# UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

DEPARTMENT OF ENVIRONMENTAL AND BIOSYSTEMS ENGINEERING

# EVALUATION OF WASTE MANAGEMENT SYSTEMS FOR TEA FACTORIES IN KENYA

## A Case Study of Nyansiongo Tea Factory, Nyamira County.

By

STELLAH BONARERI OIRERE
F56/77438/2009
BSc. Environmental and Biosystems Engineering (UoN)

A Thesis Submitted in Partial fulfillment for the Degree of Master of Science degree in Environmental and Biosystems Engineering in the Department of Environmental and Biosystems Engineering in the University of Nairobi.

2015

## Declaration of Originality

**Name of Student:** Stellah Bonareri Oirere

**Registration:** F56/77438/2009

**College:** Architecture and Engineering

**Faculty/School/Institute:** Engineering

**Department:** Environmental and Biosystems Engineering

**Course Name:** Master of Science in Environmental Biosystems Engineering

**Title of Work:** Evaluation of Waste Management Systems for Tea Factories in Kenya: A Case Study of Nyansiongo Tea Factory, Nyamira County

1) I understand what plagiarism is and I'm aware of the university policy in this regard.
2) I declare that this research proposal is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other works or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements.
3) I have not sought or used the services of any professional agencies to produce this work.
4) I have not allowed, and shall not allow anyone to copy my work with the intention of passing it off as his/her work.
5) I understand that any false claim in respect of this work shall result in disciplinary action in accordance with University of Nairobi anti-plagiarism policy.

Signature: ______________________

Date: __________________________

# DECLARATION

I declare that this is my original work and has not been submitted to any other university for a degree award.

Signature……………………………. Date…………………….

**Stellah Bonareri Oirere**

This thesis has been submitted for examination with our approval as the University supervisors.

1. Signature………………………… Date…………………….

**Eng. Daniel Amedi Mutuli**
**Department of Environmental and Biosystems Engineering**
**P.O Box 30197**
**Nairobi**

2. Signature………………………… Date…………………….

**Mr. Emmanuel Beauttah Kinyor Mutai**
**Department of Environmental and Biosystems Engineering**
**P.O Box 30197**
**Nairobi**

# ABSTRACT

## Evaluation of Waste Management Systems for Tea Factories in Kenya

## A Case Study of Nyansiongo Tea Factory

Waste management is a great challenge in most processing industries in Kenya. This study was specifically carried out to assess the effectiveness of the waste management system in tea processing factories in Kenya with a case study of Nyansiongo tea factory. The study identified the types of waste generated during tea production mainly through observations, the identified solid wastes at every stage of tea production were then sampled and weighed and their weights recorded, the wastewater was also sampled and analysed empirically for Biochemical Oxygen Demand ($BOD_5$), Chemical Oxygen Demand (COD), pH and Electrical Conductivity (EC), boiler data was also collected and analysed to determine the efficiency of the boiler.

Solid waste in Nyansiongo tea factory was found to be 0.01% of the total tea production. The largest amount of solid waste generated was organic at 95.6% while inorganic solid waste was only 4.4%. The highest amount of solid waste was generated from the withering stage due to spillages at 242.3 kilograms per month while the least was generated at the sorting area at 21.8 kilograms per month. Solid waste generated from the factory is not disposed as recommended by National Environment Management Authority (NEMA); the waste is not segregated (different types of wastes are not disposed separately). Wastewater is generated due to the cleaning processes at the factory.

The major cleaning which is done weekly generates about $140m^3$ of wastewater and minor cleaning which is done daily generates about $40m^3$ of wastewater. The wastewater was analysed empirically and the results indicated that $BOD_5$ levels measured 101.1mg/L against the NEMA recommended maximum discharge limits of 30mg/L while the COD levels measured 340.0mg/L against the NEMA recommended maximum discharge limits of 50mg/L.

The calorific value of the wood fuel used at the factory was determined using a bomb calorimeter and the data was used in calculating the efficiency of the boiler. The boiler efficiency was found to be 85.1% which could be improved by harnessing the energy that is lost through the flue gas and the piping system. It was found that dry flue gas generated the highest amount of heat loss at 7.5% and the least amount of heat loss was 0.18% due to moisture in the fuel.

The factory waste management system was found to be partially compliant with the available national standards for waste management.

**Key words**: pollution, standards, solid waste, flue gas, wastewater, production

# DEDICATION

This work is dedicated to my loving family, my parents Mr. and Mrs. Zablon Oirere, my husband Jorum Owuor and my daughter Melissa Margaret for their continued inspiration, encouragement and support.

# ACKNOWLEDGEMENTS

I would like to sincerely thank my supervisors Eng. Daniel Mutuli and Mr. Emmanuel Mutai who amidst their busy work and research schedules spared time to go through my work, provided the apparatus to make the work implementable and tirelessly guided and advised me throughout the entire research.

Pauline Oyugi the Factory Unit Manager, Nyansiongo Tea Factory who gave me the necessary assistance required and facilitated the collection of samples from the field. I am also indebted to Mr. James Owuor for being handy during sample collection from field and his timely advice during sample preparation and analysis. Special gratitude goes to Prof. Elijah Biamah, former Chairman and Eng. Prof. Ayub Gitau the current Chairman of the Department of Environmental and Biosystems Engineering for their profound encouragement and guidance. The teaching and technical staffs of the Department of Environmental and Biosystems Engineering are highly appreciated. The National Commission for Science, Technology and Innovation (NACOSTI) who funded the field trials and sampling are highly appreciated.

Much appreciation goes to University of Nairobi and Gandhi Smarak Foundation who partially paid my tuition fees while pursuing my studies. I also recognize the relentless moral support and encouragement I received from my parents Mr. Zablon and Mrs. Wilkister Oirere and siblings without which I would not have achieved my goal. Lastly, much appreciation goes to my classmates namely: Vitalis Too and Eng. Stephen Nguli with whom we encouraged and motivated one another in the course of our rigorous coursework and research.

May the almighty God bless you!

## TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF PLATES

# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ACEEE | American Council for an Energy-Efficient Economy |
| ADF | Australian Defense Forces |
| APHA | American Public Health Association |
| ASDS | Agricultural Sector Development Strategy |
| ASME | American Society for Mechanical Engineers |
| AWWA | American Water Works Association |
| BMF | Broken Mixed Fannings |
| BOD | Biochemical Oxygen Demand |
| $BOD_5$ | Five-Day Biochemical Oxygen Demand |
| BP | Broken Pekoe |
| COD | Chemical Oxygen Demand |
| CPCB | Central Pollution Control Board |
| CTC | Curl, Tear, Cut |
| EATTA | East African Tea Traders Association |
| EC | Electrical Conductivity |
| EMCA | Environmental Management and Co-ordination Act |
| EMS | Environment Management Systems |
| EPA | Environmental Protection Agency |
| EPZ | Export Processing Zone |
| FAO | Food Agriculture Organization |
| FDS | Factory Door Sales |
| HDPE | High-Density Polyethylene |
| ICS | International Classification for Standards |
| JICA | Japan International Cooperation Agency |
| KTDA | Kenya Tea Development Agency |
| LDPE | Low-Density Polyethylene |
| LMTD | Log Mean Temperature Difference |
| LMTD | Log Mean Temperature Difference |
| LSD | Least Significance Difference |
| LTP | Lawrie Tea Processor |
| LWRT | Leather, Textile, Wood and Rubber |
| MSW | Municipal Solid Waste |

| | |
|---|---|
| NACOSTI | National Commission for Science , Technology and Innovation |
| NEAPC | National Environment Action Plan Committee |
| NEC | National Environment Council |
| NEMA | National Environment Management Authority |
| NTU | Number of Transfer Units |
| PCC | Public Complaints Committee |
| PD | Pekoe Dust |
| PET | Polyethylene Terephthalate |
| PF | Pekoe Fannings |
| PP | Polypropylene |
| PS | Polystyrene |
| PVC | Polyvinylchloride |
| SCDA | Special Crops Development Authority |
| SEI | Stockholm Environment Institute |
| SERC | Standards and Enforcement Review Committee |
| SWM | Solid Waste Management |
| TBK | Tea Board of Kenya |
| TRFK | Tea Research Foundation of Kenya |
| UFAF | Up Flow Anaerobic Filter |
| USEPA | United States Environmental Protection Agency |
| UTLK | Unilever Tea Kenya Limited |
| WHO | World Health Organization |
| WRMA | Water Resource Management Authority |

# 1.0 INTRODUCTION

## 1.1 Background

Tea is one of the leading cash crops in Kenya and makes significant contribution to the economy. In the year 2010, the country produced 399 metric tons of black tea. Over 95% of the tea was exported mainly in bulk earning over Kshs. 97 billion in foreign exchange according to Tea Research Foundation of Kenya (TRFK) (TRFK, 2011).

Currently, about 62% of the total crop in the country is produced by the smallholder growers who process and market their crop through their own management agency, Kenya Tea Development Agency (KTDA) Ltd., which is the largest single producer of of high quality black Cut, Tear and Crush (CTC) teas in the world. The balance of 38% is produced by the large scale estates, which are managed by major multinational firms associated with tea in the world.

Nyansiongo Tea factory is one of the 53 factories managed under KTDA. These factories have similar tea processing designs and their waste management techniques are similar. Research has also shown that the waste management employed by these factories to a larger extent does not meet the national waste management regulations. This is true with Gitugi tea factory and Githongo tea factory (Omosa, 2004).

Agro-industrial wastes are organic matter which can be recycled either by integrated waste utilization or simply returned to the place of their origin nature. Agro-industry particularly the food industry generates large amounts of liquid solid and gaseous wastes which emerge from the processing, treatment and disposal operations. The composition and quantity of agro-industrial wastes depend mostly on the source of raw materials, the nature of the products, operations and processing steps. In general food processing wastes consist of large amounts of organic material (carbohydrate, protein, fat, oil) with high values of BOD, COD and suspended solids. Due to their high nutrient content, agro-industrial wastes have high potential to cause severe pollution problems. The main pollution categories include; wastewater, solid waste and air pollution (Kittikun *et al*. 2006).

Agro industries in Kenya include coffee, tea, horticulture, dairy, canning and fruit juices among others. These industries face challenges in waste management due to large seasonal volumes of wastewater from washing and processing activities; variation in effluent strength and volume; high biodegradable effluents. Some soluble organics are difficult to remove chemically leading to water colouration by strong pigments in raw products. Liquid wastes are highly putrescible and cannot be stored for long periods of time. Air pollution from agro industries is due to odours from food processing wastewater treatment and solid waste disposal (Middlebrooks, 1979).

An efficient processing system must be based on a predictable raw material supply. However, with the liberalisation of the tea industry in Kenya and the repeal of tea planting license, tea growing has become unregulated making it difficult to absolutely predict the green leaf supply. The unplanned planting has also led to unforeseen increase in green tea leaf production which is partly responsible for congestion at the smallholder factories and excess capacity in some of the factories according to the Tea Board of Kenya (TBK, 2008).

Environmental concerns as a result of poor waste treatment and disposal strategies in Kenya are also prevalent in the smallholder tea factories. If left unchecked, it will lead to adverse effects, such as pollution of water sources.

It is with this background, that a study to evaluate waste management systems for tea factories in Kenya with a case study of Nyansiongo tea factory was conceived (Norrington-Davies and Thornton, 2011).

Management of food industry with respect to processing of tea has to deal with numerous factors, most of them caused by the actions or lack of it hence negatively affecting processing of tea and the environment at large leading to production of different types of wastes. In most cases the management does not know or recognize the factors that produce waste nor have they measured their importance. It can be said that most of the factors are not easily visible. Thus the identification of these factors and their causes, measurement of their importance is useful information that would allow management to act in advance to reduce the negative effect. This has not been done for wastes generated by tea factories in Kenya under KTDA.

Wastes from industries are customarily produced as liquid wastes(such as process wastes, which go on-site or off-site waste water treatment system), Solid waste (including hazardous wastes, which include some liquids), or air pollutants; often, the three are managed and regulated differently, depending on the characteristics of the waste and the process of producing them and regulated by specific laws. The ultimate purpose of determining waste quantities generated is to provide management with a realistic projection of information regarding the need to re-design the waste process regime with accurate and complete information on the capacity of wastes generated (Kittikun *et al*. 2006 and Stockholm Environment Institute, 2009).

However, solid and waste water quantities have not been determined in factories in Kenya under KTDA, especially Nyansiongo tea factory.

The wastewater generated by Nyansiongo tea factory is treated in naturally aerated lagoons however its quality parameters are not known hence its compliance status with the wastewater discharge limits is also not known. Appendix 8.1 shows the characteristics of pollution control problems in various agro-industries.

## 1.2 Problem Statement

Tea processing generates different types of wastes. However, the efficiency of the waste management systems for Nyansiongo tea factory is not known. Wastes from tea processing have not been characterised, quantified and their qualities are not known before they are discharged to the environment.Kenya Tea Development Agency, KTDA (formerly an authority), the body managing the tea factories in Kenya for small scale farmers does not operate sufficient (or none at all) effluent systems in most of its factories. Gitugi tea factory (under KTDA) in Othaya division of Nyeri district has experienced problems with collection, treatment and disposal of the factory washwater and storm water (Omosa, 2004).

