

ADDIS ABABA UNIVERSITY



ADDIS ABABA INSTITUTE OF TECHNOLOGY

School of Chemical and Bio Engineering

(Process stream)

“Cleaner Production Assessment in Mekanissa Alcohol and Liquor Factory”

A thesis submitted to the School of Chemical and Bio Engineering presented in partial fulfillment of the requirements for the Degree of Master of Science in Chemical Engineering (Process Engineering).

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Addis Ababa, Ethiopia

Declaration

I declare that, this thesis for M.Sc. Degree at Addis Ababa University Institute of Technology, hereby submitted by me, is my original work and it has not been submitted previously for the degree at this or any other university, and that all resources of materials used in this thesis have been duly acknowledged.

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Abstract

Mekanissa Alcohol and Liquor Factory is a branch of National Alcohol and Liquor Factory which uses molasses or technical alcohol as raw material to produce ethanol. The production process consists of five major sections i.e. molasses treatment, fermentation, distillery, liquor and utilities. Raw material and energy utilization efficiencies of all sections are evaluated based on cleaner production manual. Where, cleaner production options were assessed, filtered and evaluated for all sections.

In the fiscal year, factory produced alcohol was 71.37% of the designed capacity. Overall efficiency of the alcohol production was 81.64%; of which the efficiency of fermentation and distillery were 72% and 97.2% respectively. And it is low compared to expected performance at fermentation and distillation; which is 94.6% and 99% respectively. Average residual sugar in fermentation was 2,252 kg per day. The total absolute alcohol loss per day from the fermentation and distillation were 946.76 and 535.79 liters respectively. Molasses, technical alcohol, and water consumptions per liter of produced alcohol were found to be 4.23 kg, 1.131liters and 15.13liters respectively. Thermal energy and electric energy consumptions per liter of alcohol were found to be 14,635.552 kJ and 1,575.50kJ respectively which are higher than factory standards.

Boiler combustion efficiency and thermal efficiency were 82.66% and 71.75% respectively. All boiler energy losses are evaluated; of which, energy loss due to dry flue gas is the maximum one which is 15.69%. There are two heat integrations proposed in this study to conserve energy; one is in molasses treatment section and the other is between boiler and distillery sections. Recovery of heat from dark and white stillages, CO₂ recovery, waste water recycling and heat lost recoveries; are proposed to improve resource utilization and reducing environmental pollution.

Key words: *Cleaner production, fermentation, energy, molasses*

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Acronyms

AGEP	Addis Ababa City Government Environmental Protection Authority
BA	Bad Alcohol
BOD	Biological Oxygen Demand
°Bx	Degree brix
C	Column
CC	Concentration Column
COD	Chemical Oxygen Demand
CP	Cleaner Production
CP-EE	Cleaner Production Energy Efficiency
D	Drum
DA	Denature Alcohol
DC	Degassing Column
E	Heat Exchanger
ECOs	Energy Conservation Opportunities
EDTA	Ethylene Diamine Tetra-acetic Acid
ENA	Extra Neutral Alcohol
FI	Flow Indicator
FT	Flow Transmitter
°GL	Degree Gay-Lussac
GSE	Geological survey of Ethiopia
HHT	High High Tail
HT	High Tail
HX	Heat Exchanger
LT	Low Tail
MALF	Mekanissa alcohol and liquor factory
MX	Mixer
NALF	National alcohol and liquor factory
P	Pump
PA	Pure Alcohol

RA	Recovered Alcohol
RS	Rectified Spirit
TRS	Total Reducing Sugar
UNEP	United Nation Environmental Program
UNIDO	United Nation Industrial Development Organization
WS	White Stillage

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Industries are the major source of environmental pollution, both globally and locally. Over the past decades, world industrialization has responded to environmental pollution in the following sequenced ways (UNIDO, 2002). By ignoring the problem of environmental pollution; by diluting or dispersing pollution, to be less harmful; by controlling pollution and wastes after they are created (pollution control or waste treatment approach); by developing environmental based technologies like control of material flow streams during the production process (facilitate reuse and recycling); Recently, by implementing cleaner production through prevention of pollution and waste generation at their source.

One of the current main challenges of rapid industrialization is resource utilization and environment sustainability. Factories are utilizing resources extensively which is damaging to environmental and human being (Jing K.). Large international conference on the environment was held in Stockholm, Sweden, for the first time to introduce the issue of environmental pollution. And the United Nations conference, held in 1972, on environment was one of the first attempts to emphasis from a sectoral towards a more comprehensive approach that would include all aspects of environmental protection (UNIDO, 2002).

Pollution prevention (cleaner production):- Cleaner production is continuous application of an integrated preventive environmental strategy applied to processes, products, and services to increase overall efficiency and reduce human and environment risks. Since waste treatment does not prevent the creation of wastes, it is not generally included in the definition of cleaner production (Berkel, 1995). The key difference between waste treatment and cleaner production is timing. Waste treatment measure after-the-event (“react and treat” approach). But, cleaner production is a forward-looking, (“anticipate and prevent” approach) (Kazmierczyk, 2002). Cleaner production does not necessarily eliminate need of end-of-pipe treatment. But, it is a strategy for the continuous improvement of resources, processes, services and products to reduce waste generation at their source (Kazmierczyk, 2002). This includes practices that conserve natural resources by reducing or eliminating pollutants through increased material (like, raw

materials, energy, water and land) utilization.

CP for services incorporates environmental concern on designing and delivering of services. CP for products is used to reduce impacts of products on the environment through raw materials extraction, product manufacturing, use and last disposal of the products. CP for production processes helps to minimize consumption of raw materials and utilities used per unit product; to replace the use of toxic and dangerous materials by less toxic or safe materials; to minimize the quantity and toxicity of all emissions and wastes at their source before generated and released to environment. Cleaner production is considered a management tool, as it involves rethinking and reorganizing the activities carried out inside an enterprise.

Cleaner production is called a “win-win” strategy, because it protects the producers, the environment, and the consumer at the same time improving industrial efficiency, profitability and competitiveness of company. Cleaner production should not be considered simply as an environmental strategy; because it does not deny economic and industrial growth, but it makes growth to be environmental friendly. Some industries in the world implement and develop efficient material utilization technologies and management strategies to reduce their resource consumption per unit of product. However, developing countries like Ethiopia are lagging behind such efficient technologies (Alebachew, 2011).

To assess performance of factory production processes, cleaner production is a tool on investigating factory production efficiency and stage of environmental pollution. Alcohol production process use raw materials like sugar, starches and cellulose. One of the most widely used raw material for alcohol (ethanol) production is molasses which is the by-product of sugar factories. Ethanol production factory use huge amount of water, energy, molasses and various types of chemicals, which could generate a large amount of wastes during inefficient material utilization. Thereby, molasses based alcohol industries are grouped under chemical industries which produce numerous environmental pollutants during less material utilization. The biochemical oxygen demand (BOD) and chemical oxygen demand (COD) of molasses based distillery typically range between 35,000-50,000 and 100,000-150,000 mg/liter respectively (Patel, 2018). Factory considered as an environmental hazard when there is high BOD and COD in the waste during alcohol production (Patel, 2018). Thus, factories should increase their resource utilization efficiency and install waste treatment plant.

Mekanissa Alcohol and Liquor Factory (MALF) is branch of National Alcohol and Liquor Factory (NALF) established in 1949 E.C by an Armenian citizen. It was under Awash wine factory and produces alcohol and wine until 1971 E.C. The Ethiopian government beverage corporation was separated the alcohol producing factory from awash wine factory and joined to National Alcohol and Liquor Factory in 1971 E.C (factory). Now it is the biggest alcohol producer of NALF which is 19,200 liters per day. Indeed, for the increased alcohol production, at the same time wastes are increased.

The present Mekanissa alcohol and liquor factory have grown to the highest quality and taste of its variety products. Therefore, cleaner production is helpful to stay competitive in market both with environment protection and resources utilization. To be implemented cleaner production successfully and sustainably, the concept must have the support of middle and top management.

1.2. Problem statement

Most factories in Ethiopia have the problem of proper utilization of resource. These resources are usually discharged as a waste to the environment in the form of liquid, gas or solid due to poor production process and poor maintenance. Mekanissa alcohol and liquor factory is one of Ethiopian factories which produce ethanol from molasses raw material and did not assess inputs consumption per unit product.

Due to unwanted sludge in molasses composition; molasses treatment section installed to treat molasses before entering to the fermentation section. Unwanted composition of molasses which may contain Mg^{2+} and Ca^{2+} , affect fermentation efficiency and form scale in distillery.

From the company standard data, the alcohol content in yeast propagation should be 2-3%v/v. But, the actual alcohol content of propagated yeast has been 5-6.5%v/v. This alcohol content inhibits propagated yeast and brings low fermentation efficiency. Based on molasses conversion to ethanol and CO_2 , 5,400kg CO_2 is produced per 83m³ tank. For the case of hygiene, the fermentation area is closed room and the CO_2 produced here is emitted to the working room. This CO_2 harms factory employee besides environmental pollution.

Fire tube of boiler forms scale thus steam generation efficiency is low. And, scale formed in the factory distillery (internal column and condensers) is the main problem of energy transferring during ethanol separation. And, the root cause of scale forming is the problem of water hardness.

The fusel oil that is generated in fermentation and separated from pure alcohol in distillery has a pungent odor problem and discomfort employees; besides environmental pollution. The factory already started waste treatment plant for the white and dark stillage drained from the distillery. And, operating cost of treatment plant is depending on amount and composition of wastes.

From all those problems, less material utilization leads higher waste production which brings serious environmental pollution. Therefore, the main task of this study is to investigate the production performance of MALF for improving its production efficiency and to protect environmental pollution through cleaner production assessment techniques.

1.3. Objective

1.3.1. General objective

The general objective of this study is cleaner production assessment for productivity improvement in Mekanissa alcohol and liquor factory.

1.3.2. Specific objectives

- To determine total reducing sugars, fermentable sugar, non fermentable sugars and sludge content in molasses.
- To determine residual sugar in fermented mash.
- To determine the hardness of soft water.
- To investigate material and energy balances in molasses treatment section, distillery section, boiler section and assess their energy consumptions as well as to prepare action plan.
- To draw sankey diagram of distillery and boiler sections.
- To assess production efficiency of fermentation, boiler and distillery sections.
- To investigate the waste generation part, quantify generated wastes, problem of wastes, and generate options for cleaner production.
- To suggest applicable methods or processes in order to improve material and energy utilization efficiency of the plant.

1.4. Significance of the study

Higher resource utilizing efficiency and waste minimizing performance of industries, are the main competitiveness indications. The higher resource utilized company has lower production cost which can be applied by cleaner production assessment. And, the outcome of this paper helps:

- Firstly, to Mekanissa alcohol and liquor factory to identify the main challenges and opportunities of the production process for improving productivity.
- Secondly, to the employee of the company who they hurt every day by fusel oil waste from distillery and CO₂ emission from fermentation.
- Thirdly, it provides vital information to the company to make further investigations.
- Collectively to the country concerning fuel energy consumption and pollution prevention.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Cleaner production

Cleaner production is continuous and integrated preventive environmental strategy applied to processes, products, and services to increase overall efficiency. Cleaner production can be performed by the following practice (National Cleaner Production Centre).

- i. Better housekeeping: - appropriate managerial controlling and operational actions to prevent: wastes, leaks, spills and to change existing operational instructions by better one.
- ii. Substitution of raw material: - substitute by renewable materials or by less toxic.
- iii. Process modification: - modification of operational procedures, equipment utilizing and process controlling to run the processes more efficiently and lower waste generation.
- iv. Equipment modification: - modifying current used equipment and utilities for better process.
- v. Technology change: - changing current used technology to minimize waste generation.
- vi. On-site recovery: - re-use of wasted materials in the same process for another purpose.
- vii. Production of useful byproduct: - reprocessing wastes to useful by-product as input for different business sectors and get better profit as well as reducing environmental pollution.
- viii. Product modification: - modify characteristics of product to minimize environmental loads during or after its use.

But, like off-site recycling; transferring hazardous wastes to another place; waste treatment and incineration; concentrating hazardous or diluting toxic constituents to reduce hazard or toxicity are not cleaner production practices (Berkel, 1995).

2.2. Approach of cleaner production

Cleaner production reduces generation of pollutant wastes at every stage of the production process (Berkel, 1995). “The guide to identify sources and causes of wastes, generate and evaluate CP-EE options, the cleaner production Assessment Manuals developed by UNEP in 1996 and Cleaner Production – Energy Efficiency Manual in 2004” has four phases (Berkel, 1995) (Teffer, 2007):

a) Phase I: Identification of waste source

Activities of the first phase are; conduct process flow diagram; inputs and outputs evaluation; conducting material and energy balances; selecting wasteful processes and assigning cost of wastes.

b) Phase II: Evaluation of waste causes and generation of recovery options

Activities of this phase are; identification of causes of waste; generation of CP options and selection of CP options.

c) Phase III: Evaluation of generated and selected CP options

Activities of the third phase are; evaluation according to environment, economy and technically.

d) Phase IV: Performing and continuation

Activities of the last phase are; CP plan preparation; implement feasible CP measures; controlling CP progresses; announcing and training sustain cleaner production.

Advantages of properly implemented cleaner production are rapid recovering of return on any capital or operating investments; helps to have efficient use of energy and raw materials; minimizing production cost, increases production efficiency; product yield and enhances productivity, reducing final waste treatment cost and final disposal; increase processes efficiency and better quality control results in economic growth and contribute to enhance company competitiveness (Berkel, 1995).

This study is a case study on alcohol production. So, to assess using cleaner production method, it needs production process steps and standards. Thereby, alcohol production process steps are described below.

2.3. Process description of alcohol production

2.3.1. Introduction

Various traditional fermented beverages are produced in Ethiopia on small scale and usually for local consumption. Tej, Tella, Borde, Korefe, Keribo and Areki are among the varieties of traditional alcohols being consumed in Ethiopia (Tafere, 2015).

The word “alcohol” is derived from Arabic word called al-kuhul which is named to many families of alcohol. Alcohols are characterized by one or more hydroxyl (-OH) groups attached to a carbon atom of an alkyl group (hydrocarbon chain). Alcohols may be considered as organic

derivatives of water (H₂O) in which one of the hydrogen atoms has been replaced by an alkyl group. According to which carbon of the alkyl group is bonded to the hydroxyl group, alcohols classified to primary, secondary or tertiary (mazel).

Ethanol (ethyl alcohol) is class of organic compound with C₂H₅OH molecular formula. It is the only alcohol used to beverage obtained from fermentation of molasses, plant matters, fruits, grains, and even dairy products (mazel). Absolute ethanol has 0.794kg/lit specific density at 20 °C and its boiling point is 78.32°C at 1 atmospheric pressure. The unit measurement of alcohol is Gay Lussac degree (°GL) which is volume by volume (v/v) alcohol to water percentage or proof gallon which is twice of Gay Lussac degree (Perry, 1984). Ethyl alcohol is an important industrial chemical used for dyes, food, medicine, cosmetics and pharmaceutical industries, solvent in the synthesis of organic chemicals, and used as fuel at this time (Perry, 1984).

2.3.2. Raw material used for ethanol production

Ethanol is produced from various kinds of raw materials and is chosen based on the regional availability and economic efficiency (Shinnosuke Onuki, 2008). And these raw materials are:

- i.** Sugar containing materials like sugar cane, sugar beet and sugar sorghum,
- ii.** Starchy materials like corn, potato (Quintero, 2008), cassava (Leng, 2008) and wheat (Murphy and Power, 2008) and,
- iii.** Lignocellulosic biomass like maize silage (Oleskowicz-Popiel, 2008), barely hull (Kim, 2008), and paper sludge (Marques, 2008).

2.3.3. Ethanol production methods

Ethanol can be produced by the following methods (Data, 2011):

- i.** Fermentation of carbohydrates (the method used for alcoholic beverages) using yeasts,
- ii.** The hydration of ethylene (the "synthetic" route) using steam and,
- iii.** Biomass waste using bacteria.

This study focuses on sugar cane molasses based alcohol production process by the method of fermentation using yeasts and described in detail as follow.

2.3.4. Molasses based ethanol production process

2.3.4.1. Molasses and its qualitative effect on ethanol production

Molasses is derived from the Latin ‘mel’ meaning ‘honey’ (Rein P. P., 2006). And it is the residual syrup obtained during sucrose crystallizing in sugar factory. Good quality of molasses, appropriate used yeast strain and process control methods are the main crucial activities in alcohol production. Better quality of molasses with high brix and TRS gives higher alcohol production. And it reduces process water requirement besides improving the quantity of dark stillage formed per litre of alcohol (Qazi, Dr. G.N., 2014). The fermentable sugar content of molasses plays an important role in alcohol yield. Molasses may contain high calcium salts concentration which are yeast growth inhibitor and may encourage glycerol formation. Sterilization of sugar at high temperature in presence of salts (phosphates) and proteins can produce yeast toxins. Yeasts may tolerate 16 to 20% non-fermentable dissolved solids in industrial fermentation (Mirkena, 2014).

2.3.4.2. The four mainly sections of molasses based ethanol production processes

2.3.4.2.1. Molasses pre-treatment section

Molasses pre-treatment section is used to treat molasses from any unwanted matter. Certain minerals, such as Magnesium and Calcium which may form scale in steam operating equipment are examples of unwanted matter in molasses. Molasses treatment section operates at 70-80°C temperature and acidic media for the help of separating unwanted sludge obtained in molasses. The precipitated solids are then washed for reducing the sugar losses.

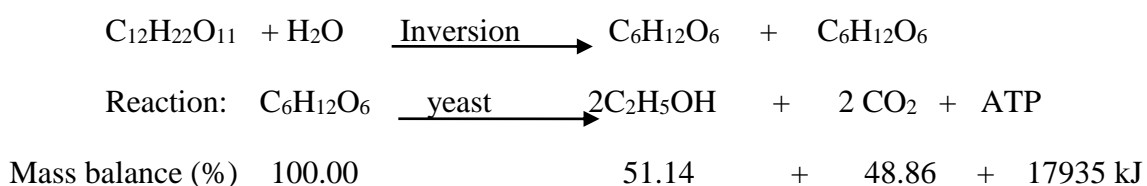
Treatment of molasses before entering to fermentation; improves fermentation efficiency by reducing osmotic stress on yeasts; reduces enzyme consumption, bacterial infection and fermentation time during fermentation. And reduces scale formation, steam consumption and concentration of dark stillage in distillery.

2.3.4.3. Fermentation section

There are aerobic fermentation (yeast propagation) and anaerobic fermentation processes in this section. Aerobic fermentation is the increasing of population and sizes of dry yeast where, anaerobic fermentation is the formation of alcohol in the absence of air. Alcoholic fermentation is a metabolic process in which sucrose and reducing sugars are converted into ethanol and carbon dioxide in the absence of oxygen with biochemical catalysts/enzymes like yeasts, moulds

and bacteria. If oxygen is present, yeast undergoes aerobic respiration which produces CO₂ and water rather than ethanol (Forests, 2009). An anaerobic fermentation process carried out under controlled conditions of temperature and pH during break down of sucrose.

Still now, the first choice for ethanol production is *saccharomyces cerevisiae* yeast based fermentation process. The feed in fermentation is inoculated mostly with 10% by volume of propagated yeast and allow fermenting for two to three days. In the anaerobic reaction, every mole of glucose is converted into 2mole of ethanol, 2mole of carbon dioxide, and 2mole of ATP along with 56kcal of heat. ATP is a nucleoside tri-phosphate used in cells as co-enzymes which is capable of transporting chemical energy within the cell for metabolism (Forests, 2009). Yield of ethanol is expressed as the volumetric production of ethanol per unit mass of molasses consumed in the fermentation. One of the methods used to check ethanol yield in the conversion of sugar to ethanol is the updated Gay-lussac equation and it is described as follow.



The maximum theoretical yield obtained from the Gay-Lussac equation is 51.14 mass units of ethanol produced per 100 mass units of dextrose (Paturau, 1989). But, the maximum practical yield is 48.40 mass units of ethanol per 100 mass units due to side reactions. Acetic acid, glycerol and succinic acid are example of side reaction products (Murtagh, 1999; Paturau, 1989). Thereby, maximum practical yield from the Gay Lussac equation is 94.6%.

Ethanol percentage of fermented mash is mostly 8–12% v/v due to side product happened during fermentation. The residue of the fermented mash out from distillery as liquid waste is termed as, dark stillage, vinasse, distillery slop, or spent washes (Pathade, 2003). The volume of dark stillage obtained in distillation is inversely proportional to the fermented mash alcohol content. Therefore, high ethanol content of fermented mash obtained will reduce volume of dark stillage and improve energy consumption in distillation. The lower residual sugar in fermented mash can lower the COD of dark stillage in distillery. For every 1% residual sugar (based on glucose), expected COD increment is 16g/l (LA, 1979).

2.3.4.4. Distillery section

Distillation is defined as a process in which a liquid or vapor mixture of two or more substances is separated into its component fractions of desired purity based on their boiling point difference. As the feed has diverse compositions, liquid outlets at intervals along the column allow the withdrawal of different fractions having different boiling points. The "lightest" products (those with the lowest boiling point) exit from the top of the columns and the "heaviest" products (those with the highest boiling point) exit from the bottom of the column.

Distillation column is provided by direct injection of steam in the column bottom or re-boiling part of column bottom liquid in a heat exchanger (called re-boiler). Overhead vapors are condensed in heat exchanger (called condenser). A part of liquid obtained in condenser is returned to upper part of column as reflux to provide cooling to the up flowing vapors thereby increasing separation efficiency of column. Distillation design is grown day to day according to product quality and energy utilization efficiency (DESHPANDE).

Recently designed distillation of alcohol production plants is called energy-saving multi-pressure distillation plants (DESHPANDE). Recently distillation column is designed to operate at multi-pressure in similar principles to multiple effect evaporators; to reduce energy consumption, by-product formation and lower scale formation in mash column trays. These distillation columns are operating under different pressures. Thermal energy from columns operating under pressure is recycled to columns under vacuum for energy conservation (DESHPANDE). Multi-pressure distillation plant is particularly interesting for ENA producing plants. Here, usually, the mash column is operated under vacuum and is heated by overhead alcohol vapors from the rectifying column. Thereby, steam supply to the mash column is saved. Similarly, other columns are also operated in-pair using overhead vapors from one to heat the other column. Thereby, 50% of the energy consumption to produce a liter of alcohol can be saved. The level of impurities in alcohol from such plants is lower, compared to plants with mash column operating at normal pressure.

The fermented mash from fermentation section is pumped to a continuous distillery process where steam is used to heat the mash to its boiling point in the stripper column (ASTM, 1997). Vapors with rich ethanol, evaporates and removed from the top of the column and condenses using coolant in heat exchanger before transferred to another step. The ethanol stripped stillage

falls to the bottom of the stripper column and is pumped to dark stillage storage. With efficient distillation, the stillage should contain less than 0.1% ethanol but, when distillation is not optimal, the stillage may contain significant ethanol content. For each 1% ethanol left in dark stillage, the COD of the dark stillage is increased by more than 20 g/lt (ASTM, 1997). Therefore; improper control of distillation process affects cost of waste treatment plant besides alcohol loss.

Alcohol losses in distillation are small and distillation efficiencies are usually higher (LAVARACK, 2003). And, most distillation efficiency is 99% (Paturau, 1989). Production yield is used to compare fermentation processes efficiency, distillation efficiency and helps to monitor production performance of process plant. Generally the conversion efficiency of sugar to ethanol and separation efficiency of distillery is summarized in table (2.1) below.

Table 2. 1 General fermentation and distillery efficiency

Fermentation			Distillery				Remark
Fermentation efficiency based on Gay-Lussac equation	Fermentation yield in kg of alcohol per kilogram of sugar (glucose) in feed	Fermentation yield in litres of ethanol per tonne of fermentable glucose in feed	Overall distillery yield (%)	Overall ethanol yield in kg per kilogram of Fermentable sugar (glucose) in feed	Overall yield in litres ethanol per tonne fermentable sugar (glucose) in feed	Overall yield in litres ethanol (96%) per tonne fermentable sugar (glucose) in feed	
100%	0.5114	644	99.0%	0.506	638	664	Maximum Gay-Lussac yield, not achievable
94.6%	0.484	610	93.7%	0.479	603	629	Maximum obtainable yield
94.0%	0.481	606	93.1%	0.476	600	625	Good yields
92.0%	0.470	592	91.1%	0.466	587	611	
90.0%	0.460	579	89.1%	0.456	574	598	
88.0%	0.450	567	87.1%	0.446	561	584	
86.0%	0.440	554	85.1%	0.435	548	571	Fermentation designed in 1970s and 1980s
84.0%	0.430	542	83.2%	0.425	536	558	

Input molasses and utilities consumed per unit product is different based on production process performance and table (2.2) below summarizes consumption of each inputs.

Table 2. 2 Resource consumptions per liter of alcohol product

Raw material inputs	Amount
Molasses (kg)	4.237 (V, 2016)
Water dilution (lt)	12.267 (V, 2016)
Steam (kg/lt of alcohol)	2.6-2.8 kg/litre of alcohol (DESHPANDE)
Yeast (g/lt of alcohol)	0.703 g/lt of ethanol (Mirkena, 2014)
DAP (kg/ lt of alcohol)	1.0 (Mirkena, 2014)

2.3.4.5. Effluent characteristics and treatment

Dark stillages are waste materials with high organic loads, and a complex composition of tannins, melanoidins and phenols generated in distillery during alcohol separation. Some of the negative characteristics of dark stillage as seen in table (2.3) below are; low pH, high amount of COD, sulfates, nitrogen, potassium and these characteristics affect suitability of environment. The combination of different processes starts by an anaerobic treatment followed by an aerobic or physico-chemical process which gives better results in the removal of organic load and color of dark stillage. Treated dark stillage can be used in agriculture without the risk of pollution (Chowdhary, 2018). The pollutant waste of distillery has different characteristic depending on molasses source and cane growing soil type. Dark stillage general characteristic of different country is summarized in table (2.3).

Table 2. 3. General characteristics of dark stillage in different country

Characteristics in (mg/l Except pH)	India (IJIRAE, 2015)	Espain (Españ-a-Gamboa, 2011)	Germany (Frankfurt, 2000)	Ethiopia (Mirkena, 2014)
Liter of spent wash per liter of alcohol	14-15	-	14-18	15
Temperature(°C)	95	-	-	60 – 100
Color	Dark Brown	Dark Brown	Dark Brown	Dark Brown
Odor	Jiggery	Jiggery	Jiggery	Jiggery
pH	3 – 4.5	4.46–4.8	4.2 – 4.4	4.3 – 4.6
BOD	50,000 – 60,000	39,500	34,000	30,000 – 40,000
COD	110,000 – 190,000	84,900–95,000	70,000	85,000-95,000
TS	110,000 – 190,000	-	70,000 – 95,000	80,000-90,000
TSS	13,000 – 15,000	-	2,800 – 3,400	-
TDS	90,000 – 1,50,000	-	-	-
Chlorides	8,000 – 8,500	-	-	5,000-6,000
Phenols	8,000 – 10,000	34	-	-
Sulfate	7,500 – 9,000	1,500–3,480	2,670	2,000-5,000
Phosphate	2,500 – 2,700	-	-	800-1,200
Lead	-	0.02–0.48	-	-
Potassium	8,000 - 11,000	4,893–11,000	3,200	80,00-10,000
Total nitrogen	1,000 - 8,000	153–1,230	800	1,000 – 1,200
Calcium	5,000 – 6,500	-	-	500 – 600

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Materials

❖ Reagents:

Concentrated hydrochloric acid is used to convert sucrose to reducing sugar (glucose and fructose). Sodium hydroxide solution 6N is used to neutralize the acidic reducing sugar solution. Standard Fehling solution A ($\text{Cu SO}_4 \cdot 5\text{H}_2\text{O}$) and standard Fehling solution B (NaOH) are used to prepare phenol solution where phenol solution is used in the titration of reducing sugars in molasses. Lead acetate solution 10% w/v (leading solution) is used to clarify the reducing sugar where potassium oxalate and sodium-orthophosphate solution (De-leading solution) is used to remove any excess lead acetate. Methyl blue 1% w/v and phenolphthalein indicators are used to indicate end reaction during titration. pH 10 buffer solution, 1% EBT solution and 0.01 Molar EDTA solution are used to calculate soft water hardness.

❖ Apparatus:

Equipment used during analysis of input materials and output products were 50ml beaker; 250ml volumetric flasks; 500ml and 250ml Erlenmeyer flasks; 250ml, 10ml, 5ml, pipettes (graduated); 50ml bulb pipette; 25ml cylinder; 50ml funnel and 50ml burette.

Analytical balance was used to measure mass of known volumes. Refractro-meter, constant temperature water bath and centrifuge were used to know sludge content of input molasses. pH meter was used to know pH of input molasses, fermentation fluids, distillery fluids and all output wastes. Digital density meter was used to measure alcohol content of input technical alcohol, denature alcohol and pure alcohol. Laboratory scale distillation (Maligand) was used to measure alcohol content of fermented mash and waste streams. Thermocouple was used to measure surface temperature of fluid pipes and equipments. Flue gas analyzer (E6000-5DS) was used to measure composition and temperature of flue gas emitted from boiler. Temperature and pressure transmitters were used to measure temperature and pressure of fluids in side machines or pipes.

3.2. Methods

3.2.1. Data collecting and monitoring

Besides field inspection and process controlling, laboratory work and previous data were considered to understand the production process operations, utility sections, type of raw material used and produced products. The existing production processes, water supply and waste generation systems, boiler steam generation and distribution systems were carefully checked. Process flow diagrams were drawn and inputs-outputs of all process steps and each production process were understood first.

Useful data of raw materials and products of the fiscal year are collected as much as possible. And the main data are, data of molasses, alcohols, sulphuric acid, DAP, furnace oil, naphtha oil, electric consumptions and water consumptions. The unknown input or output data are collected averagely at present working condition. All density of fluids in calculation was measured by weighing known volume of fluids in balance.

3.2.2. Raw material analysis

i. Water analysis

Water supply of the factory is unknown. So, the total water consumption for processes, washing, cleaning at each unit operation were measured using installed digital flow meter and by average material balance calculations. Hardness of process water, softened water of boiler and liquor were checked by titration setup using EDTA at factory.

ii. Input molasses analysis

Molasses consumption per tank was calculated by measuring the input-output brix. Where, the average density of molasses at each step is determined by weighing known volume of molasses. Brix of molasses was measured by refractro-meter at factory. Total reducing sugar and non-fermentable sugar amount of molasses were conducted by titration using Frelli standard procedure at factory. Fermentable sugar is calculated from the balance of total reducing sugar and non-fermentable sugar amount. Input molasses was analyzed collectively to estimate all unwanted sludge content in molasses by centrifuge separator.

3.2.3. Analysis at fermentation section

- i. Aerobic fermentation (yeast propagation):** yeast population and alcohol content of propagated yeast were conducted by microscope and laboratory scale distillation (Maligand) respectively at factory. Yeast propagation air input was analyzed by gas analyzer at AAiT.
- ii. An aerobic fermentation:** Alcohol content (°GL) and residual sugar of fermented mash were conducted by laboratory scale distillation and titration setup by Frelli standard procedural method at factory respectively.

3.2.4. Analysis at distillery section

Alcohol content of all the bottom, side and top streams of the five columns are conducted by alcoholmeter, density meter (measures volume by volume and weight by weight) and laboratory scale distillation equipments at factory. And alcohol content of all input-output streams is used to investigate alcohol loss quantities.

Total steam flow rate, temperature, pressure and volumetric flow rates were collected by sensors and transmitters. Input energy of each column (distillation) is calculated using known kilogram of steam and specific enthalpy from steam table at given temperature and pressure.

3.2.5. Analysis at liquor section

Input alcohols and output liquors were measured using alcohol meter and density meter (both volume percent and weight percent) at the factory.

3.2.6. Material and energy balances

Based on standard collected data and analyzed data through laboratory, material balance was determined at each sections and unit operations of the production process to identify material loss quantities and material wastage equipments or sections. Alcohol loss, liquor loss, waste water, white stillage, dark stillage, fusel oil and other wastes were calculated from input-output material balances.

Energy balance is applied in molasses treatment section, distillery and boiler sections to identify energy wasteful parts and assess any energy saving opportunities. Surface temperatures and flue gas composition were directly measured using digital thermocouple and flue gas analyzer (E6000-5DS) respectively. For energy audit case, different surfaces are measured at different air condition (morning, day, evening and night) to get average heat losses. Steam condensate flow

rate from steam trap was measured directly.

3.2.7. Characterization of wastes

The calorific value of naphtha oil and fusel oil was measured by calorific test method at Geological Survey of Ethiopia individually and by mixing 1:1 ratio for the purpose of mixing.

Color, odor, TDS and pH of dark stillage were checked by visualization, conductivity meter and pH meter at the factory. BOD and COD were done at Addis Ababa city Government Environmental protection authority using Incubator and Digester respectively.

3.3. Cleaner production assessment

Cleaner production assessment is conducted by examine and evaluate the production process, energy generation, steam distribution systems and utilization efficiencies mainly by three phases.

- Identification of waste source: - was made by conducting material and energy balances at each process steps. To ease the bulkiness of this section, the two concepts are treated separately in chapter five and six.
- Identification of causes of wastes: - identified based on factory standards and laboratory analysis help to increase production efficiency and reduce volume or composition of wastes.
- Option generation: - It is means of eliminating and control of each waste causes. Waste recovering options generated here are evaluated for technical, environmental and economic viability.

CHAPTER FOUR

4. BACKGROUND INFORMATION OF THE RESEARCH SITE

4.1. Process description of Mekanissa alcohol and liquor factory

Mekanissa alcohol and liquor factory (MALF) is branch of National Alcohol and Liquor Factory (NALF) which located in the south west of Addis Ababa.

It has been producing pure alcohol (PA); denature alcohol (DA) and different liquors for greater than 50 years. Currently the factory has a distillation capacity of 6,480,000 litres of pure alcohol and 432,000 litres of denature alcohol per year.



Figure 4. 1 Mekanissa alcohol and liquor factory

Pure alcohol is the first desired product in MALF distillation and has an alcoholic content of greater than 96.2 %v/v. it is used for production of different types of liquors in the company and used for medicine, perfume, cosmetics, chemicals and plastics as well as for laboratory purposes (Perry, 1984).

