recommendations.

### **7.1 Conclusions**

From this research, and within the constraints of the study, the following observations are summarized.

Looking at the past ten seasons' data, the average TCD is found to be 5344.54 tons of cane which exceeded the designed capacity. The average TCD was increasing for the last nine seasons due to the increase in demand of sugar in the country. Hence, the factory is unquestionably in need of additional power to cope up with this increase in demand.

It is also observed that the power generation efficiency is quite low because of

- the higher moisture content of the bagasse, 50.04%, while most foreign sugar mills have attained 45% and below.
- the low pressure and relatively low temperature of the steam generated in the boilers. (20 bars and 365 °C at the inlet of the power turbines below its design parameters)
- the uncontrolled excess air level e.t.c...

The average steam generation efficiency of the boilers is between 58.7% - 61.7% at the current moisture % bagasse and excess air level. If the moisture % bagasse is improved to 45% while leaving the excess air level as it is, the efficiency of the boilers will be improved to 61%-64.2%.

The boilers efficiency will greatly improve (lie between 63.9% - 64.6%), if the excess air level is also regulated to 50% in addition to the moisture content of bagasse, now it reaches as high as 129% for the boiler whose furnace has direct contact with the open air (shown in Figure 4.1-13) and as low as 60.77% for the new boiler, Boiler IV.

If both bagasse moisture content and excess air levels are controlled to 45% and 50%, respectively, the steam to bagasse ratio (the boiler evaporation coefficient) will be improved from 1.97-2.06 to 2.38-2.39.

These will increase the amount of surplus bagasse to 99,921.05 tons per year, while it is currently 56,611.32 tons i.e. from 17.2% to 30.23% of the bagasse produced.

The amount of steam to be generated by using this surplus bagasse will be 238,811.31 tons/year. Using this steam, 23,489,064.0 kWh of energy will be produced throughout the year.

The power generation efficiency of the power turbines is found to be 76.4% at 20 bars and 365 °C live steam at inlet. This can be enhanced taking simple housekeeping measures to 77.15% by regulating the live steam pressure to 22 bars and temperature to 370 °C. Additional 103 kW power can be generated if the existing conditions of the turbines are improved.

If the lower power factors of the electric motors are improved through proper application of the capacitor banks to at least 0.9, 346.73 kW power (3,037,354.8 kWh per year of energy) can be saved.

Totally, additional 30,456,154.8 kWh per year of electricity can be generated if all the proposed energy saving opportunities are implemented which improve the cogeneration efficiency of the plant from 72.8% to 76.75%.

This will save the unnecessary cost of 14,844,094.19 Birr paid for electricity to power the irrigation pumps or help alleviate the additional power demand of the factory.

## **7.2 Recommendations**

In MSF less attention is given to energy generation and utilization efficiency. But for the sake of its survival and to contribute its part to the country's energy development goal, MSF should assess the generation and utilization efficiency and utilize their energy resources properly.

The factory is also losing huge amount of energy assets in the field. The sugar cane leaves and tops are very important fuels in many countries. So MSF should devise a mechanism to use these energy resources in the future.

Huge amount of molasses was being wasted due to absence of demand. But MSF has currently installed an ethanol distillery which needs more steam and electricity. Hence, the sugar factory needs to explore other energy sources like sugar cane leaves and tops other than bagasse to fuel the boilers.

The factory should properly set the mills (mill setting), to reduce the pol percent and moisture percent of the bagasse. It has to install a bagasse dryer which uses the energy of the flue gases and regulate the excess air level to the furnace to enhance the efficiency of the boilers. The boilers' furnaces should properly be sealed; it is observed that they are damaged.

### **7.3 Future Outlook**

Researches and developments must be conducted continuously towards energy generation and utilization efficiencies in the factory. If detailed energy audit were done, there would be further enhancement of the power generation and utilization efficiency. The detailed energy audit may show a number of rooms to be improved to minimize the energy losses and improve the productivity of the factory.

