ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
FACULTY OF TECHNOLOGY
DEPARTMENT OF MECHANICAL ENGINEERING

ENERGY ASSESMENT, GENERATION AND UTILIZATION EFFICIENCY IN ETHIOPIAN SUGAR FACTORIES

(CASE STUDY IN METEHARA SUGAR FACTORY)

A Thesis Submitted to the School of Graduate Studies of
Addis Ababa University in Partial Fulfilment of the
Requirements for the Degree of
Master of Science in Mechanical Engineering
(Specialization in Industrial Engineering)

By: YOHANNES BERHANE (GSR/2045/98)

Thesis Advisor: PROFESSOR SUBRAMANIYAM

June 2007

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
FACULTY OF TECHNOLOGY DEPARTMENT OF MECHANICAL ENGINEERING

Energy assessment, generation and utilization efficiency in Ethiopian sugar factories
Case study: Metehara Sugar Factory

By: Yohannes Berhane

Approved by Board of Examiners:

Chairman, Department	Signature	Date
Graduate Committee (DGC)		
Advisor	Signature	Date
Examiner	Signature	Date
Examiner	Signature	Date

DECLARATION

I hereby declare that the work which is being presented in this thesis entitled "Energy assessment, generation and utilization efficiency in Ethiopian sugar factories case study in Metehara Sugar Factory" is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for the thesis have been duly acknowledged.

Yohannes Berhane Date
(Candidate)

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

Dr. Subramaniyam Date
(Project advisor)

ACKNOWLEDGMENT

Thanks and praise to the almighty GOD!

I am deeply grateful to my thesis advisor Dr. Subramaniyam, whose enthusiasm, creative ideas, assistance and suggestions greatly contributed to this thesis work.

I would like to thank also all Metehara Sugar Factory workers who insisted me to collect the necessary data for my thesis work; particularly Engineer Endalkachew, technical head of the factory, Engineers FIkru Mekdem and Abyi.

I am also indebted to all of the members of mechanical engineering department of Addis Ababa University for their being cooperative and provided me with different facilities to attend my MSC and to conduct this thesis work. As well as to my classmates

At last but not least my deepest appreciation goes to my family and friends who are always with me.

July 4 2007
Addis Ababa

Table of contents

Acronyms

HCS	Hydro carbons
HHV	Higher heating value
HVA	Hangler Vondar Amsterdam
LPCD	Land preparation and cultivation department
LHV	Lower heating value
MSF	Metehara sugar factory
MIS	Management information systems
OPEC	Organization of petroleum exporting countries
TCD	Tones of cane per day
TPA	Tones per annum
VOCS	Volatile organic compounds

List of tables

List of figures

Addis Ababa University

Energy assessment, generation and utilization efficiency in Ethiopian sugar factories (Case Study: Metehara Sugar Factory)

Abstract

By: Yohannes Berhane

Submitted to Faculty of Technology
Department of Mechanical Engineering
In Partial Fulfillment of the Requirements for the Degree of
Master of Science in Mechanical Engineering

Our country's economy has been growing rapidly for the last four consecutive budget years. But among the key infrastructures and base for development Energy is the main. Moreover energy is being a unit or measurement of a nation's economy as a result to continue the momentum of economic growth; we have to give attention to energy. Although Ethiopia generates almost 99% of its electricity form hydropower, around half of the countries foreign currency's income is put away to import petroleum.

But there are so many opportunities locally which can reduce the oil import. That is by using the available energy effectively and efficiently, searching for other resources and shifting petroleum usage by locally available fuels are among the solutions. All the above suggested solutions are possible in sugar factories.

The aim of this thesis is then to asses the energy resources in the sugar factories and to observe their energy generation and utilization efficiencies from their available resources and accordingly to identify problems in relation to energy in sugar factories. And finally to suggest alternatives based on measurements, collected data and foreign sugar factories experience.

Chapter one

1. Introduction

1.1 BACKGROUND AND JUSTIFICATION

The sugar industry future is at stake. In the local context, the cost of production is increasing and in the international sense, sugar price is decreasing. These factors will impact negatively in the industry if measures are not taken to mitigate these effects. Factory modernization, centralization and exploitation of the by products for more value added products are measures that will ensure long term viability of the industry.
Among the by products energy resources like Bagasse and molasses are the ones. As a result Ethiopian sugar factories must utilize this by product effectively and efficiently.

Many foreign sugar mills are producing and selling electricity from excess bagasse, leaves, trashes and tops of sugar cane in addition to self sufficiency. In addition to this many countries like Brazil and India are being beneficiaries by producing the alcohol ethanol for vehicles fuel from the other important by-product Molasses. How ever, Ethiopian mills are using the expensive imported oil in addition to their Bagasse as furnace fuel. They are not also using other by products like leaves for energy generation. There is also the opportunity to use molasses form sugar factories to blend with petroleum to be used as an alternative fuel. This shows as that there is a room to work towards energy assessment and efficiency in the Ethiopian sugar factories.

Energy efficiency does not mean rationing or having to do without energy. Rather, energy efficiency means identifying wasteful energy use, and taking action to reduce or eliminate that waste. Production levels should not be affected, only the amount of energy and the expense incurred in generating that production. The objective is to reduce energy costs, and consequently, increase profitability. [31]

When we translate this energy efficiency to the sugar industry, it is not only reducing or eliminating the wasteful energy in the factory but also contributing some amount of electricity to the grid from the surplus Bagasse and alternative fuel from Molasses.

Some of the problems associated in energy efficiency of the sugar industry

- The cost of energy like petroleum is increasing from time to time as a result Energy efficiency is fundamental.
- It is also possible to generate additional profit from the by products
- To be competitive in the market, production cost must be as minimum as possible
- Population around the factories needs electrical energy
- Bagasse burning incorporated with the release of CO_2, this pollution must be minimized
- Based on literatures there is surpluses Bagasse in every sugar industry other than for the factories energy use.
- Other miscellaneous by-products are not being used as energy sources
- From 3-100% ethanol from molasses and petroleum mixture is being used as a fuel for vehicles in many countries.
- Saving foreign currency
- Generally supports the country's economy.

This thesis addresses problems encountered by the sugar factories with respect to energy starting from the resources and through energy generating equipments like boilers, turbines, turbo generators up to the end energy users of the factories machinery as well as the capacity of the sugar factories to contribute energy to the country.

1.2 Thesis Objectives

The general objective of this study is to identify the problem associated with the energy generation and utilization of the sugar factories and to recommend the possible solutions. Consequently the factories and in general the country could be benefited by:

- Reduce energy generation cost
- Minimizing resource wastage
- Minimizing CO_2 emission
- exporting the surplus electricity to the grid
- exploit other energy resources
- Getting additional profit

And the specific objectives are:

1. To survey the condition of the selected industry
2. To asses the way that the factories energy generation and utilization
3. To identify ways of efficiency improvement
4. To compute investment required for implementing efficiency improvement
5. To compute the saving that the factory could get due to the improvement
6. To show the general benefits to other existing as well as new sugar factories.
7. To asses the feasibility of molasses and the miscellaneous energy source by- products
8. To prepare a flow chart that describes sugar manufacturing process

1.3 METHODOLOGY

The methods employed to achieve the objectives of the research are:

1. **Literature Survey**: - A review of literature is conducted on the area of industrial energy use and efficiency in related to sugar factory. Available books, journals, case studies, previous research works, policies & guidelines are surveyed in order to have a clear understanding of the subject matter.

2. **Data collection**

   The necessary data for the thesis are collected from different sources. The necessary data are:

- amount and composition of bagasse generated

Addis Ababa University

Energy assessment, generation and utilization efficiency in Ethiopian sugar factories (Case Study: Metehara Sugar Factory)

Abstract

By: Yohannes Berhane

Submitted to Faculty of Technology
Department of Mechanical Engineering
In Partial Fulfillment of the Requirements for the Degree of
Master of Science in Mechanical Engineering

Our country's economy has been growing rapidly for the last four consecutive budget years. But among the key infrastructures and base for development Energy is the main. Moreover energy is being a unit or measurement of a nation's economy as a result to continue the momentum of economic growth; we have to give attention to energy. Although Ethiopia generates almost 99% of its electricity form hydropower, around half of the countries foreign currency's income is put away to import petroleum.

But there are so many opportunities locally which can reduce the oil import. That is by using the available energy effectively and efficiently, searching for other resources and shifting petroleum usage by locally available fuels are among the solutions. All the above suggested solutions are possible in sugar factories.

The aim of this thesis is then to asses the energy resources in the sugar factories and to observe their energy generation and utilization efficiencies from their available resources and accordingly to identify problems in relation to energy in sugar factories. And finally to suggest alternatives based on measurements, collected data and foreign sugar factories experience.

- energy generation capacity
- energy consumption
- energy equipments
- factory energy efficiency
- problems concerning energy efficiency
- energy policies
- amount and capacity of miscellaneous energy sources and
- amount of molasses produced in the country

These data can be collected by

1. Conducting interviews with the respective personal of the factory
2. May distributing questioners in the factory
3. By observation in the factory
4. Data from previous papers and research documents
5. Doing combustion analysis of the furnaces

3. Analysis and Evaluation

The collected data is analyzed quantitatively and qualitatively.

4. Conclusion & Recommendation

After detail analysis of the collected data conclusion and recommendation is forwarded.

1.4 Energy

Energy plays a great role when ever man lives and woks. And at this time energy is considered to be the forth fundamental resource for human beings to live next to Air, Food and Shelter. In some parts of the world, it is now days difficult to live with out air conditioning. The development and living standard of any country vary directly with the consumption of energy

Energy is the power up on which all over activities depend. Energy affects everybody & every sphere of the economy. According to encyclopedia Britannica “All life flows from and depends on energy”

Moreover modern life is so much dependent on electric power that the capita consumption of electricity is often regarded as an index of the economic development. The following table shows per capita consumption of electricity for various countries.

The volatile world market prices for conventional energy resources, in particular petroleum products pose great risk for large parts of the world's economic and political stability, with sometimes dramatic effects on energy importing developing counties like Ethiopia. In this context renewable energy can help to diversify energy supply and to increase energy security.

Country	Per capita consumption [kWh/year]
Norway	11524
Australia	8000
Canada	6320
U.S.A	5860
Sweden	5549
UK	3172
Japan	1240
Ethiopia	18

Table 1.1 Per capita consumption of electricity[10]

The two essentials for a nation's survival are energy and food. Access to those commodities sets the stage for economic growth and the bases for a stable society. Shortages real and imagined of these resources jeopardize international tread, development, and, ultimately World peace.

National self reliance, not self sufficient, is a concept that can be used to resolve food and energy shortages and can be implemented in the developed as well as developing countries. Self reliance is a concept based on domestic production of essential needs; it does not preclude international tread. It requires regional planning, cooperation among various segments of society, and a commitment to national goals found in few countries today.

Money spent on renewable energy technology stays for a large part in the country it spends, while money spent of fossil fuels goes directly to the supplying country. As such investment in renewable energy contributes to a much larger extent to the economic development.

In spite of the fact that Ethiopia generates almost all of its electricity from hydro power, Oil imports consume more than one half of all export earnings. To see our country economically developed, we must strive to make a change to our energy efficiency as well as we must try to use our renewable energy resources. [19]

During the past decade, man has become increasingly aware of the limitations of energy supplied. With further increases in energy consumption expected, we are faced with the question of how long there will be sufficient reservoirs of conventional fuels for our industrialized societies. The increasingly scarcity of fossil fuels and the attendant increase in the cost of petroleum products make it imperative to find alternate energy sources during the next decade. [17]

Alternative energy sources must meet criteria to be competitive with conventional fuels. Some of the special requirements, these energy supplies will have to meet are as follows:-

1. Fuels must be capable of being stored over extended time periods
2. Storage, transportation and distribution of fuels used should be economical,
3. Handling of alternate fuels should not involve additional hazards such of fire, explosions, etc in comparison to conventional fuels.
4. Alternative fuels should not impose major engineering changes to processes and/or system using them.

1.4.1Energy Resources

Historically, energy development has involved the discovery and exploitation of the cheapest, most abundant and most useful energy sources. The major categories of energy use are lighting, heating, cooking, transportation and work performed by stationary machines. Electricity and liquid fossil fuels are the primary sources of energy for these uses.

For some time, fossil fuels, primarily coal and crude oil, have been filling the world's diverse energy needs. Fossil fuels are those fuels created when animal and plant remains from prior geologic ages are compressed in the earth's crust. They are basically non-renewable. [17]

Global energy supplies and needs are a major consideration in international relations, crude oil is supplied to the world market by relatively few countries, therefore, economic and political manipulations can become a major international problem. Of the 1,675,423 thousand metric tons of crude oil exported in 1979 above 80% were exported by the organization of petroleum exporting countries OPEC. [17]

In addition to political, economical and resources availability problems with fossil fuels environmental problems have also been created.

There are different types of renewable and non-renewable energy resources. But the main types and their share to the world is as shown below in figure 1.1. And there are some other miscellaneous energy resources where their share is under 0.1%. [28]

1.5 The Sugar Industry

The development of the sugar industry-cane and beet-has been remarkable since 1850, and although the beet industry suffered some set-backs during the two world wars nevertheless world sugar production has easily kept pace with a rapid increase in world population.

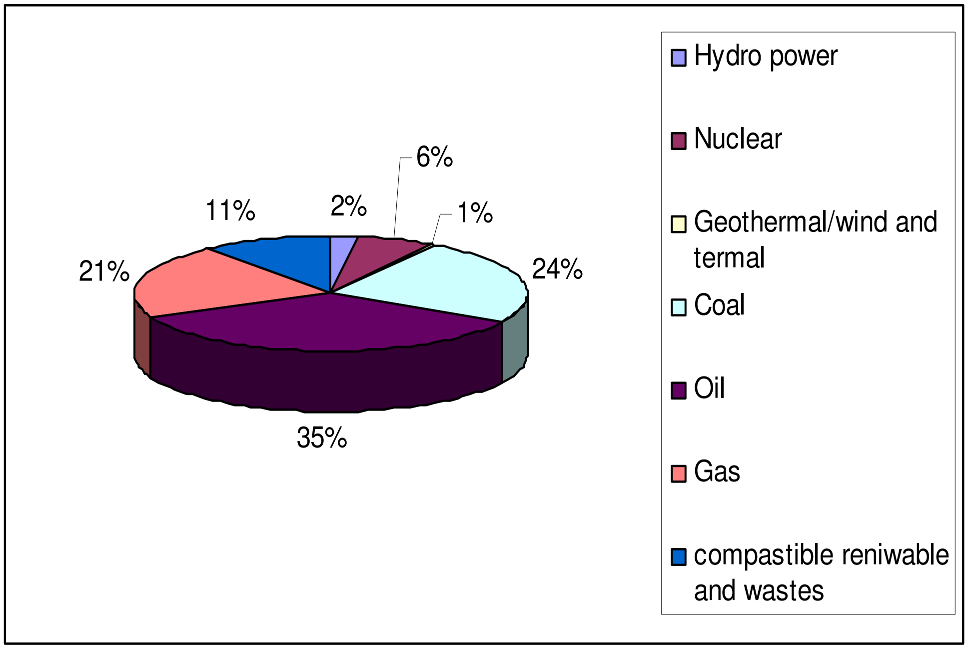


Figure 1.1 Energy resources and their share to the world [28]

In the cane sugar industry, a number of gradual but irreversible changes are taking place

1. A gradual decrease in the number of people employed in industry.
2. A fairly rapid increase of out put per work
3. A relatively constant figure or very slow increase for the physical capital per plantation. [15]

Some sugar countries like Ethiopia, having a surplus of labor and no immediate new outlets for this labor, have tried to slow down the process of mechanization and modernization. But the time is fast approaching when the change will have to be made; otherwise the gradually increasing labor bills will render the sugar concerns of these countries completely uneconomical.

Except for countries having a large proportion of their production taken up by local or assured preferential markets, it can be said that the profits derived from the manufacturing of sugar have greatly diminished during the last 10 years. Hence there has been an incentive towards diversification and this has led to more attention being paid to energy generation from the by-products of the industry like bagasse for electricity & molasses for fuel in the form of ethanol. [10]

Few countries however seem to have made sufficiently determined efforts along these lines to be really successful; the best results to date appear to have been obtained by Taiwan, Cuba, Australia, Brazil and Mauritius.

1.6 Metehara sugar factory (MSF) [33]

1.6.1 History and location

Metehara Sugar Factory is located some 200km South East of the capital city Addis Ababa, on the Addis-Dire Dawa-Djibouti road within the upper Awash Valley. It is situated at 8 53’N and 39 52’E. In the immediate vicinity of the Enterprise one can find tourist attractions such as Awash National Park, Fentale Mountain and Lake Beseka.

The establishment date of Metehara Sugar Factory goes as far back as 1965, the time when the Dutch company, named as Hangler Vondr Amsterdam (H.V.A) had surveyed the area for future sisal development. The increasing demand for sugar in Ethiopia and the suitability of the land and climate for sugar cane cultivation urged H.V.A to extend the sugar industry to Metehara Plains.

As a result in July 1965 an agreement was signed between the Ethiopian Government and the Dutch company (H.V.A) under which the company acquired a concession of 11,000 hectares of land, Subsequent to the signing of the agreement, sugar cane cultivation was started in 1966.

The Factor started producing plantation white sugar on the 9 of November 1969 with an initial crushing capacity of 1700 tons of cane per day (TCD). Since then, the factory had undergone successive phases of expansions. The first expansion was made in 1973 to raise the crushing capacity of the factory to 2450 TCD. The Enterprise was nationalized in 1975 and organized under the Ethiopian Sugar Corporation. Then the second and the third expansion took place in 1976 and in 1981, which raised crushing capacity to 3000 and 5000 TCD respectively. The Enterprise currently has a total concession area of 14733 hectares out of which about 10,300 hectares is covered with cane plantation.

Fig1.2 Metehara sugar factory

The mission of the organization is to Produce sugar of standard quality at a least possible cost and satisfy its customers; and utilizes all resources at disposal and to provide best service to the society at large and remain competitive & profitable, to be environmentally friendly in its process as well as to provide affordable living standard to its employees.

And the main Purposes of the Enterprise are to:

- Grow sugar cane and other sugar yielding plants
- Process and produce sugar & sugar by products.
- Distribute and sell sugar and sugar related products within the country and abroad.
- Study, plan and implement various sugar development programs.
- Carry on scientific, industrial and agricultural research and surveys to enhance its programs.
- Possess and develop agricultural lands in the country whenever it is deemed appropriate to fulfill its purposes.
- Engage in other activities that enables the attainment of its purposes

1.6.2 ORGANIZATIONAL STRUCTURE

The Enterprise operates as an independent economic entity with relative management autonomy. The enterprise has an automated Management Information System (MIS) that enables generation of reliable and simplified information for decision making.

The Enterprise has also built Quality Management System (ISO 9001:2000) into its processes that will ensure the capability of the enterprise to deliver quality products & services to its customers.

The Enterprise has adapted a team management style and the structure comprises four broad sectors, namely, Agricultural Operations Factory and Logistics Finance and Human Resource as shown in the chart below. Support giving and advisory services are also shown in the chart.

1.6.3. AGRICULTURAL OPERATIONS

Agricultural operations comprises of various activities like topographic survey, land preparation, sugar cane cultivation and harvesting which are essential to the sustainable supply of sugar cane required by the factory.

Currently eleven commercial and semi commercial cane varieties have been used by the Enterprise. These varieties have been selected on the basis of compatibility to the soil characteristics of the area and their ability to resist prevalent diseases.

Most of the plains in Metehara are gentle and suitable for gravity irrigation where 81.7% irrigated by gravity. There are 1200km irrigation canals on the cane fields. Water drawn from Awash River is stored in 23 reservoirs whose water holding capacity ranges from 6500m to 93,000 m. The average land productivity is about 165 tons of cane per hectare, which makes the Enterprise one of the highest cane producing farm in the world. About 1.091,100 tons of cane is supplied to the factory annually.

Along with the cane plantation, the Enterprise owns 140 hectares of land covered with various types of fruits such as orange, Mango, Lemon, Grape-fruit, etc… About 3000 tons of fruits are produced annually.

1.6.4. FACTORY OPETATIONS

The factory operates for about 81/2 months annually and produces 120,000 tons of sugar and other useful by products. By-products that have economic value are molasses, bagasse and filter cake.

The average annually production of molasses is about 35,580 tons and it is a basic material from which ethanol, baker's yeast, fodder yeast, organic fertilizer, lysine, ethylene, etc… can be produced. Apart from these molasses can be mixed with materials like wheat barn, wheat meddling and oil cake to make a concentrated cattle feed.

Bagasse is a fibrous residue that remains after cane is crushed and the juice is extracted. It is used as a boiler fuel where steam needed to run the factory is produced. Part of the steam so produced is used to run steam turbines that generate about 5.2 MW of electricity. On the average, 312,115 tons of bagasse is extracted as by-products of the sugar production process.