Denature alcohol is a byproduct with alcohol content of 92-95%v/v and used for many purposes such as; clinical purposes, beauty salons and barbers, cleaning electronic equipment and for fuel purposes.

4.2. Raw materials and utilities used for production of alcohol in MALF

Molasses, sulphuric acid, yeast, DAP (Di-ammonium phosphate), salt, anti foam and utilities like Water (soft water, process water and cooling water) and steam are the main inputs used in the alcohol production.

Molasses: - Molasses is a brownish black color and a highly viscous material with 78-83°brix which is byproduct of sugar factories and principal ingredient to alcohol production factories. MALF obtained molasses from Methara, Wenji, Fincha or OMO-kuraz sugar factories. But,

when there is shortage of molasses especially in summer, MALF use another raw material called technical alcohol for the production of ethanol.

Technical alcohol: - it is ethanol, mostly used for fuel blending purpose which is produced in sugar factory using addition of cyclo-hexane or by molecular sieve tray distillation. It is used as raw material when there is shortage of molasses supply in the market especially during the summer season where the sugar factories totally stopped for maintenance. During this input raw material in MALF production process, molasses treatment and fermentation sections are neglected. But consumption of water is increased for dilution.

Sulphuric acid: - is added in molasses treatment sections and in yeast propagation section. Acid plays a great role in killing micro-organisms and lowering time of precipitation of lime and other scale forming salts obtained in molasses. Also it provides acidic media in fermentation which is suitable for the yeasts during the yeast propagation stage.

Yeast: - Are unicellular microorganisms used to convert the sugar in the treated molasses to alcohol and carbon dioxide. The company mostly uses *saccharomyces cerevisiae* yeast.

Compressed air: - Air is used to create favorable conditions for yeasts in the yeast propagation section. If there is no sufficient air (O₂), yeasts are weak in conversion of sugar to ethanol.

DAP (Di ammonium phosphate):- It is used as a nutrient for the yeasts during yeast propagation. Ammonium ion provides nitrogen for protein nucleic acid synthesis. Vitamins such as biotin, pantothenate and thiamine are stimulatory to yeast growth and ethanol tolerance.

Anti-foam: - is a solution used in the yeast propagation and fermentation tanks to prevent foam formed during fermentation reaction.

Salt: - salt (NaCl) is used to re-generate the zeolite based water softener.

Water supply: - The main source of water supply for the factory is ground water. But, when there is shortage especially in day, additional municipal water is used. Process water is the source of cooling water, soft water and all waters used in the factory.

Water softener: - The factory uses a zeolite based water softener. And softened water is used in boiler, distillery and cooling water sections. As standard, maximum water hardness of factory should be 3.5°F (35ppm) and if it is above this the softener will be regenerated by salt.

Energy supply: - The factory use both fuel energy and electrical energy to produce a liter of alcohol. Fuel energy is used for steam generation in boiler where as steam is used in distillation and molasses treatment sections. Furnace oil or naphtha oil is used as a source of fuel in MALF. Steam in distillation is used to separate desired alcohol which is ethanol where as steam in molasses treatment section is used to facilitate the molasses inversion to reducing sugar at acidic media. Electrical energy is used for driving motors of equipment such as pumps, compressors, mixers, office machines and lightings.

4.3. MALF alcohol and liquor production sections

The main process steps of Mekanissa alcohol and liquor factory are molasses treatment section; fermentation section, distillery section and liquor section. And general process flow diagram of MALF is constructed in figure (4.2) below.

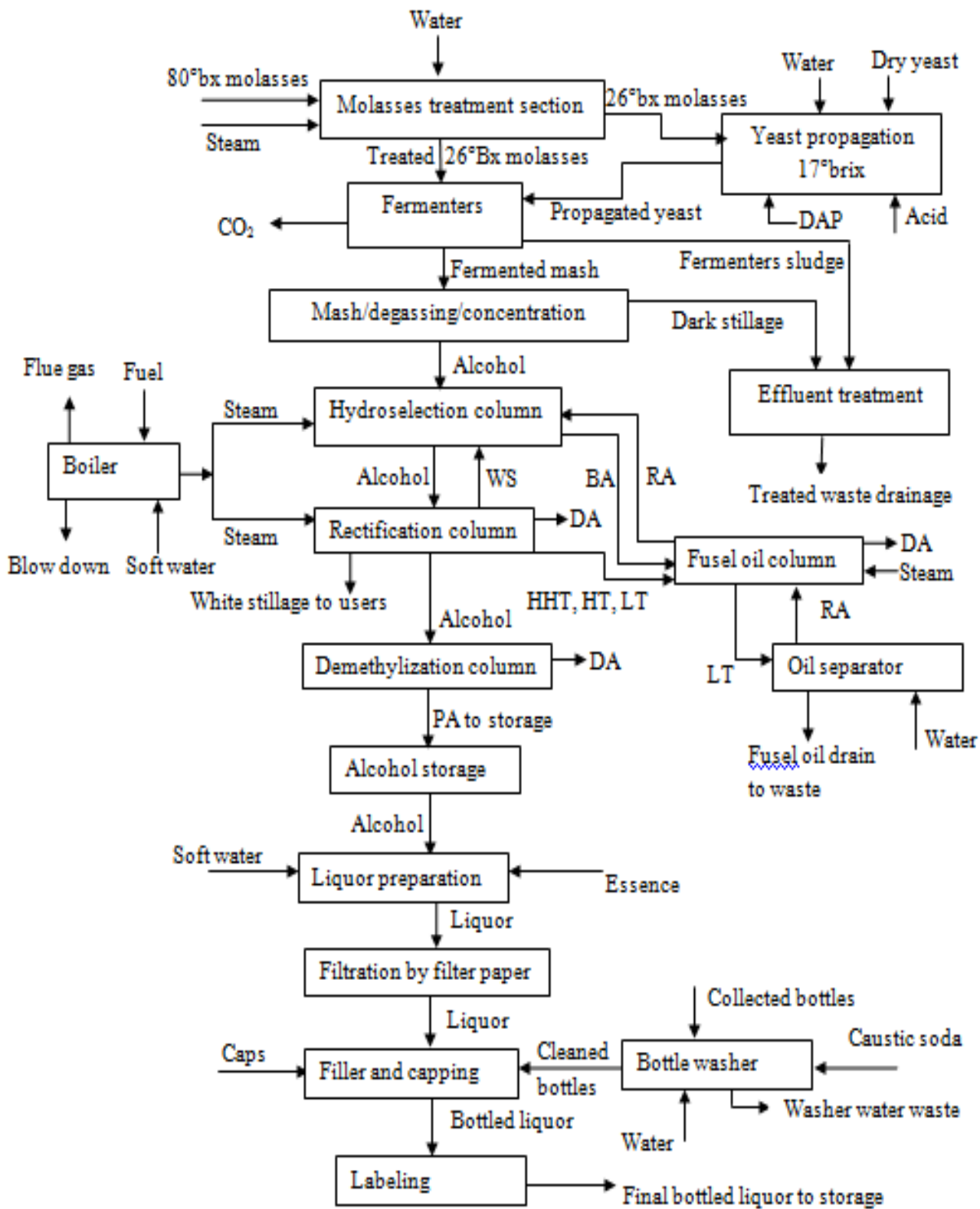


Figure 4. 2 General MALF process flow diagram

4.3.1. Molasses treatment section

Molasses treatment is the first process step in MALF. There are five drums (D-1201 to D-1205) in this section and listed as follow.

Dilution tank (D-1201):- 3040 kg/hr raw molasses with 78 to 85°brix coming from molasses storage tank is pumped to this dilution tank. And 3024 lt/hr dilution water added from distillery white stillage and fresh water as integration. Temperature in this dilution tank is maintained at 80 °C by steam control valve and pH value is corrected at 5. The hot and diluted molasses with 40-45°brix from this drum is fed to the next drum called first static decanter (D-1202).

First static decanter (D-1202):- With the help of centrifuge mixer inside this drum, sedimentation of fine-grain crystal sludge occurs from the diluted molasses comes from D-1201. Treated liquid molasses goes to the storage tank (D-1205) while under flow (semi-sludge) is collected on the bottom and sent to the sugar recovery tank (D-1203).

Sugar recovery tank (D-1203):- The under flow of (D-1202) is transferred to this tank in order to recover a part of residual sugar. Solution of this tank goes to second static decanter (D-1204).

Second static decanter (D-1204):- At this drum, unwanted sludge removed at bottom while the sugar containing liquid goes to dilution tank (D-1201) and working as continuous process.

Storage tank (D-1205):- The over flow liquid which comes from (D-1202) cooled down to 30 – 33 °C by passing through plate type heat exchanger. Then it passes through static mixer where second dilution occurs by process water in line to achieve the required final 26°brix.

Molasses treatment improves the overall process efficiency and the quality of ethanol product. The composition of molasses has many impurities where the main impurities like Magnesium and Calcium as oxide form influences scale forming in distillation and reduces the fermentation efficiency both in aerobic and an aerobic fermentation stages. The company already installed the molasses treatment section to remove all these impurities from molasses to be; faster fermentation time, higher ethanol yield during fermentation, improve heat transfer in cooling fermenters, reduce scale problems in distillation and to reduce BOD of distillers effluent. But, it is not functional since 2016 G.C until now. The company does not consider how this section is important on the followed fermentation and distillery sections based on pollution controlling and productivity improvement. Process flow steps of this section are drawn in figure (4.3) below.

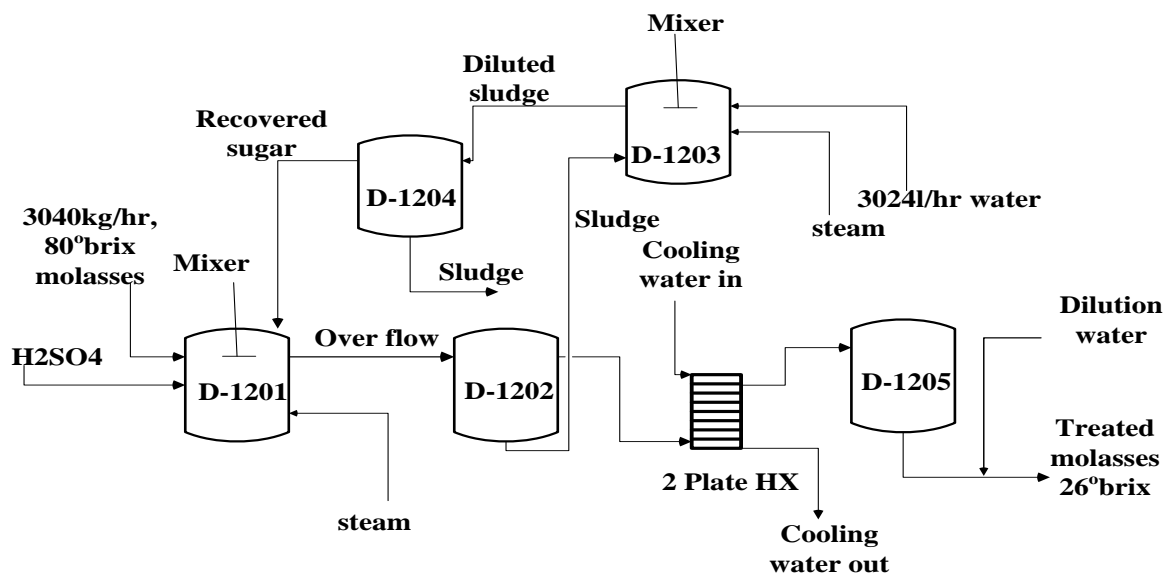


Figure 4. 3 Input – output process flow of molasses treatment section

Standard inputs and outputs of the company in this section are collected in table (4.1) below.

Table 4. 1. Company standards on molasses treatment section

Flows	Items	Amount
Inputs	Molasses	3040 kg/h with minimum sugar content of 45wt%
	Process water + white stillage	6780 kg/hr
	Sulphuric acid	10 lt/hr
	Steam	500 kg/h at 1 barG
	Solution temperature	85°C
	Electric energy	35.5 kW
	Cooling water	22 m ³ /hr at 28°C
	Seal water	0.7 m ³ /hr
Outputs	Diluted and clarified molasses	10,000 kg/hr
	Sludge	334kg/hr from material balance

4.3.2. Fermentation section

The alcoholic fermentation is performed by means of two main process steps, namely the aerobic stage (yeast propagation) and the anaerobic stage (ethanol formation). The aerobic stage basically realizes the growth of the yeast, and the anaerobic stage is conversion of sugar to ethanol.

4.3.2.1. Aerobic fermentation (yeast propagation)

Aerobic fermentation is fermentation used to propagate yeasts in number as well as sizes by controlling at proper condition. During the yeast propagation, the solution is fed with air to

increase the cells reproduction and the vitality of the yeasts. There are two propagators having 10m³ volume each. Inputs and outputs of yeast propagation tank are drawn in figure (4.4) below.

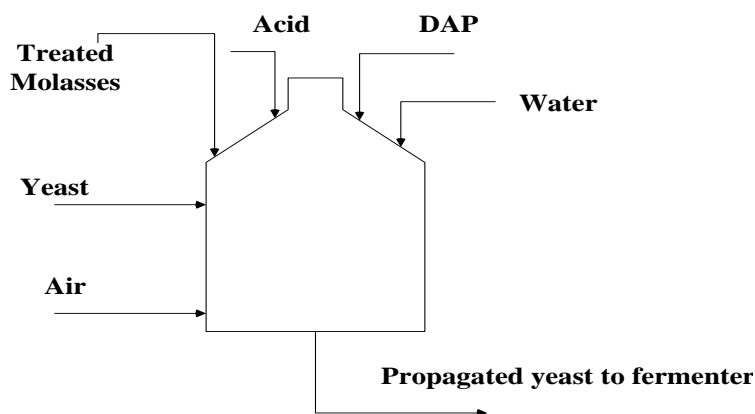


Figure 4. 4 Yeast propagation tank

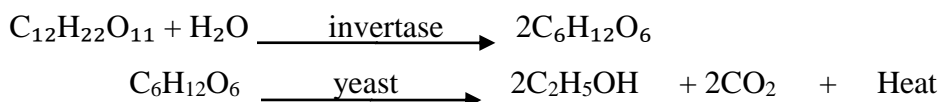
Standard inputs and expected outputs of yeast propagation are summarized in table (4.2) below.

Table 4. 2. Company standards on yeast propagation

Flows	Items	Amount
Inputs	Treated molasses	5 m ³
	Process water for dilution	5 m ³
	Solution brix	17 °brix
	Dry yeast	5 kg or per tank as dry or 5 × 10 ⁷ cells/ml as solution
	Nutrient (DAP)	230 kg at 10%
	Solution temperature	30-33 °C (controlled by jacketed cooling water)
	pH	4-4.5
	Air	140 m ³ /hr
	Fermentation time	18 hr
Outputs	Propagated yeast	140 kg as dry or 2.8 × 10 ⁸ cells/ml as solution
	Alcohol content at finish	2-3 % vol.
	Sugar content at the end	1-2 % wt.

4.3.2.2. Anaerobic fermentation

Anaerobic fermentation is a process of exothermic reaction in which yeasts convert the sugars in the molasses into alcohol, carbon dioxide and heat as shown in the theoretical equation below.



The activity of the yeast in fermentation is strongly limited by the reaction products which are carbon dioxide and temperature. If the fermentation process is not controlled in proper conditions, the reaction produces secondary products such as acetic acid, methanol and higher alcohols.

There are six fermenters with 144 m³ each works on the same cycle of: cleaning, yeast footing and mash feeding; conversion and termination steps. Fermenters are batch mode and are scheduled sequential mash feeding to be continuous process.

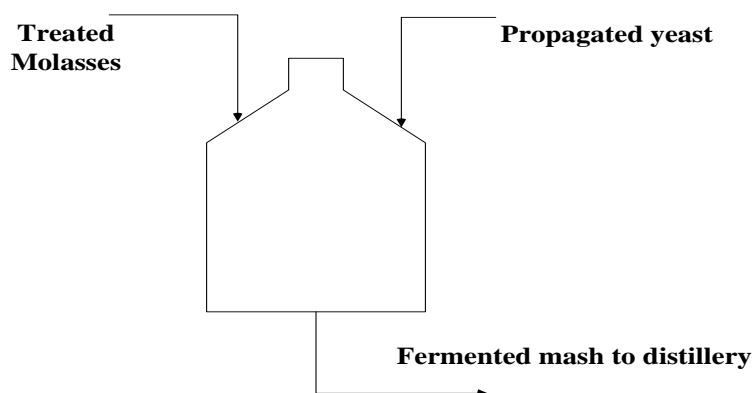


Figure 4. 5 Fermentation tank

Tankers have side entering mixer to homogenize the solution and helps to remove carbon dioxide formed during reaction which is toxic for yeasts. But, all the mixers are not functional. Fermentation without mixers especially for larger volume tanker decreases fermentation efficiency. Standard inputs and outputs in anaerobic fermentation are shown in table (4.3).

Table 4. 3. Company standards on fermentation

Flows	Items	Amount
Inputs	Treated molasses volume	73 m ³
	Propagated yeast	10 m ³ per tank
		140 kg dry yeast or 28×10^7 cells/ml
	Batch net volume	83 m ³
	Solution temperature	30-33 °C (controlled by jacketed cooling water)
	Process water or white stillage	1,600 litre per tank for washing
	Electric energy	120 kW
	Jacketed cooling water	190 m ³ /hr at 28°C
	Seal water	2 m ³ /hr
	pH	5
Fermentation time	48 hr	
Outputs	Alcohol content of fermented mash	8-12% vol.
	Carbon dioxide	670 kg/hr and 5400kg per 83m ³ tank averagely
	Sugar content at the end	0.2-0.5 % wt.

4.3.3. Distillery section

The alcohol in fermented mash is mainly ethanol, but side products such as methanol, esters, acids and aldehydes can be contained in fermented mash. Therefore, main aim of distillation columns is to separate ethanol from the other products.

Distillation process of MALF produce pure alcohol product and denature alcohol byproduct; as well as dark stillage, white stillage and fusel oil as wastes. In this process the more volatile component is collected as the top product and less volatile product withdraw at bottom side.

MALF distillery system operated in six columns to produce extra neutral alcohol which is quality product. Byproducts are expected to be lower than 6 % and steam energy consumption will not exceed 3.5 kg of steam per liter of alcohol. In order to optimize the steam consumption, two double effect configurations are synchronized. Thus, steam from boiler house directly injected to rectification and hydro selection columns, and partially direct injected to fusel oil column. Rectification overhead vapor is reboiling mash/degassing/concentration columns. And the same overhead vapor of hydro-selection column is reboiling the demethylizing column. In order to achieve this thermal integration between the columns, rectification column is working in over pressure, hydroselection column and fusel oil columns are operating at atmospheric condition, while mash/degassing/concentration columns and demethylizing column are operating under vacuum condition. And the six MALF columns are listed as follow.

i. Mash/Degassing/Concentration column (C-1510/20/30)

This distillation has three sections: the bottom called mash column, the middle degassing column and the upper where vapor released called concentration column. Fermented mash from the buffer tank is entered to degassing column passes through concentration (E-1531) and fusel oil (E-1561) shell and tube heat exchanger to get heat. Where, the vapor flows through the shell and the mash through the tube. When the mash is heated, at the same time vapor get condensed and collected in the drum. Degassing column and concentration column are constructed from copper material. So, sulfur dioxide and CO₂ gases in fermented mash undergo a chemical reaction in the presence of copper to be soluble then separated from product and removed in the form of solid. When the fermented mash enters to the degassing column then to mash column, heated by the means of re-boiler in the bottom and the vapor formed here goes to concentration column. This vapor condensed in (E-1531) and then fed to hydro-selection

column. The dark stillage with residual alcohol content lower than 100ppm is discharged by pump from bottom of mash column.

Graphical input-output representation of the first column is drawn in figure (4.6) below.

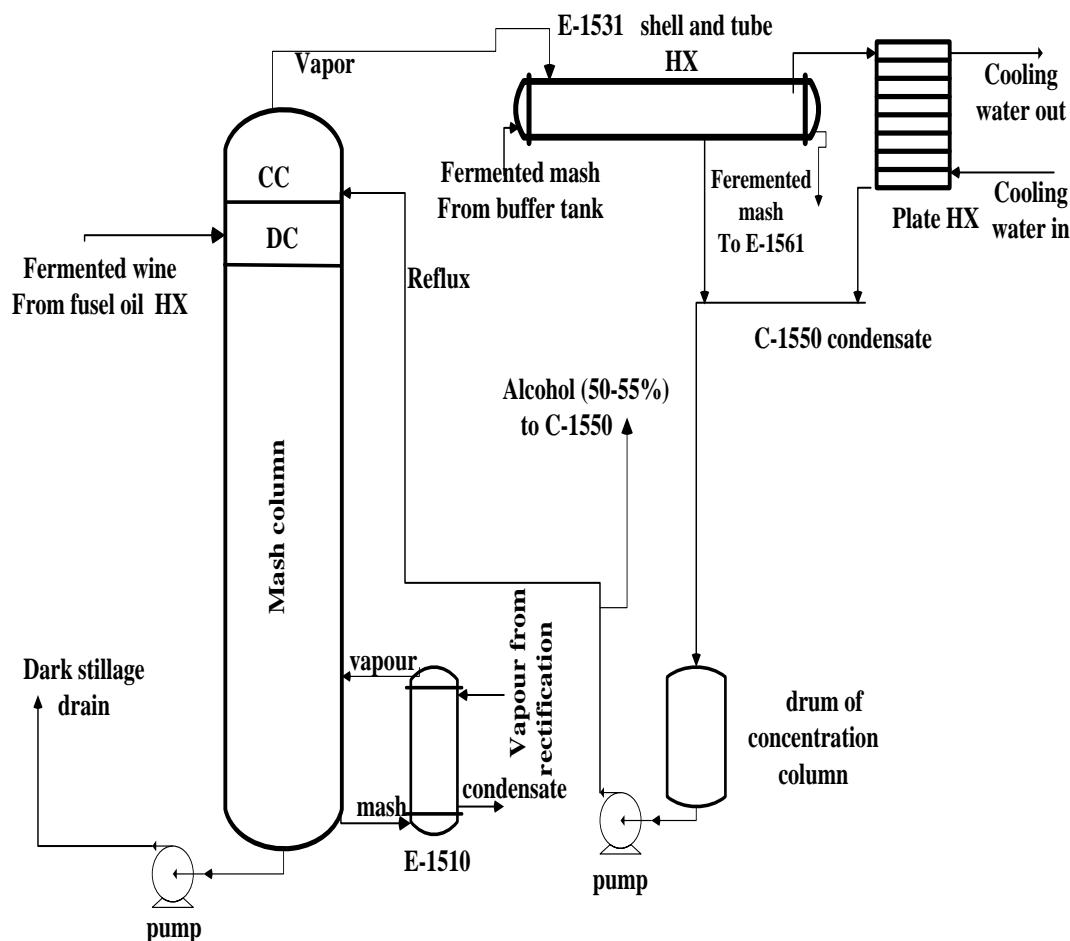


Figure 4. 6 Inputs – outputs process flow of Mash/Degassing /Concentration columns

ii. Hydro selection column (C-1550)

Hydro selection column is heated by direct steam injection. Condensates from concentration column with alcohol content vary from 50 to 55% and still rich of impurities is purified in hydro-selection column. This column called extractive distillation and the bad alcohols are removed at the top of the column. The main aim of this column is to lower the alcohol content to 10% by diluting with softened water and part of white stillage that comes from bottom product of rectification column. Alcohol is recovered at the bottom of hydroselection column and then sent to rectification column. Overhead vapor of hydroselection column goes to demethylization heat

exchanger to integrate heat and to condense the vapor itself at the same time. Excess vapor of this column condenses by guard condenser which works by cooling water. The condensed vapor that comes from Demethylization heat exchanger and guard heat exchanger is collected in D-1551 and reflux to hydroselection column by pump. The top products of this column are methyl alcohol, Esters, Acids, and Aldehydes which called bad alcohols are sent to fusel oil column. Bad alcohols and denature alcohol of this column are separated from the reflux line.

Figure (4.7) show the schematic diagram of hydroselection column with its inputs and outputs as well as other equipment.

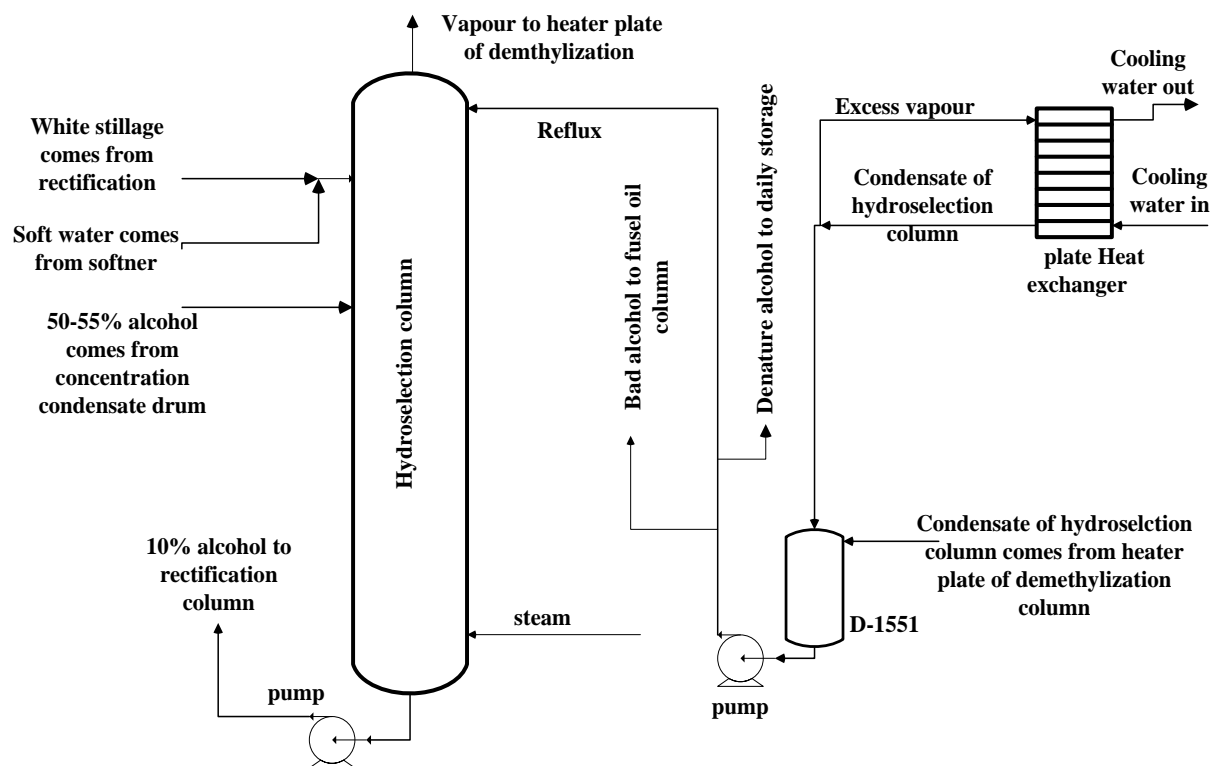


Figure 4. 7 Inputs – outputs process flow of Hydro-selection column

iii. Rectification column (C-1540)

The 10% alcohol fluid that comes from hydro-selection column is concentrated to 96.2% in rectification column and extracted two trays below the top of the column then sent to demethylization column. Other side products of this column are HHT (High High Tail), HT (High Tail) and LT (Low Tail) are extracted side product based on temperature difference then sent to fusel oil column for more clarification from any higher alcohol which decreases product quality.

Overhead vapor of rectification column is condensed in mash column re-boiler (E-1510). The re-boiler heats indirectly the mash column by rectification vapor through shell and tube heat exchanger and at the same time, vapor of rectification column condensed here. If any excess vapor comes from reboiler, there is guard plate heat exchanger to condense and provides pressure regulation for rectification column. All condensates of rectification column are then collected in the reflux drum and recycled to the column as reflux and denature alcohol extracted from this condensate is sent to denature alcohol storage.

The white stillage (spent lees) from the bottom of rectification column under level control is sent to (D-1560) for providing heat partially to fusel oil column and the rest white stillage goes to molasses treatment section for dilution purpose. And the other part of white stillage goes to hydro-selection column. Inputs-outputs of rectification column are drawn below in figure (4.8).

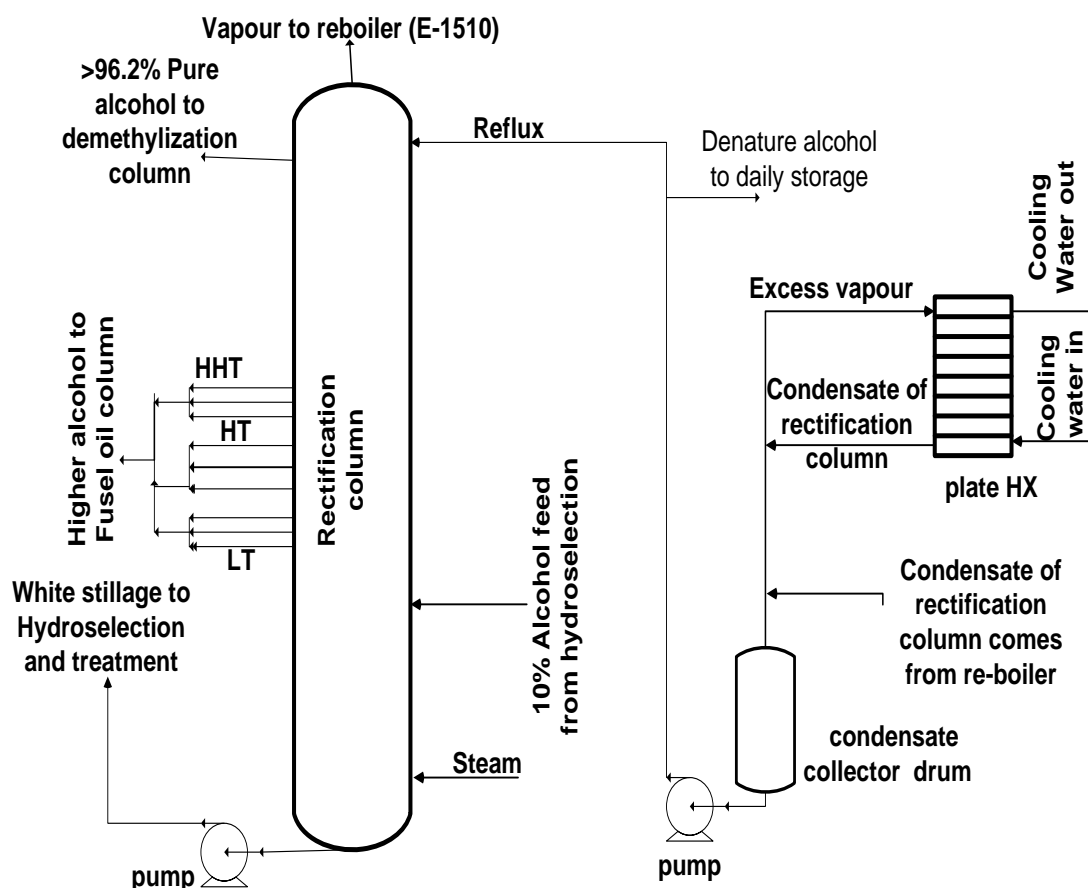


Figure 4. 8 Inputs – outputs process flow of Rectification column

iv. Demethylization column (C-1570)

The alcohol extracted from rectification column is fed to demethylization column where

practically any trace of methanol is removed. The demethylizing column is indirectly heated by integrated heat exchanger from hydro-selection column. Methanol rich denature alcohol is withdrawn from the column reflux and sent to denature alcohol storage. Extra neutral alcohol (pure alcohol) is out from the bottom side of this column and sent to daily pure alcohol storage. Graphically input-output streams of this column are drawn in figure (4.9) below.

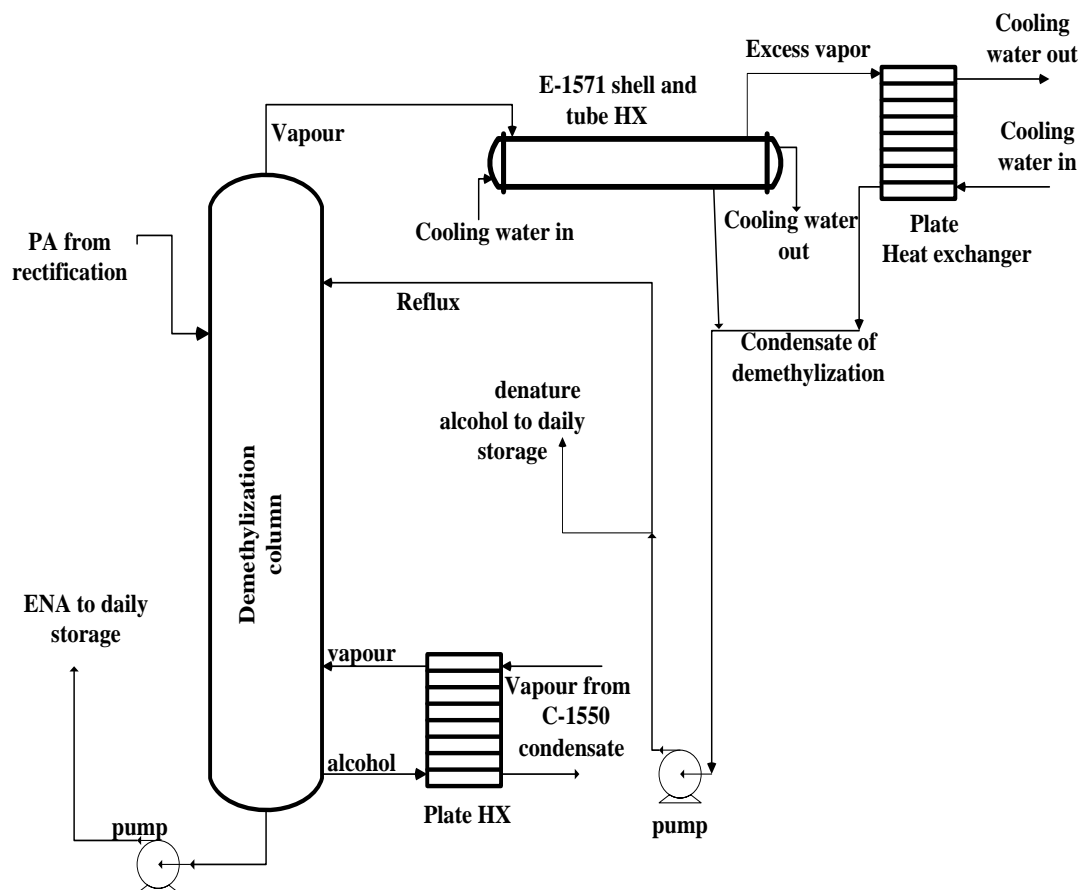


Figure 4. 9 Inputs – outputs process flow of Demethylization column

v. Fusel oil column (C-1560)

Fusel oil column get direct steam injection and partially from rectification white stillage. The main purpose of this column is to separate impurities (oil) from higher alcohol that comes from side stream (HHT, HLT and LT) of rectification column and bad alcohols from top of hydro-selection column. Recovered alcohol is sent to hydro-selection column where separated fusel-oil is drained to environment which has extremely bad odor. The overhead vapour of this column condensed by (E-1561) and if any excess vapors come out from (E-1561) is condensed by guard plate heat exchanger. The condensed vapour from both heat exchangers refluxed to the

column. Denature alcohol extracted from the reflux line and side stream of the column then sent to denature alcohol storage. Figure (4.10) below is graph of fusel oil column.