## 1.3 Hypothesis

The outcome of this research was envisaged to assist tea factories in Kenya in identifying areas in their operations that could be improved to better their waste management systems. This would lead to cleaner production systems, products and environment.

## 1.4 Objectives

The objective of this study was to evaluate the effectiveness of waste management systems for tea factories in Kenya.

### 1.4.1 Specific Study Objectives

The specific objectives were;

i. To classify the waste generated during tea production at the factory;

ii. To determine the quantities of solid waste, wastewater generated and heat waste at the factory;

iii. To determine the quality parameters of wastewater generated at during the tea process.

iv. To assess the effectiveness of the existing solid, liquid and thermal waste management system in the factory;

## 1.5 Scope of the Study

This study involved the evaluation and assessment of waste management systems for Nyansiongo Tea Factory in Kenya. This study considered the wastewater, solid and heat wastes during tea processing. The study does not cover air quality analysis and noise level assessments in the factory.

# 2.0 LITERATURE REVIEW

## 2.1 Environmental management system

An Environmental Management System (EMS) is a set of management processes and procedures that allows an organization to analyze, control and reduce the environmental impact of its activities, products and services, and operate with greater efficiency and control. An EMS is appropriate for all kinds of organizations of varying sizes in both the public and private sectors (USEPA, 2004). The EMS is built on ISO 14001's Plan-Do-Check-Act (P-D-C-A) model and is designed to help one systematically identify, control and monitor your environmental issues (USEPA, 2004).

An Environmental Management System includes:

- Defining roles and responsibilities;
- Identifying and prioritizing environmental impacts;
- Setting measurable objectives and targets;
- Verifying and establishing operational controls;
- Monitoring and measuring activities and progress; and
- Seeking continual improvement as part of a review cycle

There is not much literature on the Kenyan waste management sector with the exception of Nairobi. Even for Nairobi, the available literature dwells largely on performance description and its causes, household waste generation behaviour, and waste characteristics, (Ikiara *et al*. 2004). This has changed progressively as more industries are moving towards cleaner production and ISO certification. Some of the industries in Kenya that have successfully implemented cleaner production include Chandaria Industries Limited, Unilever Kenya ltd, Bidco Oil Refineries, HACO Industries, Twiga Chemical Industries Ltd and Pwani Oil Products Ltd. HACO Industries started implementing cleaner production in 2005. In its Resource Efficient and Cleaner Production (RECP) programme, the company specifically focused on water, material and energy efficiency, and in some production processes on wastewater reduction. The entire RECP programme achieved a saving of 11 % per year or savings of more than USD 547, 000 (Murunga, 2011). This is also further illustrated by the improved performance of Pwani Oil Products Ltd after moving to cleaner production in some of their processes. Pwani Oil Products Ltd, an integrated edible oil and bar-soap factory, had excessive water consumption leading to the generation of copious amounts of waste water. The company had old oil refining technology, which lead to generation of up to 15,840 $m^3$ wastewater per year. The process was also characterized by high levels of rejection/reworks producing up to 91,250 kilogrammes per year of nonconforming bar soaps Management of spent bleaching earth (solid waste) was also a big problem. Investing in cleaner production (Investment cost US $ 641,025) resulted in60% wastewater reduction, 90% reduction in material loss (originally 43.8 tons per year). Installation of a new edible oil refinery increased the production efficiency to 99% (Annual savings US $ 230,769) (Murunga, 2011).

In order to accomplish 'integrated waste management' which is the advanced concept of optimizing waste management in an industry, reliable data on the quantity and quality of waste are required (Matsuto and Tanaka, 2000 and Franke, 1999). Successful operation and planning of waste management systems frequently depend on accurate data of waste quantities produced. Knowledge of quantity and composition of waste is essential for the planning of waste management systems, waste management policy formulation and evaluation and for designing appropriate pollution control measures. Other reasons include a need to estimate material recovery potential, to identify sources of waste generation, to facilitate design of processing and collection equipment, to estimate physical, chemical, and thermal properties of the wastes, and to maintain compliance with local and national regulations.

Despite the central role of these aspects, there is a lack of waste data from the different sources especially due to insufficient budget and unavailable management which results in a situation where records of waste generation and composition data are missing or are not up to date. Without a good insight in the quantities of waste that can be expected, decisions about equipment and landfill space and capacity and recycling or composting method cannot be reliably made. A clear estimation of the quantities and characteristics of waste being generated is thus a key component in the development of cost effective waste management strategies (Gerlagh, *et al.*, 1999). In order to understand how much waste is generated it is crucial to undertake a waste characterization study according to internationally accepted methodologies. This means the description of the type (composition) and amounts (generated or produced waste) of waste present in a waste stream.

Developing countries have solid waste management problems different than those found in fully industrialized countries; indeed, the very composition of their waste is different than that of ‘developed’ nations. In low-income countries’ solid waste generation rates average only 0.4 to 0.6 kg/person/day, as opposed to 0.7 to 1.8 kg/person/day in fully industrialized countries, (Cointreau-Levine, 1994)

Transport of waste from households, factories, and other generation sites is also a growing problem. The rapid urbanization of much of the developing world leaves little time for adequate layout and planning; many of the most rapidly growing parts of cities are at the periphery of existing settlement. Garbage dumps, with their associated disease, odor and frequent fires (in some cases) would ideally be located on suitable land away from the most densely populated areas. These areas are becoming harder to find as population urbanize and municipal traffic increases; the transport of waste becomes longer and more time-consuming, and therefore more expensive and less efficient (Cointreau, 1994).

## 2.2 Tea Processing and Wastes Generated

Tea is an evergreen plant of the Camellia genus. Its scientific name is "*Camellia Sinensis*) and it originated in China, Tibet and Northern India. The tea plant has thick leaves, dark green in color, and a strong thick stem. The tea flowers bloom in white or pink and have a delicate fragrance. There are about 200 different species of the tea plant around the world. Tea is one of the most important non-alcoholic beverage drinks worldwide and has been gaining further popularity as an important ‘health drink’ in view of its purported medicinal value. It is served as morning drink for nearly two thirds of the world population daily. Internationally, five tea producing countries account for over 77% of the total crop produced. Kenya is ranked third in annual tea production after China and India.

Tea is one of the leading cash crops in Kenya and makes significant contribution to the economy. In the year 2010, the country produced 399 metric tons of black tea. Over 95% of the tea was exported mainly in bulk earning over Kshs. 97 billion in foreign exchange (TRFK 2011).

This represents about 26% of the total export earnings, and about 4% of Kenya’s GDP. Tea is a rural based enterprise, and contributes directly to the objectives of the Agricultural Sector Development Strategy, 2009- 2020 (ASDS), Kenya’s Vision 2030, National Development Plan and the Medium Term Plan 2008-2012. An estimated 4 million

Kenyans derive their livelihoods from the tea industry. About 50% of the workforce in the enterprise is women and thus tea contributes to gender empowerment. The crop also contributes significantly to the development of rural infrastructure and contributes to stemming rural-urban migration. It directly contributes to environmental conservation through enhanced water infiltration, reduced surface erosion, and mitigation of global warming through carbon sequestration.

The tea produced in Kenya accounts for about 7% of the world production (Appendix 8.3) and about 22% of the export share (Appendix8.4). Over 95% of the Kenyan tea is exported as a generic product which is used to blend the low quality teas from other countries. Kenyan teas are produced hygienically following good agricultural practices and good manufacturing practices and are completely pesticide free.

Currently, Kenya produces Black CTC tea as the only major product, for which the international unit prices have stagnated. While the tea plant (*Camellia sinensis*) grows well, high costs of production have impeded commercial development of tea as a crop and commodity in the world (Tipton *et al*, 1990). There is therefore a need for product diversification and improvement of the quality of tea products to make Kenya a leading exporter of high value teas. This is a major challenge to be addressed by researchers, processors and product promoters.

Kenya has the highest productivity (yield per unit hectare) compared to other major tea growing regions worldwide which is attributable to deployment of appropriate research and development outputs in the production value chain. The research and development outputs have largely been developed by the Tea Research Foundation of Kenya (TRFK 2011).

Tea was introduced into Kenya from India by a European settler G.W.L. Caine in 1903. The country has for the last 80 years cultivated tea commercially. Over the years Kenya has grown into a formidable world tea producer, with an annual production of about 300 million kilograms and is rated as the third largest tea producer and the third biggest exporter in the world. This formidable growth has seen the tea industry grow into the most important agricultural sub-sector and the leading foreign exchange earner in Kenya.

Tea in Kenya is grown in high altitude areas between 1800 and 2700 metres above the sea level, where annual rainfall ranges from 1800 mm to 2500 mm. The tea growing areas are spread throughout the country, but mainly lie west and east of the Great Rift Valley (Hilton, 1973 and Owuor et al 2008). The industry is structured into two major sub-sectors: the large estate and small holder sub-sectors. The latter sub-sector, with average holdings ranging from less than one hectare to twenty hectares, accounts for about 66% of the total area under the crop and 62% of the total production.

The difference between all types of tea products commercially available internationally is dictated by the method of processing and the number of leaves. In Kenya, the two most common types of tea products are *Black CTC tea* and *Instant Tea*. Black Tea, which is produced by **Cut, Tear and Curl (CTC)** method of manufacture accounts for 99% of the tea produced in the country. Nyansiongo Tea Factory produces black CTC tea which makes it a typical factory in Kenya. Instant tea accounts for the remainder. Factories such as Changana (estates) and Kangaita (smallholders) are already venturing into other tea related products such as green, orthodox and decaffeinated teas (TBK, 2008).

The oversupply of green leaf in some regions has led to congestions in some factories thus overstretching the processing operations to between 16-20 hours per day. This situation has forced factories to adopt various coping mechanisms such as zoning; overloading of withering troughs; employment of more casuals; and green leaf diversions. Cases of factory level congestion was more pronounced in the west of rift valley where, during peak seasons, green leaf supplies sometimes triple daily processing capacities (TBK, 2008).

The mean capacity overutilization in the smallholder sector in the West of the Rift Valley was found to be 38%. The capacity underutilization in the smallholder sector in the East was found to be 6%. The overall capacity underutilization in the Estates in both East and West was found to be 15%.

Energy accounts for between 12% - 30% of the factories' production overheads. Factories require energy for driving machinery and steam generation. The energy sources are usually from combustible fuels (wood and furnace oil) and electricity. While the estates have established wood lots developed over a long period of time, the smallholder factories largely depend on furnace oil. Energy efficiency of furnace oil is much higher than that of wood due to consistency in steam generation. The use of furnace oil also requires less human labour. However, with the increasing costs of furnace oil, the smallholder factories are unable to break even and are slowly diverting to the use of wood fuel bought from farmers (TBK, 2008).

### 2.2.1 Leaf collection

The manufacturing process starts the moment tea leaves are plucked. The plucked leaves start to wither and at this point inadequate handling and transport would result in bruising of the leaf, heat development and initiation of uncontrolled fermentation leading to reduced quality. Care should be taken when transporting green leaf to avoid heat accumulation and bruising. The use of suspended gunny sacks about 10kg of green leaf usually allows enough ventilation to avoid heat accumulation during transport from the field to the factory, provided the leaf does not overstay in the field or in the transport vessel.

Transportation to the factory can be in any other convenient containers if tea is transported within an hour. The standard of plucking also affects the quality of made tea. A finer plucking that is two leaves and a bud standard would produce a higher quality tea that will fetch a better price. It is important to have a constant supply of leaf with consistent plucking standard so that the factory does not have to change the manufacturing conditions (TRFK, 2002).

### 2.2.2 Withering

The first stage of black tea manufacturing is withering, which refers to the changes (physical and chemical) that occur in green tea leaf from the time it is detached from the plant to the time of maceration (Owuor and Orchard, 1989). Physical withering is moisture loss of fresh tea leaf (and related physical changes), while chemical withering involves biochemical changes, which solely depend on time (Das, 2006).

This aspect of tea manufacture is very expensive in terms of space, time, energy and labour utilisation. This process is not much understood but it forms the basis of black tea processing. Withering is presumed to occur after the freshly plucked shoots are placed in the withering trough and air is blown through them for 14 to 18 hours. During this process, the most noticeable change is moisture loss which is accompanied by cell wall permeability changes which make subsequent maceration easy. This process of moisture loss and cell wall permeability changes is called physical wither (TRFK, 2002).

However, less obvious is the chemical wither. This starts immediately the leaf is detached from the bush and chemical reactions involved in senescence start. The chemical wither reactions include changes in the activity and nature of polyphenol oxidase (the enzyme responsible for turning green tea leaf to brown-black) hydrolysis of terpenoid glycosides to release terpenes, breakdown of proteins to amino acids, hydrolysis of lipids to free fatty acids, the breakdown of carotenes to simple terpenes. Although these changes may affect black tea aroma, they also affect plain black tea quality parameters. Chemical withering is mandatory for production of high quality black teas. However it is very difficult to control chemical wither duration in a commercial factory processing situation. Optimal chemical wither varies from 6 to 20 hours. Shorter chemical wither times produce green and harsh black teas, while longer withering durations result in dull black teas with low sensory evaluation (TRFK, 2002).