When cane juice is treated chemically for clarification, most of the solid impurities that settle down are removed in the form of filter cake. Filter cake is rich in organic materials and in it's dried from is used for soil amendment in cane fields. On average 35,590 tons of filter cake is removed as by-products of the sugar production process.

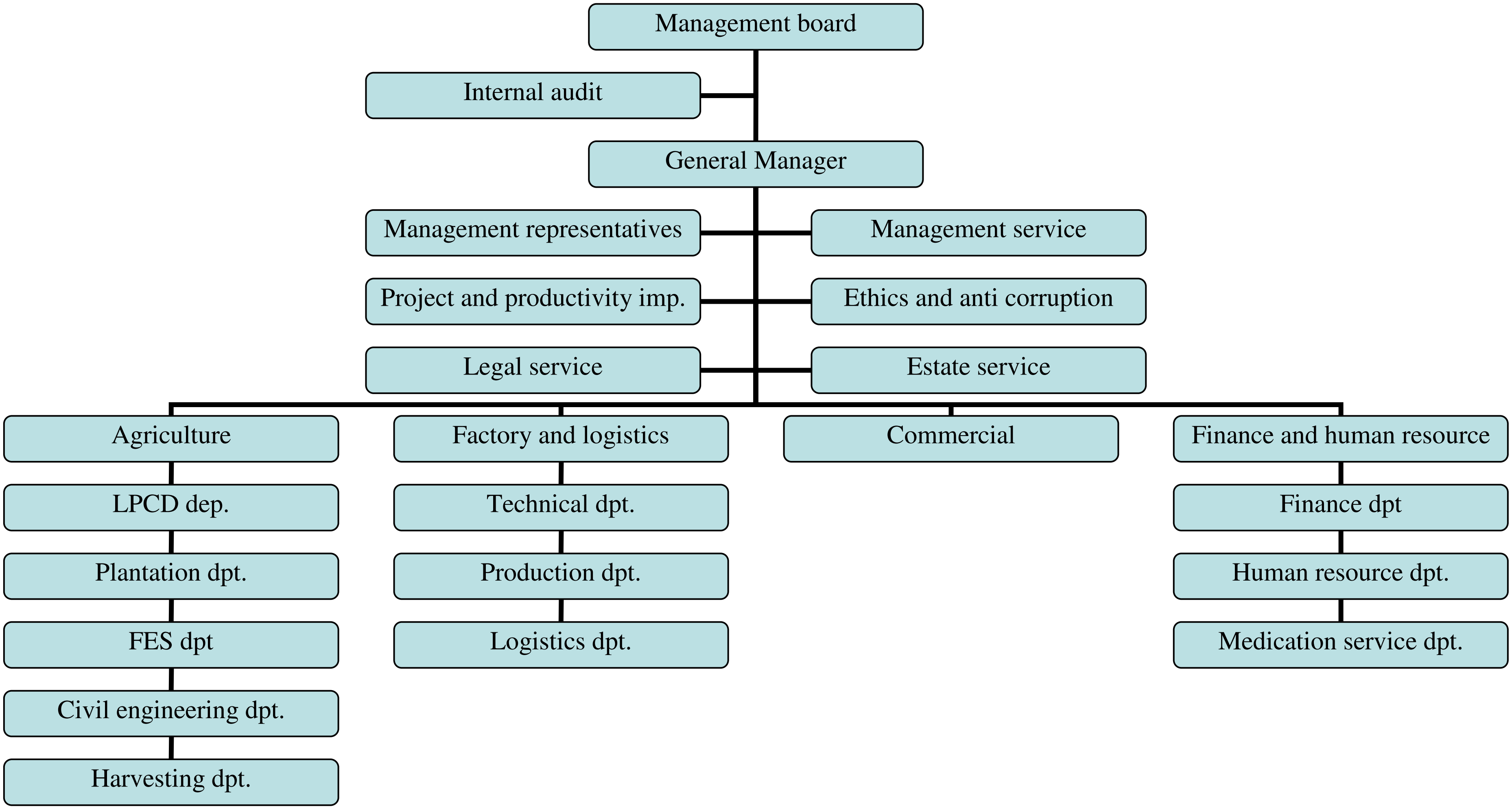
1.6.5 MARKETING

Marketable products of the Enterprise are sugar, molasses and various types of fruits.

1. Sugar

Sugar is supplied to domestic and foreign markets. The annual sales volume stands at 120,000 tons and about 65% of the annual sales volume goes to domestic market while the remaining is exported.

Fig1.3 Organizational flow chart of Metehara Sugar Factory



2 Molasses

The major part of molasses produced (20,000 tons) is exported and small part of the annual production goes to domestic cattle fatteners and distilleries.

3 Fruit

Fruit such as orange, lemon, mango and mandarin are subsidiary products of the Enterprise. About 3,000 tons of those fruits are marketed annually.

1.6.6 COMMUNICATION, SOCIAL SERVICES AND OTHER FACILITIES

Basic communication systems, social services and other facilities are available to facilitate the various activities of the Enterprise. The transport links include all whether road and railway that extends into the premises of the company giving easy access for import & export of goods.

Others infrastructures include a well built stores, comfortable residential houses, a 60-bed hospital 2 poly clinics and 4 satellite clinics. Bank, Post Office, Court and Police stations are situated in the immediate vicinity of the enterprise.

The Enterprise is equipped with modern communication system such as telephone lines, internet, TV broadcasting station and short-range radio communications.

All employees live within the concession area in the main headquarter village and 7 camps located at convenient places within the plantation. The company provides free housing, water & electricity to its employees

Recreational facilities such as cinema halls, sport fields, various clubs and swimming pools are available.

There are also other social services such as a Vocational school, 5 Elementary schools, 7 Kindergartens, a public library, different retailing shops, bakeries and flour mills.

1.6.7 HUMAN RESOURCE

The workforce includes professionals, semi professionals, clericals and manual laborers. At peak time the workforce reaches 11,000 where 3700 are permanent employees and the remaining are seasonal. The population consists of workers, their families and their dependents. The total number is estimated at 35,000.

1.6.8 FUTURE PROSPECTS

The Enterprise has already drafted its short and long term strategies that will enable it to meet future challenges. The Prospects that could make the factory cost effective and high quality sugar producer are diverse and center on agricultural and industrial activities.

1.6.8.1. Short-Term Prospects

Enhancement of productivity through improved farm management, pocket area development, land productivity improvement, reduction of down time, improvement of milling & boiling house efficiency. Cost reduction through improved labor, material and energy Utilization & managerial efficiency.

1.6.8.2 Long-Term Prospects

1. Improving the revenue generating capacity of existing internal resources.
2. Production diversification and by-Product utilization, and
3. Factory capacity expansion and annexing a back-end refinery Land development

1.7 Sugar Manufacturing Processes in MSF

At the sugar manufacturing from sugar cane is started from harvesting sugar cane plant by the sugar factory itself. The bulk of sugar cane is cut by hand with a cane knife but sometimes mechanical cutting is also being practiced in some other countries.

The cut sugar cane is then loaded to vehicles and transported to the mill. At the first end of the factories the cane is usually weighted, washed and chopped in to smaller pieces before the cane is feed to mills (Tandems) for juice extraction.

Fig1.4 Sugar cane farm

Juice extraction is mostly done by passing the chopped cane through a series of three roller horizontal mills. The rollers are laid in a triangle which are supported by a mill housing made of cast iron or cast steel, and they revolve in water cooled bearings made up of brass or bronze.

The prime objective in sugar cane milling is to extract the greatest possible amount of sucrose from sugar cane, and to make the final bagasse as dry as possible so that it will burn readily in the boilers.

The tandems are a train of six mills preceded by various combinations of cane preparation devices. The power required by the mills is obtained from steam turbines followed by gear boxes for speed reduction.

During the last few years diffusers have been installed in various sugar factories instead of mills. This new method of extracting sugar from sugar cane has proved advantages from the technical point of view. Diffusion has been accepted as an efficient way of achieving high extraction. The capital investment and maintenance costs of diffusers are lower than those of mills. Metehara sugar factory has one diffuser in tandem B between the mills.

Fig1.5 Series of mills

Next to this important process, juice extraction, the raw cane juice is weighted and carried to liming process. The fibrous part called bagasse is transported to furnaces for burning.

The liming station of the cane juice is one of the most important stations in a raw-cane sugar factory. Raw sugar cane juice is composed of a great number of organic and inorganic compounds, acids, salts etc in varying amounts. When it comes from the mill tandem, the juice is an opaque liquid varying in color from greenish-gray to dark green, and it carries suspended matter such as fine bagasse (bagacillo), gums, albumin, wax, coloring matter, particles of soil sand clay and muck. The normal cane juice has PH 5.2 – 5.4.

The gums, wax and albumin make the raw sugar juice rather viscous and it can not, therefore, be readily filtered when cold. Liming and heating causes many impurities in the juice to become coagulated and precipitated out. At the same time the acids are neutralized and any phosphates present are flocculated, adsorbing a large amount of coloring matter, solids and other impurities. Usually the lime is added to the raw sugar cane juice in the form of milk of lime, for better dispersion and quicker reaction.

The next process after liming of sugar can juice is clarification. With out good clarification of sugar cane juice, the production of good quality raw sugar is impossible. The purpose of clarification is the precipitation and removal of all possible non sugars, (organic & inorganic) and the preservation of the maximum sucrose and reducing sugars possible in the clarified juice.

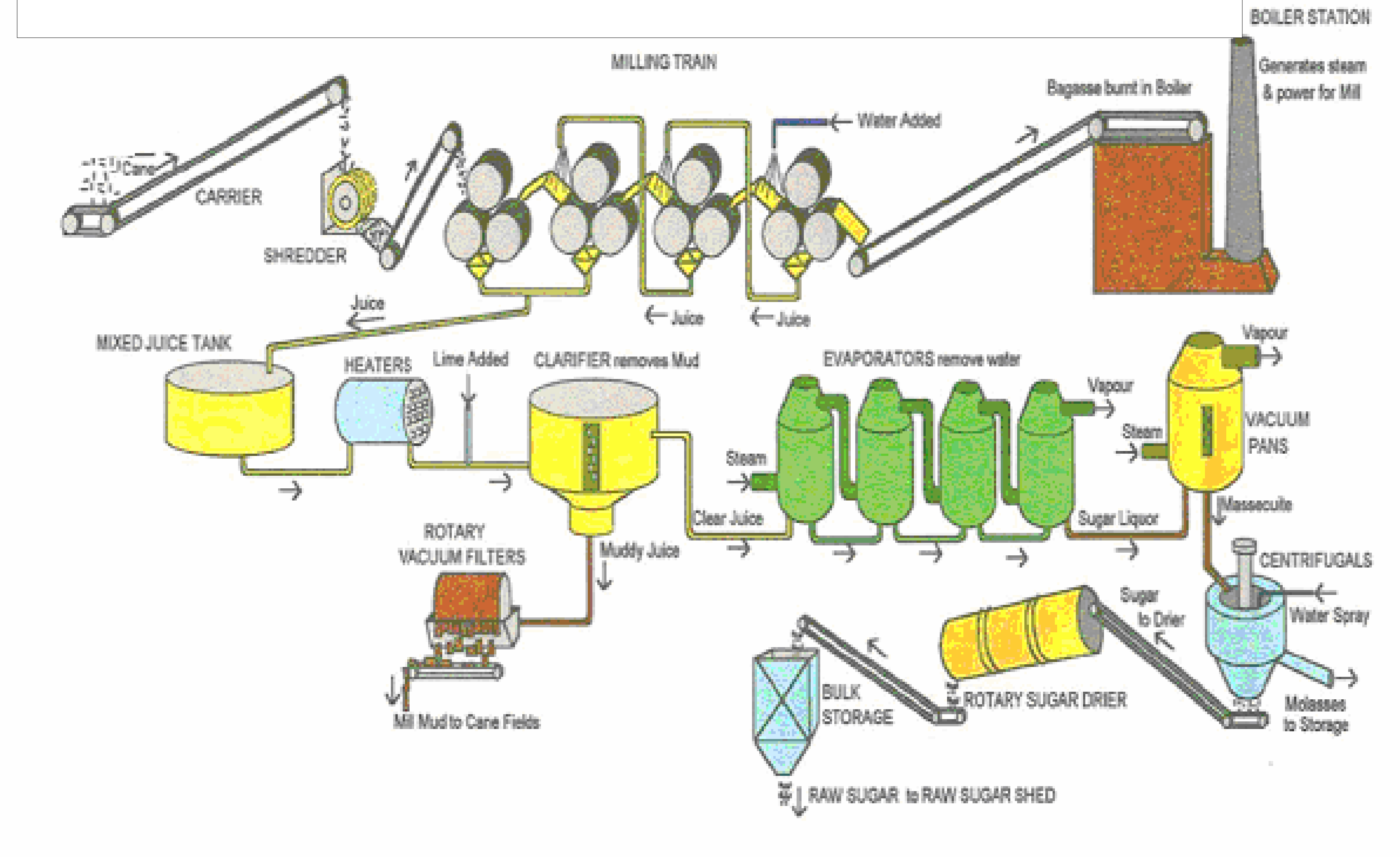
The greatest part of sugar cane consists of soluble inorganic compounds or ashes. A certain amount of fiber, mainly cellulose, also remains in sugar cane juice after crushing, which passes through the cush-cush screen in the form of bagacillo. The raw cane juice is generally limed to PH 8 in order to obtain clarified juice of about PH 6.8-7.2 clarified juice is concentrated to a syrupy consistency before it is sent to the vacuum pans to be crystallized in to raw sugar. The concentrate is made in several evaporators connected in series called a multiple effect. The juice travels from one vessel to another because of the gradual increase of vacuum. The vapors obtained in each body of the multiple effects serve to heat the calanderia tubes and to evaporate additional water in the following vessel.

And after being evaporated in a multiple effect evaporator to be a syrupy consistency, clarified juice must be evaporated further for the sugar to crystallize. This is accomplished in a vacuum to form a heavy mixture of crystals and mother liquor, called massecute.

The raw sugar massecute is then crystallized by cooling. On this process residual syrup incapable of crystallizing called black strap molasses is separated.

And finally Batch & continuous centrifugals are used to separate the liquid and hard phases of raw sugar.

Fig 1.6 Schematic diagram of sugar manufacturing process [13]



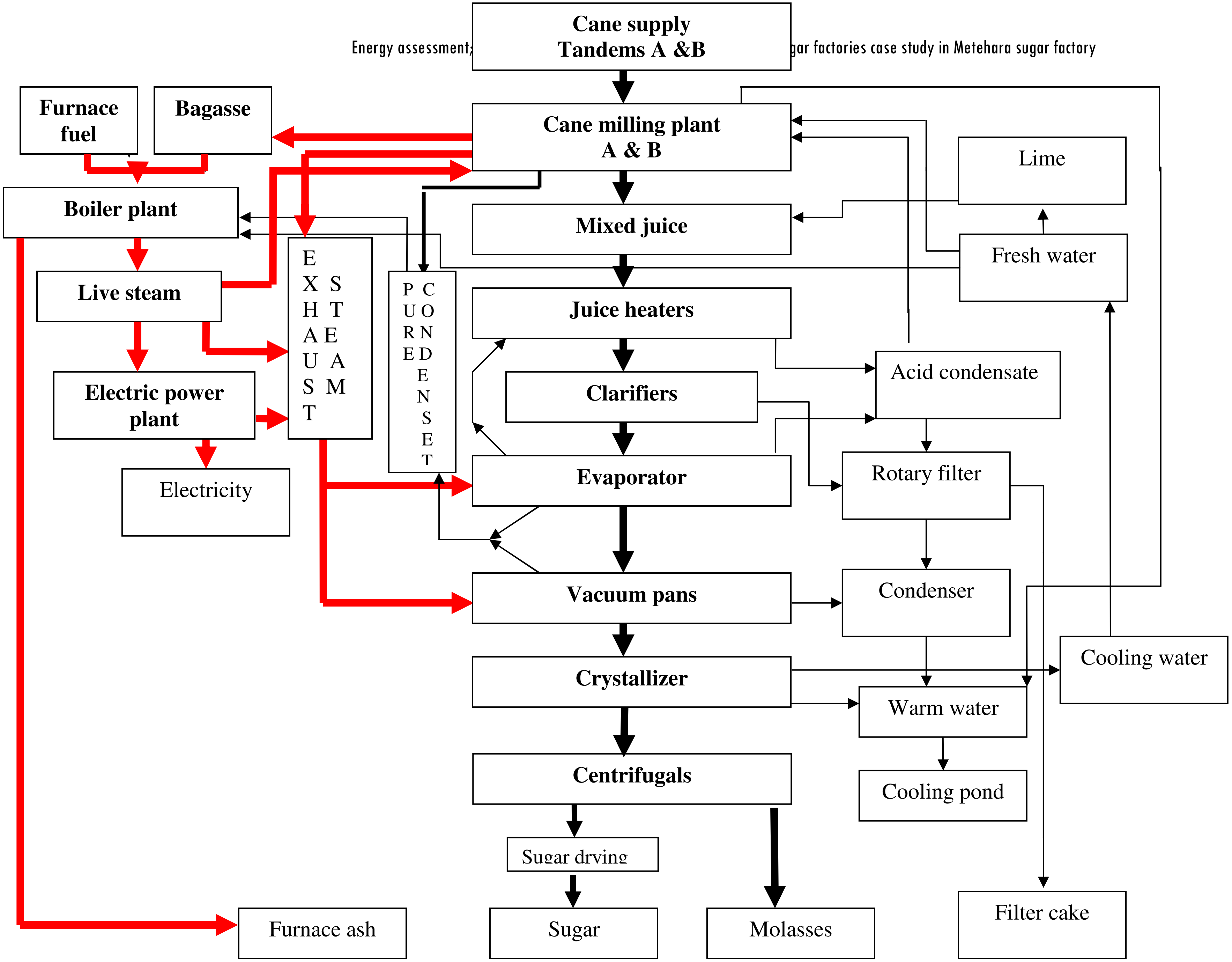


Fig 1.7 over all sugar production process flow chat of MSF (the bold lines are lines of energy flow)

Chapter Two

Energy in sugar factories

2.1 Energy resources of Sugar factories

Now days in many international sugar factories, the energy obtained from this industry is not only considered as a by-product. Countries like Brazil, USA, India and Mauritius are being benefited from energy of sugar factories highly.

There are mainly three energy resources in sugar factories namely

1. Bagasse
2. Molasses
3. Leaves tops and trashes of the cane plant

But the main and only energy resource being used by Ethiopian sugar factories is bagasse.

2.1.1 Bagasse

2.1.1.1 Chemical and physical composition

Bagasse, the fibrous residue of the cane stalk after crushing and extraction of the juice, consists of water, fibers and relatively small quantities of soluble solids. Its composition varies according to the variety of cane, its maturity, the method of harvesting, and finally the efficiency of the milling plant. [15]

On the average, we can estimate:

Moisture	46-52% (av. 49.0%)
Fiber	43-52% (av. 48.7%)
Soluble solids (mostly sugar)	2-6% (av. 2.3%)

By definition, the fiber of the bagasse is that component which is insoluble in water; it consists mainly of cellulose, pentosans and lignin. Cellulose is a polysaccharide having the general formula $(C_6H_{10}O_5)_n$ and is the main constituent of vegetable tissue. It rarely occurs in nature in the pure state but is generally intimately mixed with lignin, pentosans, gums, tannins, fats, coloring matter, etc. The pure cellulose fraction of all plant tissues is basically the same chemical substance consisting of long polymer chains of glucose. Differences in the properties of cellulose are due primarily to different degrees of polymerization. It is suspected that bagasse cellulose has a polymer chain of 2000-3000 units.

According to its degree of solubility in caustic soda, cellulose is classified as:

α-Cellulose: which is insoluble in a 17.5% solution of caustic soda at room temperature.

β-Cellulose: which is soluble in a 17.5% solution of caustic soda, but easily precipitated when the solution is acidified.

γ-Cellulose: which is soluble in a 17.5% solution of caustic soda and not precipitated by acids, but precipitated by alcohol.

The specific gravity of cellulose is about 1.55.

Only α–cellulose is considered as the pure form of cellulose, while that portion of the plant material which is soluble in cold 17.5% caustic soda is called hemicellulose. This differs from cellulose in being composed of pentose rather than glucose units and less highly polymerized (probably short chains of about 40 units). Holocellulose is the term used to indicate both the cellulose and hemicellulose originally present in wood, and, by extension, bagasse. [15]

Various methods are available for the quantitative determination of cellulose, and probably the one more commonly used with bagasse is the Cross and Bevin method, (Tappi standard T17m). However, for a large number of analyses, for comparative purpose, the Kurschner and Hoffer method is the most suitable.