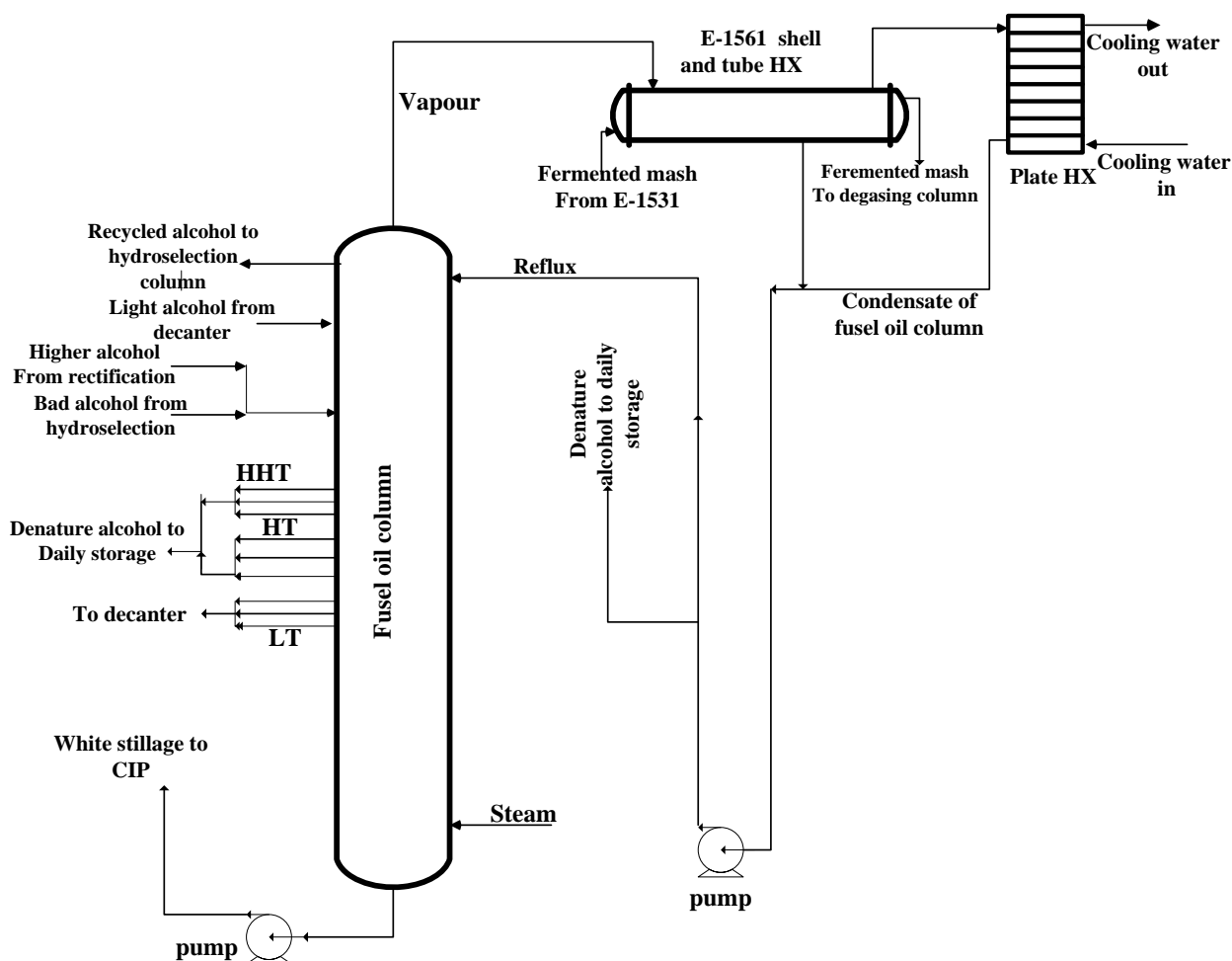


Figure 4. 10 Inputs – outputs process flow of Fusel oil column

Decanter (DS-1560) is oil separator drum where fusel oils in fusel oil column are separated by density difference with the addition of cooled water. Oils are drained to environment and any recovered alcohol is recycled to fusel oil column.

vi. Washing column (C-1580)

In order to reduce the emission to the atmosphere as well as to reduce alcohol losses, the vents from vacuum pumps are washed in a vent scrubber called washing column. Washer liquid used here is cooled white stillage comes from D-1560 bottom. Recovered alcohol is sent to fusel oil column.

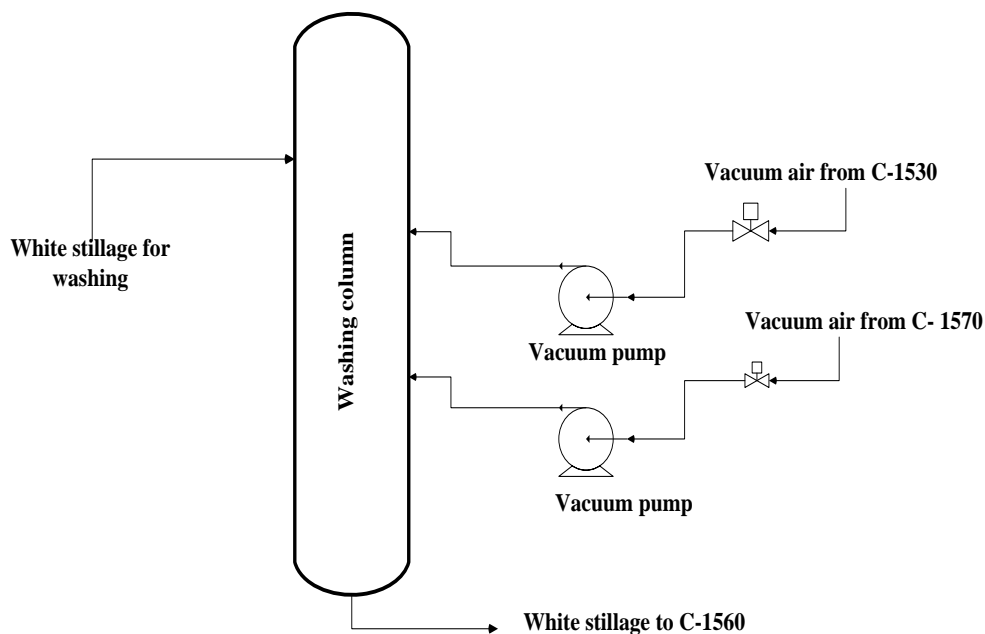


Figure 4. 11 Washing column inputs-outputs flow lines

Standard inputs and expected outputs of MALF distillery section are collected in table (4.4).

Table 4. 4. Company standards of distillery section

Flows	Items	Amount
Inputs	Fermented mash	10,000 kg/hr with minimum ethanol content 8%
	Softened water	1100 kg/hr
	Steam (saturated)	2750 kg/hr at 1 barG
	Pressure	3 barG
	Temperature	144 °C
	Electric energy	85.5 kW
	Cooling water	225 m ³ /hr at 28°C
	Seal water	2.0 m ³ /hr
Out puts	ENA (pure alcohol)	18,000 lt/d with >96.2% alcohol percent
	Denature alcohol	1,200 lt/d with >92% alcohol percent
	Dark stillage/spent wash (vinasse)	From material balance
	White stillage/spent lees	From material balance
	Fusel oil	From material balance

4.3.4. Liquor production section

Raw materials used in alcoholic liquor production of Mekanissa alcohol and liquor factory are pure alcohol, soft water, sugar and essence. There are different liquors according to their alcohol content and colorant as shown in table (4.5) below.

Table 4. 5. Different liquors of MALF

Types of liquors	Concentration of Alcohol (%v/v)
Ouzo	40
Double Ouzo	43
Baro's Dry Gin	40
Fernit	37
Bitter	15
Aperitif	33
Cognac	37
Brandy	40
Coffee	30
Lemon	28
Pineapple	30
Orange	30
Supermint	24
Pernod	45
Vodka	40

Source NALF

4.3.4.1. Inputs used for liquor production

Pure alcohol: - pure alcohol produced from distillery with >96.2% vol. is main raw material of liquor production. Where, soft water used for preparation of liquors is comes from softener.

Syrup preparation: - syrup is prepared from sugar and water for smoothing taste of liquors.

Essence: - as the factory produce different liquors as shown above, it uses different essences.

4.3.4.2. Liquor production process steps and their descriptions

- i. Liquor preparation (Mixing): - Liquor preparation is mixing of pure alcohol and soft water. Then, transferred to filtration after organoleptic tastes are fulfilled. The alcohol water proportion is different as their grade (alcohol concentration) is different.
- ii. Filtration: - After liquor is prepared in the preparation tank, it is filtered by filter paper and goes to aging tank and temporary storage until filled in bottles.
- iii. Bottle washing: - Returned empty bottles collected from customer are still labeled and with their metal closures on the bottle's neck. For reuse, the bottle's label and remaining part of the metal closures must be removed and the bottles are to be thoroughly cleaned. The aim of bottles cleaning is to remove all visible dirt inside and outside of the bottles and also to kill micro-organisms at higher temperature. Cleaning is done by caustic soda at concentration of 1% wt/v. Sodium hydroxide in order to achieve better cleaning. Inspection is applied to cleaned bottles after washer ensuring if they are cleaned or not.
- iv. Filling and capping: - Here prepared liquor is filled in washed bottles and closed up by aluminum closures. Filled bottles are inspected manually (visually by light inspection method) for removing any foreign matters before and after filler.
- v. Labeling: - filled bottles are labeled by automatic machine. After all processes, produced liquors stored in liquor storage.

4.3.5. Utility

This study mainly considered on highly influenced utilities to the production process which are boiler and softener. Hard water is the main source of scale formation in materials. The scale formed in boiler, distillations and condensers influence heat transfer efficiency. So, this study analyzed the hardness of soft water and resulted in chapter five below.

4.4. MALF waste handling practices

The factory is trying to handle wastes in environmental friendly. But, their handling practice and cost of handling is not efficient. Especially resource such as sugar and alcohols are part of wastes which could be converted to product. And for water and waste water drained from the production process, there is no method to reuse or treatment practice for other purpose.

CHAPTER FIVE

5. MATERIAL BALANCE

5.1. Analysis results

To investigate working performance of production process it requires material auditing in every step and section based on laboratory analysis as well as standards.

5.1.1. Raw material analysis

5.1.1.1. Water analysis

Process water analysis: - Hardness of process water was analyzed using titration setup and the average value was 9°F (degree French). And its pH was 7.13.

Softener water analysis: - Hardness of soft water for alcohol production at MALF was analyzed using titration setup and the average value was 6.8°F (degree French). And its pH was 7.13. Water hardness of liquor section soft water was obtained 4.2 °F where its pH was 7.13.

5.1.1.2. Analysis of input molasses

i. Determination of total reducing sugar (TRS) in molasses

Measure 10g of 81.0 Brix molasses in analytical balance. Then prepare 1000ml solution of this 10g molasses by adding distilled water in volumetric flask and mix it. And take 50ml of the above solution by pipette to 100ml volumetric flask. Add 5ml of hydrochloric acid and boil it at 70°C for 20 minute in water bath and cool it. After cooled, add 3-5 drop of phenolphthalein indicator and neutralize the acidic solution by 10% Na(OH) until it becomes pink. Add distilled water to the inverted and neutralized solution till 100ml.

Phenol solution is prepared by Mix 10ml of Fehling solution A (Cu SO₄.5H₂O) and 10ml of Fehling solution B (NaOH) in volumetric flask until copper color. Then add 30ml of distilled water to Fehling solution. And for titration, add 30ml of prepared sample to phenol solution in the Hotplate stirrer and mix until bricks red color. Then add methyl blue indicator to know the reaction end point. Then add measured sample by burette to the gluconic acid until bricks red color. Take the burette reading value which is 10.5ml. So, total volume taken for titration is 40.5ml.

$$\text{TRS} = \frac{\text{Fehling factor} \times \text{invert sugar factor constant} \times \text{diluted sample} \times 2}{\Delta V} = 50.86\% \text{wt.} \quad (5.1)$$

Where, Fehling factor is 1; inverted sugar factor is 0.103; and diluted sample is 100.

ii. Unfermentable sugar content

Measure 20g 81.0 °brix molasses by balance and prepare 125 ml solution by adding distilled water. Add 2g *saccharomyces cerevisiae* yeast and put in 32°C constant temperature water bath for 24 hrs. After fermentation is completed, add 25ml lead acetate (10%) to fermented mash for filter aid. Add distilled water until 250 ml in volumetric flask and mix it for homogeneity. Filter 125ml homogenized sample solution by filter paper (watman no. 9) 9mm diameter. Then add 10ml potassium oxalate to filtered 125ml for de-leading any excess lead. To precipitate the lead oxalate, add distilled water until 250ml then filter by watman no. 5 (9mm diameter) filter paper.

Prepare phenol solution and put in Hotplate stirrer. Add 18ml of watman no. 5 filtered sample to phenol solution in the Hotplate stirrer. Add 3-5 drop of methyl blue indicator to the solution in the Hotplate stirrer. Add measured ml of filtered sample to the solution in the Hotplate stirrer until the blue color sample changed to bricks red color. Then consumed volume to change the color is equal to 50ml by adding the first 18ml and 32ml during titration.

$$\text{Unfermentable sugar} = \frac{5.127}{\Delta V \times F.F \times D.F} = 2.5635\% \text{wt.} \quad (5.2)$$

Where; F.F is Fehling factor, D.F is dilution factor which is 0.04 and 5.127 is invert sugar factor.

iii. Fermentable sugar content

$$\text{Fermentable sugar} = \text{Total reducing sugar} - \text{Unfermentable sugar} = 48.2965\% \text{wt} \quad (5.3)$$

iv. Determination of molasses sludge content

There are different sugar factories in Ethiopia and MALF buy molasses from any of them. Minerals that cause scale in distillation such as calcium, magnesium and different carbonates are different depending soil type of the sugar factory. As in literature discussed calcium content of Wenji sugar factory and Metehara sugar factory is different. Thereby, it is better to take total sludge content of molasses which is obtained by centrifuge separator as shown below.

By measuring 200g 81.0 °brix molasses and preparing 500ml solution which is 40 °brix, 100ml solution was put in centrifuge at 4000 rpm for 15minutes. Obtained sludge content of molasses was 5% out of 100ml and 25% for 500ml solution. So, 81 °brix molasses has 12.5% sludge which should be removed before fermentation.

5.1.2. Yeast propagation (aerobic fermentation) analysis

i. Alcohol content of propagated yeast

Take 50ml of propagated yeast solution and put this solution to laboratory scale distillation (Maligand) to evaporate the alcohol content in the solution. Then compare the result temperature with alcohol content proportion so, the result is 6.0 %v/v.

ii. Population of propagated yeast

Prepare 100ml solution by adding 10ml of propagated yeast to 90ml of distilled water to be 10 dilution factors. Then mix it with magnetic stirrer to homogenize it and put sample of this solution in chamber. The chamber has 0.0025mm^2 area and 0.100mm depth and its chamber factor is 2.5×10^4 per ml. Then chamber is put in optical microscope and count the cells in ten 4 by 4 square of chamber. Obtain number of cells was 462.

$$\text{Cell concentration} \left(\frac{\text{cells}}{\text{ml}} \right) = \text{number of cells in 10 squares} \times \text{chamber factor} \times \text{D.F} \quad (5.4)$$

$$\text{Cell concentration} = 1.155 \times 10^8 \text{ (cells/ml)}$$

iii. Input air analysis

Fermentation section is closed for hygiene purpose and designed air compressed to yeast propagator is atmospheric air. But, by analysis using gas analyzer, oxygen content and carbon dioxide content of input air to yeast propagators is 16.6% and 0.7% respectively. Lower input oxygen and higher carbon dioxide input to yeast propagation decreases efficiency of aerobic and anaerobic fermentation by lowering size and population of yeasts.

iv. Nutrient analysis

The standard volume and concentration of DAP added to propagators is 876.6 lt at 10%. But, by calculation, it is obtained 8.5%. Thereby, yeasts will be sluggish during fermentation.

5.1.3. Fermentation (anaerobic) analysis

i. Alcohol content of fermented mash

Take 50ml of fermented mash solution and put this solution to laboratory scale distillation (Maligand) to evaporate the alcohol content in the solution. So, average result obtained 8.5 %v/v.

ii. Residual sugar content

Take 10ml sample from fermented mash tanker in volumetric flask and prepare 100ml solution for 10% sample solution by adding distilled water. Add 15ml (10%) sample to prepared phenol solution in Hotplate stirrer and wait until color changed from blue to bricks red color. Then, add methyl blue indicator to the solution and titrate by adding measured diluted sample by pipette to the solution in Hotplate stirrer until color changed from blue to bricks red color. Then volume taken to change the color is 32ml and totally consumed fermented mash is 47ml.

$$\text{Therefore, Reducing sugar} = \frac{5.127}{\Delta V \times F.F \times D.F} = 1.0908\% \text{wt.} \quad (5.5)$$

5.1.4. Distillery analysis

Alcohol content of each flow rates and wastes out from distillery are measured to investigate whether the flow rates are similar to standards. And, these values are collected in table (5.4).

5.1.5. Conclusion on test results

Soft water hardness of alcohol and liquor production is hard compare to company standard which is 3.5°F. From the above analysis, total reducing sugar and fermentable sugar content in molasses are good comparing to literature values. But, the unwanted sludge in molasses is high.

Yeast population and alcohol content of yeast propagation tank are out of company standards and this may happen due to less oxygen input air or less nutrient input which are investigated above. Residual sugar in fermentation is higher than company standard value. This may be because of yeast population or effect of fermentation homogeneity. Based on alcohol content of fermented mash and residual sugar value, fermentation efficiency of MALF is less than company standard.

Distillery wastes have higher alcohol content than company standard. Fusel oil is serious odor pollutant to humans in the company and by assessing prevention methods, using it as energy source is obtained better solution than other benefits. Besides tried to burn manually at factory (has good burn ability), its calorific value and density was measured to be 0.829kg/lit and 40.31MJ/kg respectively.

5.2. Material balance

A comparison of alcohol produced and standard design capacity for three consecutive years is presented in table (5.1) below. Where, designed capacity is 6,480,000 litres PA and 432,000 DA

per annum. From table (5.1) below, the highest production of PA and DA in 2010 E.C is 71.37% and 80.9% production efficiency of PA and DA respectively.

Table 5. 1. Alcohol production of MALF in the last three years

	Alcohol production in 2008 E.C		Alcohol production in 2009 E.C		Alcohol production in 2010 E.C	
	PA	DA	PA (96.6)	DA	PA (96.5%)	DA
July	163,180	-	368,337	32,633	238,113	18,057
August	183,542	-	456,073	33,797	477,692	34,774
September	0	-	335,225	30,833	327,785	19,828
October	282,952	18,439	336,931	31,353	215,770	15,592
November	176,857	13,726	392,624	32,294	274,398	20,254
December	372,580	30,734	419,467	32,683	531,163	38,099
January	109,041	8,576	478,053	32,661	529,760	42,318
February	300,637	24,671	362,433	26,553	402,396	29,290
March	417,851	33,697	277,104	19,491	442,739	31,983
April	338,907	32,819	469,811	35,696	482,852	34,285
May	446,477	39,520	253,402	18,222	410,694	30,019
June	445,795	41,977	341,079	23,395	291,497	22,239
Total	3,237,819	244,159	4,490,539	349,611	4,624,859	349,703

Figure (5.1) below indicates, there is scattered monthly alcohol production amounts in the last three years. To identify the causes of less production efficiency and to investigate material loss equipment need to calculate material balance in each section.

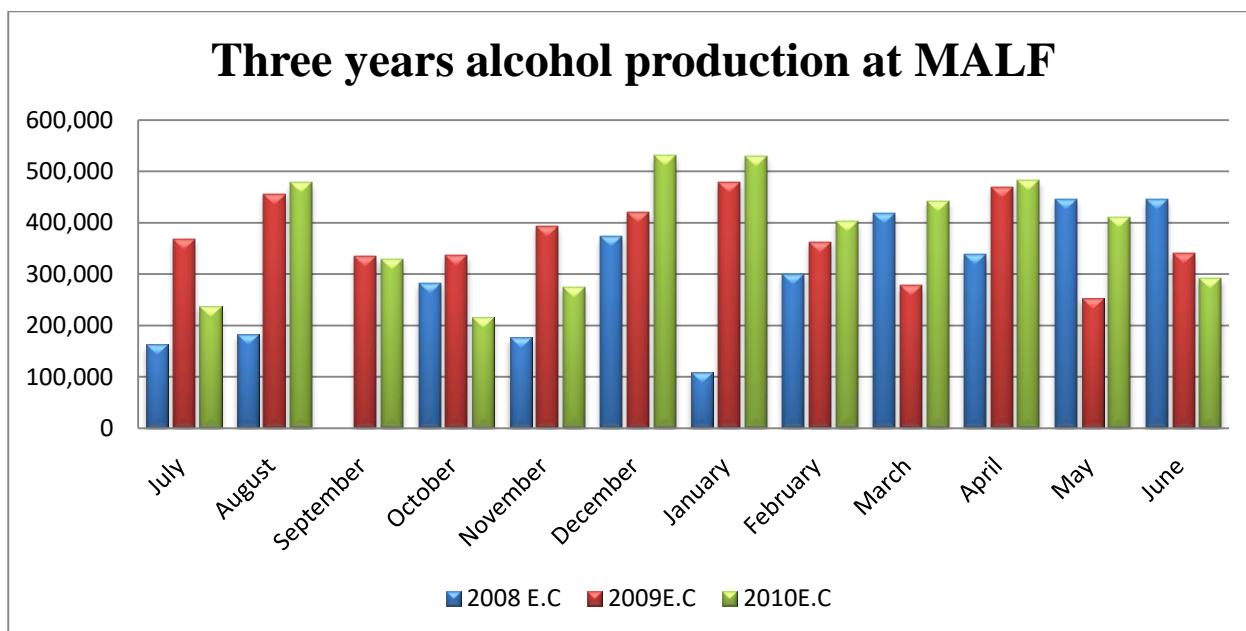


Figure 5. 1. Alcohol productions for three consecutive years

5.2.1. Over all alcohol production efficiency

The main material utilization indicator is input output conversion of resources. The overall alcohol conversion efficiency is listed below in table (5.3) for the last two years. Only over all conversion is considered here, where the fermentation and distillation efficiency is difficult to calculate due to unknown volume of fermented mash was consumed in the fiscal year.

$$\text{over all efficiency} = \frac{\text{produced alcohol amount}}{\text{fermentable sugar input}} \quad (5.6)$$

Actual fermentable sugar of MALF was obtained 48.29% from 50.86% of total reducing sugar and the rest is Unfermentable sugar. Theoretically, conversion of molasses to ethanol and CO₂, based on Guy-lussac theory is 51.14% and 48.86% respectively. So, the expected alcohol and carbon dioxide per one kg of fermentable sugar is 0.2469kg and 0.235 kg respectively.

Alcohol content of technical alcohol consumed at MALF in the fiscal year was varying depends on market available. So, depending on the written data at company logbook, the average grade was 98.4%. The same for pure alcohol and denature alcohol products, their grade is varying through the year. So, the average pure and denature alcohol grade was 96.6% and 92.5% v/v respectively for the year 2009 E.C. And for the year 2010 E.C., the average grade of technical alcohol, pure alcohol and denature alcohol was 96.2%, 96.5% and 92.5% respectively. Conversion efficiency of inputs to product for two consecutive years is calculated in table (5.2) below.

Table 5. 2. Input - output conversion efficiency of MALF in 2009 and 2010 E.C.

Input to output conversion		Units	Year	
			2009 E.C	2010 E.C
Inputs	Molasses	kg	14,006,324	13,291,500.0
	Fermentable sugar	%	48.29	48.29
		kg	6,763,653.86	6,418,465.35
	Expected alcohol from molasses	kg	3,458,932.584	3,282,403.18
	Technical alcohol consumed	kg	1,037,197.004	1,372,931.945
Total absolute alcohol input		kg	4,496,129.588	4,655,335.125
Outputs	Pure alcohol produced	kg	3,444,261.375	3,543,613.214
	Denature alcohol produced	kg	256,771.799	256,839.368
	Absolute alcohol produced	kg	3,701,033.174	3,800,452.582
	Overall efficiency	%	82.32	81.64

Efficiency obtained in table (5.2) above is categorized in yields typical for fermentation designed in 1970s and 1980s based on the fermentation and distillery efficiency listed in table (2.1) above. And, we can conclude that, there was material waste in the fiscal years. Therefore, investigation in each section needs to know where the material is waste.

5.2.2. Material balance on molasses treatment section

Here, there are five drums of which two require steam. In this section there is no generation and consumption of material. Based on figure (4.3) above, the material balance is calculated to be input is equal to output.

5.2.2.1. Material balance on D-1203

Let the recycled sludge from (D-1202) to (D-1203) is doubled of the total unwanted sludge obtained in laboratory to compensate (D-1202) centrifuge mixer efficiency.

$$\text{input materials} = \text{output material}$$

$$\text{water in} + \text{recycled sludge} + \text{steam } X_1 = 4,034 \text{ kg/hr.} \quad (5.7)$$

5.2.2.2. Material balance on D-1204

Based on the analysis investigated, 380 kg/hr of unwanted sludge is obtained in molasses.

$$X_1 = \text{over flow to D - 1201 } (X_2) + \text{unwanted sludge.} \quad (5.8)$$

$$\text{Therefore, } X_2 = 3,654 \text{ kg/hr.}$$

5.2.2.3. Material balance on D-1201

$$\text{input materials} = \text{output material} \quad (5.9)$$

$$\text{Recovered sugar} + \text{molasses} + \text{steam} = \text{output material} = X_3 = 6,944 \frac{\text{kg}}{\text{hr}}$$

5.2.2.4. Material balance on D-1202

Based on the analysis, 760 kg/hr recycled sludge is sent to (D-1203) for sugar recovering.

$$X_3 = \text{over flow to (D - 1205 } (X_4)) + \text{recycled sludge} \quad (5.10)$$

Therefore, $X_4 = 6,184 \text{ kg/hr.}$

5.2.2.5. Material balance on D-1205

The over flow of (D-1202) has around 42 °brix and dilution is important in bringing to 26 °brix

which is comfortable for yeast consumption. Second dilution water is calculated based on input output °brix. And, it is 3,016 kg/hr.

$$X_4 + \text{water} = X_5 = 9,200 \text{ kg/hr.} \quad (5.11)$$

Samples for brix checking were taken every four hours in the molasses treatment section with minimum volume of 350 ml. After checking, simply 2.1 lt of molasses drained to waste with its sugar daily. Therefore, at density of 1.115 kg/lt and 15.8% fermentable sugar, 0.226 litre alcohol is loss per day at maximum achievable fermentation efficiency. If multiplied this by current distillery efficiency, 0.220 lt of absolute alcohol is loss per day.

5.2.3. Material balance on fermentation section

Based on molasses analysis, 9,200 kg/hr molasses is entered to fermentation with 15.8% fermentable sugar content, 26 °brix and 1.115 kg/lt density. The fermentation is batch process and volume of tank is 81.3 m³. Molasses consumed per fermentation tank is 29,944 kg and 14,460 kg of fermentable sugar. From the analysis, residual sugar is 1.0908% wt. where the density of fermented mash is 1.044 kg/lt. Mass of fermented mash at 79.1 m³ volume of fermenter is 82,580.4 kg. Therefore, from total residual sugar balance, 900.79 kg of sugar or 580.18 liters of absolute alcohol is lost every fermented tank. But, if considered only fermentable sugar, alcohol loss per tank is calculated as follows. Unfermentable sugar in 81 °brix molasses is 2.5635% wt and in 10 °brix of fermented mash is 0.3165% wt. Therefore, 0.774% wt of residual sugar is fermentable sugar which could be converted to alcohol. And from mass of fermented mash and fermentable residual sugar loss, 639.44 kg of fermentable sugar or 411.85 lt of absolute alcohol is lost per tank. The factory uses 2.5 tankers per day, thereby 1,029.62 lt of absolute alcohol loss per day in fermentation section. If multiplied this by maximum achievable fermentation efficiency which is 94.6%, 974.03 liters of absolute alcohol is loss per day. If multiplied this by current distillery efficiency, 946.76 lt of absolute alcohol is loss per day.

Based on fermentable sugar (14,460 kg) and maximum achievable fermentation efficiency (94.6%) of the theoretical reaction; 6,683 kg of CO₂ can produce per tank; where 16,709 kg per day is emitted to environment. But, if taken at the current average alcohol content of fermented mash which is 8.5%, alcohol volume per 79.1 m³ tank is 6.72 m³. To get 6.72 m³ alcohol, 10,439.4 kg of sugar is converted to alcohol and CO₂. Related to this, 5,100.7 kg of CO₂ is produced per tank and 12,751.7 kg per day at current fermentation efficiency.

Expected alcohol per tank depending on fermentable sugar in molasses is 9,313 lt and output alcohol of fermented mash is 6,720 lt. Therefore fermentation efficiency is 72.0%.

Samples for brix checking are taken every four hours in the fermentation section with minimum volume of 350ml for each eight tankers. After checking, simply 16.8 lt of molasses is drained to waste with its sugar and alcohols daily. Therefore, at density of 1.115 kg/lt and 15.8% fermentable sugar, 1.8 lt alcohol is loss per day at maximum achievable fermentation efficiency. If multiplied this by current distillery efficiency, 1.75 lt of absolute alcohol is loss per day.

Due to the absence of mixers in fermentation, sludge is settled in bottom of fermenters. Volume of settled sludge is 143 lt per tank and for 2.5 tank per day consumption, 357.5lt of sludge is drained daily with 8.5% alcohol content averagely. Water used to clean fermenters sludge per tank is 0.8m³ and 2m³ per day.

5.2.4. Material balance on distillery

Since it is separation section, input material is equal to outputs. There are six columns in distillery section and all integrated input output flows are presented in table (5.4). Input output of individual column is shown in tables (5.7) to (5.12) where overall material balance is in table (5.6). Alcohol content, temperature, density and pH of each flow meter are measured in the factory laboratory. Each flow rate are compared to standards and presented in table (5.3) below.

Table 5. 3. Distillery section measured flow rates and alcohol contents

S. No.	Flow meter	Name of flow meters	Amount (liter/hr)		Measured parameters			
			Standard	Measured	Alcohol content (%vol.)	Temp (°C)	pH	Density (kg/lt)
Feed	FT-1404	Mash feed line	Variable	8870	9	43	4.9	1.03
1	FI – 1521	C-1520 reflux	107	Closed	-	-	-	-
2	FI – 1522	C-1520 heads(DA)	6	Closed	-	-	-	-
3	FI – 1531	Alcohol from C-1530 to C-1550)	1475	1400	59.17	43.5	4.9	0.8943
4	FI – 1551	C-1550 reflux	1483	1200	57.424	57	4.3	0.9182
5	FI – 1552	From C-1550 reflux to C-1560	105	105	57.424	57	4.3	0.9182
6	FI – 1553	Soft water to C-1550	755	755	0	85.4	7.5	1.0
7	FI – 1554	C-1550 heads(DA)	4	Closed	56.624	57	4.3	-
8	FT-1550	Steam to C-1550 (kg)	899	949	0	154	-	-
9	FI-1550	C-1540 feeding	8167	7900	9.812	98	4.5	0.9854
10	FiFT-1540	C-1550 dilution	5064	5064	0.2	116	4.3	1.0
11	FI – 1541	C-1540 reflux	5078	5000	95.712	59.8	7.2	0.8000
12	FI – 1542	C-1540 heads(DA)	13	15	95.712	59.8	7.2	0.8000
13	FI – 1543	C-1540 LT	88	88	8.112	76	3.9	0.9450
14	FI – 1544	C-1540 HT	5	5	91.312	26.4	7.5	0.8196
15	FI – 1545	C-1540 HHT	5	5	94.112	26.2	7.5	0.8125
16	FT– 1540	Steam to C-1540 (kg)	1519	1619	0	154	-	-
17	FiFT-1546	C-1540 PA to C-1570	Variable	741	96.5	50	-	0.8002
18	FI-1571	C-1570 reflux	1868	-	97.312	30	7.9	0.8025
19	FI-1572	C-1570 heads(DA)	13	11	97.312	30	7.9	0.8025
20	FI-1561	C-1560 reflux	843	-	95.812	23	7.5	0.8051
21	FiFT-1562	From C-1560 to C-1550	variable	32	93.812	55	7	0.8522
22	FI-1563	LT to DS-1560	103	103	37.212	60	4.5	-
23	FI-1564	C-1560 HT	8	11	93.112	30	5.1	0.8549
24	FI-1565	C-1560 HHT	8	8	93.412	24.8	7.3	0.8029
25	FI-1566	DS-1560 dilution From C-1560	164	164	0.2	-	-	1.0
26	FI-1567	C-1560 heads(DA)	5	15	95.812	23	7.5	0.8051
27	FT-1560	Steam to C-1560	265	265	0	154	-	-
28	FI-1580	White stillage to C-1580	401	150	0.2	28	4.3	1.0
29		Pure alcohol		759.17	96.6	-	-	0.8002
30		Denature alcohol		46.54	92.1	-	-	0.8332
31		Dark stillage		See calculation	0	67.5	4.70	1.053
32		White stillage from D-1560		See calculation	0.2	79.5	4.3	1.0
33		White stillage from C-1560		See calculation	0.2	82.2	9.14	1.0

Table (5.5) below shows selected enthalpy from steam table at given temperature and pressure, which are used to know input energy to columns.