Future work can be done to enhance the electrical energy generation by reducing the electrical and thermal energy consumption of the factory. The electrical energy consumption can be reduced by installing of energy efficient equipments, correct sizing of the equipments or reducing the loss in the energy transmission areas. For example, variable frequency drive electric motors can be considered instead of the mill turbines, energy efficient gear systems should be tried. The thermal energy consumption of the processes in the factory should also be assessed thoroughly. The advantage of installing high pressure boilers instead of the existing low pressure boilers should be examined.

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## APPENDICES

### **Appendix A:** -Additional Factory Data, Metahara Sugar Factory, as on May 10, 2010.

The following average data were collected when the factory was operating at its full capacity (nearly 5000 TCD).

#### **1. Milling Plant**

Cane crushed	5000 TCD / 208 TCH on 24 Hrs basis
Fiber % cane	13.66%
Pol % bagasse	2.485
Moisture % bagasse	49.4
GCV of bagasse (kcal/kg)	2268.34
NCV of bagasse (kcal/kg)	1793.24
Bagasse % on cane	29.5%
HHV of furnace fuel, kcal/kg	10200
Cost of furnace fuel, birr/lt	10.043 Birr/liter
Cost of electricity (Birr/kwh)	0.4805

**2. Dry exhaust available from mills, boiler feed water pump turbine & power turbines including live make up steam:**

Dry exhaust pressure (inlet)	2.2 kg/cm <sup>2</sup> (abs)
Dry exhaust temperature (Inlet)	165 °C
De- super heated exhaust steam pressure	2.09 kg/cm <sup>2</sup> (abs)
De- super heating exhaust water temperature	120 °C
De- super heating water temperature	96 °C

**3. Sulphited juice heating**

It is heated by saturated exhaust steam from 69°C to 104°C.

Specific heat of juice	0.9kcal/kg.°C
Exhaust saturated steam pressure	2.09 kg/cm <sup>2</sup> (abs)
Exhaust saturated steam temperature	120 °C

**4. Raw (mixed) juice heating**

It is heated by 2<sup>nd</sup> effect vapor.

Raw juice inlet temperature	37°C
Raw juice out let temperature	74°C
Filtrate to be added on raw juice	12% on cane
Specific heat of juice	0.9 kcal/kg °C
Lime consumption	170.866 kg/100 ton of cane
Sulphur consumption	0.349 kg/ton of cane

**5. Clear juice heating**

It is heated by saturated exhaust steam.

Clear juice % cane	96 %
Saturated exhaust steam pressure	2.09 kg/cm <sup>2</sup> (abs)
Saturated exhaust steam temperature	120 °C
Clear juice in let temperature	83 °C
Clear juice out let temperature	114 °C
Specific heat of juice	0.9kcal/kg. °C

**6. Pan boiling**

It is boiled by vapor from vapor cell.

Vapor pressure	2.0 kg/cm <sup>2</sup> (abs)
Vapor temperature	113 °C – 115 °C
Vapor required per ton of A Massecuite	0.5 tons (Standard data)
Vapor required per ton of B Massecuite	0.4 tons (Standard data)
Vapor required per ton of C Massecuite	0.5 tons (Standard data)

**Appendix B:-** The boilers' design technical specifications and properties of the feed water, steam and flue gas in MSF

Description		Boilers # 1, 2 & 3	Boiler # 4
Steam generation (tons/hr)	NCR	20 – 25	45 – 55
	MCR	25 – 28	55 – 60
	Peak	30	65
Superheated Steam Temperature (°C)		375	380
Superheated Steam Pressure (kg/cm <sup>2</sup> )		22	23
Feed water temperature to dearator		90	95
Feed water temperature to economizer (°C)		103-105	103-105
Feed water temperature after economizer (°C)		120-130	120-130
Feed water pressure pump discharge (kg/cm <sup>2</sup> )		26	30
Feed water pressure to economizer (kg/cm <sup>2</sup> )		23-25	23-25
Inlet air temperature (°C)		170-210	220-260
Flue gas temperature before air heater (°C)		270-290	280-310
Flue gas temperature after air heater (°C)		170-190	180-200
Flue gas temperature at economizer outlet (°C)		130-150	130-150
Flue gas temperature to the atmosphere (°C)		145 – 160	145 - 160