Pentosans are a form of hemicellulose which on hydrolysis yield xylos, arabinose and uronic acid. Under the action of boiling HCL, the pentosans change to furfural. [15]

$C_5H_8O_4 \rightarrow C_5H_{10}O_5 \rightarrow C_5H_4O_2$

Pentosan Pentose Furfural

This reaction is made use of in the quantitative determination of the pentosans: originally the method of Tollens et al. now superseded by the volumetric bromate-bromide method.

Lignin is the name given to a group of high-molecular-weight substances, generally associated with cellulose and hemicellulose. Its chemical structure is largely aromatic, composed of benzene rings which contains some free and many more methylated phenolic groups, but the complete structure and size of the polymer have not yet been satisfactorily established. The method of Goss and Philips with hydrochloric acid is generally used for lignin determination in bagasse.

Structurally, the cane stalk consists of various types of fiber tissue (see Fig. 6). The two most important types of fibrous residue, which occur in bagasse, are:

(i) The tough, hard-walled, cylindrical cells of the rind and vascular tissues, or true fibers.
(ii) The soft, thin-walled, irregularly shaped parenchymatous cells of the inner stalk tissue, or pith.

Note that vessel segments also associated with the vascular bundles, because of their non- fibrous character and because any depithing steps will remove a large portion of the cells, are generally considered as a pith fraction.

The true fiber and the pith have almost the same chemical composition, but their structure differs widely, and they occur in the ratio by weight of 2.5:1 approximately.

The true fibers have a fairly high ratio of length to diameter, approximately 70, and a relatively high coefficient of expansion and contraction upon wetting and subsequent drying. This results in close bonding of one fiber with another and accounts for the strength, cohesiveness and ability to felt of bagasse fibers when subjected to pulping processes.

The pith cells are of irregular size and shape and are characterized by their absorbent properties. They do not bond together and so tend to weaken any pulp in which they are incorporated, and further prevent its rapid drying. However, they can absorb many times their weight of liquid and have thus found a limited use, mainly as a carrier for molasses, in the preparation of animal feed.

2.1.1.2 Calorific Value of Bagasse

Many formulas have been proposed to determine the calorific value of bagasse; amongst the better known the more reliable are that of Pritzelwitz van der Horst of Java and that of Hessey of Australia. [15]

(a) Pritzelwitz van der Horst:

Gross caloric value: 4550 – 10 S% – 45.5 W% in kcal/kg
Net calorific value: 4250 – 10 S% – 48.0 W% in kcal/kg

(b) Hessey:

Gross calorific value: 4636 – 12.3 S% – 46.46 W% in kcal/kg
Net calorific value: 4324 – 12.3 S% – 49.04 W% in kcal/kg

Both formulae are expressed in cal/kg, W is the moisture in the bagasse, and S the soluble solids (mainly sugar) expressed as percentages.

On average the calorific value of bagasse can be taken as:

Gross calorific value: 2340 kcal/kg (4200 BTU/lb.)
= 9769.2kJ/kg
Net calorific value: 1920 kcal/kg (3450 BT U/lb.)
= 8027.7kJ/kg

Note that the net calorific value takes into account the impossibility in practice of cooling. The full fuel specification of bagasse is shown in tables 2.1 and 2.2 below.

Down the products of combustion sufficiently to condense the moisture present and recover its latent heat. Hence the net calorific value is a more realistic measure of the heating power of the fuel considered.

The proximate and ultimate analysis of bagasse as fired can be assumed to be given in Table 2.1.The fuel substitutes for bagasse are generally fuel oil or coal, occasionally natural gas and even more rarely wood. The calorific value of these substitutes is given in Tables 2.2.

TABLE 2.1 Energy property of bagasse [15]

Proximate analysis		*Ultimate analysis*	
Fixed Carbon	7.0% by weight	Carbon	23.7% by weight
Volatiles	42.5	Hydrogen	3.0
Moisture	49.0	Oxygen	22.8
Ash	1.5	Moisture	49.0
		Ash	1.5

TABLE 2.2 Calorific values of bagasse substitute's resources [15]

Type of fuel	Gross cal. Value	Net cal. Value
Fuel oil	10.000 kcal/kg	9,300 kcal/kg
Bituminous coal (average)	6,700 kcal/kg	6,500 kcal/kg
Natural gas	12,250 kcal/kg	11,200 kcal/kg
Wood = (green) 30% moisture	3,255 kcal/kg	2,800 kcal/kg
Wood = (air-dried) 15% moisture	3,990 kcal/kg	3,600 kcal/kg

The equivalence of these fuels in terms of bagasse can be expressed as a ratio of the respective calorific value, due allowance being made, however, for the respective boiler efficiencies which vary according to the type of fuel fired. The efficiency of bagasse furnaces is given the following approximate figures:

Efficiency	Fuel oil	coal	Gas	Wood
Based on G.C.V	84	82	82	70
Based on N.C.V.	90	85	89	82

TABLE 2.3 Common bagasse furnaces[15]

	Step grate	Horse shoe	Ward	Spreader stoker
G.C.V of bagasse (kcal/kg)	2340	2340	2340	2340
N.C.V. of bagasse (kcal/kg)	1920	1920	1920	1920
Exit temp. feed water (^{o}c)	180	180	180	180
Inlet temp. feed water (^{0}c)	85	85	85	85
Excess air required (%)	80	70	40	30
Losses: (as % of G.C.V.)				
Moisture in fuel loss (%)	18.0	18.0	18.0	18.0
Flue gases loss (%)	13.2	13.0	11.0	10.4
Unburned fuel loss (%)	4.0	2.5	2.0	2.0
Radiation and unaccounted (%)	6.0	4.0	2.5	2.5
Boiler efficiency				
Based on G.C.V.	58.8	62.5	66.5	67.1
Based on N.C.V.	71.6	76.1	81.0	81.7
Kg steam generated/kg				
Bagasse as fired:				
7 kg/cm , saturated	2.39	2.45	2.70	2.72
10 kg/cm , 250 c	2.23	2.37	2.52	2.54
20 kg/cm, 300 c	2.16	2.30	2.45	2.47
40 kg/cm , 350 c	2.04	2.17	2.31	2.33

The fuel replacement value of bagasse is as shown below. This fuel replacement value is calculated based on the energy content of the fuels, amount of energy that can be extracted from the fuels and based on the cost of fuel. [15]

0.18 tone of fuel oil
0.28 tone of bituminous coal
0.15 ton of natural gas
0.55 ton of wood (air dry) is equivalent to 1 ton of bagasse.

2.1.1.3. Availability of Bagasse

For convenience and uniformity, quantitative measurements of bagasse are generally expressed: either in terms of mill run bagasse (approx. 49% moisture) or in terms of bone dry bagasse weight.

Surplus bagasse is rarely weighed at the factory, hence unless the bagasse is baled; weight estimates of loose bagasse are often unreliable.

For raw sugar factories the steam requirements can be evaluated as follows:

(a) Old factory, partially electrified: 500-550 kg steam/ton cane.
(b) Modern factory, electrified, low/medium pressure, quadruple, etc.: 450-500 kg steam/ton cane.
(c) Modern factory, electrified, medium/high pressure, quintuple, etc.: 425-450 kg steam/ton cane.

These factories should reach thermal balance with fiber % cane at approximately:

(a) 11- 12%
(b) 10 – 11%
(c) 9 – 10%

This indicates that a fair amount of surplus bagasse should be available at every raw sugar factory, except in very special circumstances.

2.1.1.4. Storage of Bagasse

(a) General

The cost of bagasse, whether it is to be sold on a calorific value basis or on a purely surplus basis, has generally to be increased by the cost of handling, storage and transportation.

Apart from its direct utilization as combustible in the furnaces of the sugar factory boilers, it is very rare indeed for mill run loose bagasse to find an immediate use. Its low density (about 160 kg/m) and relative inflammability make it a bulky and costly material to handle and transport.

Owing to the presence of sugar, moisture and yeast in the bagasse, fermentation to alcohol soon occurs, and in turn in the presence of heat and large volumes of carbon dioxide, and significant changes occurs in the quantity and quality of the fibrous raw material. It must be pointed out, however that the pith is attacked more quickly than the fiber and opinion varies about the "deterioration" taking place, some authors considering it as a useful biological dispatching system.

(b) Baling and storage

The presses used for baling are heavily reinforced and enlarged versions of the hay baler. Their capacity varies between 100 and 200 tons of mill bagasse per 24 hours. The bales are about 46 X 56 X 81 cm in size and are held by two steel wires which circle the bale lengthwise. A bale weighs approximately 115 kg and contains initially about 59 kg fiber and 56 kg moisture, the density being around 550 kg/cm. There are also presses producing smaller bales of 30 X 30 X 50 cm weighing about 40 kg, density 890 kg/m.

The bales are stacked in such a way as to provide air channels for the moisture to escape freely. The standard stack is about 37 m long by 20 m wide by 9 m high and would contain some 12,000 bales, i.e. approximately 700 tones dry fiber. The stacks have to be spaced to provide for fire protection and road access; thus 36 stacks in 4 parallel rows would require an area of 140 X 470 m, i.e. 0.384 tons dry fiber/m.

Stacks should only be erected on cleaned, slightly raised and well drained soils. In wet climates, protection form the rain is essential but a proper roof over the piles of baled bagasse generally proves too costly. In practice, corrugated asbestos sheets are used to cover the stacks like shingles; if galvanized iron sheets are used they should be dipped in asphalt to withstand the corrosive action of the acetic acid rising from the piles. After 3 months storage the bales have generally cooled to normal air temperature and their moisture content averages 20%.

As a further precaution against rotting, due to wetting by rain, it is advisable to sprinkle the top and outside bales of the stack with boric acid.

If all the above precautions are taken, losses due to deterioration after 12 months storage should not exceed 10% on a dry fiber basis.

(C) The Ritter system

Essentially, the system is to store bagasse in bulk and to keep the bagasse pile wet with a biological liquor to prevent deterioration of the fibrous material.

Ritter originally experimented with his system in 1930, but the first industrial utilization took place, in 1956, at the Ngoye Paper Mill at Felixon, South Africa.

The biological liquor consists mainly of lactic acid bacteria with sufficient molasses as nutrient so that the bacteria can reproduce satisfactorily. It has a PH value of 4.0-4.5, which prevents any undesirable micro-organisms from developing in the bagasse pile and causing fibrous deterioration of loss.

The mill run (or partly depithed) bagasse is conveyed from the sugar mill to an elevated channel, where it is mixed with biological liquor to from a 4% suspension and flushed to a large slab of concrete which is used as storage area. The concrete floor is traversed in one direction by a number of parallel draining channels allowing the liquor to be re circulated by a pump.

The bagasse forms at first a large pyramid and by directing the flow of bagasse the pile can be adjusted with ease, the sides inclined at an angle of 45. For small capacities, a stacking height of 15 meters is sufficient, while for larger mill capacities of up to 300 tons per day, the storage height can go up to 25 meters, in which case a mechanical flushing device is used to lift the bagasse towards the top of the pile.

2.1.1.5 Experience of foreign Sugar factories in using bagasse

Over the years, cane sugar factories worldwide and more particularly those in island countries like Hawaii's, Mauritius and Leunion devoid of any fossil fuel resources, have invested in energy efficient equipment and adopted energy conservation measures with the objective of reducing energy demand in cane processing and maximizing energy export in the form of electricity to the public grid.

In Mauritius one factory with a cane crushing capacity of 300 tones cane per hour is equipped with 2x140t/h boilers producing steam at 82 bars at 525^0c which is fed to 2x35mw condensing extraction turboaltenator. The net electricity exported is 110kwh/tone cane. This means that a cane sugar factory processing around 1 million tones of cane can accommodate a power plant of generating 440 GWH.

By investing in mill efficiency and giving attention to this important energy resource, Bagasse, Mauritius had a positive outcome in that significant improvements were made in energy use and conservation in cane processing.

In addition to generating energy for the whole process of sugar factories, Bagasse based power plants are also available in different countries. For example the following table shows that bagasse based power plant in Mauritius up to the year 2002.

Energy generating and exporting from excess bagasse is at this time mash activity in addition to sugar manufacturing in many countries. Hawaii's largest sugar producer converts ≈ 250,000 tone of bagasse to electricity and exports ≈ 100,000 Kwh to utility grid. And factories of different countries like Philippines, Thailand are generating averagely 20kw/TCH processed.

Indonesia's sugar mills produces about 8.3 millions of bagasse annually about 1.1 MT of bagasse is produced in excess for the sugar plants normal requirements.

Table2.4: Bagasse based Power Plants in Mauritius up to year 2000 [24]

Factory	Tones cane per hour	Power	Start Date	Units from Bagasse (GWh)	Units from Coal (GWh)	Total Units from Bagasse & Coal (GWh)
FUEL	270	F	Oct 1998	60	115	175
Deep River Beau champ	270	F	April 1998	70	85	155
Belle Vue	210	F	April 2000	105	220	325
Medline	190	C	1980	20	-	20
Mon Tresor Mon Desert	105	C	July 1998	14	-	14
Union St Aubin	150	C	July 1997	16	-	16
Riche en Eau	130	C	July 1998	17	-	17
Savannah	135	C	July 1998	20	-	20
Mon Loisir	165	C	July 1998	20	-	20
Mon Desert Alma	170	C	Nov 1997	18	-	18
Total		3 F 7 C		360 GWh 235 GWh F 125 GWh C	420 GWh	780 GWh

F= firm or bagasse during crop and coal during intercrop

C= continuous or bagasse during crop season only.

*2.*2 Combustion

Sugar factories generate their electricity, steam to drive mills and for processes are by burning bagasse in furnaces. The process of burning fuels in a furnace to generate energy is called combustion.

Combustion occurs when fossil fuels, such as natural gas, fuel oil, coal or gasoline, react with oxygen in the air to produce heat. The heat from burning fossil fuels is used for industrial processes, environmental heating or to expand gases in a cylinder and push a piston. Boilers, furnaces and engines are important users of fossil fuels. [26]

Fossil fuels are hydrocarbons, meaning they are composed primarily of carbon and hydrogen. When fossil fuels are burned, carbon dioxide (CO_2) and water (H_2O) are the principle chemical products, formed from the reactants carbon and hydrogen in the fuel and oxygen (O_2) in the air. The simplest example of hydrocarbon fuel combustion is the reaction of methane (CH_4), the largest component of natural gas, with O_2 in the air. [26]

When this reaction is balanced, or stoichiometric, each molecule of methane reacts with two molecules of O2 producing one molecule of CO2 and two molecules of H2O. When this occurs, energy is released as heat.

$CH_4 + 2O_2 => CO_2 + 2H_2O$

Reactants => Products + Heat

In actual combustion processes, other products are often formed. A typical example of an actual combustion process is shown in Figure 2.1

The combining of oxygen in the air and carbon in the fuel to form carbon dioxide and generate heat is a complex process, requiring the right mixing *turbulence*, sufficient activation *temperature* and enough *time* for the reactants to come into contact and combine. Unless combustion is properly controlled, high concentrations of undesirable products can form. Carbon monoxide (CO) and soot, for example, result from poor fuel and air mixing or too little air. Other undesirable products, such as nitrogen oxides

(NO, NO_2), form in excessive amounts when the burner flame temperature is too high. If a fuel contains sulfur, sulfur dioxide (SO_2) gas is formed. For solid fuels such as coal and wood, ash forms from incombustible materials in the fuel.

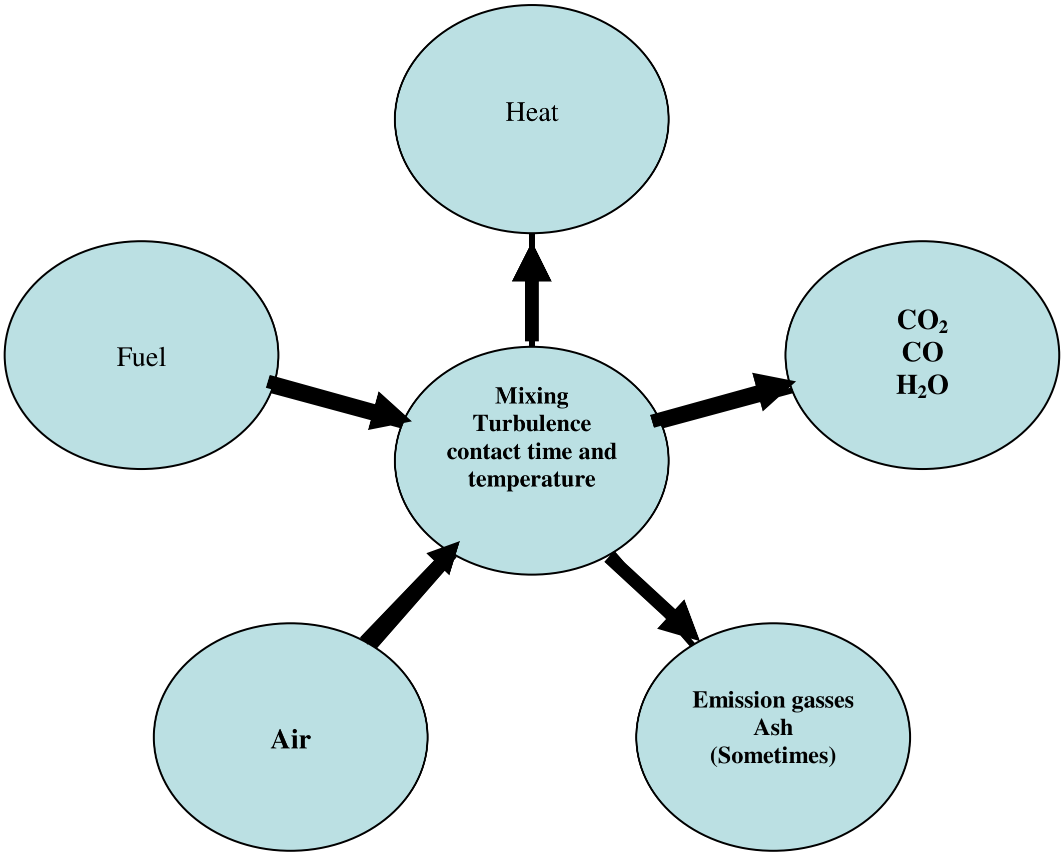


Figure 2.1 Combustion Diagram

2.2.1 Combustion Analysis

Combustion analysis is part of a process intended to improve fuel economy, reduce undesirable exhaust emissions and improve the safety of fuel burning equipment. Combustion analysis begins with the measurement of flue gas concentrations and gas temperature, and may include the measurement of draft pressure and soot level.

To measure gas concentration, a probe is inserted into the exhaust flue and a gas sample drawn out. Exhaust gas temperature is measured using a thermocouple positioned to measure the highest exhaust gas temperature. Soot is measured from a gas sample drawn off the exhaust flue. Draft is the differential pressure between the inside and outside of the exhaust flue. Once these measurements are made, the data is interpreted using calculated combustion parameters such as combustion efficiency and excess air. A more in depth analysis will examine the concentration of the undesirable products described earlier.

Why Perform Combustion Analysis?