Table 5. 4. Enthalpy of columns depending on their pressure and temperature

Parameters	Units	Steam head	C-1510	C-1540	C-1550	C-1560	C-1570
Pressure	bar	5.5	0.48	2.5	1.3	1.2	0.9
Temp	°C	154	80.7	127	101.3	105	76
Specific evaporation enthalpy (h_{fg})	kJ/kg	2,096.63	2,304.98	2,181.2	2,237.6	2,250.4	2,265.7

Table (5.6) below indicates the overall material balance and alcohol balance of distillery section. With a simple input output balance, efficiency of distillery section is determined as 97.2%. This efficiency indicates there is alcohol loss in distillery section. Therefore, investigation in each column is required to know where the material is lost. There is no generation or consumptions in the columns. So, by simple input-output balance, material loss and alcohol loss in each column is investigated in table (5.7) to (5.12) below.

Table 5. 5. Overall material balances

	Items	Mass flow rate (kg/day)	Alcohol percent (%)	Absolute alcohol (kg/day)
Inputs	Fermented mash	219,266.4	6.94	15,217.09
	Soft water	26,400.0	0	
	Steam	67,992.0	0	
outputs	Pure alcohol	14,579.644	95.85	14,791.67
	Denature alcohol	930.684	87.77	
	Dark stillage	189,590.544	0	
	White stillage (alcohol loss)	111,749.872	0.377	
	Distillery efficiency is 97.2%			

Table 5. 6. Material balance on Mash/Degassing/Concentration column (C-1510/20/30)

	Items	Mass flow rate (kg/hr)	Alcohol percent (%)	Absolute alcohol (kg/hr)
Input	Fermented mash	9136.1	6.94	634.05
Output	Distillate to C-1550	1,223.40	51.82	634.05
	Dark stillage	7,912.7	0	
	Loss	0	0	

Table 5. 7. Material balance on Hydro-selection column (C-1550)

	Items	Mass flow rate (kg/hr)	Alcohol percent (%wt.)	Absolute alcohol (kg/hr)
Inputs	Distillate from C-1530	1223.40	51.82	665.908
	FI-FT-1562	27.27	87.42	
	Soft water	755.0	0	
	White stillage	5,064	0.16	
	Steam input	949.0	0	
Outputs	FI-1550 to C-1540	7784.66	7.91	663.644
	FI – 1552	96.41	49.66	
	Material loss	137.6	1.645	2.264

Table 5. 8. Material balance on Rectification(C-1540)

	Items	Mass flow rate (kg/hr)	Alcohol percent (%wt.)	Absolute alcohol (kg/hr)
Inputs	Diluted alcohol from C-1550	7784.66	7.91	615.467
	Steam	1619	0	
Outputs	Pure alcohol to C-1570	602.55	95.85	615.467
	Heads (DA)	12.00	94.994	
	LT to C-1560	83.16	6.82	
	HT to C-1560	4.0980	88.46	
	HHT to C-1560	4.0625	91.96	
	C-1550 dilution white stillage	5,064	0.16	
	White stillage to D-1560	3,690.997	0.16	
	Material loss	0	0	

Table 5. 9 Material balance on Fusel oil column (C-1560)

	Items	Mass flow rate (kg/hr)	Alcohol percent (%)	Absolute alcohol (kg/hr)
Inputs	FI-1552	96.411	49.66	60.971
	LT from C-1540	83.160	6.82	
	HT from C-1540	4.0980	88.46	
	HHT from C-1540	4.0625	91.96	
	DS -1560 Dilutions	745.0	0	
	Vapor from D-1560	896.30	0.16	
	Steam	265	0	
Outputs	FI-FT-1562	27.27	87.42	49.311
	HT to DA storage	9.404	86.45	
	HHT to DA storage	6.423	92.32	
	FI-1567 to DA storage	12.0765	94.49	
	White stillage to CIP (alcohol loss)	2,055.755	0.567	11.660
	Fusel oil waste ranged 30-48 lt/day with average 39lt/day			

Table 5. 10. Material balance on (D-1560)

	Items	Mass flow rate (kg/hr)	Alcohol percent	Absolute alcohol (kg/hr)
Input	White stillage from C-1540	3,690.997	0.16	5.860
Outputs	White stillage to C-1560	896.30	0.16	2.0582
	White stillage to C-1580 and DS-1560	400.0	0.16	
	White stillage to molasses treatment (alcohol loss)	2,394.697	0.16	3.802

Table 5. 11. Material balance on Demethylization column

	Items	Mass flow rate (kg/hr)	Alcohol percent (%)	Absolute alcohol (kg/hr)
Input	FI-FT-1546	616.29	95.85	590.736
Outputs	PA to daily storage	607.465	95.85	590.736
	DA to daily storage	8.8275	96.28	
	Alcohol loss	0	0	0

From individual column material balance, hydroselction column, fusel oil column and (D-1560) which is attached with rectification column are main alcohol wasteful parts of distillery section.

Every four hours, 700ml pure and denature alcohol is taken to check required qualitative and organoleptic tests. And after sampling, this alcohol is going to be reprocessed. Then, 4.2lt alcohol is reprocessed daily. And based on distillery efficiency, 0.1176 litre of alcohol is loss besides other production costs. Average naphtha consumption per liter of alcohol production is 0.35639lt. Then, daily 0.1176lt of alcohol and 0.042lt of fuel is lost due to reprocessing sampled alcohol.

5.2.5. Boiler water balance

Water fed to boiler is 4,500 kg/hr. Applicable steam output is 3,333 kg/hr and condensate drained through steam trap is 15 kg/hr at 61°C.

Input water = steam output + drained condensate + blowdown steam

Then, wasted water through blowdown is 1,152 kg/hr.

5.2.6. Water balance

Process water and cooling water consumptions of the alcohol production at night is 9,820 kg/hr and 2,325 kg/hr respectively. And, at day time is 13,673 kg/hr and 2,620 kg/hr respectively. So,

the average process water and cooling water consumption is 11,747 kg/hr and 2,472.5 kg/hr respectively. Water balance is calculated by input output balance.

Seal water sent to waste measured 900 kg/hr (reducing from 1,423 kg/hr by valve adjusting) at molasses treatment and 1,250 kg/hr at fermentation; totally 2,150 kg/hr (reducing from 2,670 kg/hr by valve adjusting).

5.2.6.1. Cooling water balance

Average cooling water consumed from cooling tower is 2,472.5 kg/hr which is evaporated by cooling water fans. When there is power interruption, much water is drained to waste and then required water make up to replace waste water. and when the level of cooling water is decreased, cooling efficiency in heat exchangers is reduce and power loading of cooling fans is increased. Thereby, electric energy consumption is increase. So, needs level controller in cooling tower.

5.2.6.2. Process water balance

Consumed water from process water storage tank is equal to water used by utilities. And, Consumed water from process water storage tank is equal to the summation of water consumed for; boiler, distillery, cooling tower, molasses treatment, seal waste water and other wastes. So, undetected other waste water is 12.5 kg/hr. From over all alcohol material balance, 776.22lt/hr is produced. Therefore, 15.13lt of water is used to produce one liter of alcohol.

5.2.7. Material balance on liquor section

Liquor is prepared by adding pure alcohol and soft water. There is no alcohol loss in this section except the insignificant loss due to mixing.. Filler machine is used to fill liquor to bottles. So, there may be liquor losses in this step. After capping the filled bottles, transferred to labeling and packing steps. Here, there might be breakage of bottle and as consequence liquor is lost. Table (5.13) below indicates, the balance of input alcohol to output liquors where the loss is concluded averagely.

Table 5. 12. Over all input-output material balance in liquor section

Months	Liquor produced and consumed raw materials in 2010 E.C.											Total balance	
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May		Jun
Absolute alcohol taken (kg)	266,917.4	280,432.9	242,122.4	167,590.4	191,751.0	315,085.2	250,522.7	253,755.6	225,978.6	227,225.0	285,796.3	343,617.8	3,050,795
Outputs (bottle)													
Gin 890ml	711,075	530,640	468,435	546,555	258,123	746,640	648,582	345,954	36	259,788	520,296	596,184	5,703,158
Gin 1000ml	-	-	-	-	173,004	153,432	55,128	278,403	507,420	250,074	229,380	534,081	2,180,922
Gin 750ml	-	-	-	-	-	-	768	-	-	-	-	-	768
Ouzo 890ml	232,485	264,720	356,145	55,680	133,962	198,519	113,349	239,868	3,645	38,553	120,687	28,164	1,658,754
Ouzo 1000ml	-	-	-	-	65,634	-	56,226	90	173,304	156,381	72,453	-	524,088
Double ouzo 750ml	-	29,445	-	-	-	-	1,296	-	-	-	-	-	30,741
Ouzo 750ml	-	-	-	-	1,752	-	4,449	2,832	-	-	-	-	9,033
Cognac 890ml	-	34,920	34,200	23,070	17,565	34,935	-	23,619	23,400	-	53,934	22,770	268,413
Supermint 890ml	-	156,675	44,865	-	-	-	-	-	-	-	-	-	201,540
Fernit 890ml	-	23,340	-	-	-	-	-	-	-	-	-	-	23,340

Lemon 890ml	-	50,235	7,875	7,635	-	-	-	-	-	-	-	65,745	
Aperitif 890ml	-	-	-	-	-	-	26,346	-	-	-	-	26,346	
Vodka 750ml	-	-	-	-	-	-	-	-	38,895	-	-	38,895	
Converted absolute alcohol (kg)	266,710.5	283,809.9	251,188.4	177,772.9	191,629.7	325,026.7	258,454.9	260,890.3	223,356.7	222,685.2	291,146.8	352,541.1	3,105,211
Absolute alcohol lost (kg)	206.95	(-3,671.04)	(-9,066.0)	(-10,182.45)	121.31	(-9,941.47)	(-7,932.17)	(-7,134.67)	2,622.0	4,539.84	(-5,350.49)	(-8,923.29)	(-54,712.11)
Total broken bottle	4,569	7,607	6,570	4,176	5,359	7,753	6,013	5,047	4,991	4,446	5,928	8,532	70,991
Loss bottles after filler	267	416	506	385	350	313	297	165	285	334	699	945	4,962
Known loss (birr)	>142,190.48	>161,886.00	>148,620.00	>98,268.00	>143,212.01	>158,334.00	>126,054.00	>100,746.00	>663,499.85	>1,063,722.4	>148,644.00	>210,276.00	>3,165,452.7

Cost of liquor and bottle of liquor in the fiscal year is 60 and 78 birr respectively. Monthly alcohol losses normally are liquors because all inputs are added in liquor preparation and are considered as liquor. Mostly company liquors are 890ml bottle volume and 15-43% alcohol content where the calculation for lost bottles after filler is done by 40%. Therefore, the above table is calculated according to these values. From total alcohol and bottle balance in liquor section; 8,792.92 birr/day is lost averagely. Some input-output alcohol balance of months resulted negative as seen in table (5.13). And this indicates alcohol content of liquor or volume of liquor is not controlled correctly during production process.

5.3. Wastes test results

Table 5. 13. Flow rate and laboratory test results of wastes

Parameters	Dark stillage	Whit stillage
Flow rate (lt/hr)	7,502	2,938.45
Color	dark brown	White
Lt of waste per Lt of alcohol	9.65	3.79
COD (mg/l)	121,250	1150
BOD (mg/l)	10,090	-
pH	4.7	4.5
Temperature (°C)	67.5	65
Conductivity (μ^s)	68,300	372
TDS (mg/l)	16,000	195
TSS (mg/l)	11,325	2
Total hardness (mg/l)	18,000	90

Wastes are pollutant depending on the literature value of wastes to drain. This thesis proved that, waste of the factory must be treated before drained to environment. Due to its integration waste drainage per liter of alcohol product is good compared to literature value. Test result of fusel oil and collecting method is represented in table (5.15) and figure (5.2) respectively.

Table 5. 14. Laboratory test results of naphtha and fusel oil

Tests	Naphtha	Fusel oil	1:1 ratio of naphtha and fusel oil
GCV(MJ/kg)	46.136	40.31	41.61
Density (kg/l)	0.818	0.829	0.821



Figure 5. 2. Fusel oil sample

CHAPTER SIX

6. ENERGY AUDIT

Energy audit classified to preliminary energy audit and detailed energy audit according to type and function of factory, depth of audit, potential and magnitude of cost reduction (ABIYE, 2011) (Tarun B Patel, 2015).

6.1. Preliminary energy audit

Preliminary energy audit is an overview to determine the energy consumption of a production process. And this audit includes; energy bill analysis, overall inspections, interviews, identifications of ECOs, saving scope estimation, setting a reference point and select areas for detailed energy audit.

6.1.1. Energy bill analysis

6.1.1.1. Introduction

Energy bill analysis is required to investigate whether the factory needs an energy audit or not; based on past recorded consumptions and production data. So, these recorded consumed energy data were compared with company standard energy data that used to produce a unit product.

Fuel consumption of MALF at the fiscal year is collected from fuel consumption log book and its cost from factory finances department.

6.1.1.2. Standard energy consumption per unit product

MALF is the updated design of alcohol and liquor factory which is material and energy are integrated. So, it is better to compare energy consumption with company standards. Standard thermal and electrical energy consumptions are given in company process descriptions. To assure the standards given at paper are correct, individual thermal energy and electric energy consumptions are investigated through all sections.

Thermal energy consumption in distillery section according to standard given is 2,750 kg steam per hr and investigated in material balance section is given as 2,833 kg steam per hr. Designed total alcohol production per day is 19,200 litres. And maximum thermal energy consumption in distillery is 3.5 kg per unit litre of alcohol. Molasses treatment thermal energy consumption is 500 kg/hr. Therefore, maximum total steam energy consumption per litre of alcohol is calculated

in equation (6.1) below.

$$\frac{\text{Thermal energy}}{\text{litre of alcohol}} = \frac{\text{maximum kg of steam used}}{\text{litre of alcohol}} \times \text{specific enthalpy of saturated steam} \quad (6.1)$$

Specific evaporation enthalpy of saturated steam is 2,096.63kJ/kg from table (5.5) above. So, maximum thermal energy consumption per liter of total alcohol is 8,648.60 kJ.

Electrical energy consumptions are investigated for all sections depending on their given nameplate. Designed electric energy consumptions for all motors are recorded and presented in appendix (B). The total kW motors may consumed in production process as designed is 525.68 kW. But fermentation mixers are not functional, recovery mixers and pumps of molasses treatment are not functional, molasses treatment blower and one of the yeast propagation blowers are not functional. Working hour of pumps and mixers are ranging from less than half an hour to 24 hours. Maximum total kWh of motors is 7,716.537kWh. And, there are 105 in numbers 36W double fluorescent lamp for lighting in the factory and 69 of them are working. Then the total kWh consumed by fluorescent lamp is 49.680 kWh. Therefore, the standard kWh of electric energy used to produce a liter of alcohol in the fiscal year was 7,766.217kWh. Thereby, total electric energy consumption per day in the fiscal year was calculated in equation (6.2) below.

$$\text{Electric energy} = \text{maximum kWh} \times \frac{3600\text{sec}}{\text{hr}} = 27,958,381.2\text{kJ} \quad (6.2)$$

By dividing daily kJ of electric energy to daily alcohol production, standard electric energy intensity is 1,456.17 kJ/l of alcohol.

6.1.1.3. Monthly energy cost of MALF in the fiscal year

The price of fuel consumed in the fiscal year is taken averagely as 13.585 birr/liter for furnace oil and 16.5875 birr/liter for naphtha oil according to price of Ethiopian petroleum agency. The specific gravity and the gross calorific value (GCV) of furnace oil are 0.991 kg/l and 41.84 MJ/kg respectively. And for naphtha oil, is 0.818kg/l and 46.136 MJ/kg (ASHRAE, 2018).

Billing for electricity is varying according to voltage consumption and number of phases used in the factory. The factory use three phases induction motor and 380 voltages line, so according to Ethiopia Electric Power Corporation the tariff is 0.5778 birr/kWh flat rates. Monthly furnace oil, naphtha and electric cost are given by equation (6.3), (6.4) and (6.5) respectively.

The consumption of furnace oil, naphtha and electric city is given at Appendix A.

$$MFC = \frac{13.585 \text{ Birr}}{\text{litre}} \times \text{monthly furnace used in litre} \quad (6.3)$$

Where, MFC is Monthly furnace oil cost in (birr/month)

$$MNC = \frac{16.5875 \text{ Birr}}{\text{litre}} \times \text{monthly naphtha used in litre} \quad (6.4)$$

Where, MNC is Monthly naphtha cost in (birr/month)

$$MEC = \frac{0.5778 \text{ Birr}}{\text{kWh}} \times \text{monthly Electric used in kWh} \quad (6.5)$$

Where, MEC is Monthly electric cost in (birr/month)

Table 6. 1. Mekanissa alcohol factory energy bill analysis of year 2010 E.C

Months in fiscal year	Furnace oil cost (birr)	Naphtha cost (birr)	Total fuel cost (birr)	Electric cost (birr)	Total energy cost (birr)
July	598,419.25	983,539.23	1,581,958.48	9,629.284	1,591,587.76
August	1,855,683.83	915,630.0	2,771,313.83	119,150.38	2,890,464.21
September	1,434,209.21	495,850.14	1,930,059.35	87,771.64	2,017,830.98
October	855,557.49	238,860.0	1,094,417.49	91,753.98	1,186,171.47
November	1,162,020.15	99,525.0	1,261,545.15	91,940.61	1,353,485.76
December	2,482,713.09	45,317.05	2,528,030.14	52,960.6	2,580,990.74
January	2,035,589.99	457,815.0	2,493,404.99	77,865.95	2,571,270.93
February	1,610,270.81	258,765.0	1,869,035.81	107,648.24	1,976,684.05
March	1,432,742.03	1,020,106.37	2,452,848.40	85,039.24	2,537,887.64
April	1,512,866.36	1,085,237.19	2,598,103.55	73,609.62	2,671,713.17
May	612,588.41	1,695,176.15	2,307,764.56	120,356.29	2,428,120.85
June	-	2,035,866.81	2,035,866.81	118,209.46	2,154,076.27
Total	15,592,660.62	9,331,687.94	24,924,348.56	1,035,935.29	25,960,283.85

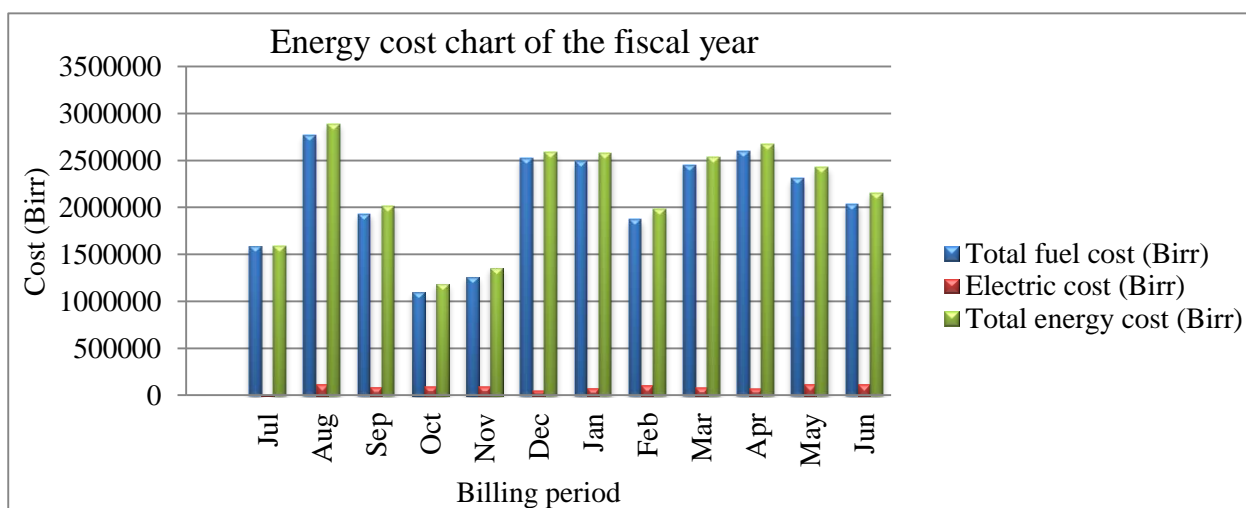


Figure 6. 1. Fuel and electric cost of MALF

Table (6.1) and figure (6.1) above indicates, energy cost of MALF is undulation across the month and this is clue to understand less energy utilization efficiency.

6.1.1.4. MALF monthly energy intensity

Monthly energy intensity is defined as required energy to produce a unit product. Monthly fuel and electricity energy intensity is given below by equation (6.8) and (6.9) respectively. Since the gross calorific value and density of furnace and naphtha is different, their energy supply is also different. Therefore, first calculate individual monthly energy using equation (6.6) and (6.7) below and use the sum of them as energy used per liter of alcohol. Monthly liters of furnace, liters of naphtha used and liters of alcohol produced are written in appendix (A).

$$\text{MFE} = \text{GCV}(\text{KJ}/\text{kg}) \times \rho(\text{kg}/\text{lt}) \times \text{furnace used}(\text{litres}) \quad (6.6)$$

$$\text{MNE} = \text{GCV} \times \rho(\text{kg}/\text{lt}) \times \text{Naphtha used}(\text{litres}) \quad (6.7)$$

MNE = monthly naphtha energy, ρ = density of naphtha and GCV is naphtha gross calorific.

$$\text{MFEI} = \frac{(\text{MFE} + \text{MNE})(\text{KJ})}{\text{Monthly alcohol produced (litre)}} \quad (6.8)$$

$$\text{MEEI} = \frac{\text{Monthly Electric Energy (KJ)}}{\text{Monthly alcohol produced (litre)}} \quad (6.9)$$

Monthly energy intensity of MALF is collected in table (6.2) below.

Table 6. 2. Monthly MALF fuel and electric energy intensity

Billing period	Furnace Energy (kJ)	Naphtha Energy (kJ)	Total fuel Energy (kJ)	Fuel Energy Intensity (kJ/Litre)	Electric Energy Intensity (kJ/Litre)
July	1,826,464,532.00	2,077,299,308.00	3,903,763,840.00	16,394.58	249.159
August	5,663,822,977.12	1,933,870,573.44	7,597,693,550.56	15,905.01	1,525.33
September	4,377,419,751.12	1,047,267,990.07	5,424,687,741.19	16,549.53	1,629.85
October	2,611,288,670.66	504,487,975.68	3,115,776,646.34	14,440.27	2,589.42
November	3,546,658,267.28	210,203,323.2	3,756,861,590.48	13,691.29	2,046.66
December	7,577,609,513.76	95,712,579.83	7,673,322,093.59	14,446.27	601.85
January	6,212,923,313.04	966,935,286.72	7,179,858,599.76	13,553.04	894.29
February	4,914,785,933.52	546,528,640.32	5,461,314,573.84	13,571.99	1,635.40
March	4,372,941,699.6	2,154,531,511.97	6,527,473,211.57	14,743.39	1,167.64
April	4,617,493,068.72	2,292,092,070.06	6,909,585,138.78	14,309.94	927.49
May	1,869,710,899.92	3,580,323,136.29	5,450,034,036.21	13,270.30	1,788.19
June	0	4,299,884,145.49	4,299,884,145.49	14,751.04	2,524.35
	Average energy intensity			14,635.552	1,575.50

Figure (6.2) and (6.3) below indicates fuel and electric energy intensity of MALF.

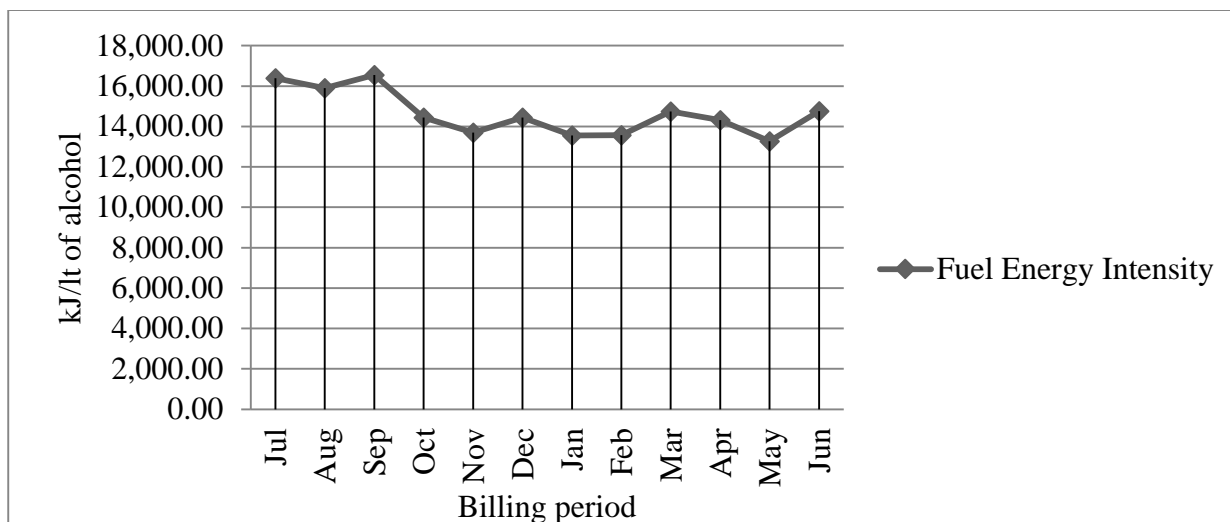


Figure 6. 2. Fuel energy intensity of MALF

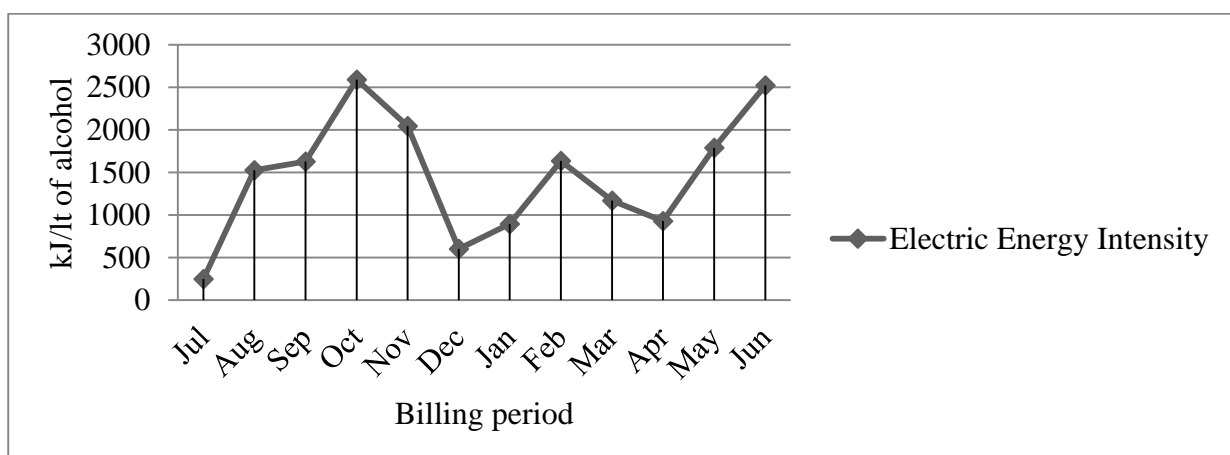


Figure 6. 3. Electric energy intensity of MALF

6.1.1.5. MALF energy utilization analysis

As seen in figure (6.2) above, fuel consumption practice is slightly smooth as compared with electric consumption. The higher pick of fuel energy intensity is in September and lower in May. This indicates at higher molasses input or higher furnace used than naphtha, fuel energy intensity is increased. The energy intensity difference between the higher and lower intensities is 3,297.2kJ/lt. During first months of budget year, the graph shows that the factory consume more energy than the last months. The cause may be due to careless energy utilization and lower production.

Same in the figure (6.3) above, the higher pick of electric energy intensity is at October where,

alcohol production is lower of all the months and the lower pick is July (may wrong data recording) and then December where alcohol production is higher than all months. This indicates at lower production consumes more electric than at higher production. The difference between the higher and lower energy intensity is 1,987.57kJ/lit.

6.1.1.6. Comparison of actual and standard energy intensity of MALF

It can be seen that there is a significant difference between the energy intensity of MALF as compared to its standards. Monthly average fuel energy intensity of MALF is 14,635.552 kJ/lit. And the standard energy intensity is 8,648.60kJ/lit. Hence, the difference fuel energy intensity between actual and standard is 5,986.952kJ/lit.

Same for electric energy intensity, the lower data obtained at July may be wrong so use the second lower electric energy intensity then monthly average electric energy intensity of eleven months is 1,575.50kJ/lit. The standard electric energy intensity of MALF is 1,456.17kJ/lit. So, the difference between actual and standard electric energy intensity is 119.334kJ/lit.

6.1.1.7. MALF cost comparison with standards

The following data helps to get difference in annual energy cost due to lower efficiency of fuel and electricity energy consumption.

- MALF alcohol production in the fiscal year = 4,624,859lt of alcohol (Table 5.1),
- Average cost of furnace oil and naphtha is 13.585 birr/lit and 16.5875birr/lit respectively.
- Gross calorific value of furnace oil and naphtha is 41.84MJ/kg 46.136MJ/kg respectively.
- Difference in fuel energy intensity = 5,986.952kJ/lit of alcohol,
- Cost of electricity = 0.5778birr /kWh flat rate,
- Difference in electricity energy intensity = 119.334 kJ/lit = 0.0331kWh/lit of alcohol.

Difference in annual energy cost due to lower efficiency of fuel and electricity are obtained using Equation (6.10) and (6.13) respectively.

$$AC_{\text{fuel}} = DEI_{\text{fuel}} \times \frac{\text{FAPC} \times \text{CF}}{\text{GCV}} \quad (6.10)$$

Where; AC_{fuel} is difference in annual cost due to lower fuel energy intensity; DEI_{Fuel} is difference of fuel energy intensity; FAPC is factory annual production capacity; CF is cost of fuel (birr/lit) and GCV is Gross calorific value of fuel oil (kJ/lit).

The factory use furnace and naphtha oils. Annual alcohol production using furnace and naphtha

are shown separately in appendix (C). Cost and GCV per litre of furnace and naphtha is different. So, let $Z = \frac{FAP \times CF}{GCV}$ to get difference in annual cost due to lower fuel energy intensity of furnace oil and naphtha individually. And “Z” is calculated in equation (6.11) and (6.12) below.

$$Z_{\text{furnace}} = \frac{FAP_{\text{furnace}} \times CF}{GCV_{\text{furnace}}} \quad (6.11)$$

Where: FAP_{furnace} is annual alcohol production using furnace; CF_{furnace} is cost of furnace (birr/lt); and GCV is Gross calorific value of furnace oil (kJ/lt).

$$Z_{\text{furnace}} = \frac{3,167,383.0 \frac{\text{lt alcohol}}{\text{yr}} \times 13.585 \frac{\text{birr}}{\text{lt of furnace}}}{41,840 \frac{\text{kJ}}{\text{lt of furnace}}} = 1,028.42 \text{ lt.} \frac{\text{birr}}{\text{kJ.yr}} .$$

$$Z_{\text{naphtha}} = \frac{FAP_{\text{naphtha}} \times CN}{GCV_{\text{naphtha}}} \quad (6.12)$$

FAP_{naphtha} is annual alcohol production using naphtha; CN_{naphtha} is cost of naphtha (birr/lt) and GCV is Gross calorific value of naphtha (kJ/lt).

$$Z_{\text{naphtha}} = \frac{1,457,476.0 \times 16.5875}{46,136} = 524.01 \text{ lt.} \frac{\text{birr}}{\text{kJ.yr}} .$$

By adding equation (6.11) and (6.12), substitute to equation (6.10). Therefore, $Z_{\text{fuel}} = 1,552.44 \text{ lt. of alcohol.} \frac{\text{Birr}}{\text{kJ.yr}}$.

$$AC_{\text{fuel}} = DEI_{\text{fuel}} \times \frac{FAP \times CF}{GCV} = DEI_{\text{fuel}} \times Z_{\text{fuel}} = 9,294,344.37 \frac{\text{Birr}}{\text{yr}}$$

$$AC_{\text{electric}} = DEI_{\text{electric}} \times FAP \times CE \quad (6.13)$$

Where; AC_{electric} is difference in annual cost due to lower electric energy intensity; DEI_{electric} is difference of electric energy intensity (kWh); FAPC is factory annual production capacity and CE is cost of electric (birr/kWh). Then, AC_{electric} is equal to 88,580.65 birr/yr. Total annual loss due to inefficient energy utilization is then 9,382,925.021 birr/yr as given by equation (6.14).

$$AC_{\text{total}} = AC_{\text{electric}} + AC_{\text{fuel}} \quad (6.14)$$

6.1.1.8. Concluding on energy utilization efficiency

Based on the above data, the factory lost 9,382,925.021 birr due to less energy utilization efficiency in the fiscal year. So, the factory requires total energy audit.

6.1.2. MALF production process inspection and identifications of ECOs

6.1.2.1. Introduction

Thermal and electrical energy audit of the factory is conducted through inspection of boiler section operational system, steam distribution lines to molasses treatment and distillery sections. Electric supply for motors of pumps, compressed air distribution systems, lighting and production process systems are conducted through visual inspection, document reviewing and interview with factory employees to identify energy conservation opportunities (ECOs). The following production processes are selected for inspection and audit investigations.

6.1.2.2. MALF alcohol production process inspections

Distillation and molasses treatment sections are the most energy consuming operations in the factory. Both sections consume thermal and electrical energy. Electric energy is mainly used to drive motors of pumps, mixers, air compressor and fans.



Figure 6. 4. Factory molasses treatment (a) and distillery columns (b)

From the assessments, the following energy conservation opportunities are obtained.

6.1.2.2.1. ECOs identified in distillery and molasses treatment sections

- i. Scheduled cleaning and maintenance of equipment,
- ii. Controlling frequent production interruptions due to power on/off,
- iii. Recycle steam condensates from steam trap,
- iv. Energy recover from large quantity of effluent 67 °C Temperature which is drained to waste,
- v. Insulation to some parts of steam lines and heat exchangers which are not insulated,

vi. Integrations on input output production processes.