In Kenya plain teas are produced during the peak crop periods, while flavoury black tea are produced mainly from the clonal leaf from some areas of the country during the slow growth (low crop) seasons. Plain teas were presumed to benefit only from physical withering. However it is now known that both plain and flavoury black teas are affected by physical wither. Hard physical withers (high moisture loss below 72% moisture content) enhance the quality of the production of the flavoury teas. However for plain teas the hard physical wither reduces the levels of some plain tea quality parameters like theaflavins, brightness and thearubigins. Thus, plain black teas benefit from controlled physical wither, the quality actually deteriorates when too much moisture is lost from the leaf (TRFK, 2002).

Physical wither enhances factory throughput. The softly withered leaf is bulky and this slows down rotorvane output, and dryers may not cope with excess moisture in the leaf. Consequently, withered leaf should have up to 72% moisture content if the dryers are to give optimum throughput.

During periods of increased tea production, many factories usually face constraints in processing especially in the withering section. Studies have shown that the two-stage withering technique where chemical and physical withers are done at distinct stages make black teas with similar quality as black teas made through conventional one–stage withering technique where physical and chemical withers are done concurrently. However in a two-stage wither, chemical wither must be done before physical wither and during the process, black tea quality can be enhanced by using cold air to achieve physical wither. This knowledge has led to development of tanks which occupy less space but hold more leaf and use less electricity as suitable vessels for chemical wither. Where tanks are not installed, factories can alternate over-loaded withering troughs with normal loads.

Upon achieving chemical wither, the normal-loaded troughs can be subjected to forced physical wither using high speed (velocity) air current. After physical wither has been achieved the leaf is removed for maceration, while the leaf in the over-loaded troughs is sub divided into those emptied troughs then subjected to forced physical wither. This process allows the factory to hold up to 35% more leaf in the factory than it could under traditional trough withering system.

The constraint in withering space is more acute during peak crop seasons when the black teas produced are generally plain. Such teas can be manufactured without quality loss if chemical withering time is reduced to as short as six hours. The reduction of chemical withering time would permit factories to start processing early and thus create extra processing time. Additionally, the same enables the factory to use one withering trough more than once a day, thus enabling the factory to hold more leaf.

Since leaf processed during peak crop periods produces plain black tea, and because for such teas softer withers make superior teas, factories which can cope with soft withers without suffering reduction in throughput at the rotorvanes or dryers as a result of some engineering modifications, can use tank wither only. In such manufacturing processes, all moisture is removed during drying. Due to increased surface areas macerated leaf, energy may be more efficiently utilised as moisture losses through evaporation are achieved faster. Economic survey has shown that it is more cost effective to install some withering tanks in factories than to build new factories or expand old factories with traditional withering technique (TRFK, 2002).

The wastes associated with this process are minimal as a result of broken hessian nets or holes on the troughs.

**Plate 2.1: Withering Process**

### 2.2.3 Leaf Maceration

Almost all tea produced in Kenya is by unorthodox maceration, usually using one rotorvane and three Crush, Tear and Curl (CTC) machines in series or on rotorvane and a Lawrie Tea Processor (LTP). This is most suitable because the teas produced are mostly plain teas, and it is not necessary to preserve all delicate flavour components.

Teas made by unorthodox maceration are generally much smaller in particle size than those made by traditional (orthodox) maceration, and they give brighter, brisker and more coloured infusions. This is also of advantage to the tea market which has moved towards tea bags and “quick brew teas” over the last twenty years. It seems probable that more and more teas from Kenya would be processed using unorthodox techniques with only a small percentage of specialist tea utilizing orthodox methods of maceration (TRFK, 2002).

The object of the maceration step is to mix up the catechins and the enzymes in the tea leaf tissues, and to allow free access of oxygen. This allows fermentation to proceed, producing theaflavins and thearubigins respectively. In delicate flavoury teas, other chemical reactions may be of equal importance, but this is not thought to be the case in Kenya plain teas. Thus it follows the rapid, severe maceration would cause maximum leaf disruption and lead to a finished product that has the characteristics desired of Kenya tea.

The first step in maceration is usually the use of a rotorvane. It consists of a cylinder containing a rotating central shaft. Spiral vanes on the shaft propel the leaf along the cylinder, and distortion and twisting of the tea leaf tissues occur by rubbing and shearing action of the leaf against projections coming out of the cylinder casing. This whole process is designed to disrupt the cellular structure of the leaf.

After rotorvane maceration leaf usually passes through a series of CTC machines which consist of two rollers rotating at different speeds in opposite directions. The surface of the rollers is serrated and their rotation in different directions produces more leaf cellular disruption by crushing and stretching and cutting it into small particles.

The LTP is an alternative to CTC and maybe used in conjunction with a rotorvane. It is based on the principle of a hammer mill, with the rotating hammers disintegrating the leaf very quickly. In some factories this is considered sufficient for fermentation, but in others an extra cut with a CTC, usually in the middle of fermentation is thought to be an advantage.

The next result of these maceration processes is to produce small particles of leaf and stalk that have had their internal structure broken down to allow air to easily reach the internal structure of the leaf, leading to even fermentation. The macerated leaf is known as dhool.

The waste generated from the process is mainly rejects dust and stalks/fibres.

**Plate 2.2: CTC**

### 2.2.4 Fermentation

This is the stage of manufacture where the major chemicals changes occur. In essence, fermentation requires allowing oxygen to permeate the macerated leaf so that the endogenous catechins can be converted through enzyme-catalysed reactions to theaflavins and thearubigins. Some of the aroma compounds are also formed during fermentation.

Originally, the procedure was for leaf to be felt in thin layers on slabs, so that air would penetrate naturally. However, oxygen requirement of leaf macerated by unorthodox means is much higher than that processed by orthodox means. This led to the use of air forced through the fermenting dhool to increase the oxygen level available for fermentation. The air also helps cool the dhool, as the chemical reactions of fermentation generate heat (TRFK, 2002).

The most fermentation system in Kenya utilises George-Williamsons (G.W) trolleys. These have perforated metal base with a plenum chamber underneath. After loading with dhool the G.W trolley is then attached to a duct with humidified air forced through its plenum chambers and hence through dhool, thus aerating the fermenting leaf.

Because the air is humidified, the fermenting dhool does not dry out. It is possible that humidification could be dispensed with at the later stages of fermentation, causing a slight loss of moisture from the dhool, and reducing the load on the dryer. At these later stages there are less chemical reactions generating heat and oxygen demand is lower.

The second effect of humidification is that of temperature control, Use of the correct temperatures for fermentation is very important. The reason for this lies in the nature of the biochemical reactions producing theaflavins and thearubigins. Increasing the temperature does not produce the same result in a shorter time. Higher temperatures favour the production of thearubigins, thus producing a strong, coloured tea that can easily turn out flat and muddy. Lower fermentation temperatures on the other hand favour the production of theaflavins, higher flavour index and brighter coloured teas. Thus temperature control can change the type of tea produced. It is envisaged that, in the future when these reactions are better understood, it may be possible to change the temperature regime of fermentation to produce exactly the sort of tea that is required by the market.

The fermentation of dhool in deep fermenting beds can easily lead to the formation of “balls” of dhool, which in turn lead to uneven fermentation. This has resulted in many factories using a mid-fermentation ball break, although doubt has been expressed at its usefulness. While there is often no detectable difference between teas that have or have not received such a ball break, it is still a useful precaution for those times when processing conditions are not ideal.

A more recent development is the use of continuous fermentation machines. There are a host of different designs, but at the moment there are three basic types:

**The moving belt fermenter-** Dhool is fed onto the firs of a series (usually 3 or 4) of variable speed moving belts, usually with humidified air blowing through. Transfer from one belt or from one part of the belt to the next can be accompanied by ball –breaking, and fermentation time controlled by the speed of the belt.

**Trough fermenter (Linsay fermenter):-**The dhool is fed into a trough and moved along by longitudinal or transverse rotating screws or vanes. The turning of the dhool allows aeration and also prevents ball formation.

**Fixed bed fermenters: -** The dhool is fed into a trough a perforated base plate through which air is blown. The dhool is then mechanically dragged along the length of the trough.

The waste produced from the process is fermented liquor.

**Plate 2.3: Fermentation bed**

### 2.2.5 Drying

This is the process that stops fermentation and produces a stable product of low moisture content that can be shipped and endures storage. Changes do occur in black tea after drying, but they are small and have negligible effect on tea quality if drying is done well. In essence the process of drying tea consists of exposing the tea to a flow of hot air. Traditionally in a conventional dryer the system is designed such that the driest tea is exposed to the air first and the wettest tea (straight from fermentation) last. This is usually achieved by having the tea pass on a belt through the same stream of air 4 to 6 times, with the wettest tea farthest from the air inlet. This allows the maximum utilisation of the air, but recycling is not possible because of moisture pickup (TRFK, 2002).

A recent development in drying technology is the advent of the fluid bed dryers. In this form of drying the tea enters a horizontal tunnel, the base of which is a perforated plate. Hot air is blown vertically through the plate, and the dhool forms a fluid bed, it is suspended in a fluidizing hot air. This not only gives rapid, even drying, but a combination of the air pressure and decline in leaf density forces the drying tea along the tunnel, thus removing the need for a moving tray. There are various advantages of this system; moving parts are few leading to easier maintenance. The exhaust air from the end of the tunnel can be recycled at the beginning of the tunnel, thus saving on fuel. Considerable fibre can be extracted during drying using a cyclone. Finally the tea produced has a greater bulk density; therefore more mass can be packed in a standard container. As shipping cost depend on volume, not weight, shipping costs are reduced. Fluid bed dryers are slowly replacing conventional dryers in the Kenyan tea factories.

The source of fuel for dryers is a problem. Due to recent increases in the price of oil, wood is favoured by the estate sector. This is much more difficult to achieve in small holder sector as most factories in this sector have problems obtaining sufficient wood fuel. Consequently, oil-fired boilers are mostly used, resulting in increased production costs.

Based on current estimates, about 10% of the production cost of tea is the cost of wood fuel. If this is replaced by oil, this figure can rise to 35%. The latter also results in a loss of valuable foreign exchange. It is possible that in the future, a considerable proportion of energy required in tea production could be supplied by solar energy collectors built into factories. This would release land currently used for fuel wood for productive purposes, and reduce the expenditure on oil imports.

The possible wastes at this stage are heat losses.

**Plate 2.4: Dying Process**

### 2.2.6 Sorting

After drying the fibre is removed from the tea before it is graded by size. The dried tea is then conveyed to the electrostatic fibre extraction rollers to clean the teas by removing fibre thus enhancing the value and imparting quality to the tea. This process is known as sorting. The main grades, which are also called primary grades and comprise of 85-95% of the tea are fibre free, are sold at much higher prices than the fibrous off grades. The grade distribution as ratio of primary to secondary grades, which affects the total income of the factory is heavily influenced by the original plucking standard, with coarser plucking leading to more secondary grades. The size distribution can also be manipulated by adjustments of CTC settings so that the factory maximizes on the grades it sells best (TRFK, 2002).

The grades obtained are Broken Pekoe 1 (BP1), Pekoe Fannings 1 (PF1), Pekoe Dust (PD) and Dust 1 (D1) as Primary Grades and Fannings 1 (F1), Dust and Broken Mixed Fannings (BMF) as Secondary Grades.

The sorted and graded teas are then packed for auction according to the East Africa Tea Traders Association (EATTA) regulations and dispatched to Mombasa. Other PF1 teas are packed in 500gms and 250gms poly tubes for sale at the factory gate as Factory Door Sales (FDS).

The waste generated from the process is mainly rejects dust and stalks (fibres).

**Plate 2.5: Sorting**

### 2.2.7 Shipping

Most tea is transported from the producing country to the consuming country which may be far. The packaging must be designed to maintain the quality of the tea during transportation of more than three months. The two major factors to be considered in designing the packaging material are the prevention of moisture uptake (to prevent mould growth) and the prevention of taints.

Traditionally, this has been achieved by the use of wooden tea chests lined with aluminum foil. There are however, moves in various parts of the world to replace these chests. The chests are expensive and non-reusable wooden containers which consume large amount of wood in their production. This poses a major challenge environmentally and economically.

The replacement of the tea chest is polyethylene or aluminum foil lined multi-wall paper sack. The sack is an effective barrier to moisture and taint, and can be transported in containers. The sack also costs less than half the price of a tea chest. It is also possible that sacks can be used with slip-sheets, thus allowing more tea to be shipped per container. The use of this system could result in a considerable saving in packaging costs, especially if tea is containerized at the factory.