1. Improve Fuel Efficiency

The largest sources of boiler heat losses are shown Figure 2.2. Heat energy leaving the system exhaust flue (or stack) is often the largest single source of lost fuel energy and is made up of the Dry Gas loss and Latent Heat Loss. Although some flue loss is unavoidable, an equipment *tune-up* using combustion analysis data can often significantly reduce this source of heat loss and save fuel costs by improving fuel efficiency. [26]

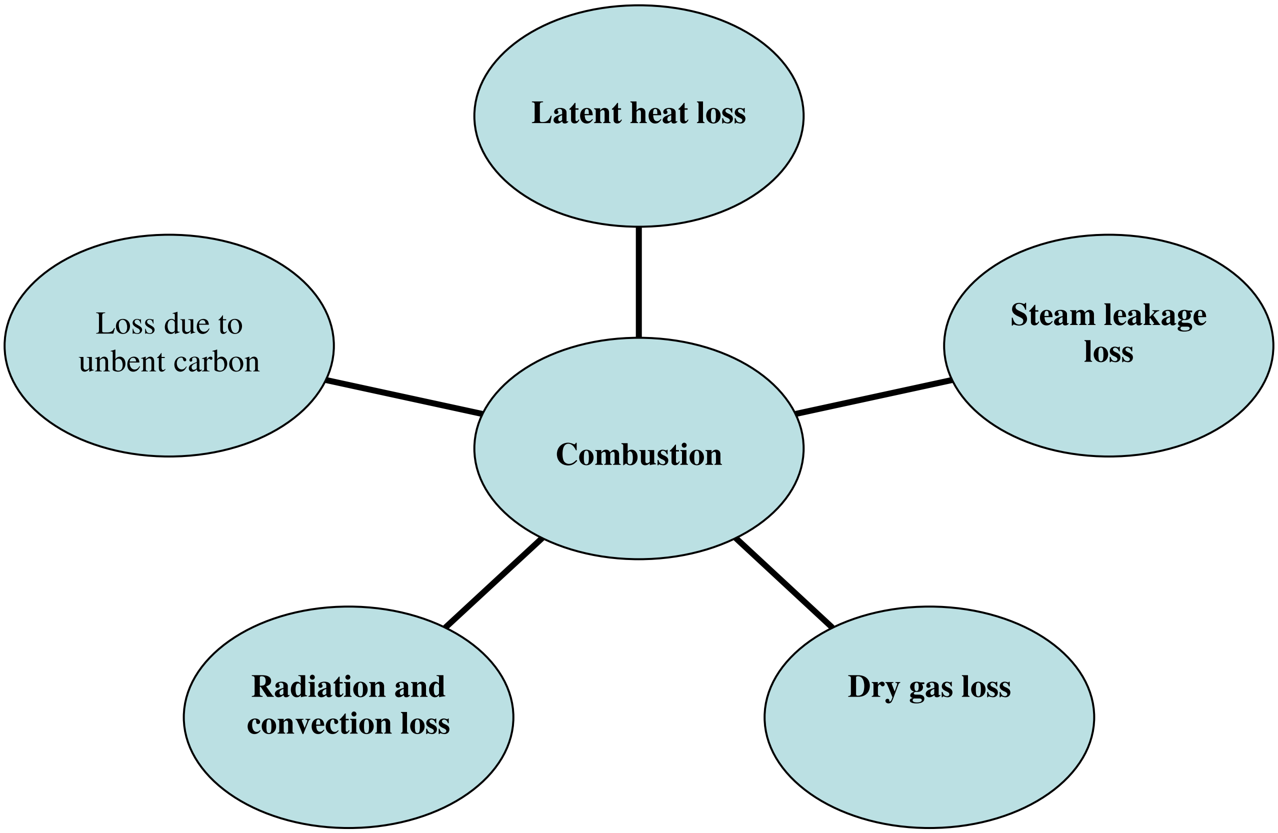
2. Reduce Emissions

Carbon monoxide, sulfur dioxide, nitrogen oxides and particles are undesirable *emissions* associated with burning fossil fuels. These compounds are toxic, contribute to acid rain and smog and can ultimately cause respiratory problems. Combustion analysis is performed to monitor toxic and acid rain forming emissions. [26]

3. Improve Safety

Good equipment maintenance practice, which includes combustion analysis, enables the boiler technician to fully verify and maintain the equipment operating specifications for safe and efficient operation. Many boiler manufacturers suggest that flue gas analysis be performed at least monthly. Boiler adjustments that affect combustion will tend to drift with time. Wind conditions and seasonal changes in temperature and barometric pressure can cause the excess air in a system to fluctuate several percent. A reduction in excess air can cause, in turn, a rapid increase of highly toxic carbon monoxide and explosive gases, resulting in rapid deterioration in system safety and efficiency. Low draft pressures in the flue can further result in these combustion gases building up in the combustion chamber or being vented indoors. Excessive draft pressures in the flue also can cause turbulence in the system. This can prevent complete combustion and pull explosive gases into the flue or cause flame impingement and damage in the combustion chamber and to the heat exchanger material. [26]

Figure 2. Boiler Heat losses



2.2.2 What is to be measured?

Combustion analysis involves the measurement of gas concentrations, temperatures and pressure for boiler tune-ups, emissions checks and safety improvements. Parameters that are commonly examined include:

- Oxygen (O_2)
- Carbon Monoxide (CO)

- Carbon Dioxide (CO_2)
- Exhaust gas temperature
- Supplied combustion air temperature
- Draft
- Nitric Oxide (NO)
- Nitrogen Dioxide (NO_2)
- Sulfur Dioxide (SO_2)

1. Oxygen, Carbon Monoxide and Carbon Dioxide

As described earlier, simple combustion involves the reaction of oxygen in the air with carbon and hydrogen in the fuel, to form carbon dioxide and water and produce heat. Under ideal conditions, the only gases in the exhaust flue are CO_2, water vapor and nitrogen from the combustion air. When O_2 appears in the flue exhaust, it usually means that more air (20.9 percent of which is O_2) was supplied than was needed for complete combustion to occur. Some O_2 is left over. In other words, the measurement of O_2 gas in the flue indicates that extra combustion air, or *Excess Air,* was supplied to the combustion reaction. When too little air is supplied to the burner, there is not enough oxygen to completely form CO_2 with all the carbon in the fuel. Instead, some oxygen combines with carbon to form carbon monoxide (CO). CO is a highly toxic gas associated with incomplete combustion and efforts must be made to minimize its formation. This effort goes hand-in-hand with improving fuel efficiency and reducing soot generation.

As a rule, the most efficient and cost-effective use of fuel takes place when the CO_2 concentration in the exhaust is maximized. Theoretically, this occurs when there is just enough O_2 in the supplied air to react with all the carbon in the fuel supplied. This quantity of supplied air is often referred to as the *theoretical air.* The theoretical air required for the combustion reaction depends on fuel composition and the rate at which the fuel is used (e.g. pounds per hour, cubic feet per minute, etc.). In real-world combustion, factors such as the condition of the burner and the burner design also influence the amount of air that is needed. The theoretical air is rarely enough.

2. Exhaust Gas Temperature and Supplied Combustion Air Temperature

Heat leaving the exhaust flue with the hot gases is not transferred to do useful work, such as producing steam. This heat loss becomes a major cause of lower fuel efficiency. Because the heat content of the exhaust gas is proportional to its temperature, the fuel efficiency drops as the temperature increases. When determining heat loss from the flue, the temperature of the supply air is subtracted from the flue gas temperature. This gives the *net* temperature and accounts for the heat supplied to the system by the supply air. Some heat loss is unavoidable. The temperature in the flue needs to remain high enough to avoid condensation inside the stack. One process for recovering some of the heat loss in the exhaust is to use the hot flue gases to preheat the supply air before it is introduced into the combustion chamber.

3. Draft

Draft refers to the flow of gases through the heat generating equipment, beginning with the introduction of air at the back of the burner. Once combustion occurs, the heated gas leaves the combustion chamber, passes heat exchangers and exits the exhaust stack. Depending upon the design of the equipment, draft is *natural*, meaning combustion air is pulled in by buoyant heated gases venting up the stack, or it is *mechanical*, meaning air is pushed or pulled through the system by a fan. Often, draft relies on a combination of both natural and mechanical means. Adequate draft is typically verified by measuring the pressure in the exhaust stack. The manufacturer of the fuel burning equipment provides specifications for the required draft pressure and locations for making the draft measurement. Measurement is important since environmental influences such as changes in barometric pressure and ambient temperature can influence the flow. Typical draft pressures are in the range of –0.5 to 0.5 inches of water column. Excessive draft can prevent heat transfer to the system and increase the flue temperature if the excess air percentage is not elevated. If the excess air increases from the high draft, the flue temperature will decrease. Low draft pressures can cause temperatures in the flue to decrease, allowing water vapor to condense in the flue, forming acid and damaging the system.

4. Nitrogen Oxides (NOx)

Nitrogen oxides, principally nitric oxide (NO) and nitrogen dioxide (NO_2), are pollutant gases that contribute to the formation of acid rain and smog. Nitrogen oxides result when oxygen combines with nitrogen in the air or in the fuel. NO is generated first at high flame temperatures and then oxidizes further to form NO2 at cooler temperatures in the stack or after being exhausted.

The NO concentration is often measured alone, and the NO_2 concentration is generally assumed to comprise an additional five percent of the total nitrogen oxides. The nitrogen oxide gas concentrations are sometimes combined and referred to as the *NOX* concentration.

5. Sulfur Dioxide (SO_2)

Sulfur dioxide combines with water vapor in the exhaust to form a sulfuric acid mist. Airborne sulfuric acid is a pollutant in fog, smog, acid rain and snow, ending up in the soil and ground water. Sulfur dioxide itself is corrosive and harmful to the environment.

Sulfur dioxide occurs when the fuel contains sulfur and where the emission levels are directly related to the amount of sulfur in the fuel. The most cost-effective way to reduce sulfur emissions is to select a low-sulfur or de-sulfured fuel.

6. Hydrocarbons (HCs)/Volatile Organic Compounds (VOCs)

Organic compounds are sometimes present in the combustion exhaust products because of incomplete combustion. Hydrocarbons (HCs), or volatile organic compounds (VOCs), are best reduced through proper burner maintenance and by maintaining the proper air/fuel mixture.

7. Soot

Soot is the black smoke present whenever fuel oils or solid fuels are burned. Excessive soot is undesirable because it indicates poor combustion and is responsible for coating internal heat transfer surfaces, preventing good thermal conductivity. Over time, serious damage to the heat exchanger can occur. Soot is primarily unburned carbon, and is formed for the same reasons CO is formed—insufficient combustion air, poor mixing and low flame temperature. As with CO, it is usually impossible or impractical to entirely eliminate soot formation for some fuel types.

2.2.3 Using the Measurements

Once flue gas and temperature measurements are made, *combustion parameters* are calculated to help evaluate the operating performance of the furnace or boiler. Typical combustion parameters include:

- Excess Air
- Carbon Dioxide
- Combustion Efficiency
- Emissions Conversion

1. **Excess Air**

Excess air is determined by measuring the concentration of non-reacted O_2 in the flue gas. A good approximation for excess air, expressed as a percent, can be calculated from the equation below.

$$\%\ \text{excess air} = \frac{\%O_2 - \frac{\%CO_2}{2}}{20.9 - (\%O_2 - \frac{\%CO_2}{2})} * 100$$

2. **Carbon Dioxide**

Instruments using electronic sensors determine the CO_2 concentration in real time by measuring the O_2 concentration in the flue exhaust and calculating CO_2.

The CO_2 concentration is determined using the following equation

$$\%\ CO_2\ \text{(by volume)} = CO_2(\max) * \frac{(20.9 - \%O_2 measured)}{20.9}$$

CO_2 (max) is the theoretical maximum concentration produced for the fuel used.

3. Combustion Efficiency

Combustion efficiency is expressed as a percent and determined by subtracting individual stack heat losses, as percents of the fuel's heating value, from the total heating value of the fuel (100%). Dry gas loss and latent heat loss due to H2 in the fuel are typically the largest sources of stack loss. Others can be included, such as heat loss from moisture in the air and fuel and losses from the formation of CO rather than CO_2. This basic form for calculating efficiency is described in the ASME Power test code 4.1 and is applicable for losses other than flue losses when determining total system efficiency by the *Heat-Loss* method. [10]

$$\%\text{ Net combustion efficiency} = 100- \frac{flueheatlosses}{fuelheatingvalue} * 100$$

Flue heat losses = $Lg + Lh + Lm + Lco + L_{ash} + L_R$ (Individual heat losses are described in this section.)

Where: Lg = heat loss due to dry gas

Lh = heat loss due to moisture from burning hydrogen

Lm = heat loss due to moisture in fuel

Lco = heat loss from the formation of CO

L_{ash} = heat loss due to unburned carbon in the ash

L_R = Radiation and undeterminable heat losses

Fuel heating value: HHV or LHV

Heat loss due to dry gas (Lg)

Lg = Wg x Cp x (Tflue – Tsupply)

Where: Wg = the weight of the flue gases per pound of as-fired fuel.

Cp = specific heat of the exhaust gas mix.

$Tflue$ = flue temperature

$Tsupply$ = combustion supply air temperature

Heat loss due to H_2O from combustion of hydrogen (Lh)

Where the fuel has high hydrogen content, latent heat loss from the water formation can be very significant.

$$Lh = 8.936 \times H \times (hl - hrw)$$

Where: 8.936 = weight of water formed for each hydrogen atom

H = fractional hydrogen content of the fuel

hl = enthalpy of water at the exhaust temperature and pressure

hrw = enthalpy of water as a saturated liquid at fuel supply temperature

Heat loss due to moisture in fuel (Lm)

Moisture in the fuel is determined from lab analysis of the fuel and can be obtained from the fuel supplier.

$$Lm = \textbf{fraction fuel moisture} \times (h_l - h_{rw})$$

Where: hl = enthalpy of water at exit gas temperature and pressure

hrw = enthalpy of water at fuel supply temperature

Heat loss due to the formation of carbon monoxide (L_{co})

Carbon in the fuel reacts with oxygen to form CO first, then CO2, generating a total of 14,540 Btus of heat per pound of carbon. If the reaction stops at CO because of insufficient O2 or poor mixing of fuel and air, 10,160 Btus of energy are lost.

$$L_{co} = \frac{\%CO}{\%CO_2 + \%CO} * 10{,}160 * Cb$$

Where Cb = fractional carbon content

Heat loss due to unburned carbon in the ash (L_{ash})

For bagasse furnaces, Heat loss due to unburned carbon in the ash is usually around 2% of the total heat. If the carbon content of the ash is known it is also possible to calculate the loss due to this unburned carbon.

L_{ash} = mass of carbon in the ash per kg of fuel * carbon heating value

But it is usually estimated as 2% of the total fuel heating value.

Heat loss due to radiation and other undeterminable losses (L_R)

The heat loss due to radiation and some other loss which can not be determined easily are accounted about 6% of the total heat.

CHAPTER THREE

3. DATA COLLECTION AND ANALYSIS

3.1 Data collected

For undergoing the research work in Metehara sugar factory data has been collected from many sources; documentation archival records, interviews, direct observation, readings measurements and questionnaires.

Generally, two types of data have been collected: primary data and secondary data. Primary data is obtained by the researcher, and is the result of own studies of the problem. It includes the collection of information through direct observation, personal interviews, and conducting conversation. The secondary data, on the other hand, is the result of other people's research in the same problem area, or from other related problem areas. It includes the study of document, web-sites and other historical and documentary records relevant for the research.

The researcher has also assessed the existing energy generation condition by conducting combustion analysis by using "KANE – MAY KM9104" combustion analyzer. This is used to know the flue gas components and their concentration as well as the flue gas temperature from which one can calculate the amount of the different losses and combustion efficiency.

Metehara sugar factory has four boilers namely boilers 1, 2, 3 and 4. The boilers are bi-drum types which can fire bagasse and auxiliary oil. The oil type being used by the furnaces is heavy oil of gross and net calorific values of 41868 KJ/Kg and 40518.9 KJ/kg respectively. This furnace fuel is injected to the furnaces by atomizing using steam pressure of 10-15 Kg/cm^2.

And the wet bagasse form the mills is directly transported by using chain conveyors, distributed to all the furnaces and feed through holes on the top of the furnaces called chutes. The designed combustion parameters of the boilers are shown in the following tables.

Fig. 3.1 Boilers of MSF

Table 3.1 Design parameters of combustion

Parameters	Boilers 1,2,3	Boiler 4
Moisture content of bagasse %	49-50	49-50
Inlet air temperature ^{o}c	170-210	220-260
Flue gas temperature before air heater ^{o}c	270-290	280-310
Flue gas temperature after air heater ^{o}c	170-190	180-200
Flue gas temperature at economizer outlet ^{o}c	130-150	130-150
O_2 in flue gas	4-6	4-6
Draft at air heater air outlet kg/cm^2	40-55	70-100
Draft at air heater gas outlet kg/cm^2	-10- -40	-10--15
Draft at air heater gas outlet kg/cm^2	70—80	-140--160
Furnace draft kg/cm^2	-1--5	-1--5
Draft at economizer gas outlet kg/cm^2	-100--120	-160--180
Furnace fuel presser kg/cm^2	5-10	5-10
Atomizing steam pressure kg/cm^2	10-15	10-15

The feed water, super heating station and steam distribution at the researcher read from different control panels are discussed in the following table.

Fig 3.2 Boiler control panel of MSF

Table3.2 Feed water properties and steam generation capacity

Feed water temperature to economizer ^{o}c	103-105
Feed water temperature after economizer ^{0}c	120-130
Feed water pressure pump discharge kg/cm^{2}	26-30
Feed water pressure to economizer kg/cm^{2}	23-25
Steam drum level	50$\pm$10
Super heating outlet steam kg/cm^{2}	19-22
Super heating out let temperature ^{o}c	350-380
Steam generation normal ton/hr	20-25 for boilers 1,2,3 & 40-50 for boiler 4

Table3.3 Steam distribution

Plant	Pressure (kg/cm^2)	Temperature (^{o}c)	Quantity (ton/hr)
Power plant	20-22	350-375	40-50
Mill A	20-22	350	10-15
Mill B	20-22	350	20-25
Evaporation make up	0.9-1.25	120-130	20-36
Clarification	5-7	160-170	5-6
Sugar drying	3	130-140	-

And the powers as well as the mill turbines technical data are discussed as shown below

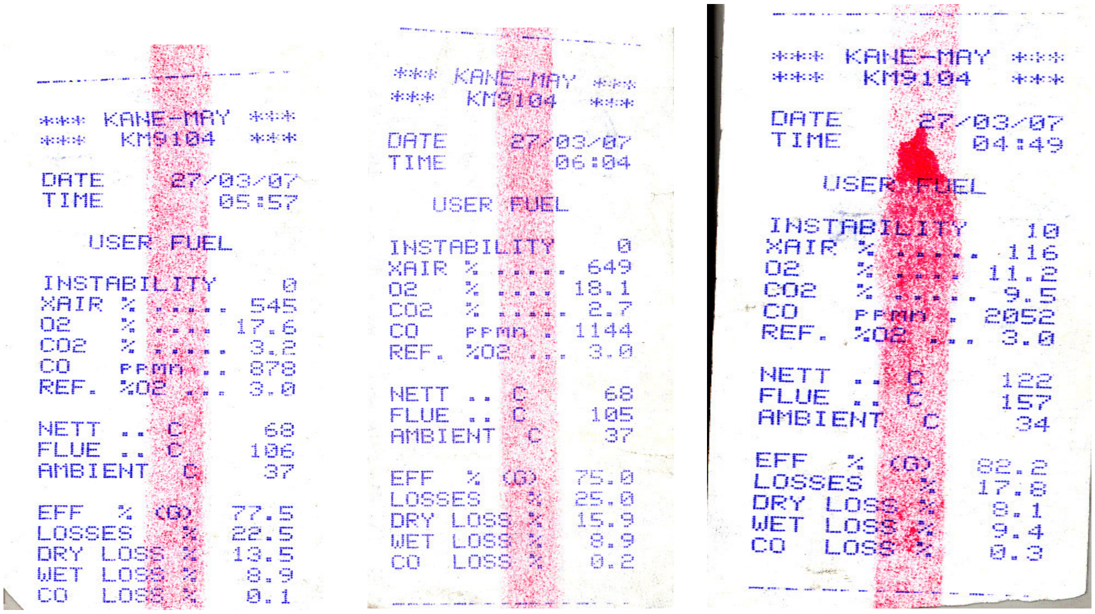
Table 3.4 Power turbine technical data

Manufacturer	Brown Boveri
Type	DGX- e4024
Manufacturing number	HT 324 290/80
Live steam pressure	21.6 bar
Live steam temperature (nominal)	350^{o}c
Live steam temperature (max)	450^{o}c
Live steam flow	31t/h
Speed	11935 rpm
Generation output	3,180 kw

Table 3.5 Mill turbine technical data

Turbine serial number	604
Normal rating	670HP
Normal rated turbine speed	9870rpm
Steam pressure at stop valve	21kg/cm^2
Steam temperature at stop valve	340^{o}c
Steam pressure in exhaust branch	1.25 kg/cm^2
Steam consumption	5750kg/h

As discussed earlier the combustion data is obtained by making combustion analysis. This is done five times for each boiler during five different days and the average data obtained are used for calculation. Although the analyzer is capable of calculating the different combustion parameters , the analyzer used do not have bagasse parameters; as a result the combustion parameters are calculated manually. Samples of the obtained data are shown below.



```
*** KANE-MAY ***
***  KM9104  ***

DATE     27/03/07
TIME        05:57

   USER FUEL

INSTABILITY     0
XAIR % .....  545
O2   % ....  17.6
CO2  % .....  3.2
CO    PPMn ..  878
REF. %O2 ...  3.0

NETT .. C      68
FLUE .. C     106
AMBIENT  C     37

EFF   % (G)  77.5
LOSSES    %  22.5
DRY LOSS  %  13.5
WET LOSS  %   8.9
CO  LOSS  %   0.1
```

```
*** KANE-MAY ***
***  KM9104  ***

DATE     27/03/07
TIME        06:04

   USER FUEL

INSTABILITY     0
XAIR % .....  649
O2   % ....  18.1
CO2  % .....  2.7
CO    PPMn . 1144
REF. %O2 ...  3.0

NETT .. C      68
FLUE .. C     105
AMBIENT  C     37

EFF   % (G)  75.0
LOSSES    %  25.0
DRY LOSS  %  15.9
WET LOSS  %   8.9
CO  LOSS  %   0.2
```

```
*** KANE-MAY ***
***  KM9104  ***

DATE     27/03/07
TIME        04:49

   USER FUEL

INSTABILITY    10
XAIR % .....  116
O2   % ....  11.2
CO2  % .....  9.5
CO    PPMn . 2052
REF. %O2 ...  3.0

NETT .. C     122
FLUE .. C     157
AMBIENT  C     34

EFF   % (G)  82.2
LOSSES    %  17.8
DRY LOSS  %   8.1
WET LOSS  %   9.4
CO  LOSS  %   0.3
```

Fig 3.3 Samples of combustion analysis results

Fig 3.4 During combustion analysis

And the overall overview of sugar production and energy consumption are discussed in table 3.5. And the total sugar production of MSF is shown in the figure 3.5

NO	ITEMS	UNIT	YEAR							Average
			99/2000	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	
1	Quantity of sugar cane crushed	Ton	10021329	1037569	1021283	1049631	1131771	1062376	1147809	2353110
2	Quantity of sugar produced	ton	115380	115537	115642	116500	120335	120821	125316	118504
3	Amount of bagasse obtained	Ton	301750	301385	297992	314857	345645	309568	328373	314224
4	Amount of furnace fuel consumed	Liter	2291842	3538362	2516704	2418588	650061	206900	599019	1745925
5	Bagasse equivalence of the furnace fuel	ton	12732.456	19657.57	13981.69	13436.6	3611.45	1149.444	3327.883	9699.58
6	Total bagasse consumed (including fuel equivalence)	Ton	321407.57	315366.7	311428.6	318468.45	346794.4	312895.9	338072.6	323490
7	% Bagasse obtained per crushed cane	ton/ton	27.8	29.04722	29.1782	29.996923	30.54019	29.13921	28.60868	29.1872
8	Bagasse consumption per quantity of sugar produced	ton/ton	2.7856437	2.729573	2.693041	2.7336348	2.881908	2.589748	2.697761	2.65158
9	total steam generated	ton	611301.13	581038.6	571918.5	598289.67	599838.6	563059.3	648512.1	596280
10	Steam consumed per ton of cane	Ton/Ton	0.6	0.56	0.56	0.57	0.53	0.53	0.565	0.55929
11	Steam generated per tone of bagasse	ton/ton	1.90195	1.842422	1.836435	1.8786466	1.729666	1.79951	1.918263	1.89762
12	cost of furnace fuel	Birr	9167368	14153448	10066816	10158070	2925275	931050	2695586	7156802

Table 3.6 Seven years overall overview of sugar production and energy consumption

Fig 3.5 Tones of sugar production for seven years

3.2 Data analysis

3.2.1 Bagasse

As it has been stated in the literature part; 30% of the sugarcane crushed goes to bagasse. According to the data collected 29.5% of the sugarcane crushed is bagasse; which is almost same with other countries production. From this one can conclude that the shortage of bagasse fuel is not due to the inability of bagasse production.