**Appendix C:-** Questionnaire to collect data for the bagasse-fired steam boilers

1. Boiler No. \_\_\_\_\_
2. Type of boiler \_\_\_\_\_
3. Steam generation capacity \_\_\_\_\_ tons/hr
4. Total installed capacity of steam generation \_\_\_\_\_ tons/hr
5. Daily consumption of oil (for auxiliary firing) \_\_\_\_\_ liters
6. Daily consumption of bagasse \_\_\_\_\_ belled/lumped
7. Higher heating value of the fuel \_\_\_\_\_ KJ/kg K
8. Moisture content of the bagasse \_\_\_\_\_ %
9. Methods of Blowdown \_\_\_\_\_
10. Boiler blowdown flow rates \_\_\_\_\_
11. Waste heat recovery from blowdown \_\_\_\_\_ Y/N
12. Pressures and temperatures
  - 12.1 Steam pressure at boiler outlet \_\_\_\_\_ kPa
  - 12.2 Steam temperature at boiler outlet \_\_\_\_\_ °C
  - 12.3 Water temperature at boiler inlet \_\_\_\_\_ °C
  - 12.4 Combustion air temperature \_\_\_\_\_ °C
  - 12.5 Flue gas temperature \_\_\_\_\_ °C
13. Flue gas analysis
 

CO <sub>2</sub> _____	%
O <sub>2</sub> _____	%
CO _____	%
N <sub>2</sub> _____	%

**Appendix D: - Format for Electric Motor Data Collection**

Company: \_\_\_\_\_

Date: \_\_\_\_\_

Location: \_\_\_\_\_

Process: \_\_\_\_\_

Department: \_\_\_\_\_

Driven Equipment: \_\_\_\_\_

**Motor Name Plate Data**

Manufacturer \_\_\_\_\_

Model \_\_\_\_\_

Serial Number \_\_\_\_\_

Type : Squirrel cage/Slip ring \_\_\_\_\_

Size (hp/kW) \_\_\_\_\_

Synchronous Speed (RPM) \_\_\_\_\_

Full-Load Speed (RPM) \_\_\_\_\_

Voltage Rating \_\_\_\_\_

Full-Load Amperage \_\_\_\_\_

Full-Load Power Factor (%) \_\_\_\_\_

Full-Load Efficiency (%) \_\_\_\_\_

**Motor Operating Profile:**

No of hours of operation

I Shift \_\_\_\_\_

II Shift \_\_\_\_\_

III Shift \_\_\_\_\_

Annual Operating Time \_\_\_\_\_ hours/year

**Measured Data [using clamp on meter]**

Supply Voltage

$V_{RY}$  \_\_\_\_\_

$V_{YB}$  \_\_\_\_\_       $V_{avg}$  \_\_\_\_\_

$V_{BR}$  \_\_\_\_\_

Input Amps

$A_a$  \_\_\_\_\_

$A_b$  \_\_\_\_\_       $A_{avg}$  \_\_\_\_\_

$A_c$  \_\_\_\_\_

KVAR \_\_\_\_\_

KVA \_\_\_\_\_

Power Factor (PF) \_\_\_\_\_

Input Power (kW) \_\_\_\_\_

Motor Operating Speed \_\_\_\_\_ RPM

At frequency of \_\_\_\_\_

Driven Equipment Operating Speed \_\_\_\_\_ RPM

## CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this thesis entitled “**ENHANCING POWER GENERATION CAPACITY OF METAHARA SUGAR FACTORY**” is original work of my own, has not been presented for a degree in any other university and that all sources of material used for the thesis have been duly acknowledged.

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Tatek Zewdie

(Candidate)

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Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

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Edessa Dribssa (Dr.-Ing.)

(Thesis Advisor)

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Date