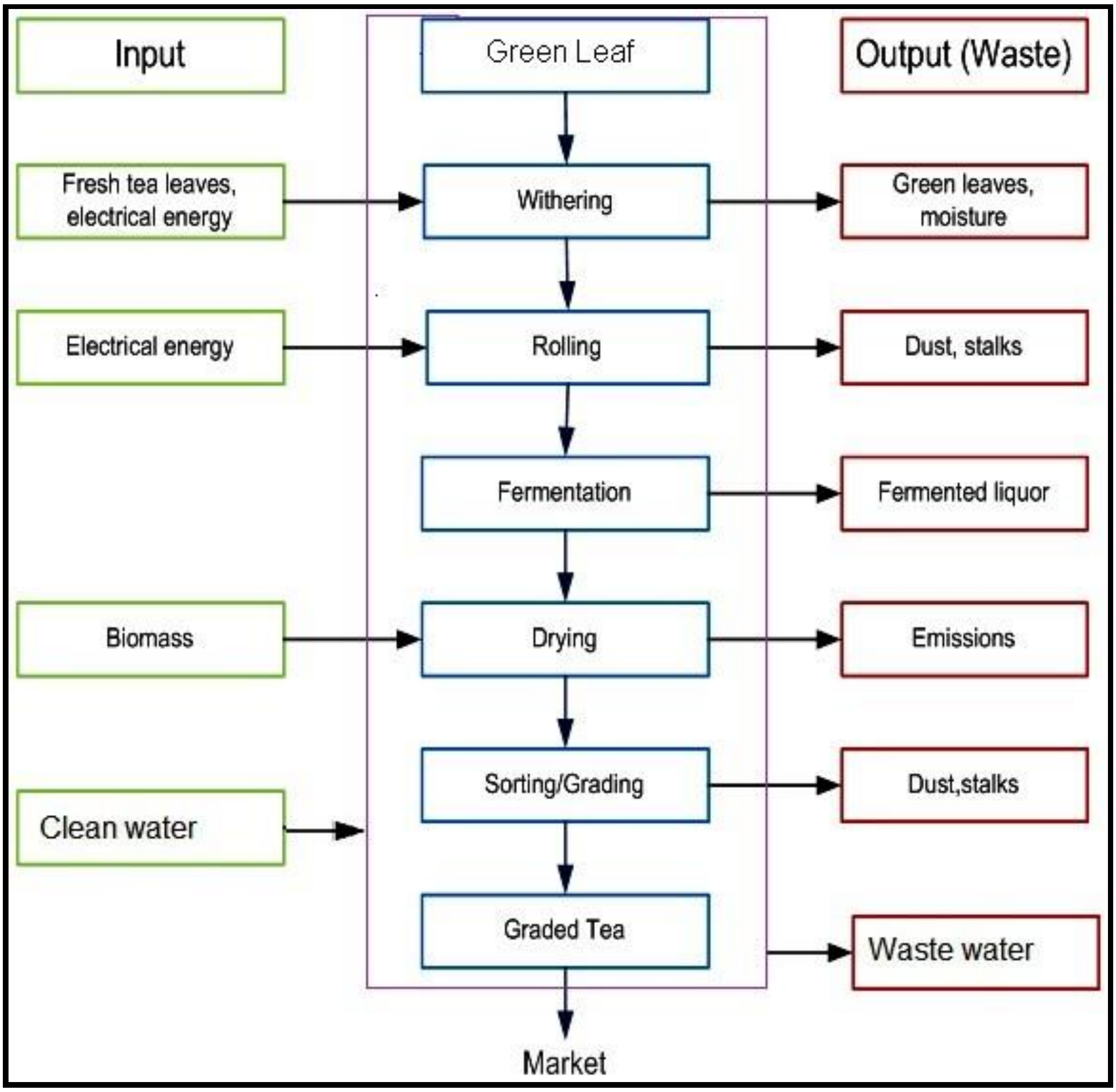


**Figure 2.1: Schematic diagram for Tea processing and wastes generated**

### 2.3 Policy Statement

KTDA is committed to effective management services to the smallholder tea sub-sector in the production, processing and marketing of high quality tea for the benefit of their farmers and other stakeholders. Their key goal and objective is to meet and exceed their customers' expectations in providing quality products and associated services. They also endeavor to continually maintain and improve efficient and effective Quality Management Systems meeting both the regulatory and the ISO 9001:2000 requirements.

KTDA is yet to obtain ISO certification for environmental management systems as per ISO 140001:2004.

## 2.4 National Environmental Legal Framework

Presently environmental legislation in Kenya is provided under the Environmental Management and Co-ordination Act (EMCA), which was enacted as a framework law and contains provisions for the environment management systems of proposed and ongoing projects respectively in Kenya. Under the EMCA a number of institutions were created and the following section provides a brief outline on the institutional framework of the EMCA.

### 2.4.1 Environmental Management and Co-ordination Act

The EMCA, 1999 is framework legislation for environmental management in Kenya. Under the EMCA a number of institutions were created and the following section provides a brief outline on the institutional framework of the EMCA.

#### 2.4.1.1 Institutional Framework of the EMCA

In order to operationalize the Act, the Environment Management and Coordination Act (EMCA) established various administrative structures. These included the National Environment Council (NEC), the National Environment Management Authority (NEMA), the Public Complaints Committee (PCC), the NEMA Board, Provincial and District Environment Committees, the Standards Enforcement and Review Committee (SERC) and the National Environment Tribunal amongst others.

The apex body under the Act is the NEC which amongst other things is charged with the responsibility of developing the national environmental policy in Kenya as well as to set annual environmental goals and objectives.

The NEMA is the organ that has been established to exercise general supervision and coordination over all matters relating to the environment in Kenya. Further the NEMA is the Government’s principal instrument in the implementation of all policies relating to the environment.

The PCC was formed to investigate environmental complaints against any person, submit their findings/recommendations to the NEC and to submit periodic reports of its activities to the NEC.

The SERC has been established under the Act to advise the NEMA on the criteria and procedures for the measurement of environmental quality in Kenya. Environmental quality relates to air quality, wastewater quality, waste quality, noise quality, land use quality, etc.  Additionally the SERC is required to recommend to the NEMA minimum environmental quality standards for all environmental parameters for which subsidiary legislation is or has been promulgated(EMCA, 1999).

Under the EMCA there is subsidiary legislation which includes:

#### 2.4.1.2 Waste Management Regulations, 2006

The Waste Management Regulations of 2006 is comprehensive and covers the management of various kinds of waste in Kenya. Generally it is a requirement that a waste generator now segregates their waste (hazardous and non-hazardous) by type and then disposes the wastes in an environmentally acceptable manner.

Under the regulation, it is a requirement that waste is transported using a vehicle that has an approved "Waste Transportation License" issued by the NEMA. Wastes generated in Kenya must be disposed off in a licensed disposal facility.

#### 2.4.1.3 Water Quality Regulations 2006

These Regulations were enacted in 2006 to be applied to drinking water, water used for industrial purposes, water used for agricultural purposes, water used for recreational purposes, water used for fisheries and wildlife, and water used for any other purposes. The same regulations also provide guidelines on the effluent being discharged to the environment from industrial activities. Some of the standards have been reproduced in table 2.1 below.

**Table 2.1: NEMA Standards for effluent discharge into the environment**

| Parameter | Maximum levels permissible |
|---|---|
| Suspended solids (mg/L) | 30 |
| Total dissolved solids (mg/L) | 1200 |
| pH | 6-9 |
| Oil and Grease (mg/L) -where conventional treatment shall be used | Nil |
| Biological Oxygen Demand $BOD_5$ days at 20 $^oC$ (mg/L) | 30 |
| Chemical Oxygen Demand COD (mg/L) | 50 |

Source: EMCA (2006)

### 2.4.2 Water Resource Management Authority (WRMA)

WRMA was established as a corporate body through a gazette notice No. 8140 of 14th November 2003 pursuant to the Water Act (2002) and was operationalized in July 2005. The Authority is the lead agency in the management of water resources in the country and its overall development objective is to ensure rational, effective management of the water resources and equitable access for the various competing needs.

The role of WRMA among other functions is to regulate and protect water resources from adverse impacts. In line with this role WRMA has developed guidelines for effluent discharge to surface water resources as presented below.

**Table 2.2: WRMA Standards for effluent discharge into the environment**

| Parameter | Maximum levels permissible |
|---|---|
| Suspended solids (mg/L) | 30 |
| Total dissolved solids (mg/L) | 1200 |
| pH | 5-9 |
| Oil and Grease (mg/L) -where conventional treatment shall be used | Absent |
| Biological Oxygen Demand BOD5 days at 20$^{o}$C (mg/L) | 30 |
| Chemical Oxygen Demand COD (mg/L) | 100 |

Source: WRMA (2006)

### 2.4.3 Standards by International Bodies

Various international bodies have formulated guidelines for wastewater from different types of industries. These bodies include United States Environment Protection Agency (USEPA), Central Pollution Control Board (CPCB), World Health Organization (WHO), and Food Agriculture Organization (FAO) among others. The tables below present some of the discharge limits for food industry by different bodies.

**Table 2.3: Wastewater Discharge Standards by CPCB**

| **Parameter** | **Discharge limits** |
|---|---|
| pH | 6.0 – 8.0 |
| Total suspended solids | 100 mg/l. |
| Oil & Grease | 10 mg/l. |
| BOD | 30 mg/l |
| COD | 250mg/l |

Source: CPCB(2008)

**Table 2.4: Wastewater Discharge Standards by WHO**

| **Parameter** | **Discharge limits** |
|---|---|
| pH | 6.0 – 9.0 |
| Total suspended solids | 30 mg/l. |
| Oil & Grease | 15 mg/l. |
| BOD | 30mg/l |
| COD | 40mg/l |

Source: WHO (2006)

**Table 2.5: Wastewater Discharge Standards by FAO**

| **Parameter** | **Discharge limits** |
|---|---|
| pH | 6.0 – 9.5 |
| Total suspended solids | 100 mg/l. |
| BOD | 30mg/l |

Source: FAO (1992)

## 2.5 International Best Practices

In India there is a Central Pollution Control Board (CPCB) which has been entrusted to frame and implement Rules & Regulations in the country to prevent any further pollution and also control such pollution which are already being contributed by their industries. It is in this context that the CPCB formulated Minimal National Standards (MINAS) in respect of the liquid wastes and emissions for the Tea Processing Industry (CPCB, 2008)

Factory waste is categorized into solid waste; wastewater and air emissions. The solid waste from a tea industry is either used as fertilizer or used for making other by products. The by products include;

- Caffeine;
- Polyphenols (valuable anti-oxidant);
- Pigments (Edible colours);
- Polymers (tea polyphenols can be used to replace some of the phenol in phenol formaldehyde resins);
- Animal feeds (under investigation);
- Foaming agent;
- Vinegar;
- Tea seed oil (alternative to groundnut and olive oils for cooking, cosmetics and pharmaceuticals) and
- Furfural.

Source of wastewater in the tea industry is the domestic sector since the industrial process is basically dry in nature. Hence it is recommended that the domestic waste thus generated be treated in simple treatment system prior to its final disposal. The wastewater so generated may be treated in septic tank. Partially treated effluent from the septic tank should either be disposed off in soak pits or to be further treated in up-flow anaerobic filter (UFAF).

To manufacture one kg black tea on an average 4.5 – 5.0 kg of green tea is required. Alternately, it may be mentioned that 1 kg of green tea produces nearly 0.22 kg black tea.

The total solid waste which can no more be reused in the process is 2.0% of the black tea produced. 0.3% of this waste is recycled using some special technique. Thus, 1.7% solid waste has no use value to the black tea producers but this 1.7% waste material is not really a waste. This is normally sold to select reprocessing units where some chemicals by product are recovered from this waste. The process of recovery involves some chemical waste. For example, during detail study it was observed that a plant producing 800 tonnes of CTC tea annually generates solid waste to the extent of 16 tonnes (Mauskar, 2007).

Technologies like Combined Heat and Power systems (cogeneration) and waste heat utilisation help in achieving pollution control and energy efficiency. Use of nonconventional energy through solar dryers, biomass gasifiers and wind generator will prove to be a boon to energy intensive industry like tea processing in future (Rudramoorthy *et al*, 2000).

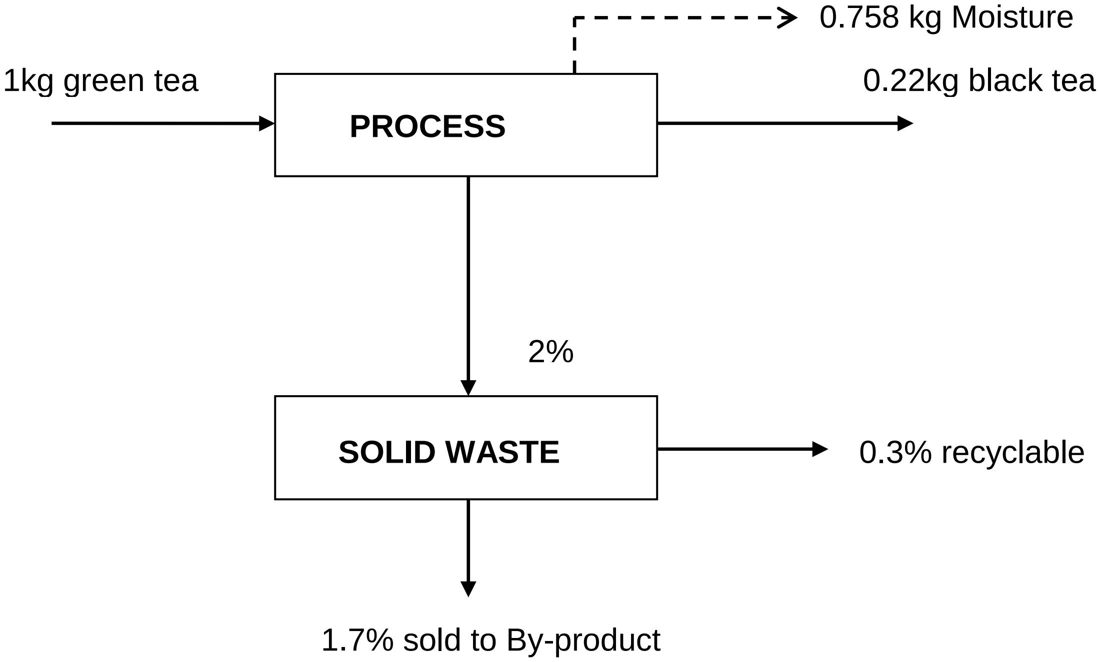


**Figure 2.2: Waste generation and utilisation in India**

## 2.6 Cleaner Production Mechanism

UNEP, 2000 defines Cleaner Production as the continuous improvement of industrial processes, products, and services to reduce the use of natural resources, prevent pollution at source and reduce waste generation at source in order to minimize risks to people and the environment. Cleaner production can be applied to the processes used in any industry and to industrial products themselves. For production processes, cleaner production results from one or a combination of several measures including conserving raw material, water and energy, eliminating toxic raw materials and reducing the quantity and toxicity of all emissions and wastes at source during the production process (COWI,2000). For products cleaner production includes the reduction of negative impacts along the life cycle of a product from raw material extraction to its ultimate disposal.