3.2.2 Steam

The average steam production of Metehara sugar factory for the last seven years is 596279.7tons. Based on the literatures and according to foreign energy efficient sugar factories 550 kg of steam is required per ton of cane. The practice in Metehara sugar factory is also same, which is 0.56 tone/hr of steam per ton of sugar cane crushed.

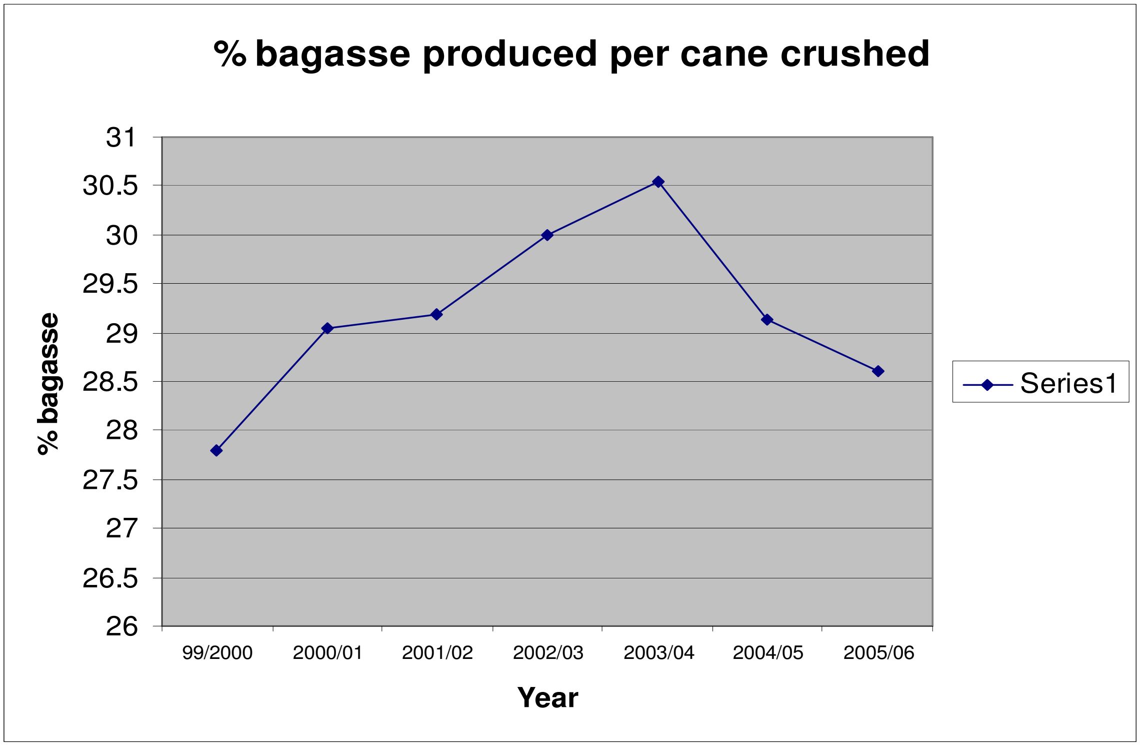


Fig 3.6 % Bagasse produced per cane crushed

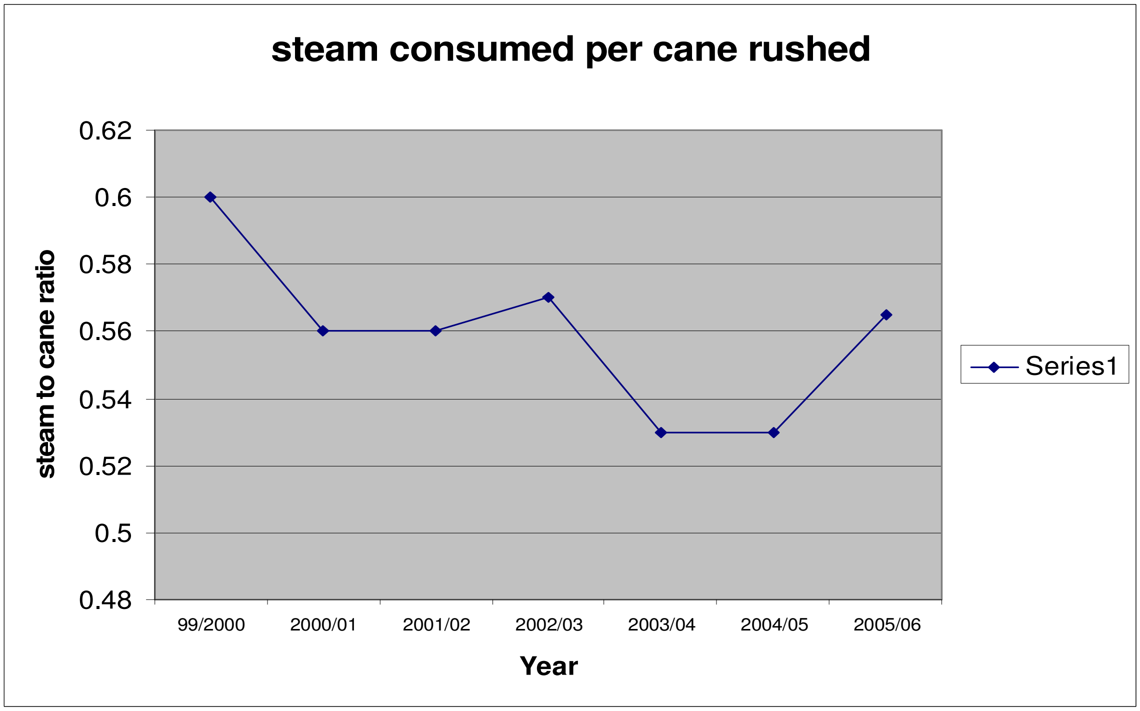


Fig 3.7 Steam consumption per can crushed

But when we see the amount of steam generated per each ton of wet bagasse it is on an average 1.9 ton. According to different resources, the average practice is about 2.3 tones of steam per ton of bagasse burned.

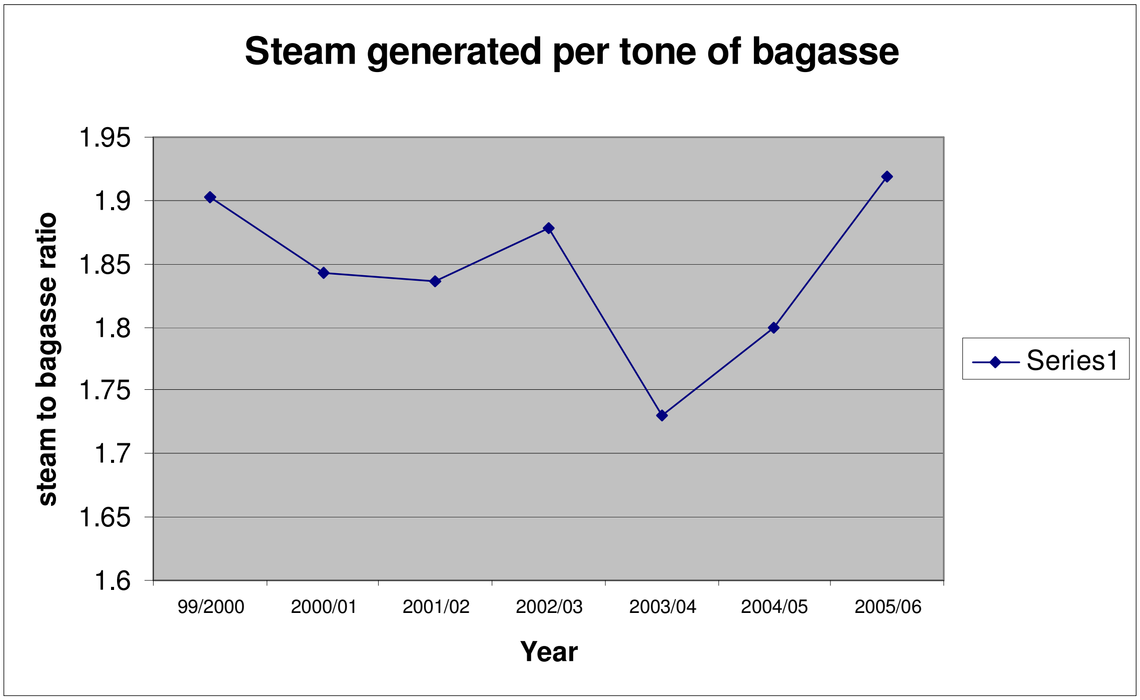


Fig 3.8 Amount of steam generated per ton of bagasse

The amount of steam required in MSF is 596,279.7 ton

The standard bagasse required should be $\frac{596,279.7}{2.3}$

= 259252tone

But MSF produces about 314,224.3 tones, and then excess bagasse that should be available is:

= 314224.3 – 25952 = **54,972 tone**

3.2.3 Furnace fuel (oil) consumption

Although using of furnace fuel is not being practiced in many sugar factories.

The amount of oil burned in MSF for the last seven years is shown in Fig 3.8 below.

As the figure shows us that, on an average 1,745,925 liters of furnace fuel is used each year for the last seven years and the amount of money used to buy this imported expensive fuel is on an overage birr 7,156,802 per year averagely for the last seven years

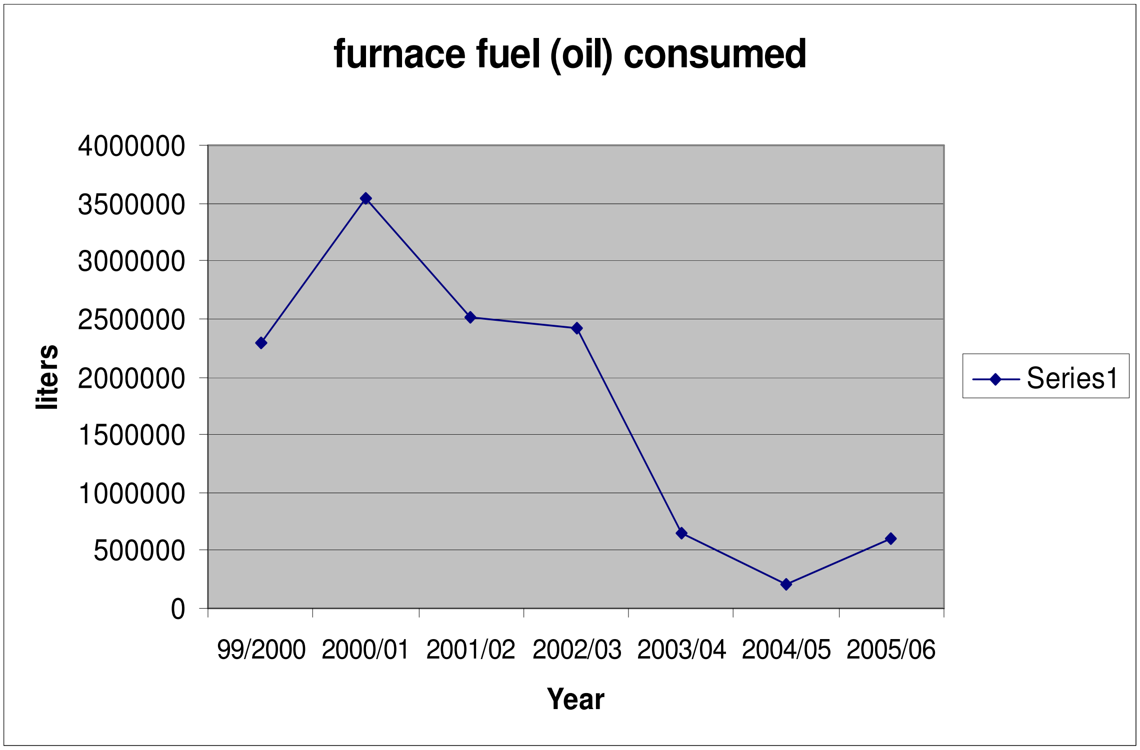


Fig 3.9 Furnace fuel consumption

It is obvious that usage of furnace fuel is due to the shortage of bagasse, and the equivalent amount of bagasse which can replace the furnace fuel being used is 9699.58 ton as shown in table 3.6. This means that if MSF reduces its present bagasse consumption by 9699.58 tones it can avoid fuel oil consumption fully.

From the analysis of the energy intensity of MSF it can be seen that there is a significant difference between energy activities of the plant as compared to the world average practices. The following figure (fig 3.10) shows clearly how much the company has actually spent for energy which was not necessary. Averagely the factory allocated birr 7,156,802 for the last seven years.

As the reason for using furnace fuel of the boilers is due very high consumption of bagasse for the generation of steam, the combustion efficiencies of the boilers are calculated as follows

3.2.4 Boiler efficiency

The performance of boilers may be expressed as the ratio of the heat output to the heat input. If the heat input is expressed in terms of HHV of the fuel per kg of the fuel, then the output heat is the heat absorbed by water and steam per kg of fuel burnt. The boiler efficiency depends on the performance of the economizer, super heater air pre heaters and the furnaces; that is on the combined efficiency of its components. [10b]

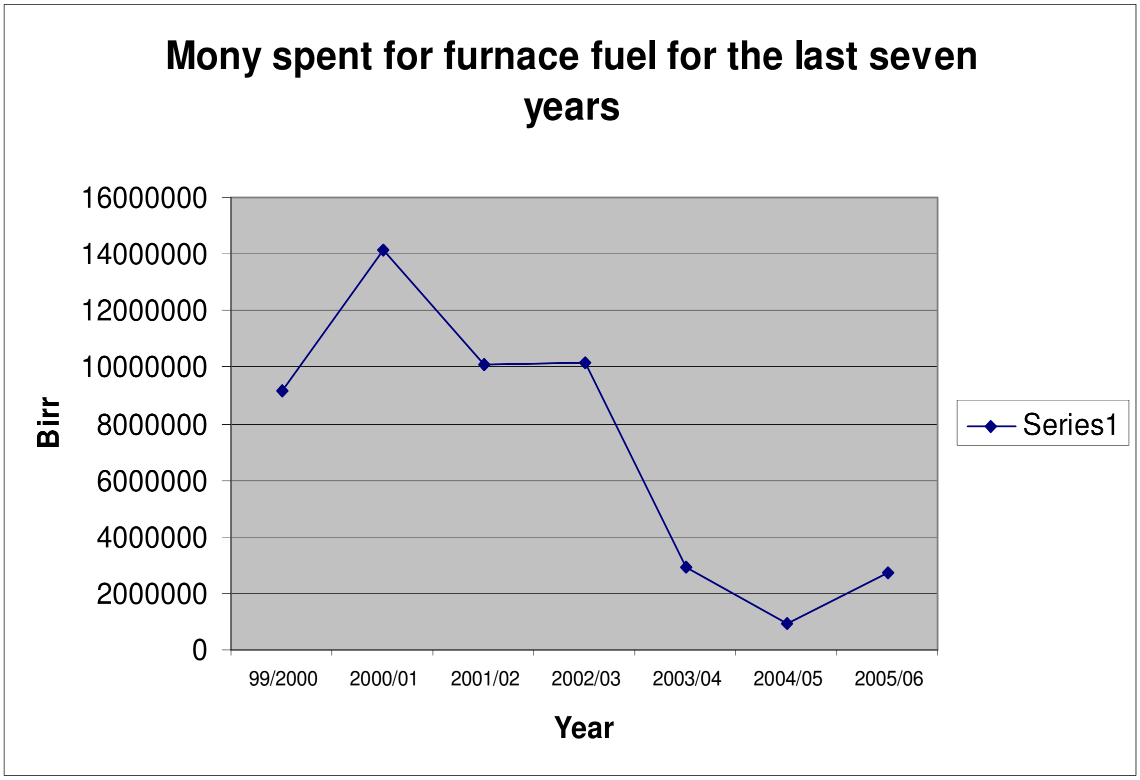


Fig 3.10 Money spent for furnace fuel (oil)

The main causes of heat losses for most types of furnaces and especially for solid fuels like bagasse furnaces are:

1. Heat loss due to dry gas
2. Heat loss due to moisture from burning of hydrogen in the fuel
3. Heat loss due to moisture in the fuel
4. Heat loss from the formation of CO
5. Heat loss due to unburned carbon in the ash
6. Heat loss due to radiation and unaccounted

3.2.4 Analysis for individual boilers

1. Boiler one

Based on the measurement made for boiler 1, the average values of the main parameters obtained are the following.

Oxygen = 11.35 %

Carbon dioxide = 8.85%

Carbon monoxide=.95%

Flue gas temperature = 151.3^{o}c

Ambient temperature = 34.5^{o}c

And % nitrogen = (100-22.35-8.85-0.95) = 78.68

1. **Excess air**

$$\%\text{ excess air} = \frac{\%O_2 - \frac{\%CO_2}{2}}{20.9 - (\%O_2 - \frac{\%CO_2}{2})} * 100$$

$$= \mathbf{108.3\%}$$

2. **Heat loss due to dry gas (Lg)**

$$Lg = Wg*Cp*(T_{flue} - T_{amb})$$

$$Wg = \frac{(44*8.85 + 32*11.35 + 28*.97 + 28*76.68)*0.178}{12(8.85 + 0.97)}$$

= 4.5 kg/kg fuel

$Cp = ((.240 - 0.000038(T_{flue} -200))*4.1868$

$= 0.997 KJ/kgK$

And $T_{flue} - T_{amb} = 151 - 34.5 = 116.8$

Then $Lg = 4.5 *0.997*116.8$

= 524KJ/kg fuel

3. **Heat loss due to moisture from burning of hydrogen in the fuel**

$Lh = 9*(0.02134)(h_g - h_f)$

$= 9*(0.02134)*(2748 - 146.7)$

H_g and h_f are obtained from steam tables at the given temperatures.

= 498.8 KJ/Kg fuel

4. **heat loss due to moisture in the fuel**

$Lm = \text{fractional fuel moisture} * (h_g - h_f)$

$= 0.5 * (2748 - 146.7)$

= 1301 KJ/kg

5. **Heat loss due to the formation of carbon monoxide Lco**

$$L_{co} = \left(\frac{\%CO}{\%CO_2 + \%CO} * 10{,}160 * Cb \right) * 2.326$$

$= 415 .5 kJ/kg$

6. **Heat loss due to unburned carbon in the ash L_{ash}**

L_{ash}= 2% of the fuel heat

= 209KJ/KG

7. **Heat loss due to radiation and unaccounted L_r**

L_r=6% of the fuel heat

= 628 Kg/Kg fuel.