“i-iii” ECOs are simple and can handle with low or no cost using factory employee through scheduled program. Whereas “iv”, “v” and “vi” ECOs require further data collection.

6.1.2.3. Inspection of boiler section and steam distribution lines

MALF boiler is three- pass fire tube an Italian designed boiler. Boiler is used to generate steam using fuel and soft water inputs. The soft water and fuel inputs are controlled by automatic controllers. Outlet pressure of steam from boiler is controlled by manual valves with the help of installed steam pressure gauges. Fuels used in the factory are furnace oil and naphtha oil interchangeably. Steam is distributed through pipes installed to all steam required systems. And steam trap condensates of these sections are drained to waste. Inspection of boiler and steam distribution lines is conducted using visual inspection common sense and interview with factory workers to get the following energy conservation opportunities.

6.1.2.3.1. ECOs identified in boiler section and steam distribution lines

Energy recovery opportunities in boiler and steam distribution lines are related to combustion, heat transfer and avoidable losses. From the investigations the following ECOs are obtained.

- i. Insulation to some opened parts of steam lines,
- ii. Having softened boiler input water,
- iii. Periodic water side boiler de-scaling ,
- iv. Reuse condensates of steam traps,
- v. Periodic soot removing from boiler,
- vi. Install economizer with boiler,
- vii. Input-output integration to recover energy.

ECOs listed from “i-v” above are simple to implement by scheduled maintenance program and controlling input standards of the factory with no or low cost. “vi” and “vii” ECOs need further data collection and conducting detail investigation.

The figure (6.4) below shows, scale formed in boiler fire tube as a consequence of poor cleaning and hard input water which makes less energy utilization.

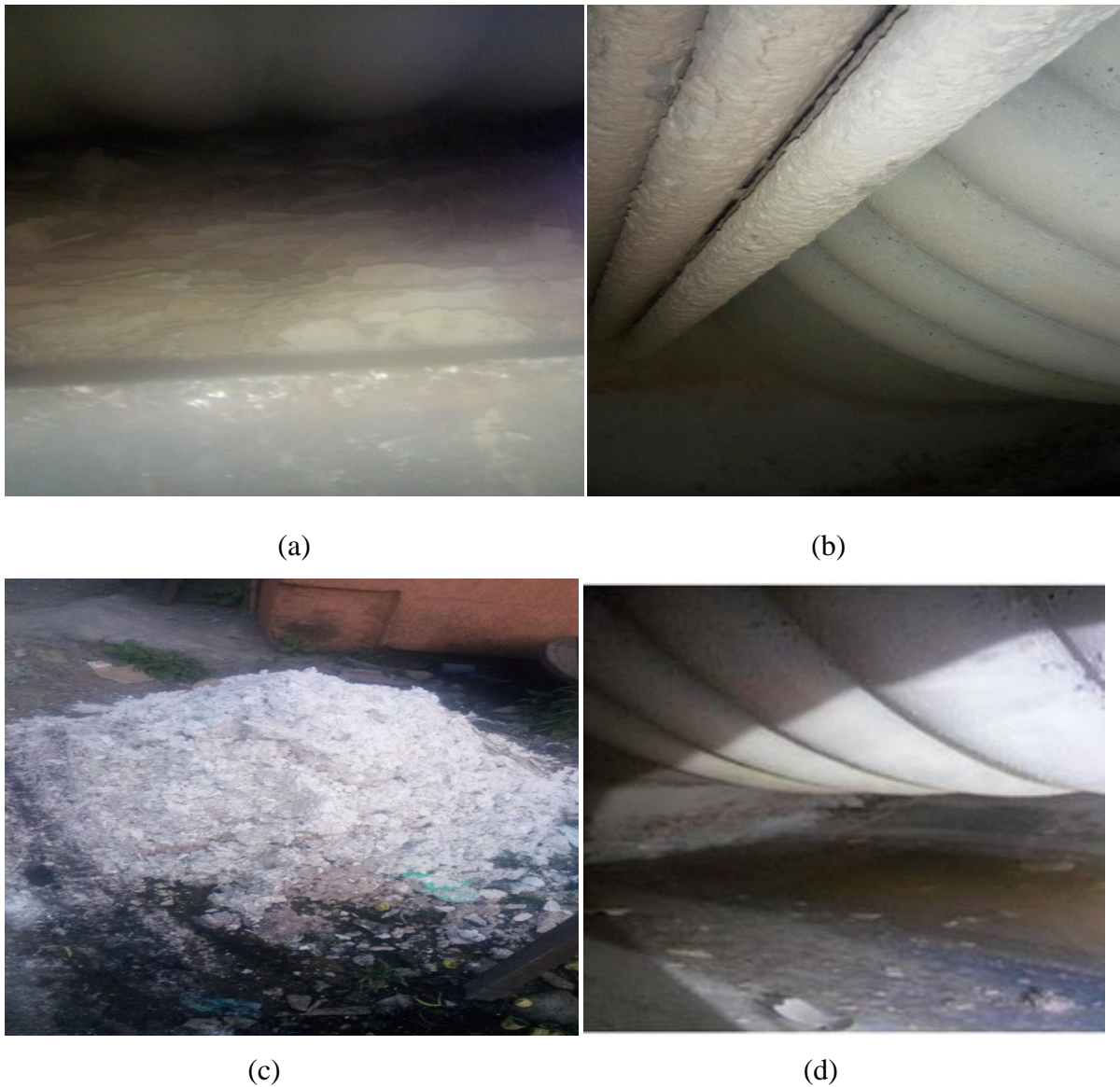


Figure 6. 5. Boiler image before and after cleaning

Figure (a) and (b) are boiler water side tubes before cleaning. Where; (c) is carbonates (mostly calcium carbonate) cleaned from boiler fire tube surface. And picture (d) is cleaned boiler surface.

6.1.2.4. MALF motors inspection

There are many three phase induction motors in the factory used for the supply of power to move pumps, mixers, fans and air compressors. Inspection of the motor system is conducted using visual inspection, common sense and interview made with shift electricians and electrical engineer of the factory. During inspection, pumps are seen exposed to many dirty as shown

below in figure (6.6).



Figure 6. 6. Exposed pumps

6.1.2.4.1. Identified ECOs in factory motors

- i.** Caring the exposed electric motors to dirt and water entering to them during cleaning,
- ii.** Conduct and improve efficiency of less efficient motors.

ECO number one is simple to implement by assigned person with no or low cost. But, ECO number two requires further data investigation.

6.1.2.5. Compressed air distribution system inspection

The factory used air-cooled, screw type single stage compressor. The application of compressor is used to open pneumatic ball valves and control valves. Unless dusts collected on some parts of pneumatic valves and water entering during cleaning that can be handled simply by authorized employee, there is no ECOs that requires detailed audit in this system.

6.1.2.6. Selected MALF major energy consuming sections

From preliminary energy audit above, major thermal energy consuming systems of MALF are molasses treatment section, distillery section and boiler section. And their detail energy audit can be performed by assessment of their energy performance.

6.2. Detailed energy audit

6.2.1. Instruments used to conduct detail energy audit

Instruments used to conduct energy audit are; installed flow meters, thermocouple, thermometer, tap rule, temperature and pressure gages, temperature and pressure transmitters, density meter, alcohol meter, balance and portable combustion analyzer (E6000-5DS). And the collection method is by direct measuring, recording from factory log book and factory standards; interview with employee of the factory.

6.2.2. Molasses treatment section detailed energy audit

Steam is direct injected to (D-1201) and (D-1203). Molasses input to (D-1201) is at 25°C. To reduce water consumption, white stillage is used 50% of total water input for molasses dilution.

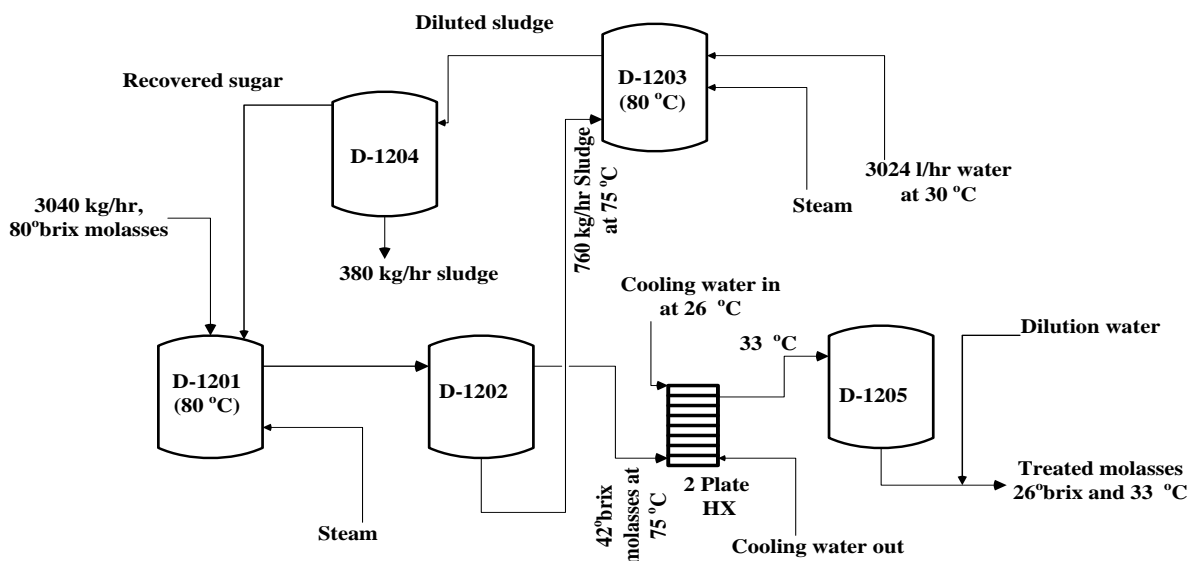


Figure 6. 7 Molasses treatment process flow diagram

Depending on figure (6.7) above, energy balance of this section is performed below.

i. Energy balance on D-1203

Inside temperature of the insulated drum is controlled at 80°C by injecting direct steam.

$$\text{input energy} = \text{output energy}$$

$$\text{Process water energy } (Q_1) + \text{white stillage energy } (Q_2) + \text{recycled sludge energy } (Q_3) + \text{steam energy } (Q_4) = \text{output energy } (Q_5) \quad (6.15)$$

Output mass of (D-1203) from material balance is 4,034 kg/hr. Let temperature at the output of

the drum is equal to inside solution temperature which is 80°C. And specific heat capacity of molasses is given below (Rein P. , 2007).

$$C_{p_m} = 4.187(1 - 0.007 \times B) \quad (6.16)$$

Where; C_{p_m} = Specific heat capacity of the molasses in KJ/kg°C, B = Brix % of molasses.

$Q_1 = M \times C_{p_w} \times \Delta T = 1,512 \frac{\text{kg}}{\text{hr}} \times \frac{4.18 \text{kJ}}{\text{Kg}^\circ\text{C}} \times (30 - 25)^\circ\text{C} = 8.778 \text{ kW}$. Where; M is mass flow rate of water, C_{p_w} is specific heat capacity of water and ΔT is change of temperature.

$Q_2 = M \times C_{p_{WS}} \times \Delta T = 1,512 \frac{\text{kg}}{\text{hr}} \times \frac{4.18 \text{kJ}}{\text{Kg}^\circ\text{C}} \times (65 - 25)^\circ\text{C} = 70.224 \text{ kW}$. Where; M is mass flow rate, $C_{p_{WS}}$ is white stillage specific heat capacity and ΔT is temperature change.

$Q_3 = M \times C_{p_m} \times \Delta T = 760 \frac{\text{kg}}{\text{hr}} \times \frac{3.015 \text{kJ}}{\text{Kg}^\circ\text{C}} \times (75 - 25)^\circ\text{C} = 31.825 \text{ kW}$. Where; M is molasses mass flow rate, C_{p_m} is molasses specific heat capacity at 40°brix and ΔT is temperature change.

$Q_5 = M \times C_{p_r} \times \Delta T = 4,034 \frac{\text{kg}}{\text{hr}} \times \frac{3.953 \text{kJ}}{\text{Kg}^\circ\text{C}} \times (80 - 25)^\circ\text{C} = 243.596 \text{ kW}$. Where; M is mass flow rate of diluted molasses, C_{p_r} is specific heat capacity of diluted recovered sugar which is 8°brix and ΔT is change of temperature. By calculating C_p from equation (6.16) and substituting Q_1 , Q_2 , Q_3 and Q_5 to equation (6.15), steam used is obtained.

$Q_4 = Q_5 - Q_1 - Q_2 - Q_3 = (243.535 - 8.778 - 31.825 - 70.224) \text{ kW} = 132.708 \text{ kW}$. And, this is steam injected directly to (D-1203).

ii. Energy balance on D-1204

There is one input and two outputs in (D-1204). From material balance, 4,034kg/hr material is entered and 380 kg/hr sludge drained to waste. Therefore, energy balance is calculated as follow.

input energy (Q_6) = output energy to [D - 1201 (Q_7)] + output energy to waste (Q_8) (6.17)

$Q_6 = M \times C_{p_r} \times \Delta T = 4,034 \frac{\text{kg}}{\text{hr}} \times \frac{3.953 \text{kJ}}{\text{Kg}^\circ\text{C}} \times (75 - 25)^\circ\text{C} = 221.478 \text{ kW}$. Where; M is mass flow rate of recovered molasses, C_{p_r} is specific heat capacity of diluted recovered sugar which is 8°brix and ΔT is change of temperature.

$Q_7 = M \times C_{p_r} \times \Delta T = 3,654 \frac{\text{kg}}{\text{hr}} \times \frac{3.953 \text{kJ}}{\text{Kg}^\circ\text{C}} \times (70 - 25)^\circ\text{C} = 180.55 \text{ kW}$. Where; M is mass flow rate of water; C_{p_r} is specific heat capacity of diluted recovered sugar which is 8% °brix and ΔT is change of temperature. Substitute Q_6 and Q_7 to equation (6.17) to get drained energy. Energy goes to waste with sludge = (Q_8) = $Q_6 - Q_7 = (221.478 - 200.615) \text{ kW} = 40.92 \text{ kW}$.

iii. Energy balance on D-1201

Temperature of the drum is controlled at 80°C by injecting steam. Input and output materials are calculated above in material balance calculations.

$$\text{input energy} = \text{output energy}$$

$$Q_7 + \text{steam energy}(Q_9) + \text{molasses energy}(Q_{10}) = \text{output energy } (Q_{11}) \quad (6.18)$$

$$Q_{10} = M \times C_{p_m} \times \Delta T = 3,040 \frac{\text{kg}}{\text{hr}} \times \frac{1.842 \text{ kJ}}{\text{kg} \cdot ^\circ\text{C}} \times (25 - 25)^\circ\text{C} = 0 \text{ kW.}$$

$$Q_{11} = M \times C_{p_m} \times \Delta T = 6,944 \frac{\text{kg}}{\text{hr}} \times \frac{3.015 \text{ kJ}}{\text{kg} \cdot ^\circ\text{C}} \times (80 - 25)^\circ\text{C} = 319.820 \text{ kW.}$$

Substitute Q_{11} , Q_7 and Q_{10} to equation (6.18) to get steam energy consumed in D-1201.

$$Q_9 = (Q_{11} - Q_7 - Q_{10})\text{kW} = (319.820 - 0 - 180.55)\text{kW} = 139.27 \text{ kW.}$$

iv. Energy balance on D-1202

Over flow of (D-1202) to (D-1205) through plate heat exchanger is 6,184 kg/hr with 75°C.

Therefore, energy entered to heat exchanger is calculated below.

$$Q_{12} = M \times C_{p_m} \times \Delta T = 6,184 \frac{\text{kg}}{\text{hr}} \times \frac{3.015 \text{ kJ}}{\text{kg} \cdot ^\circ\text{C}} \times (75 - 25)^\circ\text{C} = 258.955 \text{ kW.}$$

v. Energy balance on plate heat exchangers

There are two plate heat exchanger to reduce the diluted molasses temperature from 75 °C to 30-33°C. So, the energy should be removed in heat exchanger is calculated in equation (6.19) below.

$$Q_m = M \times C_{p_m} \times \Delta T \quad (6.19)$$

$$Q_m = 6,184 \frac{\text{kg}}{\text{hr}} \times \frac{3.015 \text{ kJ}}{\text{kg} \cdot ^\circ\text{C}} \times (75 - 30)^\circ\text{C} = 233.06\text{kW.}$$

Water coolant used to cool this molasses is then 18.6m³/hr. Where; the input cooling water is 27°C and output temperature is 30°C.

6.2.2.1. Collected data used in energy audit of molasses treatment section

Measured data in appendix (H) below includes, size of steam pipes, external surface temperatures of fluid distribution lines, ambient temperature, length and diameter of drums and fluid distribution pipes. The areas of all the measured surfaces are calculated by equation (6.20) below.

$$\text{Area (A) of pipes} = \pi DL, \text{ circumference} = \pi D, \text{ Area of cylinder} = 2\pi r^2 + h(2\pi r) \text{ and area of conical} = \pi r s + 2\pi r^2. \quad (6.20)$$

Where; r is radius, D is diameter, L is length, h is height and s is slant.

➤ **Pipe surface heat loss due to radiation and convection in molasses treatment section**

The energy loss due to convection and radiation in watt per unit area of pipe surface exposed to the ambient temperature is given below (ABIYE, 2011).

$$Q_{(i)s} = \left\{ 0.548 \left[\left(\frac{T_{(i)s}}{55.55} \right)^4 - \left(\frac{T_{(i)a}}{55.55} \right)^4 \right] + 1.957 (T_{(i)s} - T_{(i)a})^{1.25} \sqrt{\frac{196.85V + 68.9}{68.9}} \right\} \frac{W}{m^2} \times S_{(i)A} \quad (6.21)$$

Where; $Q_{(i)s}$ is energy loss; $T_{(i)s}$ is surface temperature of the i^{th} pipe; $T_{(i)a}$ is local ambient temperature of the i^{th} pipe; $S_{(i)A}$ is surface area of the i^{th} pipe; and V is Wind velocity = 2.56 m/s. Since molasses treatment section is in closed room, wind velocity is negligible here. Therefore, equation (6.21) reduced to equation (6.22).

$$Q_{(i)s} = \left\{ 0.548 \left[\left(\frac{T_{(i)s}}{55.55} \right)^4 - \left(\frac{T_{(i)a}}{55.55} \right)^4 \right] + 1.957 (T_{(i)s} - T_{(i)a})^{1.25} \right\} \frac{W}{m^2} \times S_{(i)A} \quad (6.22)$$

By substituting the average temperature and area of individual pipes from appendix (H) to equation (6.22) above, total surface heat loss of molasses treatment section is 779.67W.

6.2.2.2. Two ECOs are identified in molasses treatment section

I. Insulating heat loss surfaces

Insulating heat loss surfaces is used to recover energy losses. Insulation saves environmental pollution by reducing temperature release to environment. Thereby, reduce green-house effect. By investigating heat loss parts, 779.67W energy is lost through 10.293m² areas. Assume 85% of lost energy can recover by insulation; then saved energy will be 662.72W. Chemical energy of naphtha is 37.74MJ/litre. Therefore, by insulating energy loss surface areas, it is possible to save 0.063lt/hr of naphtha. Or, 0.079ml of naphtha can save for every litre of alcohol production.

Insulation cost is summation of material cost, labor cost, overhead cost and any additional costs (May transporting, loading and unloading). Cost of 50 mm thickness and 48kg/m³ density of insulation foam is 612 birr per square meter and cost of 0.7 mm to 0.8 mm thickness Aluminum metal sheet used to cover insulation foam is 600 birr per square meter based on current market value. Therefore, total material cost is 1,824 birr/m².

If the company insulates the surface areas using permanent employee to reduce insulation cost, only material cost is considered and payback period is calculated in equation (6.23) below. If the company insulates by external professional employees, labor cost, overhead cost with cost of tools (drill, cutter, binder and other instruments) per square meter reaches 100-120 birr as market

cost. So, maximum payback period by considering labor cost and overhead cost is calculated in equation (6.24) below. Therefore, total cost used to insulate energy loss surface area is 1,934 birr/m².

- Designed alcohol production per year is 6,912,000lt. Yearly 546.191 liter of naphtha can save depending on the designed alcohol production and chemical energy of naphtha.
- Payback period (PP) is calculated by dividing implementation cost to saved cost.

$$PP = \frac{\text{Implimentation cost} \left(\frac{\text{birr}}{\text{m}^2} \right) \times \text{Area to insulate} \left(\text{m}^2 \right)}{\text{Cost of naphtha} \left(\frac{\text{birr}}{\text{lt}} \right) \times \text{saved naphtha} \left(\frac{\text{lt}}{\text{yr}} \right)} = 2.07 \text{ years} \quad (6.23)$$

$$PP = \frac{\text{Implimentation cost} \left(\frac{\text{birr}}{\text{m}^2} \right) \times \text{Area to insulate} \left(\text{m}^2 \right)}{\text{Cost of naphtha} \left(\frac{\text{birr}}{\text{lt}} \right) \times \text{saved naphtha} \left(\frac{\text{lt}}{\text{yr}} \right)} = 2.19 \text{ years.} \quad (6.24)$$

II. Integration for heat recovery

To reduce energy consumption and reduce coolant for the diluted molasses in plate heat exchanger, integration is identified as ECO. The molasses input is with atmospheric temperature and the white stillage coming from distillery with minimum 65°C temperature is stored in storage. This white stillage is used for cleaning fermenters and the rest is drained with its energy.

The diluted molasses out from (D-1202) has 75°C temperature that should be reduced to 30-33°C before entering to fermenters. Thereby, to reduce this, cooling water is used from cooling tower.

Raw input molasses has 80°brix and this may difficult to circulate in plate heat exchanger to increase its temperature. The integration recommended reducing this brix to 35°brix by mixing with diluted recovered molasses coming from (D-1204). By the ratio of their material flow, mixing of the two fluids, brix and temperature of mixture brings 35 °brix and 40°C respectively.

Table 6. 3. Heat integration parameters (case-1)

Stream No.	Type	Mass flow rate (kg/hr)	Specific heat capacity (kJ/kg °C)	Heat capacity (kW/ °C)	Supply temperature (°C)	Target temperature (°C)	Heat load (kW)
1	Hot	6,184	3.01	5.17	75	30	232.65
2	Hot	2,519	4.18	2.92	65	30	102.2
3	Cold	7,074	3.16	6.21	40	80	248.40
4	Cold	1,512	4.18	1.76	30	80	88.00

Where; stream (1) is over flow molasses from (D-1202); stream (2) is white stillage; stream (3) is feed diluted molasses from new proposed drum; and stream (4) is process water.

Note: “Case-1” in table (6.3) is symbolized to differentiate integrations in molasses treatment section and the other integration proposed below in boiler section which is assigned “Case-2”.

Problem table method is one of process heat integration and preferred method for heat integration. The problem table is the name given by Linnhoff and flower to a numerical method for determining the pinch temperatures and minimum utility requirements (B. Linnhoff, 1994). Minimum temperature difference (ΔT_{MIN}) is temperature difference between hot stream and cold streams. It is a bottleneck in heat recovery and is commonly referred to as the "Pinch". Let take 10°C minimum temperature differences as given in Linnhoff for chemical industry (B. Linnhoff, 1994). So, the integration by problem table method procedure, minimum hot and cold utility requirements are calculated below.

- I. Convert the actual stream temperatures T_{act} into interval temperatures T_{int} by subtracting half the minimum temperature difference from the hot stream temperatures, and by adding half to the cold stream temperatures:

$$\text{Hot streams: } T_{int} = T_{act} - \frac{\Delta T_{min}}{2} \quad (6.25)$$

$$\text{Cold streams: } T_{int} = T_{act} + \frac{\Delta T_{min}}{2} \quad (6.26)$$

Table 6. 4. Interval temperatures (case-1)

Streams	Actual temperature ($^\circ\text{C}$)		Interval temperature ($^\circ\text{C}$)	
1	75	30	70	25
2	65	30	60	(25)
3	40	80	45	(85)
4	30	80	35	85

2. Note any duplicated interval temperatures. These are bracketed in the table (6.4) above.
3. Rank the interval temperatures in order of magnitude, showing the duplicated temperatures only once in the order; see the table (6.5) below.
4. Carry out a heat balance for the streams falling within each temperature interval:

For the n^{th} interval:

$$\Delta H_n = (\sum C_{p_c} - \sum C_{p_h}) \times (\Delta T_n) \quad (6.27)$$

Where; ΔH_n is net heat require in the n^{th} interval; $\sum C_{p_c}$ is sum of the heat capacities of all the cold streams in the interval; $\sum C_{p_h}$ is sum of the heat capacities of all the hot streams in the interval; and $\Delta T_n =$ interval temperature difference = $(T_{n-1} - T_n)$.

Table 6. 5. Net heat calculation in the n^{th} interval (case-1)

Intervals	Interval temperature (°C)	ΔT_n (°C)	$\sum C_{p_c} - \sum C_{p_h}$ (kW/°C)	ΔH (kW)	Surplus or Deficit
	85				
1	70	15	7.97	119.55	D
2	60	10	2.80	28.0	D
3	45	15	-0.12	-1.8	S
4	35	10	-6.33	-63.3	S
5	25	10	-8.09	-80.9	S

5. “Cascade” the heat surplus from one interval to the next down the column interval temperature; as seen in figure (6.8) below. Cascading heat from one interval to the next implies, the temperature difference is such that the heat can be transferred between the hot and cold.

Interval Temp

85	<u>0 kW</u>		<u>147.55 kW</u>	
70	<u>119.55 kW</u>	-119.55 kW	<u>119.55 kW</u>	28 kW
60	<u>28.0 kW</u>	-147.55 kW	<u>28.0 kW</u>	0 kW
45	<u>-1.8 kW</u>	-145.75 kW	<u>-1.8</u>	1.8 kW
35	<u>-63.3 kW</u>	-82.45 kW	<u>-63.3</u>	65.1 kW
25	<u>-80.9 kW</u>	-1.55 kW	<u>-80.9</u>	146.0 kW
	(a)		(b)	

Figure 6. 8 Cascading heat (case-1)

From figure (6.8) (b), pinch temperature occurs at interval temperature of 60°C.

For maximum heat recovery and minimum use of utilities the following rules are proposed by Linnhoff and these are: do not transfer heat across the pinch; do not use hot utilities below the pinch and do not use cold utilities above the pinch.

Heat exchange networks:- Grid representation is convenient to represent a heat exchanger network as a grid; see Figure (6.9) below. The heat exchange network design for maximum energy recovery is designed by networking above the pinch (where, $C_{p_{\text{hot}}} \leq C_{p_{\text{cold}}}$) and networking below the pinch (where, $C_{p_{\text{hot}}} \geq C_{p_{\text{cold}}}$). It is rule to supply external heat only above the pinch and external cooling only below the pinch.

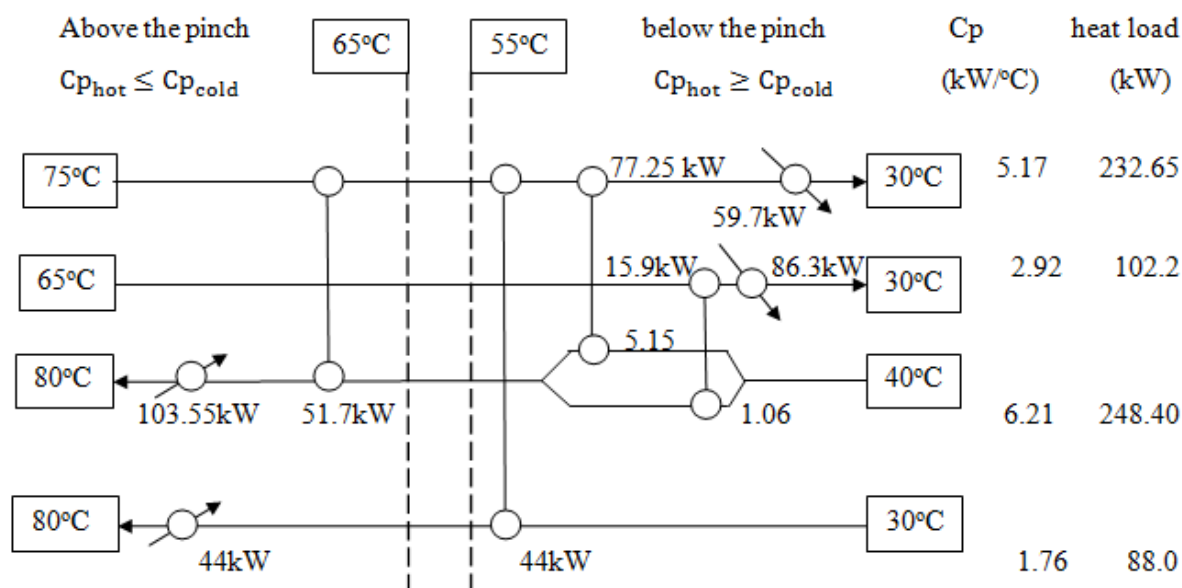


Figure 6. 9 Heat exchange network (case-1)

Minimum hot utility requirement is 147.55 kW and minimum cold utility requirement is 59.7kW by omitting the white stillage as it is.

Required energy in molasses treatment is 271.978 kW as energy balance investigated in above. But, by integrating input output materials, this amount of energy is reduced to 147.55kW. Thereby, saved energy is 124.428 kW. Water coolant also reduced from 18.6m³/hr to 2.04m³/hr. Thereby, saved coolant water is 16.54m³/hr. based on saved energy and chemical energy of naphtha, it is possible to save 11.87lt/hr of naphtha.

6.2.3. Distillery section detailed energy audit

6.2.3.1. Introduction

Distillery section consumes 9,136kg/hr fermented mash averagely. Fermented mash coming from fermenters passes through two heat exchangers to increase the temperature of fermented mash from 30 °C to 40 °C. Pure alcohol is collected from demethylation column where denature alcohol extracted from three columns. The dark stillage from mash column with 67 °C is sent to river where the white stillage from rectification and fusel oil columns is recycled partially to users and drain the rest of it as waste. Over all process flow diagram of distillery is drawn in figure (6.10) below.

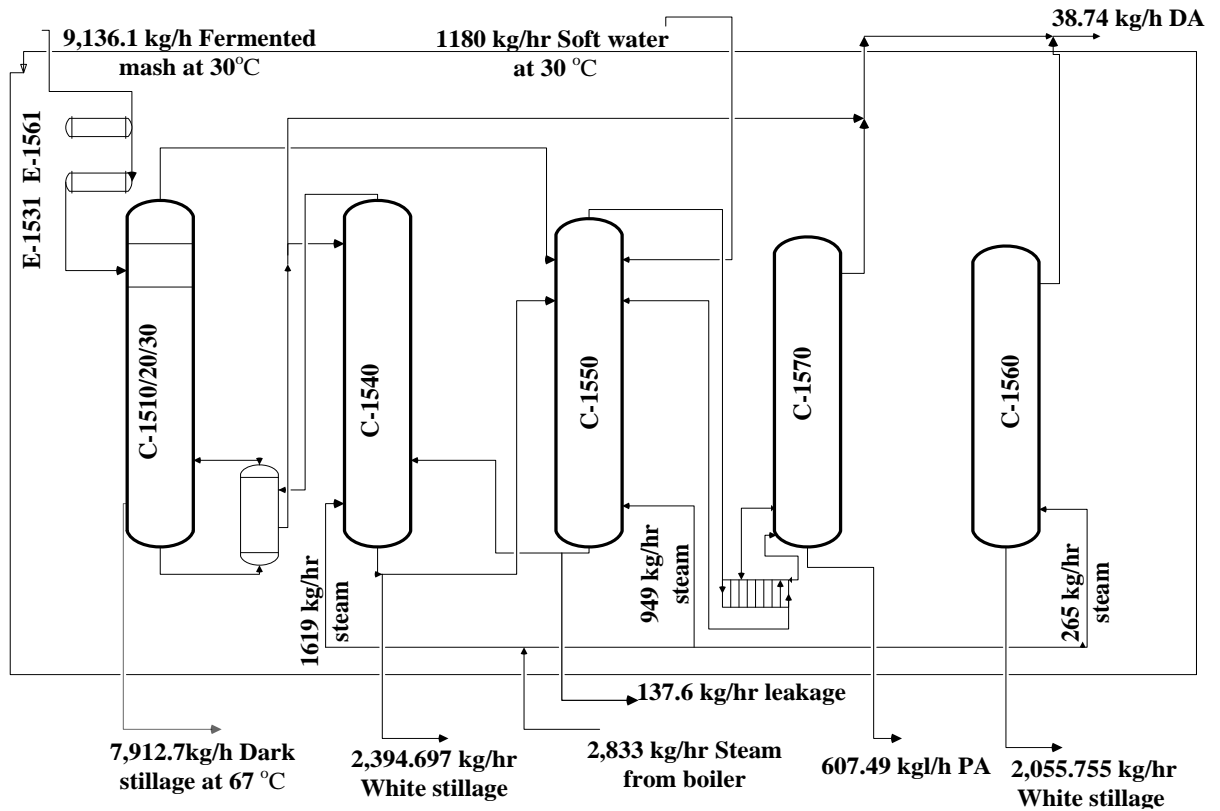


Figure 6. 10 Energy and volumetric flow rate of distillery section

6.2.3.2. Distillery section energy analysis

Based on figure (6.10) above, over all energy audit of distillery is performed by conducting input output energy balance thereby obtain energy recovery options.