Cleaner production options can be grouped into: Waste reduction at source, recycling and product modification (Murunga, 2011).

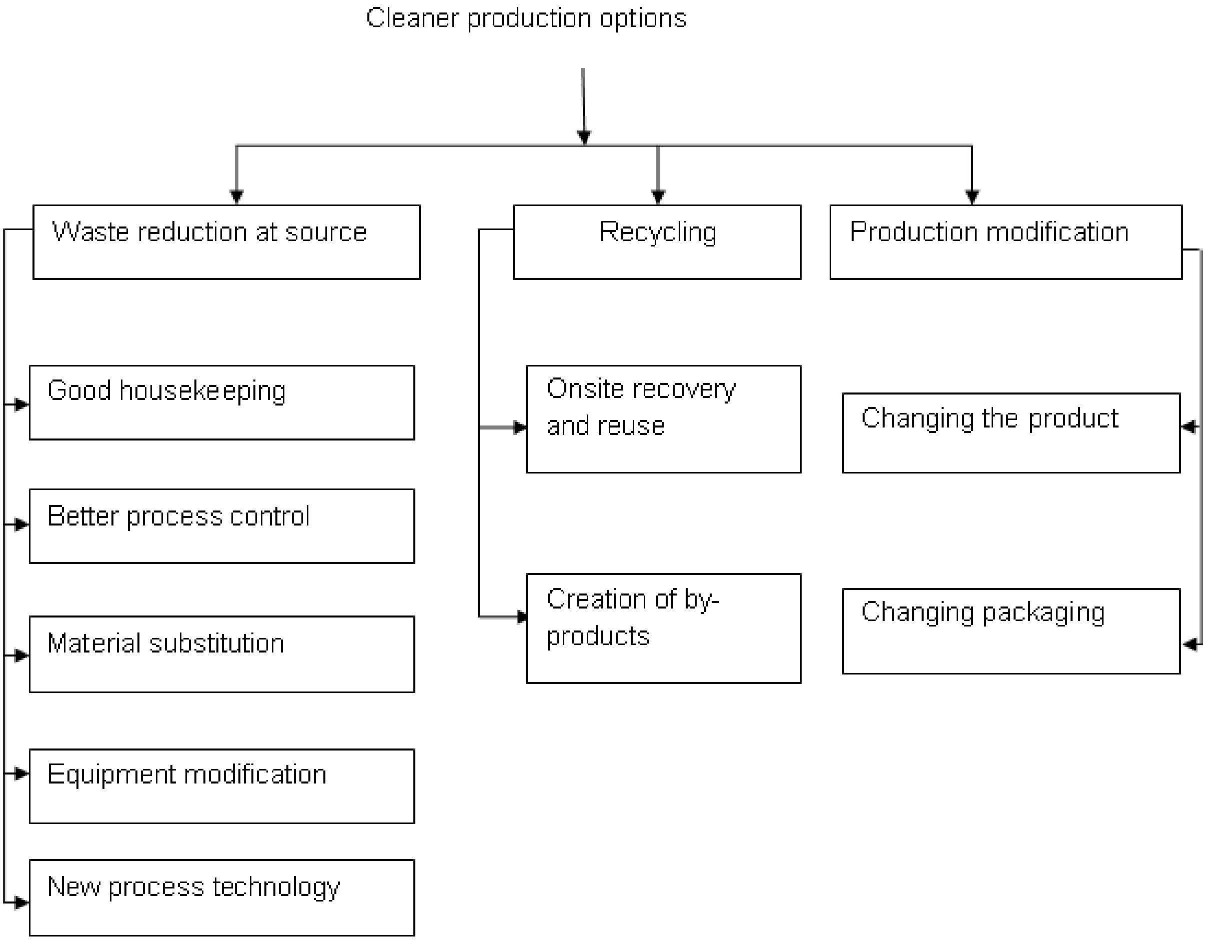


**Figure 2.3: Cleaner production options**

Source: UNEP, 2000.Mini-guide to cleaner production

**Benefits of cleaner production**

Cleaner production is relevant to all industries, whether they are small or big, whether they have a low or high consumption of raw material, energy, and water. For most companies, it has shown potential of reducing the resource consumption by 10-15% without any investment. (UNEP,et al,2000)

Cleaner production has the ability to reduce the consumption of resources and materials. Savings in energy and materials brings direct reductions in production costs, which again makes the company more competitive. Investment proposals based on cleaner production contain detailed information on the economical, technical and environmental feasibility of the planned investment. This gives a very solid basis for achieving financial support from banks or environmental funds.

Increasing consumer awareness of environmental issues has led to a spurt in demand of green products in the international markets. Consequently, if you put in conscious effort towards cleaner production, you open up new market opportunities and produce better quality products saleable at higher price. Apart from improving the economical and environmental performance, cleaner production can also improve the occupational health and safety conditions for the employees. Favorable working conditions can boost the morale of staff and at the same time foster a concern for controlling waste which helps company gain a competitive edge.

Meeting the regulatory standards for discharge of wastes (liquids, solids or gaseous) requires often installation of expensive and complex pollution control systems like wastewater treatment plants. Cleaner production leads to an all round reduction in wastes by volume, load, and even toxicity. With cleaner production the treatment of residual effluents normally becomes easier and cheaper. Cleaner production makes it much easier to implement environmental management system such as ISO 14000.Since most of the initial work will already be carried out through the cleaner production assessment. An ISO 14000 certificate can be a market opener, giving better access to export markets.

Individuals and industries may be richly rewarded for taking preventive environmental action in the form of cleaner production. Experience from both developed and developing countries, shows that cleaner production approach not only produces a cleaner environment but also results in substantial savings for industry and society (Murunga, 2011).

## 2.7 Solid Waste Management

Solid waste is the unwanted or useless solid materials generated from combined residential, industrial and commercial activities in a given area. It may be categorized according to its origin (domestic, industrial, commercial, construction or institutional); according to its contents (organic material, glass, metal, plastic paper etc); or according to hazard potential (toxic, non-toxin, flammable, radioactive, infectious etc) (Shirke, 2009).

Management of solid waste reduces or eliminates adverse impacts on the environment and human health and supports economic development and improved quality of life. A number of processes are involved in effectively managing waste. These include monitoring, collection, transport, processing, recycling and disposal. Appendix 8.2 shows waste that has been categorized in terms of origin.

### 2.7.1 Reduce, Reuse, Recycle

Methods of waste reduction, waste reuse and recycling are the preferred options when managing waste. There are many environmental benefits that can be derived from the use of these methods. They reduce or prevent green house gas emissions, reduce the release of pollutants, conserve resources, save energy and reduce the demand for waste treatment technology and landfill space (Heimlich *et al,* 1992).

#### 2.7.1.1 Waste Reduction and Reuse

Waste reduction and reuse of products are both methods of waste prevention. They eliminate the production of waste at the source of usual generation and reduce the demands for large scale treatment and disposal facilities. Methods of waste reduction include manufacturing products with less packaging, encouraging customers to bring their own reusable bags for packaging, encouraging the public to choose reusable products such as cloth napkins and reusable plastic and glass containers, backyard composting and sharing and donating any unwanted items rather than discarding them (Heimlich *et al,* 1992).

One way to manage solid waste is to reduce the waste we generate at the source. This is called "source reduction." For manufacturers, "source reduction" means producing less waste at a manufacturing facility itself. It also means designing products that have the least amount of packaging necessary to keep the product safe and of a high quality so as to meet the needs of the consumer.

For individuals, "source reduction" means reducing how much you use of an item, or deciding whether to use it at all. Writing on both sides of a sheet of paper before throwing it away is an example of source reduction. Another example is using durable clothing, appliances, furniture, and recreational equipment carefully and responsibly so that these items do not wear out so quickly.

All of the methods of waste prevention mentioned require public participation. In order to get the public onboard, training and educational programmes need to be undertaken to educate the public about their role in the process. Also the government may need to regulate the types and amount of packaging used by manufacturers and make the reuse of shopping bags mandatory.

#### 2.7.1.2 Recycling

Recycling refers to the removal of items from the waste stream to be used as raw materials in the manufacture of new products. Thus from this definition recycling occurs in three phases: first the waste is sorted and recyclables collected, the recyclables aroused to create raw materials. These raw materials are then used in the production of new products. The sorting of recyclables may be done at the source (i.e. within the household or office) for selective collection by the municipality or to be dropped off by the waste producer at a recycling centres. The pre-sorting at the source requires public participation which may not be forthcoming if there are no benefits to be derived. Also a system of selective collection by the government can be costly. It would require more frequent circulation of trucks within a neighbourhood or the importation of more vehicles to facilitate the collection (Heimlich *et al,* 1992).

Another option is to mix the recyclables with the general waste stream for collection and then sorting and recovery of the recyclable materials can be performed by the municipality at a suitable site. The sorting by the municipality has the advantage of eliminating the dependence on the public and ensuring that the recycling does occur. The disadvantage however, is that the value of the recyclable materials is reduced since being mixed in and compacted with other garbage can have adverse effects on the quality of the recyclable material

In recycling, waste materials are processed industrially and then reformed into new or similar products. Recycling includes pre-consumer waste, such as factory cuttings or shavings, as well as post-consumer waste items, including cardboard, newspapers, plastic bottles, and aluminum cans. Although recycling is often viewed as a resource conservation activity, it may offer greater return for many products in terms of energy savings. (Heimlich *et al,* 1992)

**Figure 2.4:** Colour coded recycling bins for waste separation at the source of production (www.unpluggedliving.com)

#### 2.7.1.3 Composting

Composting means the decomposition of organic materials. “Organic materials” are items that were once living matter. Paper, leaves, grass and food are examples of organic material. For many years, people have composted food and yard waste in their backyards. “Municipal Solid Waste Composting” is a relatively new way to take advantage of an age-old process. This means composting as much of a town or city’s solid waste is possible. In recent years, for example, some cities have removed fallen leaves and grass clippings from what goes to the landfill and have begun composting these materials. The EPA considers composting to be a type of recycling. While Europeans have been composting their municipal trash for almost 30 years, in the United States are just beginning to learn about how municipal solid waste composters can recycle paper, food waste, and yard waste into a soil additive that can be used in planting trees and shrubs (UNEP, 1996).

### 2.7.2 Treatment and Disposal

Waste treatment techniques seek to transform the waste into a form that is more manageable, reduce the volume or reduce the toxicity of the waste thus making the waste easier to dispose off. Treatment methods are selected based on the composition, quantity, and form of the waste material. Some waste treatment methods being used today include subjecting the waste to extremely high temperatures, dumping on land or land filling and use of biological processes to treat the waste. It should be noted that treatment and disposal options are chosen as a last resort to the previously mentioned management strategies reducing, reusing and recycling of waste as shown in figure 2.5.

**Figure 2.5:** Solid waste management hierarchy (www.sustainability-ed.org/pages/example2-2.htm)

### 2.7.3 Thermal Treatment

This refers to processes that involve the use of heat to treat waste. Some commonly utilized thermal treatment processes include:

#### 2.7.3.1 Incineration

Incineration is the most common thermal treatment process. This is the combustion of waste in the presence of oxygen. After incineration, the wastes are converted to carbon dioxide, water vapour and ash. This method may be used as a means of recovering energy to be used in heating or the supply of electricity. In addition to supplying energy incineration technologies have the advantage of reducing the volume of the waste, rendering it harmless, reducing transportation costs and reducing the production of the green house gas methane.

Today's waste-to-energy incinerators use high-technology scrubbers to remove potentially harmful gases and to collect ash that results from the burning of trash. Most importantly, these incinerators also produce energy. The heat produced by burning trash can be recovered through a steam turbine that produces electricity. In some instances, the steam itself is used to provide heat (UNEP, 1996)

#### 2.7.3.2 Pyrolysis and Gasification

Pyrolysis and gasification are similar processes they both decompose organic waste by exposing it to high temperatures and low amounts of oxygen. Gasification uses a low oxygen environment while pyrolysis allows no oxygen. These techniques use heat and an oxygen starved environment to convert biomass into other forms. A mixture of combustible and non-combustible gases as well as pyroligenous liquid is produced by these processes. All of these products have a high heat value and can be utilised. Gasification is advantageous since it allows for the incineration of waste with energy recovery and without the air pollution that is characteristic of other incineration methods.