The sum of the losses is then given by:

$Lg + L_h + L_m + L_{co} + L_{ash} + L_r$

$= 524 + 498.8 + 1301 + 415.5 + 209 + 628$

= **3576.3kJ/kg**

HHV of bagasse is 9769.2kJ/kg

The combustion efficiency is then:

$$= 100 - \frac{3576.6}{9769.2}*100$$

= **63.4%**

2. Boiler two

Based on the measurement made for boiler 2, the average values of the main parameters are the following.

Oxygen = 11 %

Carbon dioxide = 9.85%

Carbon monoxide= 0.4%

Flue gas temperature = 144.5^{o}c

Ambient temperature = 32 ^{o}c

And % nitrogen = 78.75

1. Excess air

$$\% \text{ excess air} = \frac{\%O_2 - \frac{\%CO_2}{2}}{20.9 - (\%O_2 - \frac{\%CO_2}{2})} * 100$$

= **107%**

2. Heat loss due to dry gas (Lg)

$Lg = Wg*Cp*(T_{flue} - T_{amb})$

$$Wg = \frac{(44*9.85 + 32*11 + 28*0.4 + 28*78.75)*0.178}{12(9.85 + 0.4)}$$

= 4.34 kg/kg fuel

$Cp = ((.240 - 0.000038(T_{flue} -200))*4.1868$

= 0.997KJ/kgK

And $T_{flue}-T_{amb} = 144.5 - 32 = 112.5$

Then $Lg = 4.34 * 0.996 * 112.5$

= 486.3KJ/kg fuel

3. Heat loss due to moisture from burning of hydrogen in the fuel

$Lh = 9*(0.02134)(h_g - h_f)$

$= 9*(0.02134)*(2737.8 - 105.9)$

h_g and h_f are found by interpolation

= 496kg/kg

4. Heat loss due to moisture in the fuel

$Lm = \text{fractional fuel moisture} * (h_g - h_f)$

$= 0.5 * (2737.8 - 105.9)$

= 1293.5 KJ/kg

5. Heat loss due to the formation of carbon monoxide Lco

$$L_{co} = \left(\frac{\%CO}{\%CO_2 + \%CO} * 10{,}160 * Cb \right) * 2.326$$

= 164kJ/kg

6. Heat loss due to unburned carbon in the ash L_{ash}

L_{ash}= 2% of the fuel heat

= 209KJ/KG

7. Heat loss due to radiation and unaccounted L_r

L_r=6% of the fuel heat

= 628 Kg/Kg fuel.

The sum of the losses is then given by:

$Lg + L_h + L_m + L_{co} + L_{ash} + L_r$

$= 496 + 1293.5 + 164 + 486 + 209 + 628$

= 3276.5kJ/kg

HHV of bagasse is 9769.2kJ/kg

The combustion efficiency is then:

$$= 100 - \left(\frac{3276.5}{9769.2}\right)*100$$

$$= 67\%$$

3. Boiler three

Based on the measurement made for boiler 3, the average values of the main parameters obtained are the following.

Oxygen = 11.3%

Carbon dioxide = 9.4%

Carbon monoxide=0.22%

Flue gas temperature = 105°c

Ambient temperature = 35°c

And % nitrogen = 79

1. Excess air

$$\% \text{ excess air} = \frac{\%O_2 - \frac{\%CO_2}{2}}{20.9 - (\%O_2 - \frac{\%CO_2}{2})}*100$$

$$= \mathbf{115.3\%}$$

2. Heat loss due to dry gas (Lg)

$$Lg = Wg*Cp*(T_{flue} - T_{amb})$$

$$Wg = \frac{(44*9.4 + 32*11.3 + 28*.0.22 + 28*79)*0.178}{12(9.4 + 0.22)}$$

= 4.6 kg/kg fuel

$$Cp = ((.240 - 0.000038(T_{flue} - 200))*4.1868$$

$$= 0.99 KJ/kgK$$

And $T_{flue} - T_{amb} = 105 - 35 = 70$

Then Lg = 4.6 *0.99*70

= 320KJ/kg fuel

3. Heat loss due to moisture from burning of hydrogen in the fuel

$Lh = 9*(0.02134)(h_g - h_f)$

$= 9*(0.02134)*(2683.8 - 146.7)$

$=$ **487.3**

4. Heat loss due to moisture in the fuel

$Lm = \text{fractional fuel moisture} * (h_g - h_f)$

$= 0.5 * (2683.8 - 146.7)$

= 1268.6 KJ/kg

5. Heat loss due to the formation of carbon monoxide Lco

$$L_{co} = \left(\frac{\%CO}{\%CO_2 + \%CO} * 10{,}160 * Cb \right) * 2.326$$

= 254 kJ/kg

6. Heat loss due to unburned carbon in the ash L_{ash}

L_{ash}= 2% of the fuel heat

= 209KJ/KG

7. Heat loss due to radiation and unaccounted L_r

L_r=6% of the fuel heat

= 628 Kg/Kg fuel.

The sum of the losses is then given by:

$Lg + L_h + L_m + L_{co} + L_{ash} + L_r$

= 320 + 487.3 + 1286 + 254 + 209 + 628

= 3184.3kJ/kg

HHV of bagasse is 9769.2kJ/kg

The combustion efficiency is then:

$$= 100 - \left(\frac{3184.3}{9769.2}\right)*100$$

= **67.4%**

4. Boiler four

Based on the measurement made for boiler 4, the average values of the main parameters obtained are the following.

Oxygen = 9.1%

Carbon dioxide = 11.6%

Carbon monoxide=1.6%

Flue gas temperature = 163%

Ambient temperature = 37.5 %

And % nitrogen = 77.7

1. Excess air

$$\% \text{ excess air} = \frac{\%O_2 - \frac{\%CO_2}{2}}{20.9 - (\%O_2 - \frac{\%CO_2}{2})} * 100$$

$$= \mathbf{66\%}$$

2. Heat loss due to dry gas (Lg)

$Lg = Wg*Cp*(T_{flue} - T_{amb})$

$$Wg = \frac{(44*11.6 + 32*9.1 + 28*1.6 + 28*77.7)*0.178}{12(11.6 + 1.6)}$$

= 3.4 kg/kg fuel

$Cp = ((.240 - 0.000038(T_{flue} -200))*4.1868$

$= 0.99KJ/kgK$

And $T_{flue}-T_{amb} = 163 - 37.5 = 125.5$

Then $Lg = 3.4 *0.99*125.5$

= 422KJ/kg fuel

3. Heat loss due to moisture from burning of hydrogen in the fuel

$Lh = 9*(0.02134)(h_g - h_f)$

= 9*(0.02134)*(2761.3 – 157.2)

= 499kJ/kg

4. Heat loss due to moisture in the fuel

Lm = fractional fuel moisture * (h_g - h_f)

= 0.5 * (2761.3 – 157.2)

= 1302 KJ/kg

5. Heat loss due to the formation of carbon monoxide Lco

$$L_{co} = \left(\frac{\%CO}{\%CO_2 + \%CO} * 10{,}160 * Cb \right) * 2.326$$

= 507.7 kJ/kg

6. Heat loss due to unburned carbon in the ash L_{ash}

L_{ash}= 2% of the fuel heat

= 209KJ/KG

7. Heat loss due to radiation and unaccounted L_r

L_r=6% of the fuel heat

= 628 Kg/Kg fuel.

The sum of the losses is then given by:

$Lg + L_h + L_m + L_{co} + L_{ash} + L_r$

= 422 + 499 + 1302 + 507.7 + 209 + 628

= 3567.7kJ/kg

HHV of bagasse is 9769.2kJ/kg

The combustion efficiency is then:

$$= 100 - \left(\frac{3567.7}{9769.2}\right)*100$$

= 63.4%

The efficiencies and excess air of the four boilers is summarized as follows

Table 3.7 Excess air and boiler efficiency summery

	Boiler 1	Boiler 2	Boiler 3	Boiler 4	average
Excess air %	108.3	107	115.3	66	99
Efficiency %	63.4	67	67.4	63.4	65.3

From the analysis of the energy intensity of the MSF it can be seen that there is a significant difference between the energy intensity of the plant as compared to the word average practice. This shows that there is actually a room for improving the energy efficiency of the plant. The following calculation shows clearly how much the company is actually spending for energy which actually was not necessary.

The amount of steam required per year is 596,270.7 ton.

One tone of bagasse has the capacity to generate 2.3 ton of steam.

Then the standard amount of bagasse required to generate 596,270.7 ton steam will be:

$$\frac{596279.7}{2.3}$$

= 259, 252 ton

But the total amount of bagasse including the fuel oil bagasse equivalence is 323,490 ton.

Then the loss due to inefficient fuel utilization in MSF is:

323,490-259,254 = 64,238 ton of bagasse

The monetary equivalence of the lost bagasse is:

64,238 *0 .18 *4.4 * 1000

= birr 50,876,496

Chapter four

Alternative solutions for efficiency improvement

According to the data analysis, different alternatives can be used to improve the energy efficiency of the boiler house of Metehara sugar factory. These are discussed in this chapter.

4.1Adjusting the excess air to the furnaces

As it has been discussed earlier, the excess air being used in the furnaces are 108.3 %, 107%, 115.3% and 66% for boilers 1, 2, 3 and 4 respectively. But literatures mentioned that the excess air required for all types of bagasse furnaces is 25 to 35%. This is highly deviated from the existing excess air utilization as can be seen above. [9]

Although required higher excess air comes with a price, there are a number of reasons why this occurs but stated simply supply air cools the combustion system by absorbing heat and transporting it out the exhaust flue. The more air the more the cooling. Consider to that nitrogen which makes up to about 80% of the air plays no role chemically to produce heat. It does how ever add significant to the weight of gas that absorbs heat energy. Figure 4.1 below illustrates how increasing excess air reduces combustion efficiency. From the figure it is clear that controlling excess air usage is one of the simplest ways to achieve significant fuel savings.

Adding additional excess air is often done to reduce the CO concentration. Too much excess air can actually have the reverse effect of increasing CO. this result when fuel and air no longer mix properly in the burner, reducing the time of contact between oxygen and fuel and inhibiting a complete reaction. [25]

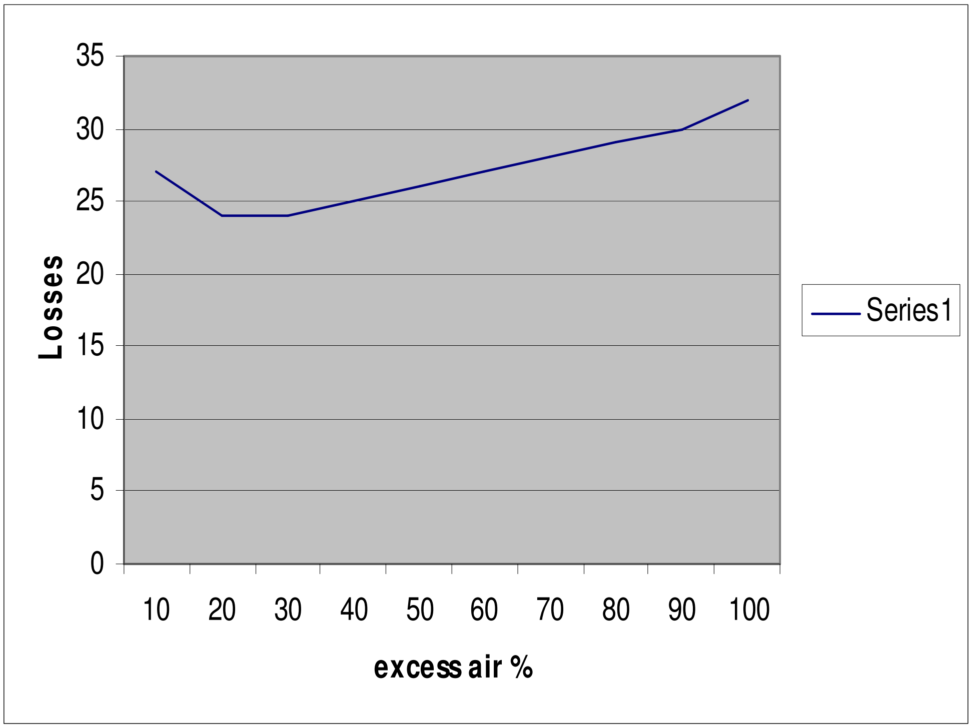


Figure 4.1 Amount of excess air and losses [10]

The average combustion efficiency of the boilers of Metehara Sugar Factory is 65.3%. and the average excess air of the furnaces is 99%. Based on the above efficiency and excess air graph (figure 4.1) if the excess air is reduced from 99% to 35% the losses will get reduced by 7%

And when we translate this savage in terms of bagasse quantity; it will be
= 7% * amount of bagasse burned per year
= 0.07*323490 ton
= 22,644.3ton

But this is more than enough the amount of bagasse which can totally replace oil usage. The very interesting thing here is that furnace oil consumption can be avoided only with adjustment of the fan that is pulling air to the furnaces. Of course there are some costs used to ball, store and transport the saved bagasse.

4.2 Reducing the moisture content of bagasse by using bagasse dryer

By reducing the moisture content of bagasse, boiler efficiency can be greatly improved resulting in excess bagasse being available for storage for off season energy needs. More over this process can result in enhanced level of electricity exported to the grid. Bagasse drying by using flue gas is widely applicable in many sugar countries like Cuba, Australia, India, Brazil and USA. [30]

In addition to energy efficiency bagasse drying will also improve sugar recovery efficiency of the mills. Because, of the fact that the mill operators will concentrate fully on the amount of sucrose extraction rather than on the bagasse moisture content.

The most widely applicable bagasse drying method in many countries is by using the flue gas in pneumatic bagasse dryer. Now a days as fuel cost is increasing highly in many sugar factories the improvement of the use of bagasse in the furnaces is an important industrial strategy.

Some successful sugar factories that reduce moisture content by using pneumatic dryer can be mentioned as follows.

1. Santo Antonio sugar factory in Brazil increases steam production by 16% by drying the bagasse from 52% to 40% moisture.
2. Salermo & Santana (1986) develop pneumatic dryer that worked with 10 ton/hr of 47% moisture content to reduce into 35% with an inlet gas temperature of 250^0c.
3. In an experimental basis there were also many dryers which can even reduce the moisture contents below 30%.

Energetic analysis shows that bagasse dryers are more energy efficient than the air pre heaters.

Typical bagasse dryer and bagasse dryer arrangement are shown in the following figures (figure 4.2 and 4.3)

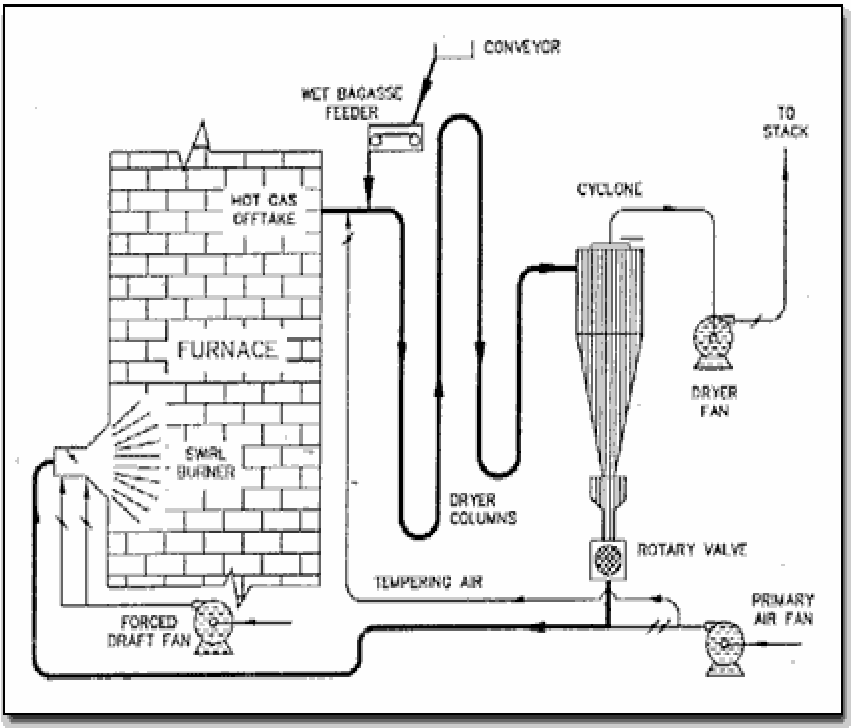


Fig. 4.2 Typical bagasse dryer

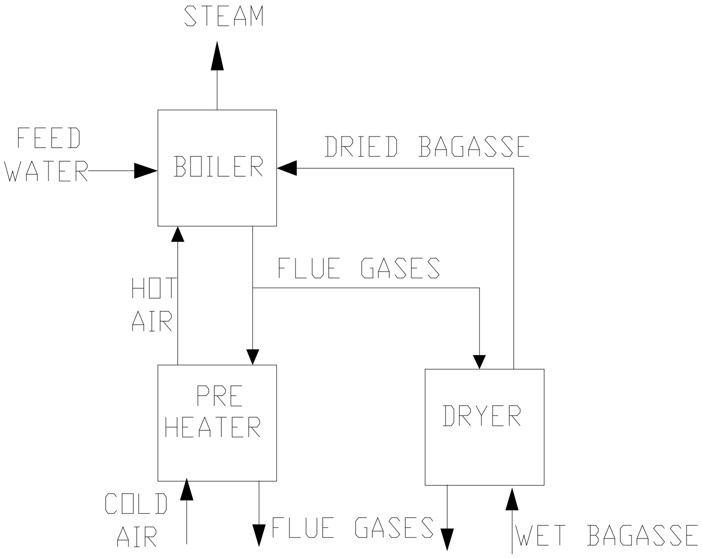


Fig. 4.3 Bagasse dryer arrangement

If it can at least reduce the moisture content of the bagasse to only 40% which is the average experience for sugar factories with installed bagasse dryer, the amount of huge amount of bagasse can be saved as discussed below.

The average heat loss due to bagasse moisture is 1291KJ/kg at 50% moisture. Had the moisture content been 40% the loss will be reduced to 1032.8KJ/kg. That means due to bagasse dryer 258.2KJ/kg of loss will be avoided. And the combustion efficiency at this time will be 71.4%.

By drying the bagasse 6% in combustion efficiency improvement will be obtained. And the equivalence amount of bagasse to be saved is:

0.06*323490
= 19,409.4 ton

4.3 using Leaves & tops of the cane plant as furnace fuel

As much as 35% of the total biomass in the cane field before harvest is in leaves and cane tops. The composition of the dry matter components of sugar cane are

Leaves + tops = 35%

Bagasse = 29%

Roots and stubbles = 11%

Soluble solids = 25% shown in the following figure.

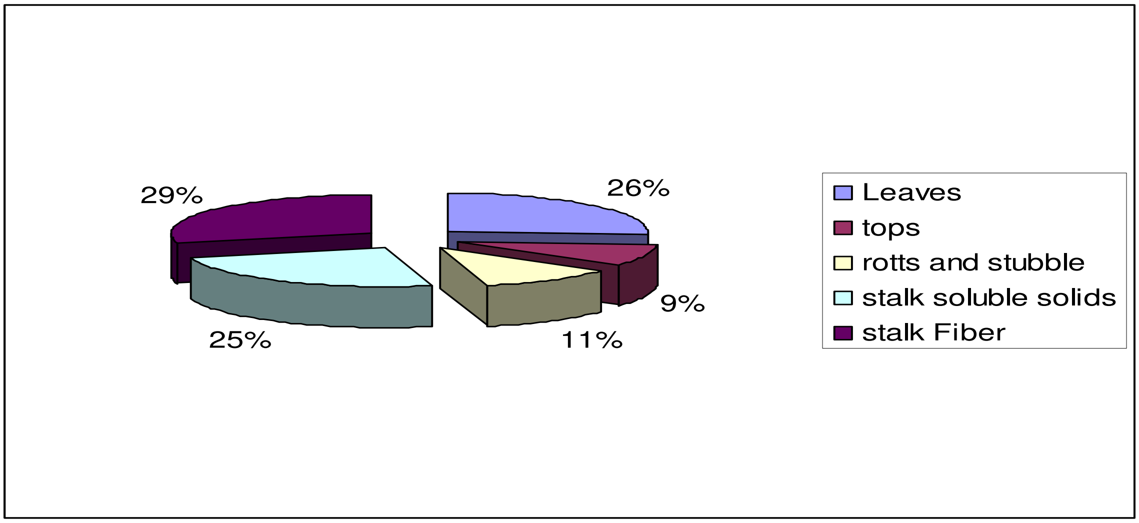


Fig 4.4 Dry matter composition of sugar cane plant

The energy property of the trashes in comparison to bagasse is also shown in the following table.