6.2.3.3. Distillery input energies

i. Steam energy input from boiler

Individual steam mass flow rate and enthalpy are given in table (5.4) and (5.5) above respectively. Steam energy is calculated by multiplying mass flow rate and its enthalpy. Three of the five columns get direct steam injection. The specific enthalpy of evaporation (h_{fg}) for saturated steam is calculated from equation (6.28) below (ToolBox, 2003).

$$h_{fg} = h_g -$$

$$h_f$$

$$(6.28) \text{ Where;}$$

h_g is saturated vapor and h_f is saturated liquid enthalpy (kJ/kg) of columns.

$$Q_{(i)s} = M_{(i)s} \times h_{fg(i)s} \quad (6.29)$$

Where; Q is steam energy, M is steam mass flow rate, h_{fg} is enthalpy of steam and “i” is column.

$$Q_{(C-1540)s} = M_{(C-1540)s} \times h_{fg(C-1540)s} = 980.91 \text{ kW} \quad (6.30)$$

Input energy to hydroselction column is calculated below in equation (6.31).

$$Q_{(C-1550)s} = M_{(C-1550)s} \times h_{fg(C-1550)s} = 589.864 \text{ kW}. \quad (6.31)$$

Input energy to fusel oil column is calculated below in equation (6.32).

$$Q_{(C-1560)s} = M_{(C-1560)s} \times h_{fg(C-1560)s} = 165.652 \text{ kW}. \quad (6.32)$$

$$\text{So, total steam energy input} = Q_{(C-1560)s} + Q_{(C-1550)s} + Q_{(C-1540)s} = 1,736.426 \text{ kW}. \quad (6.33)$$

ii. Fermented mash input energy

$$Q_{fm} = M_{fm} \times C_{p_{fm}} \times (T_{fm} - T_{amb}). \quad (6.34)$$

Where, Q_{fm} is energy of fermented mash; M_{fm} is mass flow rate of fermented mash = 9,260.28 kg/hr; T_{fm} temperature of fermented mash = 30 °C; T_{amb} is ambient temperature = 25 °C.

Specific heat capacity of fermented mash is calculated in equation (6.35) below (ABIYE, 2011).

$$C_{p_{fm}} = (3.14 + (0.000025 \times (T_{fm} - T_{amb}))) \quad (6.35)$$

$$C_{p_{fm}} = 3.140125 \text{ kJ/kg}^\circ\text{C}. \text{ Therefore, } Q_{fm} = 40.387 \text{ kW}.$$

iii. Soft water input energy

$$Q_{sw} = M_{sw} \times C_{p_{sw}} \times (T_{sw} - T_{amb}) \quad (6.36)$$

Where, M_{sw} is mass flow rate of soft water; $C_{p_{sw}}$ is specific heat capacity of water = 4.187 kJ/kg °C and T_{sw} is temperature of soft water (30 °C). Therefore, $Q_{sw} = 6.397 \text{ kW}$.

6.2.3.4. Distillery output energies

i. Energy loss due to dark stillage

$$Q_{ds} = M_{ds} \times C_{p_{ds}} \times (T_{ds} - T_{amb}) \quad (6.37)$$

Where, Q_{ds} is dark stillage output energy; M_{ds} is mass flow rate of dark stillage = 7,899.606 kg/hr; $C_{p_{ds}}$ is specific heat capacity of dark stillage and T_{ds} is temperature of dark stillage equal to 67 °C.

Specific heat capacity of dark stillage is given by equation (6.38). (ABIYE, 2011).

$$C_{p_{ds}} = (3.14 + (0.000025(T_{ds} - T_{amb}))) \quad (6.38)$$

$$C_{p_{ds}} = 3.14105 \text{ kJ/kg}^\circ\text{C}. \text{ And, } Q_{ds} = 289.486 \text{ kW}.$$

ii. Energy loss due to white stillage

$$Q_{ws} = M_{ws} \times C_{p_{ws}} \times (T_{ws} - T_{amb}) \quad (6.39)$$

Where, Q_{ws} is white stillage energy out; M_{ws} is mass flow rate of white stillage = 4450.452 kg/hr; $C_{p_{ws}}$ is specific heat capacity of white stillage and T_{ws} is temperature of white stillage equal to 75°C. Therefore, Q_{ws} is 258.806 kW.

iii. Distillery surface energy loss

Even the columns are insulated to protect heat loss, the lines used to connect these columns and some parts of steam lines are not insulated. Measured and calculated data in appendix (I) includes ambient temperature, average external surface temperature, length, diameter of pipes and drums. The individual areas of all the measured surface area are calculated by equation (6.7). The energy loss due to convection and radiation in watt per unit surface area exposed to the ambient temperature is given in equation (6.21) above. Therefore, energy loss through distillery surface area (Q_{sl}) is 6.1277kW.

Heat used to evaporate alcohol (Q_e):- Total energy balance is calculated by input output balance.

$$Q_{fw} + Q_{sw} + Q_{steam} = Q_e + Q_{ds} + Q_{ws} + Q_{sl} \quad (6.40)$$

Therefore, energy used to evaporate alcohol is 1,228.7725 kW.

6.2.3.5. Two ECOs are identified in distillery section

i. Insulating heat loss surfaces

By investigating heat loss parts, 6,127.7W energy is lost through 69.174 m² areas. Assuming 85% of lost energy can recover by insulating. Then, 5,208.55W of loss energy can save. Therefore, by insulating energy loss surface areas, it is possible to save 0.4968 lt/hr of naphtha or 0.621 ml of naphtha per litre of alcohol product. Designed alcohol production per year is 6,912,000lt. Yearly 4,292.71 litre of naphtha can save depending on the designed alcohol production and chemical energy of naphtha.

Payback period (PP) is calculated by dividing insulation cost to saved cost. Minimum and maximum payback period is calculated in equation (6.41) and (6.42) respectively. Costs are discussed in equation (6.23) and (6.24) molasses treatment energy recovery section.

$$PP = \frac{\text{Implimentation cost} \left(\frac{\text{birr}}{\text{m}^2} \right) \times \text{Area to insulate (m}^2)}{\text{Cost of naphtha} \left(\frac{\text{birr}}{\text{lt}} \right) \times \text{saved naphtha} \left(\frac{\text{lt}}{\text{yr}} \right)} = 1.77\text{years} \quad (6.41)$$

$$PP = \frac{\text{Implimentation cost} \left(\frac{\text{birr}}{\text{m}^2} \right) \times \text{Area to insulate (m}^2)}{\text{Cost of naphtha} \left(\frac{\text{birr}}{\text{lt}} \right) \times \text{saved naphtha} \left(\frac{\text{lt}}{\text{yr}} \right)} = 1.88\text{years} \quad (6.42)$$

ii. Recycling steam condensate from steam traps

Averagely 360lt condensate at 61°C is drained to waste daily. Besides water reuse for boiler water feed, energy used to heat input water in boiler degasser is decreased by recycling this condensate. Therefore, energy available to recover is calculated in equation (6.43) below.

$$Q_c = m \times C_{p_c} \times (T_c - T_a) \quad (6.43)$$

Where, Q_c is condensate energy; m is mass of condensate; C_{p_c} is specific heat capacity of condensate (assume C_p of water); T_c is condensate temperature equal to 61°C and T_a is ambient temperature. Then, Q_c is 628.1W. Based on chemical energy of naphtha and saved condensate energy, 0.060lt/hr naphtha can save.

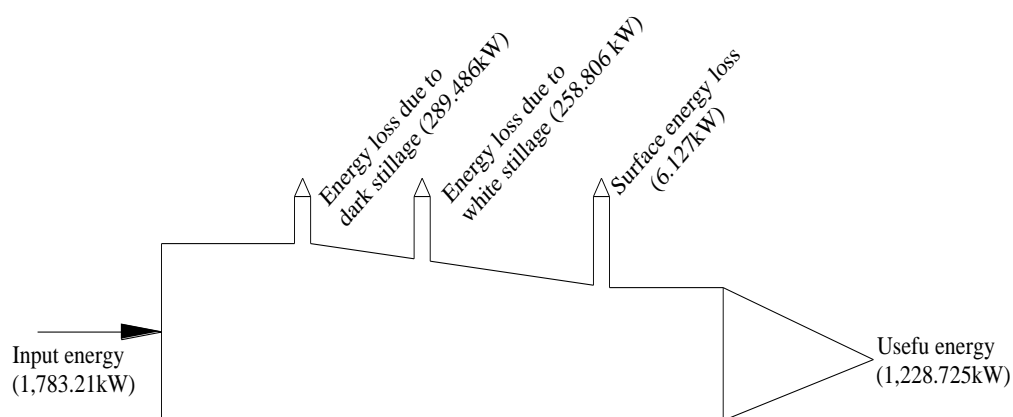


Figure 6. 11 Distillery sankey diagram

6.2.4. Boiler section detailed energy audit

6.2.4.1. Introduction

MALF boiler is fire tube type steam generator with designed 195 °C temperature and 13 bar pressure. Main function of the company boiler is generating steam for distillery and molasses treatment section.

Data/measurements required to perform boiler energy audit and determine the efficiency of boiler are surface temperature of boiler and its dimension, ambient temperature, flow rate of input fuel oil and its feed temperature, flow rate of input water and its feed temperature, flow rate of combustion air and its temperature, steam flow rate, pressure and temperature of boiler, flow rate of boiler blow down and its temperature, flue gas analysis (flue temperature, constituents of combustion products, flue excess air, and losses).

Specifications of MALF boiler are collected in table (6.6) below.

Table 6. 6. Boiler specification

	Specification	Source of data
Type	Fire tube	Catalogue
Model	PB 100 EU	Catalogue
Manufactured year (G.C)	2014	Catalogue
Designed capacity at 13 bar (kg/hr)	10,000 (steam output)	Catalogue
Hydraulic test pressure (bar)	19.5	Catalogue
Diameter (m)	2	Direct measured
Length (m)	5.4	Direct measured
Heat transfer area (m ²)	200 m ²	Catalogue
Furnace calculation temperature (°C)	295.3	Catalogue

6.2.4.2. Boiler inputs and outputs temperatures

Boiler surface temperature; ambient temperature, feed water temperature, feed fuel temperature, ambient temperature are measured and collected below in table (6.8).

Table 6. 7. Measured boiler temperatures

s. no.	Measured name	Measured temperature (°C)	Ambient temperature (°C)
1	Front boiler surface	70	26.5
2	Back boiler surface	55	27
3	Feed fuel	66	26.5
4	Feed water	58	25
5	Current working steam is produced at 180 °C temperature and pressure of 10 bar		

6.2.4.3. Analysis of boiler flue gas

Portable flue gas Analyzer (E6000-5DS) is an extractive instrument used to analyze flue gas temperature, combustion efficiency and helps to control energy utilization efficiency and output emissions. Gas analyzer takes, sample from the boiler flue outlet and analyze the sample using electrochemical gas sensors. And results are written in table (6.7) below.

Table 6. 8. Measured flue gas data

No.	Flue gas data	Reading value					Avg.
		7	8	9	9.8	10	
	Pressure (bar)						
1	Flue gas temperature (°C)	210.8	210.7	211.3	208.4	206.4	209.52
2	Ambient temperature (°C)	26.6	26.8	27.9	28.4	28.6	27.7
3	Net temperature (°C)	184.2	183.9	183.4	180.0	177.8	181.86
4	Flue gas O ₂ content (%)	11.1	10.9	10.5	9.5	7.9	9.98
5	Flue gas CO ₂ content (%)	7.4	7.5	7.8	8.6	9.8	8.22
6	Flue gas CO content (mg/m ³)	122	35	25	6	2	38
7	Flue gas excess air content (%)	113	109	101	83	61	93.4
8	Combustion efficiency (%)	81.5	81.7	82.2	83.3	84.6	82.66
9	Losses (%)	18.5	18.3	17.8	16.7	15.4	17.34
	Dry flue gas heat loss (%)	12.3	12.1	11.6	10.5	9.2	11.14
	Wet flue gas heat loss (%)	6.2	6.2	6.2	6.2	6.2	6.2
Assume for atmospheric air, Nitrogen is 79% and Oxygen is 21%.							

6.2.4.4. Furnace oil combustion analysis

Mass and energy balances of furnace oil, combustion air, and combustion products are very important for furnace oil combustion analysis.

The gross calorific value (GCV) of furnace oil is dependent on the physical composition. Composition and GCV of furnace oil are collected in table (6.9) below (M. Hissa*, 2018,).

Table 6. 9. Composition of furnace oil and their ultimate analysis

Composition of furnace oil	Symbol	Ultimate analysis (%)
Carbon	C	84
Hydrogen	H ₂	12
Oxygen	O ₂	1.5
Sulfur	S	1.5
Nitrogen	N ₂	0.5
Moisture	M	0.5
GCV (higher heating value) of furnace oil is 41.84MJ/kg.		

6.2.4.5. Air fuel ratio of furnace oil burning

The theoretical and actual air fuel ratio of furnace burning on mass basis is important to determine the flow rate of flue gases.

i. Theoretical air-fuel ratio (TAFR) of furnace oil

The standard reaction which oxidizes 1kg of furnace completely into carbon dioxide and water with inert nitrogen in the product stream is used to determine furnace oil burning theoretical air-

fuel ratio. The standard chemical reaction is, burning of 1kg of furnace oil using dry air (M.C. Barmaa, 2017) . Composition of furnace is written in table (6.9) above.

$$\text{TAFR} = \left(\frac{\{(11.6 \times C) + [34.8 \times (\text{H}_2 - \frac{\text{O}_2}{8})] + (4.35 \times S)\}}{100} \right) \left(\frac{\text{kg of air}}{\text{kg of furnace oil}} \right) \quad (6.44)$$

Substitute percent of element from table (6.11) to equation (6.44). So,

$$\text{TAFR is equal to } 13.92 \frac{\text{kg of air}}{\text{kg of furnace oil}}$$

i. Excess air supplied (EAS)

Excess air input to the burner (boiler) is calculated by the percent of Oxygen left in the flue gas.

Recorded excess air in flue gas is 93.4%. But, according to oxygen percent in flue gas, EAS is;

$$\text{EAS} = \frac{\text{O}_2\% \text{ in flue gas}}{\text{input O}_2\% - \text{O}_2\% \text{ in flue gas}} \times 100 = 90.56\% \quad (6.45)$$

Therefore, average of the two percents which is 92% is taken as EAS.

ii. Actual air-fuel ratio (AAFR) of furnace

$$\text{AAFR} = \left\{ \left(1 + \frac{\text{EAS}}{100} \right) \times \text{TAFR} \right\} \quad (6.46)$$

Where; EAS is excess air supplied. Therefore, AAFR is $26.73 \frac{\text{kg of air}}{\text{kg of furnace oil}}$

Excess air supplied = Actual air supplied - Theoretical air required = 12.81 kg/ kg of fuel.

6.2.4.6. Analysis of dry flue gases mass flow rate

To perform the actual chemical balance during burning of furnace oil with atmospheric air, it is better to normalize mass fraction of the major air composition.

Table 6. 10. Mass analysis of dry air constituents

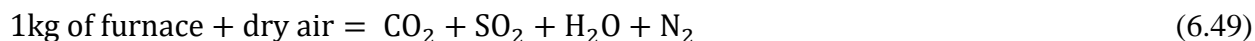
Element	dry air (y)	Molecular mass (M)	Mass of dry air (y× M)	Mass fraction of dry air $\left(\frac{y \times M}{28.84}\right)$
O ₂	0.21	32	6.72	0.23
N ₂	0.79	28	22.12	0.77
H ₂ O	0.0	18	0.0	0.00
Sum	1.0	78	28.84	1.000

Therefore, from excess air supplied and mass fraction of dry air;

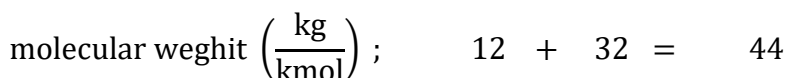
$$\text{Excess O}_2(\text{by mass}) = 12.81 \text{ kg} \times 0.23 = 2.95 \text{ kg/kg fuel} \quad (6.47)$$

$$\text{Excess N}_2(\text{by mass}) = 12.81 \text{ kg} \times 0.77 = 9.86 \text{ kg/ kg fuel.} \quad (6.48)$$

From furnace composition, combustible elements are carbon, hydrogen and sulfur. Depending on standard chemical reaction of furnace oil, when a kg of furnace oil is oxidized completely using dry air, it gives CO₂, H₂O, SO₂ and inert nitrogen (N₂) gas in the product as given below.



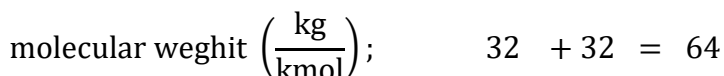
➤ Mathematically formation of CO₂:



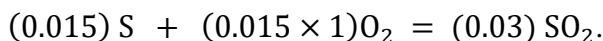
12 kg of Carbon requires 32 kg of O₂ to form 44 kg of CO₂. Therefore, 1 kg of Carbon requires 32/12 or 2.67 kg of O₂. From table (6.11), composition of carbon in furnace is 84%. Then,



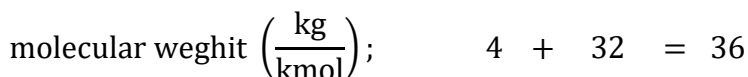
➤ Mathematically formation of SO₂:



32 kg of sulfur requires 32 kg of O₂ to form 64 kg of SO₂. Therefore, 1 kg of S requires 32/32 or 1kg of O₂. From table (6.11), composition of sulfur in furnace is 1.5%. Then, by mole balance,



➤ Mathematically formation of H₂O:



4 kg of Hydrogen requires 32 kg of O₂ to form 36 kg of water. Therefore, 1 kg of H₂ requires 32/4 or 8 kg of O₂. From table (6.11), composition of Hydrogen in furnace is 12%. Then,



Total mass of flue gas with 92 % excess air for every 1 kg fuel is the summation of individual products. Where; mass of CO₂ is 3.08kg /kg of fuel; mass of SO₂ is 0.03kg / kg of fuel; mass of H₂O is 1.08kg / kg of fuel; mass of O₂ is 2.95 kg/ kg of fuel; and mass of N₂ is 20.58 kg/ kg of fuel which is nitrogen in actual mass of flue gas.

Therefore, total mass of flue gas is 27.72kg/ kg of fuel or 2.024kg/sec.

Boiler efficiency basically can be evaluated by two methods (M.C. Barma R. S., 2017):

- i. Direct Method: - Where output steam energy is compared with heat input (fuel energy) only which do not indicate the other losses. It called as “input-output” method. And,
- ii. Indirect Method: - efficiency of boiler is the difference between input energy and different output losses. It called as “Heat loss” method and it is better to calculate boiler efficiency by indirect method which is incorporated all losses.

6.2.4.7. Input - output boiler mass balance

Inputs are furnace, water and outputs are steam to users, flue gas, blowdown steam and other leakages. Mass flow rate of furnace oil is 0.073kg/sec. Mass flow rate of Boiler input water is 4,500kg/hr and condensate drained through steam trap is 15kg/hr. Mass flow rate of blowdown and leakages is 1,152 kg/hr and Mass flow rate of steam output to users is 3,333 kg/hr.

6.2.4.8. Input – output boiler energy balance

6.2.4.8.1. Input energies

➤ Furnace oil input energy

Furnace oil contains chemical energy (heating value) and heat energy (pre-heating energy).

$$\text{Furnace energy} = \text{chemical energy} + \text{preheating energy} \quad (6.55)$$

Chemical energy of furnace (Q_c) is calculated using its heating value and mass flow rate.

$$Q_c = M \times \text{GCV} = 0.073 \frac{\text{kg}}{\text{s}} \times 41.84 \frac{\text{MJ}}{\text{kg}} = 3,054.32\text{kW}.$$

The energy due to pre-heating temperature can be obtained using equation below.

$$Q_p = M \times C_p \times (T_f - T_a)$$

Where, Q_p is furnace preheating energy; M is furnace oil mass flow rate; C_p is specific heat capacity of furnace oil (0.879 kJ/kg °C); T_f is furnace raised temperature and T_a is ambient temperature. So, Q_p is equal to 2.53kW.

➤ Energy flow rate of feed water

Input energy (Q_w) due to pre-heating feed water obtained using equation (6.56) below.

$$Q_w = M \times C_{p_w} \times (T_w - T_a) \quad (6.56)$$

Where; Q_w is water preheating energy; M is water mass flow rate; C_p is specific heat capacity of water (4.18 kJ/kg °C); T_w is water raised temperature and T_a is ambient temperature equal to 25°C. $Q_w = 172.425\text{kW}$

➤ **Energy flow rate of combustion air**

The input combustion air is at ambient temperature. So, input energy here is zero.

6.2.4.8.2. Output energies

Output energies are useful energy used in sections and the principal losses.

➤ **Energy flow rate of steam to users**

$$Q_s = M_s \times h_{fg} \quad (6.57)$$

Where; Q_s is output steam energy; M_s is steam mass flow rate and h_{es} is specific evaporation enthalpy of steam (2014.6kJ/kg) at 10bar and 180°C. And output steam energy is 1,865.18kW.

➤ **Boiler principal losses:** are boiler output energies and described as follow.

i. Heat loss (%) due to dry flue gas (L_1)

$$L_1 = \frac{M_{fl} \times C_{pfl} \times (T_{fl} - T_a)}{GCV} \times 100 \quad (6.58)$$

M_{fl} (kg/kg of fuel) is flue gas mass flow rate; T_{fl} is flue gas temperature and T_a is ambient temperature. GCV (kJ/kg) is gross calorific value of furnace oil. C_p (kJ/kg k) is specific heat capacity flue gas calculated by equation (6.59) below (Samuel Gebremariam Haile*1, 2016).

$$C_{pfl} = (0.3 + 0.000038T_{furnace}) \frac{\text{kcal}}{\text{kg k}} \quad (6.59)$$

$$C_{pfl} = 0.3112 \frac{\text{kcal}}{\text{kg k}} = 1.3022 \frac{\text{kJ}}{\text{kg k}}. \text{ And then } L_1 = 15.69\%.$$

ii. Heat loss (%) due to H_2 presence in fuel (L_2)

$$L_2 = \frac{M_{H_2O} \times (h_{fgw} + C_p(T_{fl} - T_a))}{GCV} \quad (6.60)$$

Where M_{H_2O} is 1.08kg / kg of fuel; h_{fgw} is enthalpy of water at atmospheric air which is equal to 2441.7kJ/kg and C_p (specific heat capacity of steam) is 1.88kJ/kg°C. And L_2 is 7.18%.

iii. Heat loss (%) due to moisture in fuel (L_3)

$$L_3 = \frac{M \times (h_{fgw} + C_p(T_{fl} - T_a))}{GCV} \quad (6.61)$$

M is moisture content of fuel, h_{fgw} is enthalpy of water at atmospheric air which is equal to 2441.7kJ/kg and C_p (specific heat capacity of steam) is 1.88kJ/kg°C. And L_3 is 0.033%.

iv. Heat loss (%) due to moisture in air (L₄)

$$L_4 = \frac{AAS \times y_a \times (C_p(T_f - T_a))}{GCV} \quad (6.62)$$

Where, AAS is actual air supplied (26.73kg/kg of fuel); C_p (specific heat capacity of steam) is equal to 1.88kJ/kg°C and y_a is humidity factor which is calculated as follow.

Humidity factor (γ_A):- The amount of moisture content of the air used for combustion can be found by calculating the humidity factor of the air at the inlet temperature to the boiler burner. The humidity factor of air is given by equation (6.63) below (ASHRAE, 2018).

$$\text{Humidity factor } (\gamma_A) = \gamma_A = 0.622 \frac{P_v}{P_o} \quad (6.63)$$

$$\text{Where; } P_o = P_a - P_v \quad (6.64)$$

Atmospheric pressure (P_a) is 101.325kPa and partial pressure of water (P_v) = Ø × P_{sat @ sta T&P}. Where, Ø is relative humidity (53.25%). From steam table, saturation pressure at standard condition is 0.0032Mpa. And, P_v is 1.704 kpa and P_o is 99.621 kpa. Then,

$$(\gamma_A) = 0.0106 \frac{\text{kg of water}}{\text{kg of dry air}}. \text{ And } L_4 \text{ is equal to } 0.23\%.$$

v. Heat loss (%) due to surface radiation and convection (L₅)

Heat loss from boiler is out through its exposed surfaces. The boiler is cylindrical in shape and surfaces that are exposed to the ambient are: the front and back surfaces. And, individual area is calculated as; Front and back surface area of boiler is calculated by equation (6.65) below.

$$A = \frac{\pi D^2}{4} = 3.14\text{m}^2 \quad (6.65)$$

So, energy loss through front (Q_{front}) and back(Q_{back}) is calculated by equation (6.22) above. Q_{front} is 0.691kW and Q_{back} is 0.397kW. Surface energy loss of molasses treatment and distillery section is calculated above and is totally 6.91kW.

$$L_5 = \frac{\text{Total surface energy loss (kW)}}{GCV \times \text{fuel mass flow rate (kW)}} = 0.262\%$$

vi. Heat loss (%) due to boiler blow down (L₆)

$$Q_b = M \times h_{b@110} \quad (6.66)$$

Where; Q_b is waste energy through blowdown; M is blow down mass flow rate (1,115kg/hr) and

h_b is blowdown saturated liquid enthalpy which is equal to 461.42kJ/kg.

$$L_6 = \frac{\text{blowdown energy loss (kW)}}{\text{GCV(kJ/kg)} \times \text{fuel mass flow rate (kg/sec)}} = 4.83\%.$$

vii. Heat loss (%) due to steam trap condensate (L_7)

$$L_7 = \frac{\text{steam trap energy loss (kW)}}{\text{GCV(kJ/kg)} \times \text{fuel mass flow rate (kg/sec)}}$$

$$\text{Energy loss (} Q_{sc} \text{)} = m_c \times (C_{p_w} \times (T_c - T_a)) \tag{6.67}$$

Where Q_{sc} is steam condensate energy loss, M_c is mass flow rate of drained condensate equal to 15kg/hr at 61°C, T_c is condensate temperature and C_{p_w} specific heat capacity of water. Therefore, L_7 is equal to 0.021%.

viii. Heat loss (%) due to incomplete combustion (L_8)

The amount of carbon monoxide in flue gas out through boiler chimney is part per million which is insignificant. So, we can ignore the heat energy in the calculation of the boiler efficiency.

6.2.4.9. Boiler efficiency by indirect method is calculated as follow.

$$\text{Boiler efficiency (\%)} = 100 - (L_1 + L_2 + L_3 + L_4 + L_5 + L_6 + L_7) = 71.75\%.$$

6.2.4.10. Boiler energy sankey diagram

The sankey diagram is used to understand highly energy loss parts during energy utilization.

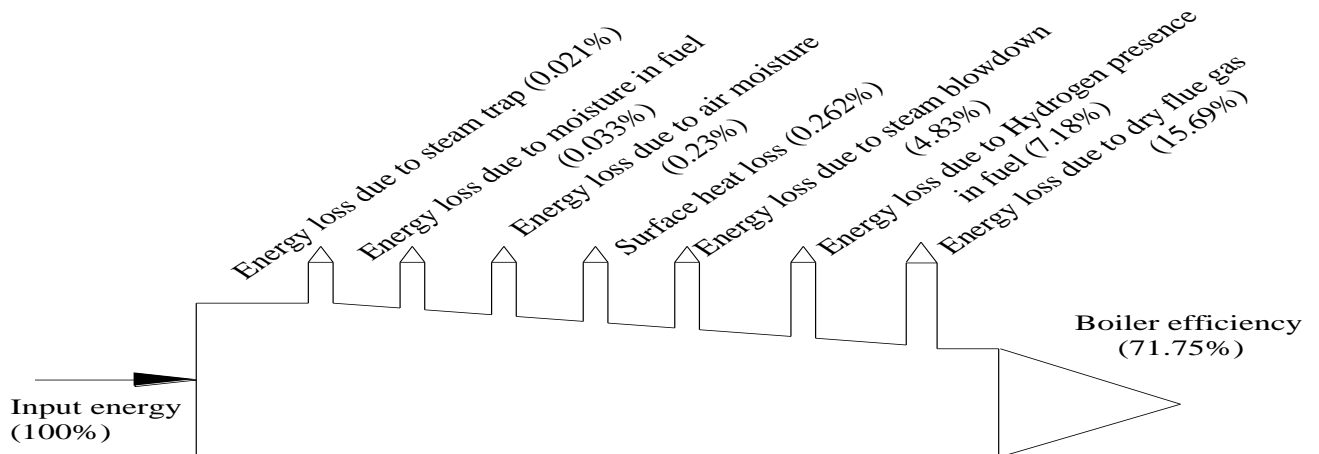


Figure 6. 12 Boiler sankey diagram

6.2.4.11. Three ECOs are identified in boiler section

i. Insulating heat loss surfaces

Boiler surface energy loss by radiation and convection through 6.28m² area is 1.09kW. By assuming 85% of lost energy can be recovered through insulation, 926.5W of loss energy can be saved. By insulating energy loss surfaces, it is possible to save 0.0884 lt/hr of naphtha or 0.111ml of naphtha per liter of alcohol product. Yearly 763.59 litre of naphtha can be saved depending on the designed alcohol production and chemical energy of naphtha. By equation (6.23) and (6.24), payback period is 0.90year and 0.96year respectively.

ii. Controlling input combustion air

Energy which could be recovered by controlling air-fuel ratio is calculated in equation (6.68).

$$Q_{EA} = M_{EA} \times C_{p_{fl}} \times (T_{fl} - T_a) \quad (6.68)$$

Where; Q_{EA} is energy loss due to excess air and M_{EA} is mass excess air.

Therefore, $Q_{EA} = 224.66\text{kW}$. By controlling air fuel ratio, 21.43lt/hr naphtha can be saved.

iii. Integration for heat recovery

Company distillery is multi-pressure distillation which is integrated materially. But still have opportunity to conserve energy. To reduce waste material temperature (protecting environmental pollution) and recover energy for inputs, integration is proposed. To reduce energy consumption, on hydroselction column the input alcohol from concentration column (FI – 1531) is proposed to increase its temperature to 80°C. Boiler input water is preheated to 58°C by steam from boiler. By integration it is possible to preheat this water to 80°C from waste energies. Specific heat capacity of alcohol mixtures can be derived from equation (6.69) below. Specific heat capacity of ethanol (C_{p1}) as well as water is 2.46kJ/kg K and 4.18kJ/kg K (Miyazawa, 2012) respectively.

$$C_{p \text{ mixture}} = \frac{m_1}{\text{mass of mixture}} C_{p1} + \frac{m_2}{\text{m mixture}} C_{p2} \quad (6.69)$$

Where; m_1 is mass of alcohol and m_2 mass of water. Therefore, C_p of (FI – 1531) is 3.17kJ/kg K. From total 4,656lt/hr white stillage waste from distillery, 420lt/hr with 75 °C is left to drain from material balance and other integrations above.

Table 6. 11. Heat integration parameters (case-2)

Stream No.	Type	Mass flow rate (kg/hr)	Specific heat capacity (kJ/kg °C)	Heat capacity (kW/ °C)	Supply temperature (°C)	Target temperature (°C)	Heat load (kW)
1	Hot	7,899	3.14	6.89	67	30	254.93
2	Hot	420	4.18	0.49	75	30	22.05
3	Cold	4500	4.18	5.23	30	80	261.5
4	Cold	1264	3.17	1.11	43	80	41.07

Where; stream 1 is dark stillage; stream 2 is white stillage; stream 3 is boiler feed water; and stream 4 is (FI-1531).

Let take 10 °C minimum temperature differences as given in Linnhoff for chemical industry (B. Linnhoff, 1994). Minimum hot and cold utility requirements are calculated by the steps below.

- a) Convert the actual stream temperatures T_{act} into interval temperatures T_{int} by subtracting half the minimum temperature difference from the hot stream temperatures, and by adding half to the cold stream temperatures:

$$\text{Hot streams } T_{int} = T_{act} - \frac{\Delta T_{min}}{2} \quad (6.70)$$

$$\text{Cold streams } T_{int} = T_{act} + \frac{\Delta T_{min}}{2} \quad (6.71)$$

Table 6. 12. Interval temperatures (case-2)

Streams	Actual temperature (°C)		Interval temperature (°C)	
1	67	30	62	25
2	75	30	70	(25)
3	30	80	35	(85)
4	43	80	48	85

- b) Note any duplicated interval temperatures. These are bracketed in the table.
- c) Rank the interval temperatures in order of magnitude, showing the duplicated temperatures only once in the order; see table (6.14) below.
- d) Carry out a heat balance for the streams falling within each temperature interval. For the n^{th} interval, from equation (6.27) above, net heat in the n^{th} interval is written in table (6.14).

Table 6. 13. Net heat calculation in the n^{th} interval (case-2)

Intervals	Interval temperature (°C)	ΔT_n (°C)	$\sum C_{p_c} - \sum C_{p_h}$ (kW/°C)	ΔH (kW)	Surplus or Deficit
	85				
1	70	15	6.34	95.1	D
2	62	8	5.85	46.8	D
3	48	14	-1.04	-14.56	S
4	35	13	-2.15	-27.95	S
5	25	10	-7.38	-73.8	S

e) “Cascade” the heat surplus from one interval to the next down the column interval temperature; as seen in figure (6.12) below. Cascading heat from one interval to the next implies, heat can be transferred between the hot and cold stream temperature difference.

Interval Temp

85	<u>0 kW</u>		<u>141.9 kW</u>	
70	<u>95.1 kW</u>	-95.1 kW	<u>95.1 kW</u>	46.8 kW
62	<u>46.8 kW</u>	-141.9 kW	<u>46.8 kW</u>	0 kW
48	<u>-14.56 kW</u>	-127.34 kW	<u>-14.56 kW</u>	14.56 kW
35	<u>-27.95 kW</u>	-99.39 kW	<u>-27.95 kW</u>	42.51 kW
25	<u>-73.8 kW</u>	-25.59 kW	<u>-73.8 kW</u>	116.31 kW
	(a)		(b)	

Figure 6. 13 Cascading heat (case-2)

From figure (6.13) (b), pinch temperature occurs at interval temperature 62°C. For maximum heat recovery and minimum use of utilities the following rules are mandatory according to Linnhoff. And, these are: do not transfer heat across the pinch; do not use hot utilities below the pinch; and do not use cold utilities above the pinch.

Heat exchange network: Grid representation is convenient to represent a heat exchanger network as a grid as seen in figure (6.14) below. The heat exchange network design for maximum energy recovery is designed by networking above the pinch (where, $C_{p_{\text{hot}}} \leq C_{p_{\text{cold}}}$) and networking below the pinch (where, $C_{p_{\text{hot}}} \geq C_{p_{\text{cold}}}$). And, supply external heating only above the pinch and external cooling only below the pinch is possible to heat or cool a fluid.