#### 2.7.3.3 Open Burning

Open burning is the burning of unwanted materials in a manner that causes smoke and other emissions to be released directly into the air without passing through a chimney or stack. This includes the burning of outdoor piles, burning in a burn barrel and the use of incinerators which have no pollution control devices and as such release the gaseous by products directly into the atmosphere. Open burning has been practiced by a number of urban centres because it reduces the volume of refuse received at the dump and therefore extends the life of their dumpsite. Garbage may be burnt because of the ease and convenience of the method or because of the cheapness of the method. In countries where house holders are required to pay for garbage disposal, burning of waste in the backyard allows the householder to avoid paying the costs associated with collecting, hauling and dumping the waste (UNEP, 1996).

Open burning has many negative effects on both human health and the environment. This uncontrolled burning of garbage releases many pollutants into the atmosphere which include dioxins, particulate matter, polycyclic aromatic compounds, volatile organic compounds, carbon monoxide, hexachlorobenzene and ash. All of these chemicals pose serious risks to human health. The dioxins are capable of producing a multitude of health problems; they can have adverse effects on reproduction, development, disrupt the hormonal systems or even cause cancer. The polycyclic aromatic compounds and the hexachlorobenzene are considered to be carcinogenic. The particulate matter can be harmful to persons with respiratory problems such as asthma or bronchitis and carbon monoxide can cause neurological symptoms.

The harmful effects of open burning are also felt by the environment. This process releases acidic gases such as the halo-hydrides; it also may release the oxides of nitrogen and carbon. Nitrogen oxides contribute to acid rain, ozone depletion, smog and global warming. In addition to being a green house gas carbon monoxide reacts with sunlight to produce ozone which can be harmful. The particulate matter creates smoke and haze which contribute to air pollution.

### 2.7.4 Dumps and Landfills

#### 2.7.4.1 Sanitary Landfills

Sanitary Landfills are designed to greatly reduce or eliminate the risks that waste disposal may pose to the public health and environmental quality. They are usually placed in areas where land features act as natural buffers between the landfill and the environment. For example the area may be comprised of clay soil which is fairly impermeable due to its tightly packed particles, or the area may be characterised by a low water table and an absence of surface water bodies thus preventing the threat of water contamination.

In addition to the strategic placement of the landfill other protective measures are incorporated into its design. The bottom and sides of landfills are lined with layers of clayor plastic to keep the liquid waste, known as leachate, from escaping into the soil. The leachate is collected and pumped to the surface for treatment. Boreholes or monitoring wells are dug in the vicinity of the landfill to monitor groundwater quality (UNEP, 1996).

A landfill is divided into a series of individual cells and only a few cells of the site are filled with trash at any one time. This minimizes exposure to wind and rain. The daily waste is spread and compacted to reduce the volume, a cover is then applied to reduce odours and keep out pests. When the landfill has reached its capacity it is capped with an impermeable seal which is typically composed of clay soil.

Some sanitary landfills are used to recover energy. The natural anaerobic decomposition of the waste in the landfill produces landfill gases which include Carbon dioxide, methane and traces of other gases. Methane can be used as an energy source to produce heat or electricity. Thus some landfills are fitted with landfill gas collection systems to capitalise on the methane being produced. The process of generating gas is very slow, for the energy recovery system to be successful there needs to be large volumes of wastes.

These landfills present the least environmental and health risk and the records kept can be a good source of information for future use in waste management, however, the cost of establishing these sanitary landfills are high when compared to the other land disposal methods.

The EPA recommends that all communities attempt to reduce as much as possible the amount of municipal solid waste (MSW) that goes to landfills. In this way we can lighten the burden caused by the trash we throw away. This is a new way to look at landfills. Landfills should be the way we dispose of our trash after as many valuable materials as possible have been reclaimed or reused. These other steps should be considered first, rather than looking at landfills as the primary way of taking care of our trash.

### 2.7.5 Solid Waste Management in Kenya

There is not much literature on the Kenyan solid waste management (SWM) sector with the exception of Nairobi. Even for Nairobi, the available literature dwells largely on performance description and its causes, household waste generation behaviour, and waste characteristics. While poor management of solid waste is a general problem in Kenya, it is probably worst in Nairobi. (Ikiara *et al, 2004*)

Solid wastes in Nairobi are a by-product of a broad spectrum of industrial, service and manufacturing processes. Primary high-volume generators of industrial solid wastes include the Leather, Textile, Wood and Rubber (LTWR) and Inorganic, Organic and Wastewater. Secondary smaller generators include auto and equipment repair shops, electroplaters, construction firms, dry cleaners and pesticide applicators. Mismanagement of these wastes typically results in pollution of the natural environment and may pose substantial danger to public health and welfare. With respect to manufacturing industries, the bulk of solid wastes are generated from: Pesticide repackaging, formulation and distribution, Pharmaceuticals, where there are over 30 manufacturing companies, plastics industry, where there are about 100 producing thermo setting, flimsy packaging, soap, perfumes, cosmetics, toiletry, cement and lime, ceramics, glass and petroleum (Ikiara *et al*, 2004).

Industrial wastes constitute about 23 per cent of the total solid wastes generated in the city. The collection and disposal of industrial waste in Nairobi is done by industries themselves. Though its disposal is done at a Municipal dumpsite, the industries have the responsibility to collect and dispose the waste at the designated dumping sites. Figure 2.5 shows the types of solid waste generated in Nairobi.

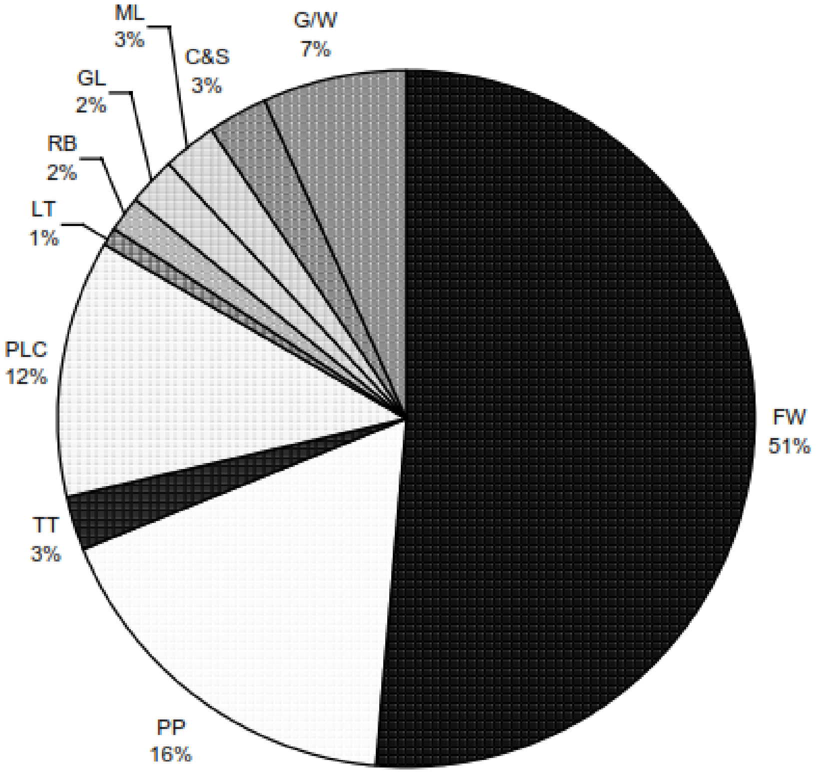


**Figure 2.6: Types of solid wastes generated in Nairobi (Source: JICA 1998)**

**Key:**

| | | |
|---|---|---|
| FW | Food Waste | 51.5% |
| TT | Textiles | 2.71% |
| LT | Leather | 0. 9% |
| GL | Glass (Containers & Others) | 2.3% |
| MT | Metals(Containers & Others) | 2.6% |
| C&S | Ceramic & Soil | 2.7% |
| G/W | Grass/Wood | 6.7% |
| PP | Paper (Recyclable & Other) | 7.3% |
| PC | Plastic (Containers & Others) | 11.8% |
| RB | Rubber | 1.5% |

## 2.8 Wastewater Management

Wastewater treatment is done to prevent the pollution of the receiving environment especially the waters. This treatment is a process that is divided into three stages namely: preliminary (physical), primary (physical) treatment and secondary (biological) treatment. Minimally, wastewater should receive primary (physical removal/settling) and secondary (biological) treatment, which can be followed by disinfection before discharge. More advanced processes (advanced or tertiary treatment) may be required for special wastes. When the effluent from secondary treatment is unacceptable, a third level of treatment, tertiary treatment, can be employed.

All industrial processes, regardless of product or size, generate waste by the very nature of their respective operations. The volume and characteristics of waste produced vary from industry to industry and even within the same industry from time to time. Thus adequate data and knowledge of the characteristics and nature of an industrial waste is a pre-requisite for finding an appropriate method for its treatment.

Industrial liquid waste is by definition the fraction of water employed non-consumptively in industrial works. Although industries use large volumes of water in their manufacturing processes and in supporting operations, only a small fraction of the water becomes part of the manufactured product or consumed or lost by evaporation. The larger part becomes spent water and may contain many pollutants. If this spent water is discharged untreated or insufficiently treated, the performance or operation of the municipal sewage treatment works may be impaired or serious water quality problems may result in receiving bodies of water (Omosa, 2004)

Contaminants and pollutants found in industrial wastewater vary, with their source and the extent of water and waste care within the manufacturing plant before discharge. The biodegradable organics, expressed in $BOD_5$ in mg/l, reach levels 100 times that of the 250 to 300 mg/l of domestic sewage (Chanlett, 1979).

Municipal and industrial wastewater treatments are very different. Compared to municipal wastewater, industrial wastewater contains different pollutants and is often more variable, concentrated, and toxic. The nature of the design, construction, and operations services are also different, as are the procurement techniques (WEF, 2008).

### 2.8.1 Physical Treatment Process

Physical processes were some of the earliest methods to remove solids from wastewater, usually by passing wastewater through screens to remove debris and solids. In addition, solids that are heavier than water would settle out from wastewater by gravity.  Particles with entrapped air float to the top of water and can also be removed (USEPA, 2004).

### 2.8.2 Biological Treatment Process

In nature, bacteria and other small organisms in water consume organic matter in sewage, turning it into new bacterial cells, carbon dioxide, and other by-products. The bacteria normally present in water must have oxygen to do their part in breaking down the sewage. With the addition of oxygen to wastewater, masses of microorganisms grow and rapidly metabolized organic pollutants. Any excess microbiological growth could be removed from the wastewater by physical processes (USEPA, 2004).

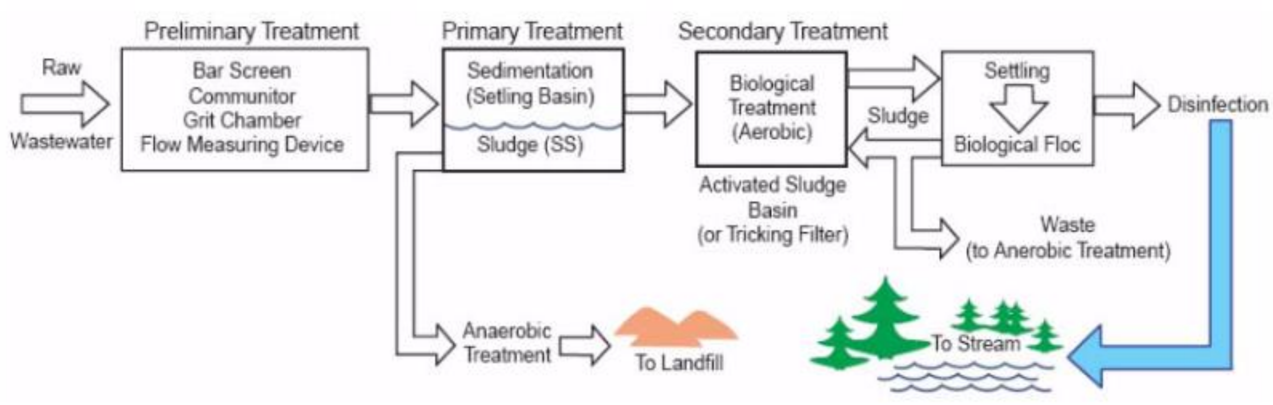


**Figure 2.7: Schematic of a typical wastewater treatment plant**

Source: (ADF, 2013).

### 2.8.3 Chemical Treatment Process

Chemicals can be used to create changes in pollutants that increase the removal of these new forms by physical processes. Simple chemicals such as alum, lime or iron salts can be added to wastewater to cause certain pollutants, such as phosphorus, to flocor bunch together into large, heavier masses which can be removed faster through physical processes.  Over the past 30 years, the chemical industry has developed synthetic inert chemicals known as polymers to further improve the physical separation step in wastewater treatment. Polymers are often used at the later stages of treatment to improve the settling of excess microbiological growth or biosolids (USEPA, 2004).

Nyansiongo tea factory utilizes the naturally aerated lagoon system for treating their wastewater. There are several different types and names for lagoons and many possible system designs. Lagoon systems include one or more pond-like bodies of water or basins designed to receive, hold, and treat wastewater for a predetermined period of time. Lagoons are constructed and lined with material, such as clay or an artificial liner that would prevent leaks to the groundwater below.