We can also see that sugar cane trashes are better in energy content than sugar cane bagasse. According to literatures to, the energy content of one hectare of sugar cane field is equivalent to 280, 730MJ distributed as follows:

24% in ethanol
37 % in bagasse and
39 % in trashes

Table 4.1 proximate and ultimate analysis of sugar cane leaves in comparison to bagasse [13]

Sugarcane (% w/w; dry)	leaves:	Bagasse
A. Proximate Analysis		
1. Fixed carbon	14.9	20.1
2. Volatile matter	77.4	75.8
3. Ash content	7.7	4.2
4. Higher heating value, MJ kg_{-1}	17.43	18.11
5. 5. Net heating values (MJ/kg)	13.550	7.860
B. Ultimate Analysis		
1. Carbon	39.8	44.1
2. Hydrogen	5.5	5.26
3. Oxygen	46.8	44.4
4. Nitrogen	0.19	

In many countries it is also being practiced to use this resource as a fuel. For example in Hawaiians sugar factories the following result was obtained in following modifications made in the factories as shown in the following chart(figure 4.5). From the chart we can conclude

Table 4.2 Fuel value, cost of production and suggested purchase price of sugarcane bagasse and cane trash [26]

Biomass	Fuel value per ton (wet) based on oil energy equivalence($)	Cost of production($)	Suggested purchased price per delivered ton($)	HHV GJ per ton	Moisture content %
Sugar cane bagasse	32	0	20	18	48-50
Sugar cane trash	48	20	32	18	26

that the potential of sugar cane trashes is much higher than other energy efficiency opportunities in the sugar industry.

But to use these trashes as an energy resource, the sugar cane field should not get burned prior to cutting. The pre-harvest burning removes approximately 80% of the trash (the tops, green leaves and dry leaves, or straw); it kills bees, snakes, and scorpions; it decreases accidents with knives and machetes; all of which increases the harvesting capacity for both hand labor and machines.

One of the greatest problems in the harvesting of green (unburned) cane is it need higher labor. There will also be increased labor hazards. In green cane it is difficult to see where the stalks are, and where the ground is, raising the risks of cutting hands and fingers with the knife. It is possible that bees, snakes, spiders, and scorpions attack the laborers more frequently. And, the edge of green sugar cane leaves have thousands of microscopic prickles that can hurt the eyes, faces and arms of the laborers.

The solution to these problems will be to develop new safety equipment and to increase the payment for each ton of stalk cut by laborers by four or five times. More mechanization is another solution.

On the other hand, even with the above problems, we note that sugar cane trash is used in many countries to produce steam and electricity.

And again since the pre-harvest burning cause environmental problems, there are international laws today that try to control this practice the international lows is come to our county to. MSF is also at this time trying to be certified by ISO 14000 (environmental friendly certificate)

Generally from the above discussion and experience of other efficient sugar factories if trashes are used as a fuel then there is a vast energy potential. But it needs high investment.

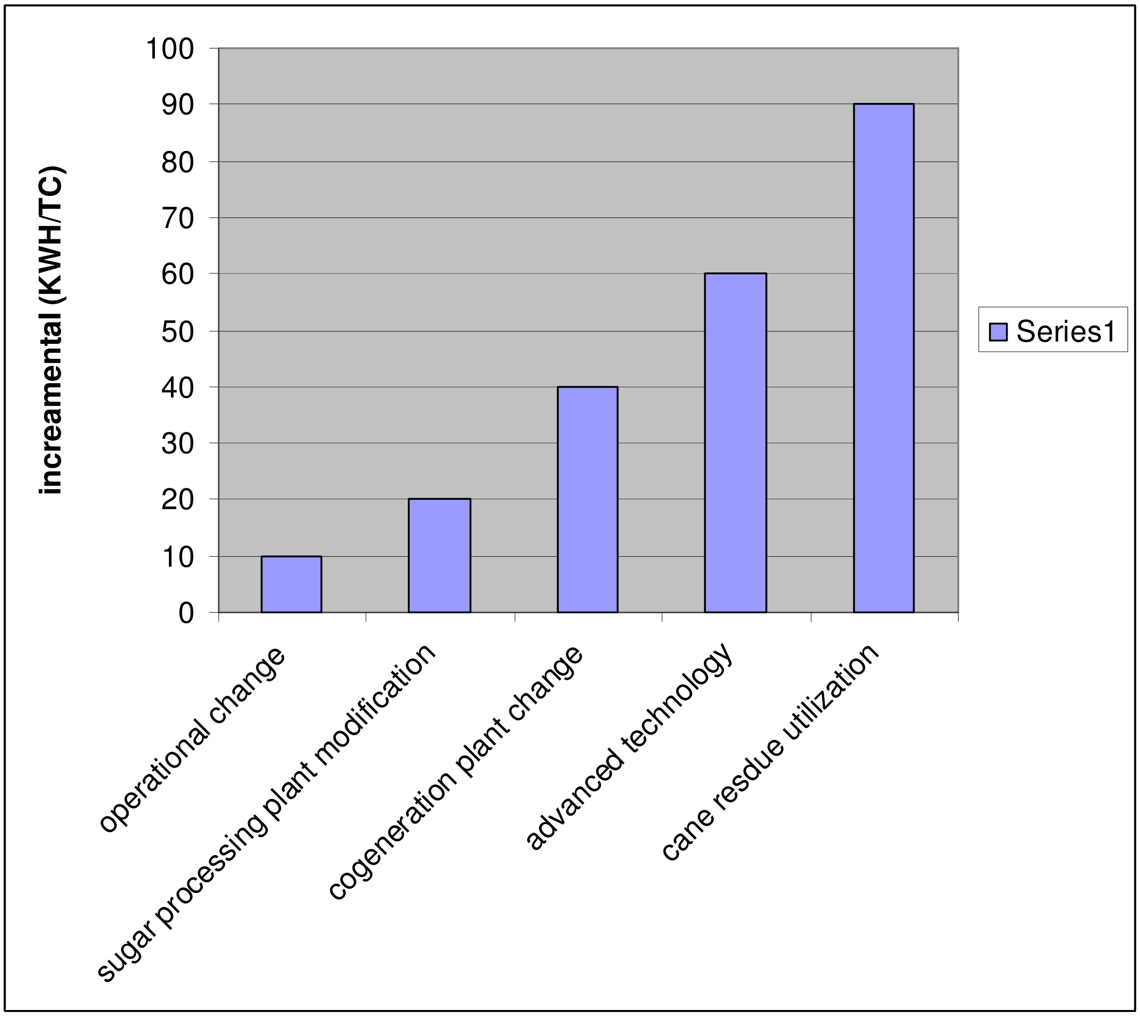


Fig 4.5 Increase in co generated power following modifications in a sugar factory [21]

.

Fig 4.6 Machine harvesting of sugar cane field with no pre burn

Figure 4.7 Manual harvested sugar cane with no pre burn

From Metehara sugar factory the total amount of sugar cane trash that can be collected is:

0.35*(total sugar cane crushed)

=0.35 * 1,147,809 = 401,733ton

And the bagasse equivalent of trash can be obtained by using the fuel value equivalence of both bagasse and trash. That is from table 4.2 the dollar fuel equivalence of bagasse is 32 and that of bagasse is 48; then bagasse equivalence of the trash obtained is:

$$\frac{32}{48} * 401{,}733 = 265{,}144 \text{ ton}$$

4.4 Implementing energy management system

For the successful energy performance of the sugar industry, there must be an energy management team or department. The boiler house performance or combustion conditions of the furnaces must be assessed at least once in three months. This is important because measures towards efficiency improvement can only be taken based on the existing conditions. There are so many simple energy management methods but can highly and remarkably improve energy efficiencies.

The one and widely being practiced in many efficient sugar factories is pinch technology analysis.

Pinch technology is a relatively modern engineering tool developed in the late 1970's and early 1980's. This new approach to evaluating the energy requirements of a site quickly identified ways of improving the overall energy use. The name "pinch technology" was applied because the technique identified the point or points in the energy flow where restrictions applied and hence limited one's ability to re-use low grade energy.

The major difference between this new technology and previous engineering approaches was the formalized methodology involving the rigorous application of thermodynamic principles. Pinch technology was initially adopted by major chemical companies and the petrochemical energy. Beet sugar was quite quick to adopt it because of the industry's energy profile and it is now being adopted by the cane industry too.

APPLICATION

Pinch technology is equally applicable to green field projects and refurbishment. In either case the objectives are to achieve:

- minimum energy consumption
- optimization of utilities
- minimum capital expenditure to achieve these

Minimizing energy consumption implies minimizing cooling water requirements too because all of the energy used ultimately has to be rejected again in some low grade form.

The technology's strengths are its overall approach to process integration (rather than optimizing a single station) and its blend of thermodynamics with commercial requirements. It also takes into account the operational requirements of the site and does reduce flexibility or availability.

THE SUGAR INDUSTRY

The application of pinch technology in the beet sugar industry is reaching maturity and most important sectors of that industry would see it as a norm for plant optimizations and new projects. The cane sugar industry is only just adopting it.

Skill’s normal approach to the application of pinch technology to existing operations is two phased: undertake an energy audit of the site followed by detailed analysis of opportunities identified in the audit.

Phase I: Audit

The audit phase would typically involve about one week of work at the site for a small team, usually 2 or 3 engineers. During the visit, the team will investigate a variety of issues and identify a series of small potential projects to achieve the objectives. Following some necessary desk work, indicative returns will be presented based on preliminary cost estimates.

Phase II: Implementation

Once the Client has reviewed the potential projects and is confident of reasonable returns, the Phase II work will undertake a full pinch analysis in co-operation with the factory staff and establish a program for the projects with fully justified returns. The involvement of the factory staff is important to the success of the analysis because only they can inject the requirements of operational flexibility and operability.

The results of the Phase II analysis provide the Client with all the information needed to undertake detailed design and to implement the project in whichever way is selected. Because the returns are frequently significant, as discussed below, an informal reporting as the work progresses allows almost instant benefits to be gained from the analysis.

4.5 What to do with the saved bagasse

With out even using sugarcane leaves and tops, by only implementing the other suggested alternatives there will be a total of 47,907ton of bagasse can be saved. As it has been discussed in the data collection and analysis part Metehara Sugar Factory has used 1,745.9ton of fuel oil in average per year for the last seven years, this fuel oil is equivalent to 9,699.58 ton of bagasse at 50% moisture. As a result, part of the saved bagasse will be used to replace the furnace oil used. The rest which is 38,207 ton will be in excess for the sugar factory. This amount of bagasse can be soled to other organizations if the demand is available or can be used for electricity cogeneration like many foreign sugar factories are doing.

As it has been shown in the literature part 1 ton of bagasse is equivalent to 0.18 ton of fuel oil, as a result of the saved bagasse is to be sold the price will be:

0.18*4.4*1000= birr 792 per ton.

4.6 Electricity generation from bagasse using existing facility of the factory

The amount of surplus bagasse = 38,207tons.

The amount of steam to be generated by using this surplus bagasse is 38207X 2.3 = 87876 ton.

The generated steam is equivalent to 87876/365 X 24 = 10tone steam/hr. through out the year.

This steam has the capacity to produce 10ton steam/hr X 114 kWh/ton steam

=1140kWh of energy each hour

And the kwh energy through out the year is: = 1140*365*24

=9,986,400 kWh

Note that this is the amount of electricity that can be generated using only bagasse and the existing energy facilities of the factory. If the sugar cane leaves and tops are used there will be very much more electricity generation capacity.

Since the factory has already installed boiler, power turbine and turbo generator for its own electrification, there is no need of investment for cogeneration equipments at the existing capacity.

But let us assume 5% for extra maintenance and depreciation of the boiler plant with respect to the increased steam production for cogeneration. Again let us include labor costs introduced due to the cogeneration; since the excess bagasse must be balled and stored for the off milling season, there a cost for balling and storing of the excess bagasse.

The average milling season days of the factory is 230 then the bagasse balled and stored is $\frac{(365-230)*38207}{365}$ = 14131.4ton

The cost of balling and storing bagasse is on an average Birr 15/ton (by taking labor cost – birr 2/h) that means 14131.4 tons X Birr 15 = birr 211970.3 Labor cost for supervision at boilers, turbo – alter and evaporator be birr 5/h due to the extra steam generated

Then 5/hr X 24 X 365 = 43,800 birr. And by assuming other indirect costs like maintenance, due to the increase in steam production 5% of the induced costs, it gives as

= 0.05 (211970 + 43,800)

= birr17,903

Then the total cost will be

211970 + 43,800 + 17,903

= birr 273,673

Now the cost of generating electricity can be calculated as follows:

(Generating cost) * (amount of energy generated) = total cost

(Generating cost) * (9,986,400 kwh) = birr 273,673

Generating cost = birr0.03 per kWh

= 3 cents/kwh

From the above calculation the factory will get additional profit by selling the generated electricity with above three cents per kWh.

Chapter five

Economical evaluation

In the last chapter, chapter five there are some generated alternatives towards energy efficiency improvement in Metehara Sugar factory. But before implementing the generated alternatives, their economic feasibility must be assessed.

A comparison of the costs and benefits of an alternative is often required to be made a judge the absolute or relative profitability of the investment made towards efficiency improvement alternatives. This chapter presents the economic and financial feasibility for the alterative energy efficiency improvement measures discussed in chapter five.

6.1 Economic evaluation methodology

The most widely and commonly used appraisal criteria: [10]

1. pay back period
2. Net present value
3. equivalent uniform annual worth
4. benefit cost ratio
5. internal rate of return

are discussed in this section.

1. The pay back period

The pay back period essentially measures the time elapsed between the point of initial investment and the point at which accumulated saving, net of other accumulated costs, are sufficient to offset the initial investment outlay. In the case of simple pay back period the interest rate is assumed to be equal to zero and the pay back period is computed as the smallest value of n that satisfies the equation:

$$\sum_{n=0}^{n_{sp}} \left(B_n - C_n\right) \geq 0$$

Where B_n and C_n represents the cash receipts (benefits) and the cash expenses (costs)respectively associated with the investment at the end of each period n. this payback period (n_{sp}) is then compared with the maximum acceptable pay back period(n_{max}) to determine weather the investment should be accepted. If n_{max} is greater than n_{sp} the proposed investment is accepted or else it is rejected. In some cases n_{max} is considered the same as the useful life time of the investment project.

2. Net present value

The difference between the present value of the benefit and the cost resulting from an investment is the net present value (NPV) of the investment. In mathematical terms:

$$\mathrm{NPV} = \sum_{J=0}^{n} \frac{B_j - C_j}{(1+i)^j}$$

Where B_j stands for benefit at the end of period j, C_j for cost at the end of period j, n the useful life of the project and i is interest rate.

3. Equivalent uniform annual worth

In the equivalent uniform annual worth method all disbursements (irregular and uniform) are converted to an equivalent annual amount that is a year end amount, which is the same each year.

If Bj and Cj represent the benefit and costs in j_{th} year respectively, the cumulative present worth of all cash flow of investment can be determined from:

$$\sum_{J=0}^{n} \frac{B_j - C_j}{(1+i)^j}$$

The equivalent Uniform annual worth (EUAW) of the investment can be determined by multiplying the cumulative present worth of all cash flow by the capital recovery factor. Thus:

$$\text{EUAW} = \left\{ \sum_{J=0}^{n} \frac{B_j - C_j}{(1+i)^j} \right\} * \left\{ \frac{i(1+i)^n}{(1+i)^n - 1} \right\}$$

4. Benefit cost ratio method

The benefit cost (B-C) ratio method of analysis is based on the ratio of the benefit to cost associated with a particular project. The first step in B-C ratio analysis is to identify the costs and benefits separately. The costs are the anticipated expenditures for construction, installation, operation, maintenance etc.

Let B and C be the present values of the cash inflow (benefits) and outflows (costs) defined by:

$$B = \sum_{j=0}^{n} \frac{B_j}{(1+i)^j}$$

$$C = \sum_{j=0}^{n} \frac{C_j}{(1+i)^j}$$

Where Bj and Cj represent the benefit and cost respectively at the end of j^{th} period, and n the useful life of the project.

5. Internal rate of return

The internal rate of return IRR is widely accepted discounted measure of investment worth and is used as an index of profitability for the appraisal of projects. The IRR is defined as the rate of interest that equates the present value of a series of cash flows to zero. In other words it is the interest rate at which the NPV of an investment is zero. Mathematically, the internal rate of return is the interest rate i^* that satisfies the equation:

$$\text{NPV}(i^*) = \sum_{J=0}^{n} \frac{B_n - C_n}{(1+i^*)^j} = 0$$

Alternatively the internal rate of return is the interest rate i^* that causes the discounted present value of the benefits in a cash flow to be equal to the present value of the costs, i.e.

$$\sum_{j=0}^{n} \frac{B_n}{(1+i^*)^j} = \sum_{j=0}^{n} \frac{C_n}{(1+i^*)^j}$$

Multiplying both sides of the net present value formula by (10.24) $(1+ i^*)^n$: and gain multiplying both sides of equation (10.22) by the capital recovery factor $\left\{ \frac{i^*(1+i^*)^n}{(1+i^*)^n - 1} \right\}$ it may be shown that the internal rate of return, $i^{*,}$ can be obtained as the following equation

$$\mathrm{NPV}\ (i^*) \left\{ \frac{i^*(1+i^*)^n}{(1+i^*)^n - 1} \right\} = 0.$$

In economic terms the IRR represents the percentage rate of the interest earned on un recovered balance of an investment. The unrecovered balance of an investment is the portion of the initial investment that remains to be recovered after interest payments have been added and receipts have been dedicated up to the desired point in time.

It may be noted that equation $\mathrm{NPV}\ (i^*) = \sum_{J=0}^{n} \frac{B_n - C_n}{\left(1+i^*\right)^j} = 0$ is a polynomial function of $i^{*.}$ A direct solution for such a function is not generally possible. Consequently the computation of IRR is either done by using iterative procedure or using Newton's approximation to the solution of a polynomial.

6.2 Estimated energy saving from energy efficiency measures.

Estimated energy saving from energy efficiency measures and the equivalence monetary amounts are discussed in the following table.

Table 6.1 Annual saving for the generated alternatives.

no	Alternatives	Bagasse savage (ton per year)	Money equivalence of the saved bagasse(Birr)
1	Adjusting excess air utilization	22,644.3	16,304,000
2	Bagasse dryer installation	19,409.4	13,974,000
3	Sugar cane trash utilization including cutting, collecting, balling, transporting and storage	265,144	190,903,000
4	Energy Management	-	500,000
	Total	307,197.70	221,681,000.00

6.3 Investment cost

The investment costs of the different alternatives generated including operating cost are discussed as follows. Where, 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.

And again the following facts and assumptions are used during the calculations.

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. Consequently no customs duty is included in the financial prices.

1. Adjusting the excess air

The furnace in MSF have excess air control device attached and are controlled based on the reading on the boiler house control room. As a result there is no need of investing. Then the cost of implementing this energy efficiency improvement alternative is zero. It simply needs only attention to adjust the induced fan based on the reading which can be done by the available control panel personnel.

2. Bagasse drying

The overall money required to install a bagasse dryer for a factory having a capacity of 5000TC per day is around birr 18,000,000. (This price is taken from personal communication by E-mail with Mr. Juan Harold Sosa Arnao (email address Jhsosa@femunicap.br) State University of campinas UNICAMP. he is an experienced bagasse dryer installer in many sugar factories in different countries like Brazil, India and Cuba).

3. Using Leaves & troops of the cane plant as furnace fuel

To use the sugar cane leaves and tops as a fuel the activities which needs investment are

1. Cost of collecting of the leaves and tops
2. Cost for balling and storing cost
3. Transportation cost

1. Cost of collecting of the leaves and tops

The cutting and collecting of the cane leaves and tops needs about five times the existing labor for involved in cutting the pre burned sugar cane plant. This is due to the fact that green gutting more difficult than pre burned cut. As a result the cost of cultivation will be five times higher than the existing amount.

The amount of labor for cutting at this time is about 1785 then the required amount for green cutting will be 5* 1785= 8925 which means that there is an increase of 7140.

And the amount of money being paid for the cutting process in Metehara sugar factor is about birr 3,638,294.24. Then the amount of money that will be encored due to green cutting will be:

5* 3, 638,294.24 = birr 18,191,471.2

And since during green cut there should be some safety equipments to protect the laborers from harmful insects and bacteria, the cost of these equipments is assumed to be equal to the labor cost. As a result the total cost will be around birr **36,382,942.4.** That means that there will be around birr 32,744,648.16 in excess due to the introduced green cutting.

2. Cost for balling and storing

For ease of handling, storing and transportation the fuel must be chopped and balled. This is usually done in the farm. The amount of money required for this is birr 15 per ton. And the amount of trash available is 401, 733 ton. Then the money required for this purpose is: 15* 401,733= birr 6,025,995 and of course birr 5,000,000 is required to purchase five balling machines.