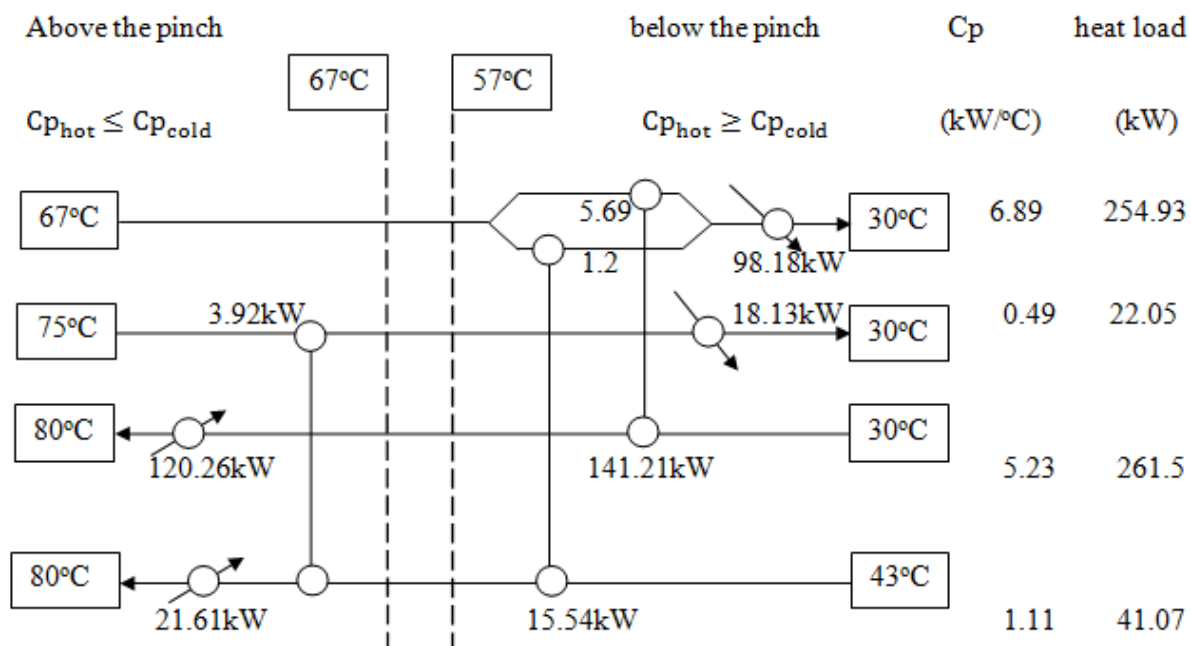


Figure 6. 144. Heat exchange network (case-2)

Minimum hot utility requirement is 141.87kW and minimum cold utility requirement is 116.31kW by omitting the white stillage as it is.

Boiler input water preheating needs 172.425kW energy from boiler steam as calculated in equation (6.56) and steam energy consumed in hydroselction column was 589.864kW as calculated in equation (6.31). But, by integration, boiler feed water preheating energy is reduced to 31.215kW; and hydroselction input energy is reduced to 570.404kW. Thereby, total saved energy is 160.67kW.

Density and GCV of naphtha are 0.818kg/l and 46.14MJ/kg respectively. And chemical energy per litre of naphtha is 37.74MJ. 160.67kW saved energy is 578.412MJ/hr and this is equal to 15.33 litre naphtha per hour or 19.16millilitre of naphtha per litre of alcohol production.

6.2.5. Motors and pumps detailed energy audit

6.2.5.1. Introduction

Motors of the factory are used to derive pumps, fans, blowers and compressors. Motors convert electrical energy to mechanical energy with the help of electric magnetic field. Magnetic field is created when current is passing through three phase AC induction motor. Power of motors ranged from 0.18 kW to 75 kW; power factor from 0.73 to 0.91; and efficiency from 84 to 94%

as seen in nameplate of motors. To know parts of electric energy losses, need detail assessment on motors of pumps, blowers and compressors.

Pumps of the factory are used to transfer liquids from one section or equipment to desired part. Designed capacities of volume flow rate and head are ranged from 0.3m³/hr to 62.5 m³/hr and head 3.1 m to 87.9 m respectively. Operating hours of the pumps ranged from 6 minute to 24 hr per day. Nameplate data and direct measured data are collected in appendix (B) to analyze energy performance of the pumps with their motors.

In order to conduct the energy analysis and thereby find the efficiency of pumps and motors, nameplate power of motors, load factor of the motors, actual power factor of motors, volume flow rate of the fluid, density of fluid, power gained by the fluid, mechanical power, pump efficiency, and overall efficiency are performed as follow.

6.2.5.2. Performance evaluation of motors

6.2.5.2.1. Data collected on motors

Nameplates are: power, efficiency, current, voltage, and power factor. And measured data using portable watt meter are: current, terminal voltage and power. Nameplate (rated) and measured values of motors are collected in appendix (D). We can see that the actual power factors and the nameplate power factors in appendix (D) are different. This shows, power utilization performance of motors is inefficient. Actual power factor (PF_{actual}) is calculated as equation (6.72) below.

$$PF_{\text{actual}} = \frac{P_m}{V_m \times I_m \times 1.72} \quad (6.72)$$

Where; P_m is measured power; V_m is measured voltage; I_m is measured current and 1.72 phase angle.

6.2.5.2.2. Load factors of motors

Load Factor is a measure of effective utilization of the load and distribution equipment, i.e. higher load factor means better utilization of the transformer, line or cable (Energy). Load factor (LF) is obtained by equation (6.73) below.

$$LF = \frac{P_m}{P_n} \quad (6.73)$$

Where; p_m is actual (measured) electric power and p_n is nameplate (rated) power of motors.

The average optimum load factor of motors is 40% (Energy). But, as seen in appendix (G), load factor values of P-1203, P-1205, P-1401, P-1402, P-1404, P-1405, P-1510, P-1570, P-1581, P-2210 and P-2401 is below the recommended value. The value shows, motors with less load factor are working inefficiently which results energy wastage. Pumps with greater than 40% load factor, are under recommended value and no need to calculate.

6.2.5.2.3. Mechanical Power of Motors

Due to the absence of torque meter, nameplate motor efficiency is used to calculate the mechanical power of the motors.

$$P_{mc} = P_m \times \text{efficiency} \quad (6.74)$$

Where; P_{mc} is mechanical power, P_m is measured electric power of motors and efficiency is nameplate efficiency of motors. And, mechanical power of motors is recorded in appendix (G).

6.2.5.3. Evaluation of pumps performance

6.2.5.3.1. Collected data on pumps

Data collection methods are included nameplate and measured pump head and fluid flow rate. Fluid density and operating hour of working pumps are also collected in appendix (E).

Total head = static head (height) + dynamic head.

Where; static head is vertical distance to targeted point and dynamic head is generated as a result of friction within the system. Dynamic head is equal to 7% to 10% losses of Horizontal pipe length plus Friction losses plus Negative suction length plus Discharge pressure required at the outlet of the pipe. By considering vertical (static head) and horizontal pipe losses of dynamic head, measured head is recorded in appendix (E).

To increase pump efficiency and reduce energy cost, it is evaluated with respect to electrical efficiency, hydraulic efficiency and mechanical efficiency. Pumps operating with optimum part load have no significant effect on the overall energy performance. Motors only with less than 40% load factor are considered on performance evaluation of pumps.

6.2.5.3.2. Hydraulic power (power gained by the fluid)

$$P_{out}(P_{hyd}) = \rho \times g \times H \times \dot{Q} \quad (6.75)$$

Where; P_{out} (kW) is hydraulic power; ρ (kg/m³) is density of fluid; H (m) is measured head of pump; Q (m³/sec) is volumetric flow rate; and g (9.81 m/s²) is acceleration due to gravity.

6.2.5.3.3. Pump Efficiency

Pump efficiency is given by equation (6.76) and recommended efficiency is 60% (Energy).

$$\text{pump efficiency} = \frac{P_{hyd}}{P_{mc}} \quad (6.76)$$

Where; P_{hyd} is power gained by fluid and P_{mc} is mechanical power input to pump. As we can see in appendix H, efficiency of pumps is below the recommended value.

6.2.5.4. Analysis on overall performance of motors and pumps

Overall efficiency of pumps with their motors can be calculated by dividing output power (power gained by the fluid) to input power of the motor (electrical energy).

$$\text{overall efficiency} = \frac{P_{hyd}}{P_m} \quad (6.77)$$

Where; P_m is measured electric power. Overall efficiency of pumps is less than required value as presented in appendix (H). So, needs detail assessment by professional electrical, mechanical and process engineers.

6.2.5.5. Identified ECOs

Pumps with less efficiency consume more electrical energy. Therefore, identified ECOs are to avoid pumps leakage, scheduled pump maintenance, training and detailed assessment.

6.2.5.6. Technical evaluation to improve pump efficiency

For efficient electric energy utilization of the above selected pumps, imbalance between the actual and design capacities is conducted in equation (6.78) below.

$$\text{Imbalance (\%)} \text{ of } P_i = \left(1 - \frac{\text{actual flow rate (Q)} \times \text{actual head (H)}}{\text{designed flow rate (Q)} \times \text{designed head (H)}} \right) \times 100 \quad (6.78)$$

Where, P_i is identified pump. Therefore, based on pump data in appendix (E), imbalance of P-1203, P-1205, P-1401, P-1402, P-1404, P-1405, P-1510, P-1570, P-1581, P-2210 and P-2401 is 57.8%, 72.6%, 7.3%, 16.1%, 72%, 46%, 90.7%, 76.1%, 95.1%, 84.7% and 6.2% respectively. The imbalance can be corrected by adjusting the flow rate and target of fluid transferred by the pump.

CHAPTER SEVEN

7. MALF CLEANER PRODUCTION ASSESSMENT

Based on the described cleaner production guide, there are four phases for assessment.

7.1. Phase I: Identification of waste source

7.1.1. Input output processes

Over all process flow steps and alcohol losses of MALF are drawn in figure (7.1) below. Material and energy balances at each step are calculated in chapter five and six above.

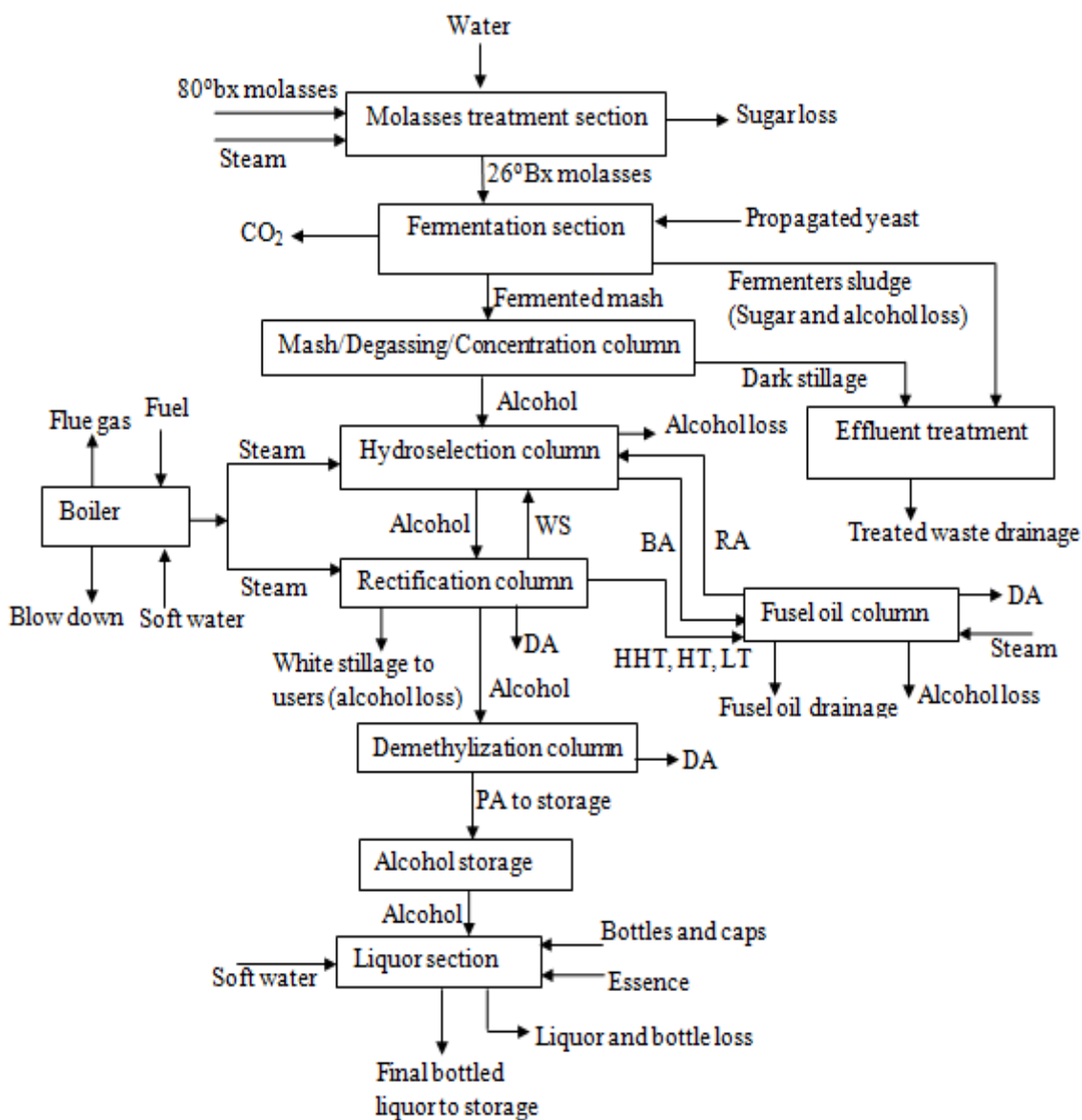


Figure 7. 1. General MALF alcohols and liquors production process flow diagram

Table 7. 1 Raw material consumption per liter of alcohol at MALF in 2010 E.C

Inputs	Units	Jul	Au	Sep	Oct	No	Dec	Jan	Fe	Ma	Apr	May	Jun	Avg.
Molasses	Kg	4.5054	4.5686	3.9758	3.458	-	3.940	4.115	4.015	3.891	4.164	3.769	6.129	4.23
Technical alcohol	Litre	0	0	0	0	1.1463	1.1944	1.1872	1.1286	1.0723	1.22	1.0223	1.075	1.131
Sulphuric acid	kg	0.005796	0.001444	0.002105	0.001492	-	0.004379	0.002208	0.001516	0.002030	0.002317	0.004169	0.005297	0.002978
Yeast	kg	0.000072	0.000072	0.000038	0.000046	-	0.000022	-	0.000024	0.000014	0	0.000091	0.000248	0.000139
Caustic soda	kg	0.01207	0.00654	0.00467	0.00649	-	0.00307	0.00063	0.01307	0.00068	0.00588	0.00680	0.00180	0.00561
DAP	kg	0.00294	0.00272	0.00305	0.00139	-	0.00176	0.00217	0.00259	0.00359	0.00269	0.00408	0.00001	0.00245
Salt	kg	0.0042	0.004187	0.005186	0.004635	-	0.001036	0.001416	0.002485	0.001807	0.003314	0.002435	0.006175	0.003352
Furnace oil	lt	0.341325	0.415873	0.437890	0.361323	0.332443	0.349451	0.333298	0.358863	0.385068	0.374228	0.276593	-	0.36058
Naphtha	lt	0.459347	0.369896	0.344826	0.347222	0.350877	0.333618	0.344187	0.216384	0.364215	0.353322	0.371711	0.421051	0.35639
Electricity	kWh	0.0692	0.4237	0.4527	0.7193	0.5685	0.1672	0.2484	0.4543	0.3243	0.2576	0.4967	0.7012	0.4376
Municipal water	Litre	2.083	-	-	2.248	1.837	-	0.804	1.054	1.247	1.062	2.403	2.600	1.704

Table (7.1) in the above shows average raw material and utility consumptions per liter of alcohol in the fiscal year. Only municipal water was known in the company. Where, consumed borehole water and used white stillage were not recorded. And the collected data in this table helps to know cost of raw material used to produce wasted product.

7.1.2. Cost of raw material in the fiscal year

The average daily consumption of inputs per liter of alcohol produced is summarized in table (7.2) below. Raw materials can be molasses or technical alcohol. And the same fuel oil is furnace oil or naphtha is used per time. Therefore, it is better to use cost of molasses and naphtha due to mostly used in the production process to know the cost of raw material per litre of product. Yearly average input consumptions per liter of product presented in table (7.1) above are taken from appendices (A) and (C) below.

Table 7. 2 Unit cost of raw material and utility per liter of alcohol

Raw material inputs	Units	Average input consumptions per liter of PA alcohol	Unit cost (birr)	cost (birr) per liter of alcohol
Molasses	Kg	4.23	0.700	2.961
Technical alcohol	Liter	1.131	14.590	-
Sulphuric acid	Liter	0.002978	11.490	0.0422
Yeast	Kg	0.0001392	66.403	0.0092
Caustic soda	Kg	0.005609	11.670	0.0655
DAP	Kg	0.002453	11.670	0.0286
Salt	Kg	0.003352	3.500	0.0117
Furnace oil	Liter	0.36058	13.585	-
Naphtha	Liter	0.35639	16.5875	5.9116
Electricity	kWh	0.4376	0.5778	0.2529
Municipal water	Litre	1.704	0.0116	0.0198
Borehole water	Liter	18.0	0.0116	0.2092
Cost of raw material per liter of alcohol product				9.5117

7.1.3. Waste materials and their lost profit

Waste stream costs are purchasing cost of raw material, product cost, processing cost, and treatment cost. Detailed analysis and amounts of each waste streams are assessed in chapters five and six above. Cost of wasted materials help to understand the potential of the problem and to create saving methods.

Based on literature review, 1% residual sugar increase 16g/lit COD in stillage and for every 1%

ethanol left in the stillage, 20 g/l COD increase. And from over all material balance, there is 180,048 lt/day dark stillage is drained with 1.0908% of residual sugar. And this increased COD amount in waste by 3,142.34 kg or 2,984.18 lt at 1.053kg/lt dark stillage density. 0.479% (535.79lt/day alcohol) of waste white stillage is alcohol. And this alcohol increased COD by 5,132.87 lt/day. Then total 8,117.048 lt of COD is increased daily due to inefficient production process. Operating cost to treat distillery wastes is in the range of 0.03 to 1.67\$/m³ (Fuat Ozyonar*, 2011). And assume 0.85\$/m³ average cost of waste treatment is used in the calculation.

Table (7.3) below indicates unit cost and total cost of wastes in each section. This table includes alcohol waste, energy loss in the form of fuel, water waste and their costs; as well as cost of raw material used to produce wasted alcohol.

Table (7.4) below indicates saved profits depend on the proposed options in each section. In this table reduced coolant water is indicates water saved by integration and its saved cost should be considered only once. Options (31) also considered only if the distillery output white stillage is free from alcohol as well as the integration between boiler and distillery is omitted.

Table 7. 3. Profit lost to waste streams

Waste streams	Waste material	Unit	flow rate	Absolute alcohol loss (lt/day)	Unit cost (birr/unit)	Total cost (birr/day)
Molasses treatment section	Fermentable sugar loss	kg/ day	0.370	0.220	65.0	14.865
	Seal water loss	m ³ / day	21.6	-	11.60	250.56
	Surface energy loss in-terms of watt and fuel oil	W	662.72	-	-	-
lt/ day		1.512	-	16.5875	25.08	
Fermentation section	Sample molasses loss	kg/day	18.732	1.75	65.0	118.24
	Fermentable sugar loss	kg/ day	2,252.0	946.76	65.0	63,970.27
	Seal water loss	m ³ / day	30.0	-	11.60	348.0
	Cleaner water	m ³ / day	12.0	-	11.6	139.2
	Sludge drained	lt/day	357.5	30.388	65.0	2,053.21
	CO ₂ emission	kg/ day	12,751.7	-	12.0	153,020.4
Distillery section	White stillage	m ³ /day	111.75	535.79	65.0	36,202.26
	Surface energy loss in-terms of kW and fuel oil	kW	5.208	-	-	-
		lt/ day	11.923	-	16.5875	197.78
	Fuel used for alcohol reprocessing	lt/ day	0.042		16.5875	1.372
	Steam condensate	lt/ day	360	-	0.0116	4.176
	Steam condensate energy loss in terms of Watt and fuel oil	W	628.1	-	-	-
lt/ day		1.44	-	16.5875	23.89	
Boiler	Surface energy loss	kW	926.5	-	-	-
	Surface loss as fuel	lt/ day	2.122	-	16.5875	35.20
	Excess air energy loss In-terms of kW and fuel	kW	224.66	-	-	-
		lt/ day	514.32		16.5875	8,531.36
Liquor section	Total profit lose due to liquor and bottle loss per day (see table 5.13 above)					8,792.92
Raw material cost used to produce wasted alcohol				1,514.908	9.5117	14,978.53
Wastes treatment cost		m ³ /day	8.117	-	23.8	193.18
Total waste per day (birr)						288,900.5

Table 7. 4 Saved profit from proposed options

Molasses treatment section	Coolant water	m ³ /day	-	397.32	11.6	4,609.0
	Energy saved in terms of kW and fuel oil	kW	-	124.428	-	-
		Lt/day	-	284.88	16.5785	4,725.45
Distillery	Fusel oil waste	Lt/day	-	39	13.585	529.815
Boiler	Energy saved in terms of kW and fuel oil	kW	-	160.67	-	-
		Lt/day	-	367.92	16.5785	6,099.56
Option (31)	Water saved	m ³ /day	-	49.34	11.60	572.32
	Energy saved in terms of kW and fuel oil	kW	-	119.35	-	-
		Lt/day	-	273.12	16.5875	4,532.26
Total saved birr per day from proposed options						21,069.42

7.2. Phase II: Evaluation of waste causes and generation of recovery options

7.2.1. Identification of cause and generation of CP option

Based on factory collected data from the factory, inspection and onsite monitoring, laboratory test results and factory standard data material auditing were investigated for all sections. Probable causes of all wastes were selected and options of cleaner production discussed in table (7.5) below.

Table 7. 5. Cause identification and CP option generation

Process sections	Waste materials	Probable causes	CP options
Molasses treatment section	Sample molasses loss	➤ Low raw material consideration	1. Recycling to fermenters
	Seal water loss	➤ molasses mix with cooling water	2. constructing recycle water storage
	Surface energy loss	➤ un-insulated steam and hot fluid pipes	3. Insulating the steam and hot fluid pipes
	Less energy utilization	➤ Low raw material consideration ➤ Lack of skills	4. Auditing energy 5. consulting engineers 6. training new technologies 7. heat integration
Fermentation section	Sample molasses loss	➤ Low raw material consideration	8. Recycling to fermenters
	Fermentation sugar loss	➤ Less fermentation efficiency ➤ Untreated molasses input	9. controlling fermentation parameter 10. use treated molasses
	Seal water loss	➤ molasses mix with cooling water	11. constructing recycle water storage
	Cleaner water consumption	➤ sludge remained in tankers bottom	12. making mixers functional 13. applying molasses treatment purpose
	CO ₂ to air	➤ chemical reaction	14. recovering for sale
Distillery section	Dark stillage	➤ molasses composition	15. reducing treatment cost 16. Producing methane
	White stillage	➤ water addition to molasses treatment and distillery	17. Reuse
	Fusel oil waste	➤ chemical reaction	18. utilizing as naphtha fuel
	Surface energy loss	➤ un-insulated steam and hot fluid pipes	19. Insulating the steam and hot fluid pipes
	Steam condensate	➤ Vapor steam condensed in pips	20. Recycling to degasser
	Less energy utilization	➤ Low raw material consideration ➤ Lack of skills	21. Auditing energy 22. consulting engineers 23. training new technologies 24. integrating
Boiler	Less combustion efficiency	➤ less input temperature ➤ input water hardness	25. Preheat input fuel 26. Following softener
	Less energy utilization	➤ Low boiler operation performance ➤ Excess input air ➤ Surface losses ➤ Scale forming	27. Controlling boiler input output parameters 28. Controlling input air 29. Insulating 30. Integration

		➤ Higher flue gas loss	31. Reusing distillery white stillage 32. Installing Economizer
Liquor section	Alcohol loss	➤ Leakages and bottle broken	33. Timely maintaining and following of rolling belts and operation machines
	Bottle and liquor loss	➤ Less efficiency of electrical and mechanical motion	
	Wrong data recoding	➤ Wrong liquor preparations ➤ Wrong liquor testing methods	34. Testing before, during and after preparation of liquors
electric al energy	Higher electric consumption	➤ Poor maintenance of pumps and compressors	35. Scheduled maintenance

7.2.2. Filtration of generated CP options

From the above generated CP options, the following in table (7.6) are filtered as direct implementable options with less cost; options which require feasibility studies and options which are needed further studies.

Table 7. 6. Filtration of CP Options

CP Option list No.	CP options	Direct implementable	Requiring feasibility analysis	Requiring further studies
1	Recycling to fermenters	✓		
2	Constructing recycle water storage		✓	
3	Insulating the steam and hot fluid pipes		✓	
4	Auditing energy	✓		
5	Consulting engineers	✓		
6	Training new technologies	✓		
7	Heat integration		✓	
8	Recycling to fermenters	✓		
9	Controlling fermentation parameter	✓		
10	Use treated molasses	✓		
11	Constructing recycle water storage		✓	
12	Making mixers functional	✓		
13	Applying molasses treatment purpose	✓		
14	Recovering for sale		✓	
15	Reducing treatment cost	✓		
16	Producing methane			✓
17	Reuse			✓
18	Utilizing as naphtha fuel		✓	
19	Insulating the steam and hot fluid pipes		✓	
20	Recycling to degasser		✓	
21	Auditing energy	✓		
22	Consulting engineers	✓		
23	Training new technologies			✓
24	Integration		✓	
25	Preheat input fuel			✓
26	Following softener	✓		
27	Controlling boiler input output parameters	✓		
28	Controlling input air	✓		
29	Insulating		✓	
30	Integration		✓	
31	Reusing distillery white stillage		✓	
32	Installing Economizer			✓
33	Timely maintaining and following of rolling belts and operation machines	✓		
34	Testing before, during and after preparation of liquors	✓		
35	Scheduled maintenance	✓		

7.3. Phase III: Evaluation of CP options

7.3.1. Evaluation of filtered CP options

The filtered cleaner production options are evaluated based on economic, environmental and technically basis.

7.4.1.1. Options list number 2 and 11

Title of option: constructing recycles water storage

Current working condition: - Currently pure water is drained to environment. And the proposed operation is storing before using in other water storage which ensures its quality.

Advantages: - Reduces water consumption and environmental pollution.

Economical Analysis: - For 1m³ water storage tankers consumes four quintal cement, 2m³ sand with average cost of 215 birr/quintal and 67 birr/m³ respectively. Total labor cost to construct this water storage is 500 birr/ m³ based on market cost. If the factory checks the quality of this water and reuse daily, the proposed storage tanker size will be 51.6 m³ which is equal size to daily waste water.

$$\text{paybak priod (PP)} = \frac{\text{Implimentation cost(birr)}}{\text{Saved cost } \left(\frac{\text{birr}}{\text{year}}\right)} = 0.35\text{yr.}$$

7.4.1.2. Options list number 3, 19 and 29

Title of the options:- Insulation the steam distribution and hot fluid pipes.

Current operation: - Some steam and fluid pipes are exposed to air and thereby energy is loss.

Proposed operation: - Insulating these surfaces thereby reduces fuel consumption.

Advantages: - Besides fuel consumption is reduced, environmental temperature that increases due to this exposed energy is reduced and it is one of CP practices.

Economic Analysis:- See individually in equation (6.23), (6.24), (6.41), (6.42) and section (6.2.3.14) (i) above.

7.4.1.3. Option list number 7

Title of the option:- heat integration.

Current working condition: - Currently energy used in molasses treatment section is 271.978 kW and this is reduced to 147.55kW by integration. Thereby, saved energy is 124.428 kW. And 11.87 litres naphtha per hour or 14.84millilitre of naphtha per litre of alcohol production can be save. (See molasses heat recovery in detail).

Proposed operation: - Input molasses to molasses treatment section is at atmospheric temperature and to increase this temperature up to 80°C needs high steam injection. Due to this high steam, two drums were used within four years. Where one is out of service and the other has leakage but on working. Therefore, proposed operation is integrating fluids to reduce fuel consumption and environmental pollution. To apply this operation, additional one drum with its mixer and one pump is required.

The current plate heat exchanger used to reduce temperature of diluted molasses out from (D - 1202) is the same in capacity with the proposed input molasses heater. The two current plate heat exchangers have 214kW capacity each. From proposed calculation, five plate heat exchangers, one drum (equal to D -1201) with its mixer and one pump (which is equal to P -1203) is required for integration.

Assumption: - assume solution mixed in the new proposed drum is efficient.

Advantages: - company fuel consumption per liter of alcohol product will be smaller than the current data and get high profit.

Economic Analysis: - Cost of required gasket plate heat exchanger range from \$100 – \$5,000 per heat exchanger. And averagely \$7,650 is needed for three exchangers (Alibaba, 2019). Additional cost for transportation and other related costs is 47% of the maximum equipment purchasing cost (P.M.Hawranek, 1991). So, total cost is 337,365birr for three heat exchangers based on 30 birr per dollar. See more comparing requirements of proposed exchangers with the current one at appendix (F). Cost of similar drum with its mixer and pump is 200,000birr and 82,500 birr respectively depending on Frilli Company cost. Total implementation cost is 619,865 birr. Saving birr from proposed integration depending on designed alcohol production is 1,758,162.47 birr/yr.

$$\text{paybak priod (PP)} = \frac{\text{Implimentation cost(birr)}}{\text{Saved cost}\left(\frac{\text{birr}}{\text{year}}\right)} = 0.35\text{yr.}$$

7.4.1.4. Option list number 14

Title of the option:- CO₂ recovering for sale

Current working condition: - Fermentation section of MALF is closed for the purpose of hygiene. There is scrubber column where CO₂ coming from fermenter is washed for any light alcohol with it and to condense the hot CO₂ by water before emitted to atmosphere. At current time operation of the scrubber column is not more functional due to less consideration of pollutant to production employee of the factory and environment.

Proposed Operation: - Proposed option is to collect and treat for production of commercial CO₂ product in the form of gas, solid or liquid. For the recovery of CO₂, various combined processes are used as washing, liquefaction, compression and refrigeration (Shah, 2012).

Assumption:- assume the CO₂ collecting method is efficient and CO₂ selling market is available.

Advantages: - Carbon dioxide is green house gas, odorless, colorless, nonflammable, acidic, tasteless and valuable gas. Fresh air contains 0.033% carbon dioxide by volume and 2.1% global CO₂ emissions rate increased annually. It is toxic and harmful to health and environment, when CO₂ concentration is above 6%. Carbon dioxide released from ethanol fermentation process can be captured, stored and utilized for beverages, oil recovery, refrigerant, fertilizer and food processing companies. CO₂ recovery from fermentation results increase in profit and revenue, besides control the environmental air pollution and health disease problems (Shah, 2012).

Economic Analysis: - The annual expected revenue from CO₂ is 55,087,344 birr per year. Cost of CO₂ recovery plant from fermentation with 550 kg/hr is \$200,000 (Alibaba, 2019). Additional cost for transportation and other related costs is 47% of the maximum equipment purchasing cost (P.M.Hawranek, 1991). Therefore, total implementation cost is 8,820,000 birr. Then, payback period will be 0.16 year.

7.4.1.5. Option list number 18

Option Title: Utilizing fusel oil drained from distillery as naphtha fuel.

Current working condition:- Fusel oil out from distillery was drained every four hour. Indeed, it is pollutant to employees of the company and to the environment. Theoretically fusel oil obtain in the distillery is 1% of pure alcohol. But, practically average 39lt of fusel oil was drained daily.

Proposed operation: - Based on the GCV result of fusel oil (which is 40.31MJ/kg), it can use

alone or by mixing with naphtha for fuel purpose. As we can see the 1:1 mixing ratio in table (5.14) above, obtained GCV result is 41.61MJ/kg which is equivalent to furnace energy. So, by further studying the, optimum mixing ratio and other mix properties like diffusivity and viscosity, it is better to use as fuel source.

Assumption:- assume mixed solution has no effect on burnability efficiency.

Advantages: - Fusel oil reuse as source of energy helps environmental protection; reduce health attacking of the employees in the factory and added profit to the company.

Economic Analysis: - Depending on its GCV which is equal to furnace oil GCV, price is proposed to be 13.585birr/lt. No need implementation cost, except may be for hose used to transfer the oil to naphtha storage. Therefore, payback period is almost zero.

7.4.1.6. Option list number 20

Title of the option: steam condensate recycling to degasser.

Current working condition:- 360 lt/day steam condensate of distillery is drained simply to environment with 61°C temperature.

Proposed operation: - Recycling to boiler feed water.

Advantages: - Besides protecting environmental pollution, fuel consumption to preheat boiler input water, water consumption will be reduced by recycle this condensate.

Economic Analysis: - From equation (6.43) above, 0.06455lt/hr naphtha or 0.081ml/lt of alcohol can save by recycle this condensate. Depending on alcohol production of the fiscal year, can save 6,214birr/yr using permanent employee of the factory. Therefore, payback period is almost zero.

7.4.1.7. Options list number 24 and 30

Title of the option: Integration

Current working condition: - Energy used to preheat boiler feed water is 172.kW. And steam direct injected to hydroselction column is 589.864 kW. Dark stillage and white stillages are drained to waste with 67°C and 65°C (white stillage from distillery out at 75°C) respectively. Input boiler water is at temperature of 58°C using steam from boiler itself.

Proposed operation: - The proposed boiler water input temperature is 80°C and proposed (FI-1531) temperature is 80°C where as the current temperature is 43°C. Therefore, proposed

operation is integrating fluids to reduce fuel consumption and environmental pollution. To apply this operation, three plate heat exchangers are required for integration.

Economic Analysis: - Cost of required gasket plate heat exchanger ranges from \$100 – \$5,000 per heat exchanger. And averagely \$7,650 is needed for three exchangers (Alibaba, 2019). Additional cost for transportation and other related costs is 47% of the maximum equipment purchasing cost (P.M.Hawranek, 1991). So, total cost is 337,365birr for three heat exchangers based on 30 birr per dollar. Saving birr from proposed integration depending on designed alcohol production is 2,197,034.28 birr/yr.

$$\text{payback priod (PP)} = \frac{\text{Implimentation cost(birr)}}{\text{Saved cost}\left(\frac{\text{birr}}{\text{year}}\right)} = 0.15\text{yr.}$$

7.3.1.1. Option list number 31

Title of the option: Reusing distillery white stillage as boiler input water

Current working condition:- Boiler input water was preheated to 58°C using steam from boiler. Whit stillage from distillery is soft water, because it is collected at the top of the column. White stillage of C-1560 is neutral pH where; whit stillage of D-1560 was acidic. 3.112m³ white stillage was used for molasses dilution and to wash fermenter where the rest is drained to waste.