While in the lagoon, wastewater receives treatment through a combination of physical, biological, and chemical processes (USEPA 1997). Much of the treatment occurs naturally, but some systems are designed to also use aeration devices that increase the amount of oxygen in the wastewater.

### Aerobic Lagoons

Aerobic describes the presence of dissolved oxygen throughout the depth of the lagoon. Aerobic lagoons can be either naturally aerated or mechanically aerated. In order to allow oxygen to penetrate the entire lagoon, aerobic lagoons tend to be very shallow and consequently require much more land area than other types of lagoons. However, if properly designed and maintained, an aerobic lagoon can treat wastewater more quickly than all other lagoon types. Aerobic lagoons also produce fewer odors than anaerobic lagoons. Aerobic lagoons are best suited for warm, sunny climates so as to avoid freezing. Because of the shallow nature of aerobic lagoons, special care needs to be taken to avoid weeds and grass growth on the bottom of the lagoon. Often the bottoms are paved or lined with materials to prevent weed growth. Occasionally the wastewater in an aerobic lagoon needs to be mixed to allow additional sunlight and to break up algae clumps that may block the oxygen and sunlight required for the natural treatment process (Miller *et al*, 2011).

### Naturally-Aerobic Lagoons

Naturally-aerobic lagoons do not use a mechanical aeration system, but rather rely on oxygen from the atmosphere or from photosynthesis by algae to maintain aerobic conditions. Naturally-aerobic lagoons must be shallow, typically only 1 to 2 feet deep and no more than5 to 6 feet (Zhang, 2001). The required design volume for a naturally aerobic lagoon is typically four to five times that of an anaerobic lagoon. The land area required to meet the design volume and shallow depth requirements make naturally-aerated lagoons generally impractical for farm use (Jones, 1999).

### Mechanically-Aerated Lagoons

Mechanically-aerated lagoons use an aeration system to add oxygen to the lagoon and mix the contents thereby increasing the degree of aeration. A power source is needed to operate the aeration system. Some operators use solar or wind power. By aerating a lagoon system one can significantly decrease the amount of land required for a lagoon and still receive the benefits of a full or partial aerobic lagoon. The required design volume for a mechanically aerated lagoon is about half of an anaerobic lagoon. Depending on the lagoon depth and the extent of aeration, the lagoon can work as a combination of both an anaerobic and an aerobic lagoon (Jones, 1999).

## 2.9 Air Quality Management

The quality of air within factory buildings is controlled by many food manufacturers. Environmental air of a specified quality (temperature, humidity and particle concentration) and quantity (fresh air volume) is required for the comfort and safety of employees. For the manufacture of some products, it is necessary to impose additional controls on environmental air quality to reduce the possibility of contamination. Also, process air that comes in contact with food must be controlled.

The controlled properties of air, especially temperature and humidity, may be used to prevent or reduce the growth rate of some micro-organisms in manufacturing and storage areas. The particle content-dust and micro-organisms can also be controlled to limit the risk of product contamination and hence contribute to safe food manufacture.

Dust control for the food industry protects the operator from inhaling fine particles, prevents dust spreading in process areas and causing cross-contamination, prevents accumulation of dust which may provide a substrate for growth of micro-organisms, and a supply of food for rodent and insect infestations. It also prevents environmental pollution and explosion.

Types of dust control equipment include dust control filters and wet scrubbing devices for small dust particles with low inertia, impingement or entrapment filters whereas for large particles with high inertia, a cyclonic device may be used.

# 3.0 THEORITICAL FRAMEWORK

## 3.1 Waste Management

Waste management is the collection, transport, processing, recycling or disposal, and monitoring of waste materials (Wikipedia, 2012). The term usually relates to materials produced by human or industrial activity, and is generally undertaken to reduce their effect on health, the environment or aesthetics. Waste management is also carried out to recover resources from it. Waste management can involve solid, liquid, gaseous or radioactive substances, with different methods and fields of expertise for each.

### 3.1.1 Solid Waste Management

Solid waste management vary from one country to another and depends on the type of waste, composition, infrastructure, land availability, labour, economic aspects, recycling strategy, public awareness, calorific value of waste, energy availability and demand and environmental impact (Agamuthu, 2002).

Landfilling is one of the primary technologies used to dispose off solid waste. It is a method of refuse disposal significantly limiting volume where waste is systematically covered by layers of earth. Buried waste degrades as a result of natural oxidation and microbial action. It is also considered the simplest, and in many areas the cheapest of the disposal methods.

#### 3.1.1.1 Design of Landfills

Landfilling is a waste management system which involves the covering of the waste daily with soil or other modern materials to prevent scavengers and other animals from the landfill area (Yedla, 2005)

The following assumptions are made:

- Waste is segregated at source and should contain very little fraction of recyclable material when it reaches the landfill site.
- Direct shipment of waste is considered in most of the cases as the proposed landfills with modified designs could be located in different parts of the mainland leaving a wider scope for minimisation of transportation cost and efficient waste collection.

$$Volume\ of\ waste\ after\ landfilling\ daily(m3) = \frac{W_d \times f_{lf} \times f_{lf} \times e_{coll}(1 + f_{cs})}{\rho_{w-lf} \times e_{lf}}$$

**3.1**

Where;

Density of waste in landfill = $\rho_{w\text{-}lf}$ t/m3

Total waste generated per day (tons) = $W_d$

Annual waste generation (tons) = $W_a$

Compostable fraction of Waste = $f_{cf}$

Non-organic/reusable fraction of Waste = $f_n$

Collection efficiency = $e_{coll}$

Fraction to be landfilled = $f_{lf}$

Landfilling efficiency1 = $e_{lf}$

Depth of fill (m) = $d_{lf}$

Let $f$cs be the ratio of volume of cover soil to the volume of waste

Let the volume of each cell be

$\text{Volume of each cell} = (\mathrm{L} \times 2\mathrm{B} \times d_{\mathrm{lf}}) - 0.5d_{lf}^2(2L + B - 5d_{\mathrm{lf}}$

Where;

$L$ = base length of landfill (with one end open)

$B$ = breadth of the base (wall to wall) (Peavy and Rowe, 1985) and 1:1 slope is assumed on all sides of the landfill.

For a cell to cater for a one year of waste, the designed volume should be equal to the volume of waste in place per year

$$(\mathrm{L} \times 2\mathrm{B} \times d_{\mathrm{lf}}) - 0.5d_{lf}^2(2L + B - 5d_{\mathrm{lf}} = \frac{W_d \times f_{lf} \times f_{lf} \times e_{coll}(1 + f_{cs}) \times 365days}{\rho_{w-lf} \times e_{lf}}$$

(Peavy and Rowe, 1985)

**3.2**

### 3.1.2 Liquid Waste Management

#### 3.1.2.1 Sewage Treatment

A high BOD indicates the presence of excess amounts of organic carbon. Oxygen depletion is a consequence of adding wastes with high BOD values to aquatic ecosystems.

The higher the BOD of a source of wastes the higher the polluting power of that waste. BOD's of certain wastes are listed in the table below.

**Table 3.1: BOD's of various waste**

| **Type of Waste** | **BOD(mg/L)** |
|---|---|
| Domestic Sewage | 200-600 |
| Slaughterhouse Wastes | 1000-4000 |
| Cattle Shed Effluents | 20000 |
| Vegetable Processing | 200-5000 |
| Dairy processing | 450 |
| Agricultural product (Potato) | 1800 |
| Brewery | 1500 |
| Beverages | 430 |

Source: Ohnishi, 2002

There are numerous ways to reduce the BOD of waste before discharging it into the water. Treatment of the wastes is aimed at removing organic material, human pathogens, and toxic chemicals.

Primary sewage treatment involves physical separation to lower the BOD of the waste. Suspended solids are removed in this step through the use of settling tanks. Primary treatment usually removes from 30% to 40% of the BOD from typical domestic sewage. Secondary treatment uses microbial degradation to reduce the concentration of organic compounds further; it involves microbial processes which can be aerobic or anaerobic. The combined use of primary and secondary treatment reduces approximately 80% to 90% of the BOD. However, because secondary treatment involves microorganisms it is extremely sensitive to toxic chemicals. Finally, tertiary treatment uses chemicals to remove inorganic compounds and pathogens (Atlas, 1995)

#### 3.1.2.2 Lagoons

A wastewater lagoon or treatment pond is a scientifically constructed pond, three to five feet deep, that allows sunlight, algae, bacteria, and oxygen to interact. Biological and physical treatment processes occur in the lagoon to improve water quality. The quality of water leaving the lagoon, when constructed and operated properly, is considered equivalent to the effluent from a conventional secondary treatment system.

Lagoons have several advantages when used correctly. They can be used for secondary treatment or as a supplement to other processes. While treatment ponds require substantial land area and are predominantly used by smaller communities, they account for more than one-fourth of the municipal wastewater treatment facilities. Lagoons remove biodegradable organic material and some of the nitrogen from wastewater.

### 3.1.3 Thermal Waste Management

#### 3.1.3.1 Heat Exchangers

A heat exchanger is a tool built for efficient heat transfer from one fluid to another, whether the fluids are separated by a solid wall so that they never mix, or the fluids are directly contacted. Heat exchangers are widely used in refrigeration, air conditioning, space heating, power generation, and chemical processing. Common types of heat exchanger flows include parallel flow, counter flow, and cross flow. In parallel flow, both fluids move in the same direction while transferring heat; in counter flow, the fluids move in opposite directions and in cross flow the fluids move at right angles to each other. The common constructions for heat exchanger include shell and tube, double pipe, extruded finned pipe, spiral fin pipe, u-tube, and stacked plate.

The Log mean temperature difference (LMTD) is often used as an 'average' temperature. In more complex systems, direct knowledge of the LMTD is not available and the number of transfer units (NTU) method can be used instead.

Basic overall heat-transfer equations to the heat exchanger

$$q = UA\Delta T \qquad \textbf{3.3}$$

Therefore heat balance over a short length is;

$$C_p G dt = UA\Delta t_m \qquad \textbf{3.4}$$

$$t_m = \frac{\Delta T_1 - \Delta T_2}{ln\frac{\Delta T_1}{\Delta T_2}} \qquad \textbf{3.5}$$

Where;

U = Overall heat transfer coefficient

G = Mass flow rate

$C_p$ = Specific gravity of the fluid

$\Delta T_1$ and $\Delta T_2$ = Temperature difference between the two fluids at the beginning and the end respectively.

Log Mean Temperature Difference

$$d(\Delta T) = -kUdA\Delta T \tag{3.6}$$

$$\int_{\Delta T_2}^{\Delta T_1} \frac{d\Delta T}{\Delta T} = -k\int_0^{A_t} UdA \tag{3.7}$$

### 3.1.3.2 Heat Transfer

Heat transfer, also known as heat flow, heat exchange, or transfer of thermal energy is the movement of heat from one place to another. When an object is at a different temperature from its surroundings, heat transfer occurs so that the body and the surroundings reach the same temperature at thermal equilibrium. Such spontaneous heat transfer always occurs from a region of high temperature to another region of lower temperature as required by the second law of thermodynamics.

### 3.1.3.3 Conduction

Heat conduction occurs as hot, rapidly moving or vibrating atoms and molecules interact with neighboring atoms and molecules, transferring some of their energy (heat) to neighboring atoms. Heat is transferred by conduction when adjacent atoms vibrate against one another, or as electrons move from one atom to another. Conduction is the most significant means of heat transfer within a solid or between solid objects in thermal contact. Fluids (and especially gases) are less conductive.

The amount of heat transfer can be calculated by use of heat transfer Fourier equations.

$$q_x = -KA\frac{\partial x}{dt} \tag{3.8}$$

$$q_y = -KA\frac{\partial y}{dt} \qquad \textbf{3.9}$$

Where;

$q =$ Heat transfer rate

$k =$ Thermal conductivity of the material

$A =$ Heat transfer surface area

$\frac{dx}{dt} =$ Temperature gradient in direction of heat flow

### 3.1.3.4 Convection

Convective heat transfer is the transfer of heat from one place to another by the movement of fluids. The presence of bulk motion of the fluid enhances the heat transfer between the solid surface and the fluid. Although often discussed as a third method of heat transfer, convection actually describes the combined effects of conduction and fluid flow (Yugnus, 2003).