The total cost is then birr 11, 025, 995

3. Transportation cost

Unlike bagasse, cane trashes are transported to the mills from the farm, only for ease of burning. But the transportation can be done by using the available cane transporting vehicles but during off milling seasons during which they are idle. As a result there is no need for investing to buy additional vehicles. But the cost of transportation is estimated as birr 100 per ton. Then the trash cost will be:

100 birr per ton * 401, 733 ton = birr 40,173,300 this amount includes fuel cost, drivers salary loading and unloading as well as maintenance costs.

The total money required to use trashes and tops as a fuel is:

40,173,000 + 6,025,995 + 36,382,942.4

= birr 82,581,937

4. Energy management

MSF must buy one combustion analyzer that is used to asses the combustion conditions of the furnaces in at least once in three months. The amount of money for this analyzer is around birr 85,000. In energy management the other activities that requires investment are preventive maintenance for energy equipments, steam optimization, efficient lighting etc. the average cost for this activities is birr 102,000. The total cost for energy management is then about birr 187,000.

5. Excess bagasse balling, storing and Handling

In implementing the above mentioned alternatives, there are some costs due to the excess bagasse obtained from the alternatives.

These are:

- bagasse baling and storing
- Handling of the stored bagasse to the furnaces.

If the above four alternatives are implemented there will be a total of 38,207 tones bagasse in excess. As mentioned earlier one tone of bagasse needs birr 15 to ball and store. That means 15 * 38,207 = 573,105 birr.

To convey the stored bagasse to the furnace chutes 50 meter long chain conveyor is required. The cost of the conveyor is birr 5,000 per meter. That means a total of 5000 * 50 = 250,000birr is required.

The total cost for excess bagasse balling, storing and Handling becomes:

573, 105 + 250,000 = birr 823,105

Table 6.2 Cost and annual saving for the generated alternatives in one year.

no	Alternatives	Bagasse savage (ton)	Money equivalence of the saved bagasse (Birr)	Cost (birr)
1	Adjusting excess air utilization	22,644.3	16,304,000	-
2	Bagasse dryer installation	19,409.4	13,974,000	18,000,000
3	Sugar cane trash utilization including cutting, collecting, balling, transporting and storage	265,144	190,903,000	46,898,995
4	Energy Management	-	500,000	152,000
5	Excess bagasse baling, storage and transportation	-	-	623,105
	Total	307,197.70	221,681,000.00	65,674,100

The total capital investment for the alternatives is the sum of the direct cost (which is the purchased equipment costs and direct installation costs), indirect installation costs, contingency costs, sales taxes and freight. The purchased equipment costs (PECs) used in this paper for each measure are based on cost information found from machinery manufacturers on the internet. Table 6.3 provides a list of various cost elements included in the capital costs. Where installation costs were not available, direct and indirect installation costs were developed using the factors 15 and 5 percent, respectively, of PEC. A contingency factor of 5 percent was added to the total costs in all cases to cover contingencies as listed below.

The Capital Investment Cost Elements are

Direct costs (DC)

Purchased equipment costs (PEC):

Direct installation costs (DIC) - 15 % of PEC:

- Foundations and supports
- Handling and erection
- Electrical
- Piping
- Painting

Indirect installation costs (IIC) - 5 % of PEC:

- Engineering
- Construction and field expenses
- Contractor fees
- Startup
- Performance test

Contingencies (C) - 5 % of PEC:

- Equipment redesign and modifications

- Cost escalations
- Delays in startup

Freight (2 % of PEC)

No	Item	Cost in birr
1	Direct costs	
	Purchased equipment costs (PEC):	41,526,471
	Direct installation costs (DIC) - 15% of PEC:	6228970.7
2	Indirect installation costs - 5 % of PEC:	2076323.6
3	Contingencies - 5 % of PEC:	2076323.6
4	Freight (2 % of PEC)	830529.4
	Total	56,891,265

Table 6.3 Total investment cost for the energy efficiency measures

6.4 OPERATING COST

Annual operating costs are composed of the direct operating costs of materials and labor for maintenance, operation, utilities, material replacement and disposal and the indirect operating charges, including plant overhead, general administration, and capital recovery charges.

A brief description is provided below for each component of the direct annual operating costs used in the cost evaluation.

Utilities: The utility requirements for the energy efficiency improvement measures consist of electricity to power instruments and auxiliary equipment

Operating and Supervising Labor: one operator is assigned for the bagasse dryer per shift and 0.5hr attention for excess air control per shift. Operator wage rates were estimated to be 5 birr/hr. Supervisory labor costs were estimated to be 10 birr/hr. but 20 supervisors for the case of trash utilization.

Maintenance: A maintenance labor cost of 0.5 hours per 8-hour shift and a maintenance material cost equal to this labor cost are taken for this purpose.

Overhead: An annual overhead charge of 60% of the total labor & maintenance cost was used.

Insurance: The cost of insurance was calculated as 1 percent of the total capital cost of the system.

Administrative Charges: The administrative charges were calculated as 2 percent of the total capital cost of the system.

Depreciation: 15 years equipment life is taken as to calculate equal annual payments over the equipment life.

Direct annual costs (DC)

Utilities:

Electricity: 0.34 birr per kWh Ethiopian electricity selling price for factory use

Operating labor

Supervising labor: 10 birr per hour 230 days a year

Operator labor: 5 birr per hour 230 days a year

Maintenance

Maintenance labor: 10 birr per hour times 0.5 hours per 8 hour shift

Maintenance materials 100% of maintenance labor

Indirect annual costs (IC)

Overhead: 60% of operating labor, supervisory labor, maintenance labor and materials

Insurance:	1% of total capital cost
Administrative charges:	1% of total capital cost
Depreciation:	15 years equipment life.

And total annual operating cost = DC + IC

No	Item	Unit	Quantity	Annual Cost in birr
1	**Direct annual costs (DC)**			
	1.1 **Utilities:**			
	Electricity: 0.34 birr per kwh	kWh	337368	1,146,945
	1.2 **Operating labor**			
	Supervising labor: 10 birr/hour 230 days a year	person	20	1,107,400
	Operator labor: 5 birr/hour 230 days a year Green cane: cutters wage, balling and transport	Person	2 1785	255,200 64,390,726
	1.3 **Maintenance**			
	Maintenance labor: 10 birr/hour 230 days a year	person	1	55,200
	Maintenance materials 100% of maintenance labor	_		55,200
2	**Indirect annual costs (IC)**			
	Overhead: 60% of labor	_		39,451,996
	Insurance: 0.5% of total capital cost	_		284,456.33
	Administrative charges: 0.5% of total capital cost	_		284,456.33
	Depreciation:	_		1,208,666
	Total			108,240,246

Table 6.4 Annual operating costs for the energy efficiency measures

6.5 Feasibility Analysis

To see the profitability of the project analysis has been made by discounted cash flow methods such as net present value method, internal rate of return method and benefit to cost ratio method. If all benefits and costs can be assigned monetary values, we 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

<1, the project is not profitable

	YEAR															Total
Item	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	
Capital investment	56.9															
Operating cost		108	108	108	108	108	108	108	108	108	108	108	4.6	4.6	4.6	
Salvage value															13	
Revenue (Saving)		221.7	221.7	221.7	221.7	221.7	221.7	221.7	221.7	221.7	221.7	221.7	221.7	221.7	234.7	
Gross cost	56.9	108	108	108	108	108	108	108	108	108	108	108	108	108	108	
Gross revenue	0	221.7	221.7	221.7	221.7	221.7	221.7	221.7	221.7	221.7	221.7	221.7	221.7	221.7	234.7	
Net cash flow	-56.9	113.7	113.7	113.7	113.7	113.7	113.7	113.7	113.7	113.7	113.7	113.7	113.7	113.7	126.7	1547.9
Discount factor	1.000	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	
Discounted cash flow	-56.9	103.35	93.916	85.38	77.65	70.60	64.126	58.328	53.09	48.20	43.88	39.79	36.27	32.973	33.32	784.03
P.W. Gross cost	56.9	98.172	89.208	81.10	73.76	67.06	60.912	55.404	50.43	45.79	41.68	37.8	34.45	31.32	28.40	852.428
P.W. Gross profit	0	201.52	183.12	166.4	151.4	137.6	125.03	113.73	103.5	94.00	85.57	77.59	70.72	64.293	61.72	1636.46

Table 6.5 Profitability analysis values for 15 years of period (values are expressed in 10^6)

From the above table:

- The net present value is 784.03 million birr
- The Benefit- cost ratio $= \frac{\Sigma \text{ P.W of gross profit}}{\Sigma \text{ P.W of gross cost}}$

$= 1636.461/852.425 = 1.9$

Since the NPV is positive, the project is acceptable and

The ratio of benefit to cost is > 1 the project is profitable.

Chapter six

Further work

Ethanol as an alternative fuel from Molasses of the sugar factories

6.1 Molasses

The other main energy resource obtained from sugar factories is a fuel for vehicles. The by-product molasses is used for the manufacturing of ethanol alcohol to be used in blend with petroleum or alone.

Residual syrup purged from a massecuite in capable of crystallizing after concentration or cooling is called blackstrap molasses. It is a dark viscous product with a rather bitter test. The U.S.A customs laboratory defines Blackstrap molasses as molasses in which non-sugar solids are more than 6% of the total soluble solids excluding foreign substance that may have been added or developed in the product. Molasses is composed of organic and inorganic matter and water. About 52% of blackstrap molasses is total sugar (sucrose, dextrose and levulose) about 10% or more is inorganic salts or ash, 10-20% water, and the balance is organic non-sugar matter. [17]

Since molasses is a by-product of sugar production and is soled considerably cheaper than raw sugar, it is in the interest of a sugar factory to produce a minimum amount of crystallizable sugar. In addition for the manufacturing of ethyl alcohol molasses is used for manufacturing of rum and animals feed.

6.2 Ethanol

Ethanol also refers to as ethyl alcohol; grain alcohol is a primary alcohol with the formula CH_3-CH_2-OH (C_2H_5OH).

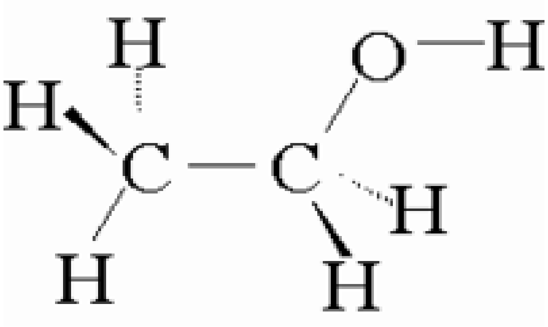


Fig 6.1 Molecular structure of ethyl alcohol

Ethanol is colorless, volatile and miscible in water in all proportions. It has a molecular weight of 46.1, boils at 78.3°c, freezes at -117.3°c and has a density of 0.789 at 20°c, a calorific value of 297728kJ/kg a latent heat of vaporization of 204cal/g and a research octane number in the range 91 to 105.

Ethanol from molasses is obtained by fermentation process:

$$C6H12O6 \xrightarrow{\text{enzyme}} 2C2H5OH + 2CO2 + \text{heat}$$

Although the main process is the fermentation, ethanol production process includes:

1. Molasses storage
2. Substrate preparation
3. fermentation
4. Distillation
5. ethanol drying
6. ethanol storage and
7. Co product treatment.

6.3 Ethanol in vehicles

Ethanol could be blended in various proportions in petrol. Ethanol is usually added 5 to 10% by volume of petrol for such application. Many states in the US have been using 10% ethanol blend in gasoline (petrol) for use in their cars. Brazil has been using up to 24 % ethanol in petrol. Engines of cars do not need any change to use petrol with up to 24 % ethanol in it. [19]

Ethanol has, apart from carbon and hydrogen, oxygen in it. This oxygen acts as oxygenating agent during combustion in the IC engine of petrol cars, two-wheelers and three wheelers thus preventing formation of carbon monoxide. Gasoline with ethanol as anti-knocking agent will not cause any damage to the engine.

Table 6.1 Comparison of fuel property

property	Ethanol	Gasoline	E85
Chemical formula	$C2H5OH$	C4 to C12	--
Octane number	98-100	86-94	96
Liters equivalent	1.5	1	1.4
Km/litre as compared to gasoline	70%	100%	72%
Fuel tank size	1.5	1	1.4
Air fuel ratio	9	14.7	10
Vehicle power	5% more	Standard	3-5% more

6.4 Ethiopian perspective of ethanol and molasses

In MSF annually on an average 30,000 tones of molasses is being produced as a by product. Small part of the molasses produced is soled to local alcohol factories, but the huge amount is being exported. [19]

As the researcher observes, there is huge amount of molasses stock in a pit due to shortage of demand. From which one pit of molasses which is stored before two years is get damaged due to rain and the sun. So it is high time to utilize this important by product as an alternative fuel for house hold consumption or for vehicles like other countries are doing.

Fig6.2 Stored Molasses in MSF

Ethiopian sugar factories produces total amount of 85,000MT sugarcane molasses per annum; which in tern has the potential to produce about 19 million liters of ethanol. Ethiopia also uses about, for example for the year 1998E.C, 1,220,783,033kg of imported petroleum [11]. On an estimate 10% blend of ethanol to petroleum there will be a reduction of 18 million liters of petrol imports and the direct foreign currency saving on this account will be $15million. [19]

Currently Ethiopia produces only 8 million liters of anhydrous ethanol per year which could support blending of only some 80 million liters of gasoline per annum on a 10% blend. And even these 8 million liters of ethanol is not also being blend with petroleum at this time rather it is being exported.

And with in the coming few years the capacity of ethanol from molasses that can be produced as a by product of sugar production will 128 million liters this is due to one new huge sugar factory in Tendaho (Afar region) as well as expansion of the existing three sugar factories. At that time there will be a capacity to blend 30 million liters of ethanol with gasoline. And the rest which is around 97 million litters of ethanol can be used for cooking.

Chapter seven

Conclusions and recommendations

As much as air and water human beings require energy for existence. Now days in the most advanced countries the cleanness of the air the people breathes, the water they drinks and the type and amount of energy consumed measures the level of development.

The world economy is very much dependent on energy resources. In addition to its economic value energy becomes a political agenda. And even energy conflicts between countries are now a day's lead to wars. Therefore it is high time to developing countries start to utilize locally available energy resources that may lead them to energy self sufficiency.

Sugar factories in many countries are at this time contributing remarkable amount of energy in addition to sugar manufacturing. More over for the factories to be competitive in the international market, it is a must to utilize each and every by product effectively and efficiently.

This study assessed the energy generation and utilization efficiencies of Metehara Sugar Factory. Based on data collected from the factory, analysis has been done. Based on the analysis problems are identified as well as possible solutions to wards energy generation and utilization efficiencies are suggested. From the study the following conclusions and recommendations are forwarded.

7.1 conclusions

- In the Ethiopian sugar factories proper attention is not given to energy generation and utilization efficiency, but for the sake of their survival and to contribute their part to the countries energy development the sugar factories must asses and utilize their energy resources and properly control energy generation and utilization conditions.

- Metehara Sugar factory is using four boilers of low pressure to generate steam for factory use as well as electrification of the factory. But the factory is using bagasse as a fuel ineffectively and in efficiently to generate the steam. The factory's steam generation is 500kg less than the steam generation of the world's average per each tone of bagasse.

- The factory is also loosing huge amount of energy assets in the field. The sugar cane leaves and tops are very important fuels in many countries.

- Now a days it is a backward activity to use petroleum as a furnace fuel in sugar factories worldwide, but our sugar factories are doing it.

- Huge amount of molasses is being wasted due to absence of demand. But in some countries factories are being installed to produce only molasses as a main product to use it as an alternative fuel by converting it in to ethanol.

- In Metehara Sugar Factory there is no well defined energy management activity. That is energy auditing is not performed in some time intervals. But in the correct practice energy auditing should be carried in some time interval and the combustion process must be analyzed at least once in three months.

7.2 Recommendations

Improving energy efficiency both by reducing quantities of energy consumed and by changing processes, offers a powerful tool for achieving sustainable development by reducing the need for investment in energy infrastructure, by cutting fuel costs, by increasing competitiveness for businesses and welfare for consumers. It can create environmental benefits through reduced emissions of greenhouse gases and local air pollutants. It can offer social benefits in the form of enhanced energy security. Generally the following recommendations are forwarded from this study.

- Enough attention should be given to energy generation and utilization just like the factory is satisfactorily doing for the sugar production starting from the milling process
- All workers in MSF are very much aware of how much sugar is produced each day. Similarly a plant wide energy management program should be devised. All workers should be aware of the importance of energy efficiency in the productivity of the plant.
- Incentives have to be given for those whom are doing well concerning energy. This should be again starting from the milling process
- The energy generation process must be assessed and controlled in some time interval.
- Researches and developments must be conducted continuously towards energy generation and utilization efficiencies.
- And generally the suggested alternatives of this study have to be properly implemented.

By implementing the alternatives generated in this thesis the factory will get the following benefits:

- Petroleum consumption will be shunned this will save birr 7,000,000 per year on an average.
- The factory will have 303.451 ton of bagasse in excess each year. This bagasse can be soled or can be used for electricity cogeneration.
- It will recruit 7140 additional man power that contributes some how to the job opportunity of the citizens.
- Reduces sugar production cost
- The factory will reduce environmental pollution due to burning of the sugar cane field. This will support the factories future to be competitive in the international market due to environmental certificates.
- The community around the factory will be benefited by getting electricity. Their villages around the factory do not get hydropower electricity

- The factory will be energy self sufficient.
- It generally supports the countries energy development policy.
- The country will save foreign currency due to the imported furnace fuel.

Bibliography

[1].A.Kostyuk and V. Frolov, steam and gas turbines, Moscow

[2].Anulya K.N Reddy barriers to improvements in energy efficiency.

[3].Attilio Biasio, Encyclopedia of energy and the environment volume II, New York, 1997.

[4].B. Vijayaraja, R. Saravana and S. Renganarayaman, energy and excergy analysis of bagasse drying, Chennai, 2005.

[5].Caffal, C., Energy Management in Industry, Center for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), Sittard, Netherlands, 1995

[6].CDM, excutive board UNFCC~CCNUCC approved baseline methodology bagasse based cogeneration connected to an electriciry grid,2004.

[7].Description of Bacharach ECA 450 Combustion Analyzer Kit 24-8400:

[8]. Suani Teixeira Coelho, Evaluations of externalities in sugar cane origin cogeneration process in brazil ,2000

[9].Douglas M Considie, P.E, energy technologyhand book Losangeles California 1977.

[10]. Assefa Abebayehu (Dr. Ing), power plant engineering, Addis Ababa, 2004.

[11].FDRE centeral statistical agency statistical abstract, Addis Ababa, January 2007.

[12].Horald Davis and Paul Hough, Sugar cane as an energy crop, Guyana, April 2006

[13].Juan H. Sosa-Arnaw, Fabiano Marquezide Olivera, Jeffersen, L.G Correa, Maria A. Silva and Silva A.Sugar cane bagasse drying Nebra, Brazil, 2004.

[14].Kurt Woytiuk, Sugar cane trash processing for heat and power production, Lulea university, 2006 .

[15].Maurice Paturau , by products of the cane sugar industry an introduction to their industrial utilization, Port Louis Mauritius, 1969

[16].Mc. Graw – Hill, encyclopedia of energy, New York, 1977.

[17].Nicholas P. Cheremisionoff, Gashol for energy production. 1979.

[18] Niconor Reece, Combined Heat and Power Generation in Jamaica's Sugar Cane Industry, Manchester, Jamaica

[19].Professional joint secretariat energy in Ethiopia status, challenges and prospects, Adis Ababa, 2000

[20].Robert A, Meyers, hand book of energy technology and economics.

[21].Scott Turn, Energy production in the Cane sugar industry, Hawaii, 2005.

[22].Series 6200CA-calc, combustion analyzers operational and service manual, Canada, 2004.

[23].Society of automotive engineers, Alcohols a motor fuel, U.S.A 1980.

[24]. S. Ramajatun, J GUkhool and D. Seebaluk, optimization of power generation in the local cane sugar factories, mouritius 1999

[25]. Semahagn, Shewangzaw, Thesis on energy utilization efficiency in Ethiopian industries case study on Mugher Cement Factory.

[26].TSI incorporated, combustion analysis basics an overview of measurement methods and calculation used in combustion analysis, USA 2004

[27].T.C. Mendoza ,Renewable Biomass Fuel As "Green Power" Alternative for Sugarcane Milling in the Philippines, *Los Baños*

[28]. UNEP, the megazin of the United Nations Environment Program entitled OUR PLANET, volume 16 no 4.

[29].V.D Graw _ Hill, encyclopedia of energy technology, New York, 1982.

[30].V.E Baikow, manufacturing and refining of row can sugar, Amsterdam, 1982

[31]. Wirnok international, Biomass energy systems and technologies (BEST), Indonesia

[32]. Personal communication by e-mail with Mr. Juan Harold Sosa Arnao (e-mail address : Jhsosa@femunicap.br) State University of Campinas UNICAMP.

[33]. http: www.Meteharasugar.com