Assumption:- assume may alcohol with white stillage out from distillery has no effect on boiler.

Proposed operation: - is recycling distillery white stillage as boiler feed water. Energy used to preheat boiler feed water is 172.kW and water consumption is 4.5m³/hr. if this option (option 31) will be implemented on the factory, 119.35kW energy which is equivalent to 11.38lt/hr naphtha and 2.06m³/hr water will be save. And it is the best CP practice which results efficient resource utilization and protects environmental pollution.

Advantages:- besides protecting environmental pollution, fuel consumption to preheat boiler input water and water consumption is reduced. And it is one of CP practices.

Economic Analysis: - Total saved birr per hr will be 212.74. Maximum required implementation cost is cost of pipe from distillery to boiler degasser and this is 15m pipe. Average cost of pipe as referred in option (30) is 21,000 birr per meter. Therefore, payback period will be 0.17yr.

7.4. Phase IV: Implementation and continuation

This phase is constructing action plan to implement cleaner production.

7.4.1. Introduction

To improve the resources utilization and thereby increase productivity and reduce environmental pollutions, identified conservation opportunities must be categorized in to short term, medium term and long term action plan.

a) Short term action

The short term action plan is done by permanent employee with no capital investment or low investment cost. Improvement program can be implemented quickly and are screened in table (7.6) above as direct implementable CP options.

b) Medium term action plan

The medium term action plan is done by modification of existing equipment and by addition other proposed operations. This action plan needs middle management and top management commitment. This term indicates the screened CP options as requiring feasibility studies in table (7.6) above.

c) Long term action plan

To increase production process efficiency and to reduce environmental pollution load up to maximum achievable values, the factory needs further studies. By monitoring CP progress, the factory can sustain its competitiveness in the market. This term screened as requiring further studies in CP options table (7.6) above.

CHAPTER EIGHT

8. CONCLUSION AND RECOMMENDATIONS

8.1. Conclusion

Cleaner production is a tool used to manage a resource and an environment which helps to grow environmental friendly. Waste sources, amounts and conservation options of all sections of the factory are investigated by cleaner production.

Controlling and monitoring production process activities in the factory are generally low in such that the factory is in low production capacity comparing to its design. Thereby, production capacity of the factory in the fiscal year was 71.37%. Overall input-output conversion efficiency of alcohol production is 81.64% and this efficiency is categorized under 1970s and 1980s designs.

Even though input molasses of the factory has good result of total reducing sugar (50.86%) and fermentable sugar (48.29%); resource utilization efficiency from reception up to end product is inefficient. Utilization efficiency of molasses, technical alcohol, energy and water are lower than factory standards.

Alcohol content of yeast propagation is much higher than its standard and yeast population is 50% lower than factory standard. This result causes to get 72% fermentation efficiency which is much lower than expected performance. Due to less conversion of sugar to ethanol in fermentation section, 1.0908%wt. sugar is loss daily from fermenters which is greater than company standard to be 0.2 to 0.5%wt. Thereby, 946.76 lt/day absolute alcohol is lost daily from fermentation.

Distillation efficiency of the factory is 97.2% which is less than the theoretical described to be 99%. As a result, 535.79lt absolute alcohol is drained to waste daily from the distillery. As well as from liquor section 8,792.92 birr is lost daily due to bottle and liquor losses.

The factory boiler thermal efficiency found to be 71.75% where as combustion efficiency is 82.66% which is lower than the theoretically recommended efficiency of fire tube boiler. The energy consumption of the factory is higher than factory standards. Standard fuel energy consumption per liter of alcohol is 8,648.60 kJ. But, the actual is 14,635.552 kJ/lt of alcohol. Standard factory electric energy consumption is 1,456.17kJ/lt of alcohol. But, the actual is 1,575.50kJ/lt. This indicates that, energy utilization efficiency of the factory is inefficient. Due to

less thermal and electric energy utilization 9,382,925.021 birr per year is lost in the fiscal year.

From total profit lose investigation, 288,900.5 birr is lost daily due to less resource utilization efficiency.

To increase the profitability of the factory and to reduce environmental loads options are generated to recover resource by cleaner production practices.

There are material and energy integrations proposed in this study. Two energy integrations (in molasses treatment and boiler sections) are proposed to recover energy thereby reduce resource consumption and environmental pollutions. Therefore, the factory can get 21,069.42 birr daily by applying these integrations.

Wastes discharged from the factory are pollutant according to its test result and they should be treated before drained to environment. Generally the factory is in low performance on raw material and energy utilization. Therefore, the screened cleaner production options can solve the entire problem described above for better performance.

8.2. Recommendations

To implement cleaner production needs top management commitment. Mekanisa alcohol and liquor factory should implement first simplest cleaner production options thereby increasing factory profit and reducing environmental wastes by efficient utilization of raw material as well as energy.

The factory should review the screened cleaner production options and implement them for the help of profit increment and pollution prevention.

Even waste treatment plant is installed; the factory should considered resource utilization efficiency to reduce waste treatment cost. Because at higher sugar and alcohol wastes, treatment cost will be increased.

The factory should reduce excess air input to the boiler to decrease energy wastage with flue gas. Generally this study recommends applying the proposed recycles; insulations as well as integrations for better energy utilization and pollution prevention.

Principle of cleaner production is a never ending process where there will always be new opportunities to conserve energy, improve production efficiency, and to reduce environmental

pollutions. Therefore, the factory should take training on cleaner production practices to bring overall efficiency in the plant.

➤ **Potential for further research studies**

To increase factory profit; to protect environmental pollution; and generally to sustain the factory in the market, the factory should assess further works on dark stillage, white stillage and fusel oil drained from the factory. Selection of feasible profit gaining methods on the areas, thereby reducing any treatment cost and environmental pollution is required for the future.

Distillery waste may use as source of fertilizers, energy (methane production). That helps to reduce pollution and treatment cost of wastes.

Even the result of fusel oil is checked with high calorific value, it needs future work to be mixed with naphtha or used alone as energy sources. The proposed mixing ratio of fusel oil and naphtha oil is considered only the calorific value but comparison on diffusivity of fusel oil and naphtha as well as other parameters should be considered.

Bibliography

- Abiye, Y. (2011, December). Addis Ababa University. Retrieved March 2019, from Addis Ababa institute of Technology.
- Alebachew. (2011). Chemical Engineering. Retrieved December 2018, from Addis Ababa University.
- Alemu, W. (2018, July 6). School of Chemical and Bioengineering, Environmental Engineering stream. Retrieved December 24, 2018, from Addis Ababa University.
- Alibaba. (2019). Retrieved may 31, 2019, from Alibaba.com:
https://www.alibaba.com/products/gasket_plate_heat_exchanger_for_cooling.html
- Ashrae. (2018). Ashare Standard thermal environmental condition. in Ashrae, American society of heating, Refrigerating and air conditioning. Northeast, Atlanta, Georgia: Inc. 1791 Tullie Circle.
- ASTM. (1997). Standard guide for evaluation of fuel ethanol manufacturing facilities . west conshohocken: American Society for Testing and Materials.
- B. Linnhoff, D. T. (1994). Pinch analysis and process integration. USA: British library cataloguing.
- Berkel, R. V. (1995). Introduction to cleaner production assessments with applications in the food processing industry. 3.
- Chowdhary, P. (2018, February 16). Distillery Wastewater: it's impact on environment and remedies. pp. 2-4.
- Data, N. (2011). Chemical industry digest. Chemicals from renewable resources , 75.
- Deshpande, G. B. overview of continuous Alcohol Fermentation and Multipressure Distillation Technology. India: Praj.
- Energy, A. P. (N.D.). Determining electric Motor load and efficiency. Retrieved 06 03, 2019, from [www.energy.gov](http://www.energy.gov/sites/prod/files/2014/04/f15/10097517.pdf): <https://www.energy.gov/sites/prod/files/2014/04/f15/10097517.pdf>
- Eremektar G, T. O. (1995). The pollution profile of alcohol distilleries treating beet sugar molasses. Water Sci Technol , 32.
- Espan˜a-Gamboa, E. (2011). Vinasses: Characterization and Waste Management & Research , 5.
- experts(CGGE), c. g. (2017, April 24-28). Training material for National Green House Gas Inventory. Retrieved April 27, 2019, from United Nations Frame work convention on climate change.

factory, n. a. (n.d.). 1-5. Retrieved October 12, 2018, from <http://www.nalf.com.et/about-us/background-of-national-alcohol-and-liquor-factory.html?start=4>.

Forests, M. o. (2009, september). Technical EIA guidance manual for distilleries. prepared for Ministry of Environment and Forests government of Indian , p. 16.

Frankfurt, T. G. (2000). Energetic reuse of distillery wastewater. CDC-TBW , 3.

Fuat Ozyonar*, B. K. (2011). Operating cost analysis and treatment of domestic wastewater by Electrocoagulation Using aluminum electrodes. Journal of environmental study volume 20 , 173-179.

IJIRAE. (2015). Treatment Processes and Technologies for Decolourization and COD Removal of Distillery Spent Wash. International Journal of Innovative Research in Advanced Engineering (IJIRAE) , 1.

Jing K., M. M. (n.d.). Estimation of CO₂ Emissions from China's Cement Production: Methodologies and Uncertainties.

Kazmierczyk, M. P. (October 2002). National Cleaner Production Centres and Programmes. In UNIDO CP Programme (p. 17). Vienna: UNIDO.

Kim, T. H. (2008). Bioethanol production from barley hull using SAA(soaking in aqueous ammonia) pretreatment. Bioresource Technology , 99(13): 5694-5702.

LA, C. (1979). optimization of resources in the fermentation and distillation stations of an alcohol distillery. sugar y Azucar , 74(11).

LAVARACK, B. (2003). Estimates of Ethanol production from Sugar cane Feedstocks. Australia : Sugar Research Institute, Mackay, Qld.

Leng, R. C. (2008). Life cycle inventory and energy analysis of cassava-based Fuel ethanol in China. Journal of Cleaner Production , 16: 374-378.

M. Hissa*, S. N. (2018,). Agronomy Research 16(S1),. Retrieved April 27, 2019, from Combustion property analyses with variable liquid marine fuels in combustion research unit.

M.C. Barma, R. S. (2017). A review on boilers energy use, energy savings, and emissions reductions. Renewable and Sustainable Energy Reviews , 5.

Marques, S. L. (2008). Conversion of recycled paper sludge to ethanol by SHF and SSF using *Pichia stipitis*. Biomass and Bioenergy , 32(5): 400-406.

mazel, P. B. (n.d.). Comparative Perspectives on Alcohol and Culture. Philadelphia.

- Mirkena, B. (2014, December). Retrieved December 25, 2018, from Addis Ababa institute of technology .
- Miyazawa, T. (2012). Specific heat capacity at constant pressure of Ethanol by flow Calorimetry. *Journal of Chemical and Engineering* .
- Murphy and Power. (2008). How can we improve the energy balance of ethanol production from wheat? *FEUL* , 87: 1799-1806.
- Murtagh, J. (1999). Molasses as feedstock for ethanol production. In *The alcohol textbook: a reference for the beverage, fuel and industrial alcohol industry*. In: Jacques, K., Lyons, T.P. and Kelsall, D.R. ed. Third edition (pp. 89–96). Nottingham: Nottingham University Press.
- National Cleaner Production Centre. (n.d.). Retrieved April 22, 2019, from No. 251/30, KirulaRoad, Narahenpita, Colombo 05. Sri Lanka: www.ncpcsrilanka.org
- Oleskowicz-Popiel, P. P.-N. (2008). Ethanol production from maize silage as lignocellulosic biomass in anaerobically digested and wet-oxidized manure. *Bioresource Technology* , 99(13): 5327-5334.
- P.M.Hawranek, W. a. (1991). *Manual for the preparation of industrial feasibility studies*, newly revised and expanded edition. Vienna.
- Patel, S. (2018). *Treatment of Distillery Waste Water*. *International Journal of Theoretical & Applied Sciences* .
- Pathade, G. (2003). *Advances in Industrial Wastewater Treatment*,. A review of current technologies for distillery wastewater treatment. In Goel, P.K. (ed.), (pp. 180-239). Jaipur, India: ABD.
- Paturau, J. (1989). *By-products of the cane sugar industry an introduction to their industrial utilisation*. Elsevier, Amsterdam: Sugar series 11.
- Perry, R. a. (1984). *Perry's Chemical Engineers Handbook*,Fifth edition. McGrawHill, New York.
- Qazi, Dr. G.N. (2014). *Opportunities For Green Chemistry Initiatives: Molasses Based Distilleries*. New DelhI: GoI Vigyan Bhawan Annexe.
- Quintero, J. A. (2008). Fuel ethanol production from sugarcave and corn: Comparative analysis for Colombian case. *Process Biochemistry*,34 , 115-119.
- Rein, P. (2007). *Cane Sugar Engineering*. Berlin : Verlas Dr. Albert Bartens KG.
- Rein, P. P. (2006). *Cane Sugar Engineeri Ng*. Baton Rouge: Dr. Albert KG.

S. Chandraju, C. a. (2012). Distillery Spentwash as an Effective Liquid Fertilizer and Alternative Irrigation Medium in Floriculture. *Research in Plant Biology* , pp. 16-23.

Samuel Gebremariam Haile*1, M. D. (2016). Energy Analysis of Distillery Systems of an Alcohol Factory by energy audit. *American International Journal of Research in Science, Technology, Engineering & Mathematics* , 50-58.

Shah, A. K. (2012). Enhanced recovery of CO₂ from fermentation process of ethanol. 2nd International Conference on Energy, Environment & Sustainable Development (EESD2012) , (pp. 2-6). MUET Jamshoro, Pakistan.

Shinnosuke Onuki, J. A. (2008). Ethanol production, purification, and analysis techniques. *Agricultural and Biosystems Engineering* (pp. 5-6). Rhode Island: Iowa State University.

Tafere, G. (2015). A review on traditional fermented beverages of Ethiopian. *Journal of Natural Sciences Research* , 2224-3186.

Tarun B Patel, K. D. (2015). An Effective implementation of energy audit . *International Journal of Application or Innovation in Engineering & Management (IJAIEM)* , 2.

Teffera, B. (2007, July). Retrieved january 25, 2019, from Addis Ababa University.

ToolBox, E. (2003). *Engineering ToolBox*, (2003). Steam and vapore enthalpy. Retrieved may 08, 2019, from Engineering ToolBox: https://www.engineeringtoolbox.com/steam-vapor-enthalpy-d_160.html [Accessed Day Mo. Year].

UNIDO. (2002). *Guidelines for National Cleaner Production Centres and Programmes*. Vienna.

V, N. S. (2016). Characterization of Molasses Spentwash collected from United Spirits Ltd., Aleppey,. *International Journal of Biotechnology and Biochemistry* .

Yewondwossen, M. (2008, August). Nazret.com. Retrieved April 2019

APPENDICES

Appendix A: Factory Energy and Material consumptions to produce litre of alcohol

Billing period	Raw material consumption		Energy consumption			Alcohol production (litre)	
	Molasses (kg)	Technical alcohol (litre)	Furnace (litre)	Naphtha (litre)	Electricity (kWh)	Pure	Denature
2010 (E.C)							
July	1,072,800	-	44,050	59,294	16,480	238,113	18,057
August	2,182,400	-	136,598	55,200	202,400	477,692	34,774
September	1,303,210	-	105,573	29,893	148,400	327,785	19,828
October	746,113	-	62,978.1	14,400	155,200	215,770	15,592
November	-	293,500	85,537	6,000	156,000	274,398	20,254
December	1,340,800	228,000	182,754	2,732	88,800	531,163	38,099
January	1,800,745	109,440.5	149,841	27,600	131,600	529,760	42,318
February	852,740	214,429.5	118,533	15,600	182,800	402,396	29,290
March	1,410,740	86,000	105,465	61,498.5	143,600	442,739	31,983
April	1,143,525	254,000	111,363	65,425	124,400	482,852	34,285
May	307,054.3	415,880	45,093	102,196	204,000	410,694	30,019
June	164,000	851,590	0	122,735	204,400	291,497	22,239
Total	1,656,424.3	13,120,543	1,147,785	562,573.5	1,758,080	4,624,859	349,703

Appendix B: Nameplates and measured values of all MALF motors

Pumps code		Nameplate (Rated) values						Measured (actual) values			
Molasses treatment section											
Motors	Quantity	I(A)	V(v)	PF	P(kW)	rpm	Eff. (%)	I(A)	V(v)	P (kW)	PF
P-1100	2	5.3	380	0.78	3	1445	-	-	-	-	-
P-1202	2	3.35	380	0.77	1.5	1395	84	-	-	-	-
P-1203	2	19.7	380	0.9	11	2920	89.4	3.61	382	1.93	0.81
P-1204	2	3.35	380	0.77	1.5	1395	84	-	-	-	-
P-1205	2	19.7	380	0.9	11	2920	89.4	3.62	383	1.5	0.62
MX-1201	2	3.35	380	0.77	1.5	103	84	-	-	-	-
MX-1202	2	3.02	380	0.73	1.1	925	84	-	-	-	-
MX-1203	2	3.35	380	0.77	1.5	103	84	-	-	-	-
MX-1204	2	3.02	380	0.73	1.1	925	84	-	-	-	-
MX-1205	2	3.35	380	0.77	1.5	103	84	-	-	-	-
K-1201	2	1.73	380	0.76	0.75	2840	-	-	-	-	-
P-2001	2	7.5	380	0.89	4	2920	85.8	-	-	-	-
P-2002	2	31.9	380	0.92	18.5	2922	90.9	37.7	383	8.27	0.33
MX-2001	2	3.3	380	0.78	1.5	1435	84	-	-	-	-
Total 59.85 kW											
Fermentation section											
P-1401	2	6.09	380	0.78	3	2880	-	2.51	390	1.13	0.66
P-1402	2	19.7	380	0.9	11	2920	89.4	11.4	386	4.13	0.54
P-1403	2	19.7	380	0.9	11	2920	89.4	9.03	387	4.60	0.76
P-1404	2	19.7	380	0.9	11	2920	89.4	8.88	387	3.82	0.64
P-1405	2	3.2	380	0.77	1.5	2950	84	1.74	385	0.53	0.46
P-1406	2	1.06	380	-	0.37	1340	-	-	-	-	-
P-1407	2	3.2	380	0.77	1.5	2950	84	-	-	-	-
P-1420	2	3.2	380	0.80	1.5	2880	86	-	-	-	-
MX-1403A	1	14.8	380	0.82	7.5	7.24	89	-	-	-	-
MX-1403B	1	14.8	380	0.82	7.5	7.24	89	-	-	-	-
MX-1403C	1	14.8	380	0.82	7.5	7.24	89	-	-	-	-
MX-1403D	1	14.8	380	0.82	7.5	7.24	89	-	-	-	-
MX-1403E	1	14.8	380	0.82	7.5	7.24	89	-	-	-	-
MX-1403F	1	14.8	380	0.82	7.5	7.24	89	-	-	-	-
MX-1404	1	14.8	380	0.82	7.5	7.24	89	-	-	-	-
MX-1405	1	3.3	380	0.8	1.5	1435	86	-	-	-	-
K-1400A	1	-	380	0.9	11	-	89.4	-	-	-	-
K-1400B	1	-	380	0.9	11	-	89.4	-	-	-	-
K-1420	1	4.4	380	0.80	2.2	2875	-	-	-	-	-
Total 119.1Kw											
Distillery section, alcohol daily storage, main storage and process water pumps											
P-1510	2	28.5	380	0.87	15	2930	-	11.53	382	4.27	0.56
P-1521	2	5	380	0.80	2.2	1420	-	-	-	-	-

P-1531	2	7.8	380	0.86	4	2950	-	4.35	383	1.65	0.54
P-1541	2	7.8	380	0.86	4	2800	-	4.0	384	1.72	0.65
P-1542	2	6.4	380	0.86	3	1450	-	-	-	-	-
P-1540	2	14.2	380	0.86	7.5	2900	-	10.0	384	3.72	0.56
P-1550	2	28.5	380	0.87	15	2930	-	15.33	384	6.08	0.60
P-1551	2	4.6	380	0.8	2.2	2900	-	2.53	382	1.20	0.72
P-1560	2	14.2	380	0.86	7.5	2900	-	7.23	383	3.04	0.63
P-1561	2	3.5	380	0.77	1.5	1410	-	-	-	-	-
P-1563	2	2.6	380	0.86	1.1	1360	-	2.3	383	0.97	0.64
P-1564	2	5	380	0.80	2.2	1420	-	2.92	383	0.98	0.51
P-1565	2	4.6	380	0.80	2.2	2840	-	3.10	382	1.27	0.62
P-1570	2	6	380	0.80	2.2	2840	-	2.72	383	0.760	0.42
P-1571	2	5	380	0.80	2.2	1450	-	-	-	-	-
P-1574	2	8.5	380	0.82	4	1420	-	-	-	-	-
P-1534	1	8.8	380	0.83	7.5	1440	-	-	-	-	-
P-1581	2	5	380	0.80	2.2	1450	-	3.15	383	0.66	0.32
P-2101	2	4.6	380	0.80	2.2	2840	-	-	-	-	-
P-2100	2	10.4	380	0.86	5.5	2900	-	-	-	-	-
P-2110	2	7.8	380	0.86	4	2880	-	-	-	-	-
P-2111	2	7.8	380	0.82	4	2880	-	-	-	-	-
P-2210	2	22.5	380	0.9	11	-	91.2	10.35	384	3.36	0.49
Total 112.2 kW											
Boiler section and cooling water: pumps and fans											
P-2301	2	2.65	380	0.86	1.1	950	84	-	-	-	-
P-2302	2	2.5	380	0.86	1.1	1441	84	-	-	-	-
P-2303	2	13.8	380	0.86	7.5	2920	84	6.20	382	3.76	0.92
P-2304	2	3.1	380	0.86	1.1	925	84	-	-	-	-
Heater					20.0						
P-2401	2	126.6	380	0.91	75	1480	94	47.1	380	26.89	0.87
P-2410	2	126.6	380	0.91	75	1480	94	90.2	380	33.27	0.56
CT -2401A ₁	1	23.6	380	0.9	11	730	91	-	-	-	-
CT -2401A ₂	1	23.6	380	0.9	11	730	91	-	-	-	-
CT -2401B ₁	1	23.6	380	0.9	11	730	91	-	-	-	-
CT -2401B ₂	1	23.6	380	0.9	11	730	91	-	-	-	-
Total 224.8 kW											
Liquor section											
P-2900	2	3.2	380	-	1.5	2840	-	-	-	-	-
P-2910	2	10.4	380	-	1.5	2840	-	-	-	-	-
MX-2900	1	7.07	380	-	3	1436	-	-	-	-	-
MX-2910	1	7.07	380	-	3	1436	-	-	-	-	-
MX-2911	1	13.7	380	-	0.18	2900	-	-	-	-	-
Total 9.18 kW											
Grand total 525.68 kW											

Appendix C: Alcohol production using furnace oil and naphtha energy

2010 E.C Months	Consumed furnace and produced alcohol (litre/month)		Consumed naphtha and produced alcohol (litre/month)		Total alcohol (litre/month)
	Furnace	alcohol	Naphtha	Alcohol	
July	44,050	129,056	50,095	109,057	238,113
August	136,598	328,461	55,200	149,231	477,692
September	105,573	241,095	29,893	86,690	327,785
October	62,978.03	174,298	14,400	41,472	215,770
November	85,537	257,298	6,000	17,100	274,398
December	182,754	522,974	2,732	8,189	531,163
January	149,841	449,571	27,600	80,189	529,760
February	118,533	330,302	15,600	72,094	402,396
March	105,465	273,887	61,498.5	168,852	442,739
April	111,363	297,581	65,425	185,171	482,852
May	45,093	163,030	102,196	247,934	410,694
June	-	-	122,735	291,497	291,497
Total	1,147,785.03	3,167,383.0	553,374.5	1,457,476.0	4,624,859.0

Appendix D: Nameplate and measured data of selected motors

Motors	Nameplate (Rated) values						Measured (actual)			
	I(A)	V(v)	PF	P(kW)	rpm	η	I(A)	V(v)	P (kW)	PF
P-1203	19.7	380	0.90	11	2920	89.4	3.61	382	1.93	0.81
P-1205	19.7	380	0.90	11	2920	89.4	3.62	383	1.5	0.62
P-2002	31.9	380	0.92	18.5	2922	90.9	37.7	383	8.27	0.33
P-1401	6.09	380	0.78	3.0	2880	80.0	2.51	390	1.13	0.66
P-1402	19.7	380	0.90	11	2920	89.4	11.4	386	4.13	0.54
P-1403	19.7	380	0.90	11	2920	89.4	9.03	387	4.60	0.76
P-1404	19.7	380	0.90	11	2920	89.4	8.88	387	3.82	0.64
P-1405	3.20	380	0.77	1.5	2950	84.0	1.74	385	0.53	0.46
P-1510	28.5	380	0.87	15	2930	-	11.53	382	4.27	0.56
P-1531	7.80	380	0.86	4.0	2950	-	4.35	383	1.65	0.54
P-1541	7.80	380	0.86	4.0	2800	-	4.00	384	1.72	0.65
P-1540	14.2	380	0.86	7.5	2900	-	10.0	384	3.72	0.56
P-1550	28.5	380	0.87	15	2930	-	15.33	384	6.08	0.60
P-1551	4.60	380	0.80	2.2	2900	-	2.53	382	1.20	0.72
P-1560	14.2	380	0.86	7.5	2900	-	7.23	383	3.04	0.63
P-1563	2.60	380	0.86	1.1	1360	-	2.30	383	0.97	0.64
P-1564	5.00	380	0.80	2.2	1420	-	2.92	383	0.98	0.51
P-1565	4.60	380	0.80	2.2	2840	-	3.10	382	1.27	0.62
P-1570	6.00	380	0.80	2.2	2840	-	2.72	383	0.760	0.42
P-1581	5.00	380	0.80	2.2	1450	-	3.15	383	0.66	0.32
P-2210	22.5	380	0.90	11	-	91.2	10.35	384	3.36	0.49
P-2303	13.8	380	0.86	7.5	2920	84.0	6.20	382	3.76	0.92
P-2401	126.6	380	0.91	75	1480	94.0	47.1	380	26.89	0.87
P-2410	126.6	380	0.91	75	1480	94	90.2	380	33.27	0.56

Appendix E: Nameplate and measured data of pumps

Pumps	Rated values		Measured values			Operating Hours (hr)
	Head (m)	Flow rate (m ³ /hr)	Head (m)	Fluid densities (kg/m ³)	Flow rate (m ³ /hr)	
P-1100	-	-	3	1400	2.17	24
P-1203	31.6	13.8	39.0	1311	4.72	24
P-1205	43	11.2	28	1311	4.72	24
P-2002	87.9	17.1	28	1000	16.0	0.85
P-1401	15.4	6	6	1044	14.28	0.33
P-1402	22	26	16	1044	30	0.5
P-1403	21	39	12.4	1044	81.3	2.0
P-1404	21	39	27	1044	8.540	24
P-1405	15.3	3	6	1051.86	4.13	0.33
P-1510	42.8	15	8.2	1053	7.271	24
P-1531	31	46.3	22	903.18	1.400	24
P-1541	38.1	8.6	22.4	802.90	5.015	24
P-1540	34.8	16.3	22	994.82	8.767	24
P-1550	58.3	16.4	16.6	980.68	7.900	24
P-1551	27.5	2.0	22	928.35	1.305	24
P-1560	61.4	6.7	35.6	994.82	2.807	24
P-1563	23	0.3	9.4	931.35	0.103	24
P-1564	30	1.25	12	990.22	1.210	24
P-1565	39.9	2.3	33.6	995.00	2.520	24
P-1570	37	1.17	14.2	789	0.730	24
P-1581	45	0.3	14.2	789	0.047	24
P-2101	22.2	10	35	789	13.43	0.1
P-2100	22.2	30	35	789	37.77	0.5
P-2210	59.8	54	42	1000	11.747	24
P-2301	-	-	2.5	1000	-	-
P-2302	-	-	-	991	-	-
P-2303	34.9	20	40	1000	1.1	24
P-2304	-	-	-	991	-	-
P-2401	37.3	300	50	1000	210	24
P-2410	37.3	300	44	1000	225	24

Appendix F: Requirements of plate heat exchanger

Parameters	Factory installed Plate Heat Exchanger	Proposed Plate Heat Exchanger (Alibaba)
Liquid flow velocity (m/s)	0.71 (by calculation)	2.5
Flow rate (kg/hr)	6,184	420 – 7,899 (from calculation)
Plate no.	37	30 - 45
Diameter (m)	0.0508	-
Dimension (L × W × H) (mm)	1418 × 460 × 2250	1150 × 740 × 2025
Connection material	stainless steel	stainless steel
Maximum Working Pressure (bar)	9	30
Structure	Plate Heat Exchanger	Plate Heat Exchanger
Allowable temperature (°C)	120	65 - 250
Transmission surface area (m ²)	13.97	3 - 15
Nominal power (kW)	214	3.92-141.21

Appendix G: Load factor, mechanical power, hydraulic power, pump efficiency and overall efficiency of motors and pumps

Motors	Load factor (LF)	Mechanical power (P_{mc}) (kW)	output power (P_{out}) (kW)	Pump efficiency (η) (%)	Overall efficiency (η) (%)
P-1203	0.18	1.73	0.15	8.7	7.77
P-1205	0.14	1.34	0.52	38.8	34.7
P-2002	0.45	-	-	-	-
P-1401	0.38	0.90	0.24	26.5	21.23
P-1402	0.38	3.69	1.4	37.0	33.9
P-1403	0.42	-	-	-	-
P-1404	0.35	3.42	0.66	19.3	17.27
P-1405	0.35	0.45	0.07	15.6	13.2
P-1510	0.28	4.27	0.17	4.0	4.0
P-1531	0.41	-	-	-	-
P-1541	0.43	-	-	-	-
P-1540	0.50	-	-	-	-
P-1550	0.41	-	-	-	-
P-1551	0.55	-	-	-	-
P-1560	0.41	-	-	-	-
P-1563	0.88	-	-	-	-
P-1564	0.45	-	-	-	-
P-1565	0.58	-	-	-	-
P-1570	0.35	0.760	0.022	2.90	2.90
P-1581	0.30	0.66	0.001	0.15	0.15
P-2210	0.31	3.06	1.34	43.73	39.9
P-2401	0.36	25.28	0.81	3.2	3.0

Appendix H: Collected data used to audit detailed energy of molasses treatment section

Equipments		Direct measured data				Calculated data		Remark
		Surface Temp (°C)	Ambient temp (°C)	Height/ length (cm)	Circumference (cm)	Area (m ²)	Energy (W)	
Drum 1201	Side	45	26	180	150	2.7000	210.17	
	Top	41	25	-	150	1.7663	35.242	
	Conical	45	26	75	150	1.1250	87.570	
	3 DN 80 valves	63	26.5	26.5	36	0.0954	50.500	Plus 8 flanges
Drum 1203	Line	45	25.5	393	30	1.1790	94.797	
	Top	44	25.5	-	150	1.7663	42.258	
	3 DN 80 valves	64	26.5	26.5	36	0.0954	52.086	Plus 8 flanges
	Steam line	60	26.5	13	37	0.0481	7.5860	
Drum 1204	Line	45	25.5	190	30	0.5700	45.83	
	Top	45	25	-	160	0.6404	53.016	
Steam distributor	Line	86	27	50	34	0.17	54.931	
	DN 50 Valve	87	27	16	26	0.0416	13.731	Plus 6 flanges
	DN 80 Valve	88	27	26.5	36	0.0954	31.952	Plus 2 flanges
Total surface area and total energy loss of molasses treatment section						10.293	779.67	

Appendix I: Collected data used to audit detailed energy of distillery section

Equipments		Measured data				Calculated data	
	Lines	Average Temp (°C)	Ambient Temp (°C)	Height or length (cm)	Circumference (cm)	Area (m ²)	Energy (W)
Column - 1510/20/30	E-1510 vapor line	55	28	14	55	0.0770	9.3122
	2DN 80 steam valve	65	30	26.5	36	0.0954	31.974
	E-1510	50	30	390	950	37.050	3,087.8
	E-1510 outlet	60	30	14	120	0.1680	23.201
	E-1510 inlet	68	25	240	90	2.1600	468.07
	E-1532	37	25	350	160	5.6000	245.25
	Line 1531	36	25	1970	14	2.7580	108.33
	D-1531	34	25	104	54	0.5616	17.163
Column - 1550	DN 100 steam valve	83	28	28	38	0.1064	31.500
	DN 80 bypass	80	28	27	43	0.1161	31.996
	Line bypass	80	28	60	35	0.2100	57.875
	2 DN 125 steam valve	83	28	30	40	0.1200	71.000
	Safety valve	73	28	60	40	0.2400	55.125
	Steam line	50	28	40	50	0.2000	18.714
	C-1550 bottom out	60	30	140	30	0.4200	58.003
	Line C-1550 to C-1560	40	25	1,060	8	0.0848	4.9095
Line E-1556 to E-1557	45	25	720	17	1.224	101.57	
Column - 1540	Steam line	66	28	30	50	0.1500	27.854
	3 DN 125 steam valve	79	28	30	40	0.1200	96.813
	DN 100 bypass	80	28	28	38	0.1064	29.323
	Safety valve	55	28	80	50	0.4000	48.375
	C -1540 bottom out	70	30	165	30	0.4950	98.108
	Line E-1545 outlet	62	25	36	22	0.0792	14.209
	Line E-1545 to D-1560	58	25	850	13	1.105	172.31
	Line C-1540 to C-1570	44	25	480	12	0.5760	44.827
Line C-1540 to C-1560	43	25	1340	10	1.3400	97.460	
Column - 1560	E-1562	40	25	350	160	5.6000	324.21
	C-1560 bottom out	56	30	140	20	0.2800	32.316
	Steam bypass	78	28	15	22	0.0330	8.656
	DN 65 Steam valve	66	28	24	35	0.0840	15.598
	Line E-1565 to E-1557	30	25	1000	12	1.2000	17.587
	D-1560	51	25	140	80	4.524	521.45
	Line D-1560	45	25	630	30	1.8900	156.84
Total surface area and total energy loss of distillery section						69.174	6,127.7