Convection is described by Newton's law of cooling, which states that *the rate of heat loss of a body is proportional to the difference in temperatures between the body and its surroundings.*

The amount of heat transfer can be calculated by use of heat transfer Fourier equations.

$$q = hAdt \qquad \textbf{3.10}$$

Where;

$h =$ Convective heat transfer coefficient

### 3.1.3.5 Radiation

Thermal radiation is the transfer of heat energy through empty space by electromagnetic waves. All objects with a temperature above absolute zero radiate energy. No medium is necessary for radiation to occur, for it is transferred by electromagnetic waves; radiation takes place even in and through a perfect vacuum. The amount of heat transfer can be calculated by use of heat transfer Fourier equations.

$$q = \in \sigma A T^4 \qquad \textbf{3.11}$$

$\epsilon$=Emissivity

$\sigma$ =Stefan Boltzmann constant

T= Absolute temperature in Kelvin

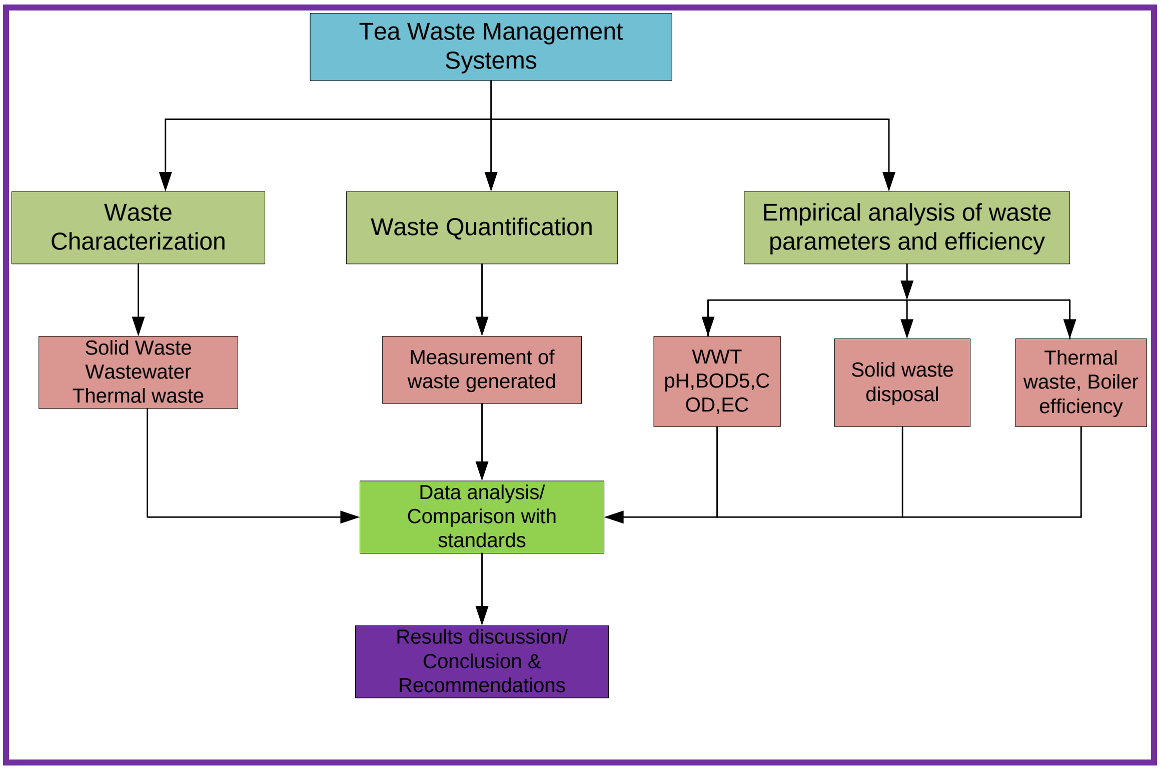


**Figure 3.1: Conceptual framework for the study**

# 4.0 MATERIALS AND METHODS

## 4.1 Site Analysis and Inventory

The study was carried out in Nyansiongo Tea Factory in Borabu District, Nyamira County. Nyansiongo Tea Factory is one of the 53 factories owned by small scale tea growers with Kenya Tea Development Agency (KTDA) as the managing agent. It was built in 1974 with a design capacity of 15 million kg green leaf per year and a throughput of 3000 kg per hour. It has a catchment of about 10750 growers from six micro-constituencies namely: West Mugirango, Kitutu, Mekenene, Nyansiongo, Gesima and Esise. Nyansiongo Tea Factory is located off Sotik-Kisii highway on geographical coordinates $0^o45'37.39''$S and $35^o0'58.67''$E with an elevation of 1893 metres above sea level. Nyansiongo area connects with one major highway i.e. Kisii – Sotik road highway with three feeder roads i.e. Kijauri – Manga road, Nyansiongo – Isoge road, Metamaywa – Kebirigo road, Nyansiongo - Omoyo feeder roads.

It experiences an average rainfall that ranges between 1300mm and 1400mm annually with a temperature range of $8^0$C and $27^0$C.The area is characterized by wet and very heavily plain remnants of the natural vegetation. This can only be seen on the very shallow hilltops and slopes. The rest of the area is completely cultivated.

In general the soils are well drained with red brown, silty clay with gradual textural change with depth. The drainage pattern of the whole area of Nyansiongo is mainly dendritic. The area consists of a rolling landscape with an altitude of 1850m-1950m above sea level, but with some steep conical hills. These tops can have an altitude of 2060m above sea level.

Maize, millet, beans and sweet potatoes are the most important subsistence crops while tea and pyrethrum are the cash crops in the area.

During this study sampling was done within the factory and along the stream for analysis. The sampling locations with their geographical coordinates for this study are presented in table 4.1 below.

**Table 4.1: Sampling locations for the study**

| **Sampling points** | **Coordinates** | **Elevation** |
|---|---|---|
| Main factory building | 0°45'37.58"S<br>35° 0'58.60"E | 1898m |
| Point 1 Entry | 0°45'38.88"S<br>35° 0'57.43"E | 1889m |
| Point 2 | 0°45'38.61"S<br>35° 0'57.07"E | 1889m |
| Point 3 | 0°45'38.70"S<br>35° 0'56.96"E | 1889m |
| Point 4 | 0°45'38.94"S<br>35° 0'57.21"E | 1889m |
| Landfill | 0°45'37.29"S<br>35° 0'56.47"E | 1890m |
| Upstream | 0°45'42.66"S<br>35° 0'45.34"E | 1870m |
| Entry point to river | 0°45'49.93"S<br>35° 0'54.37"E | 1864m |
| Point after entry | 0°45'52.11"S<br>35° 0'55.40"E | 1868m |

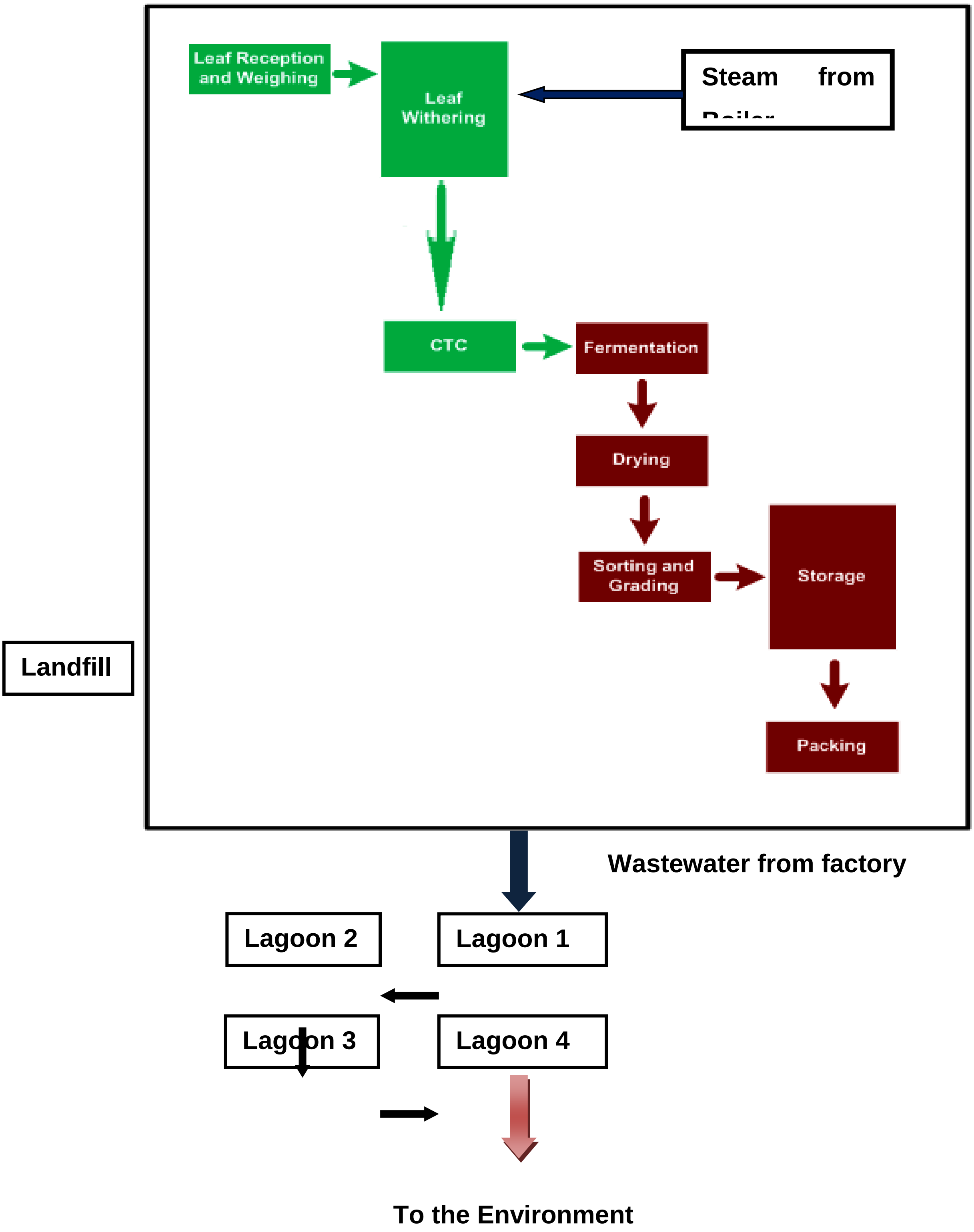


**Figure 4.1: Figure showing general factory layout**

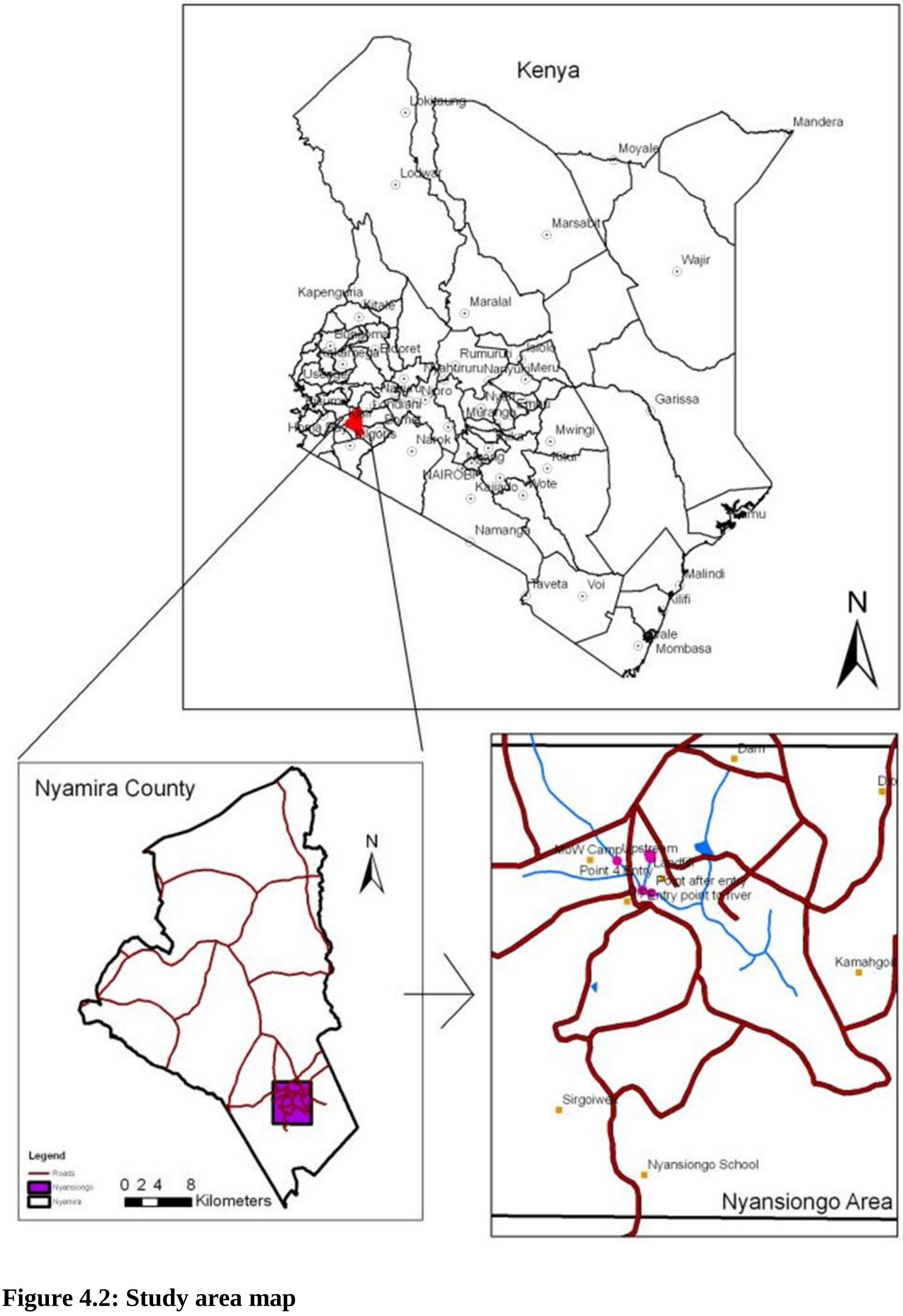


Figure 4.2: Study area map

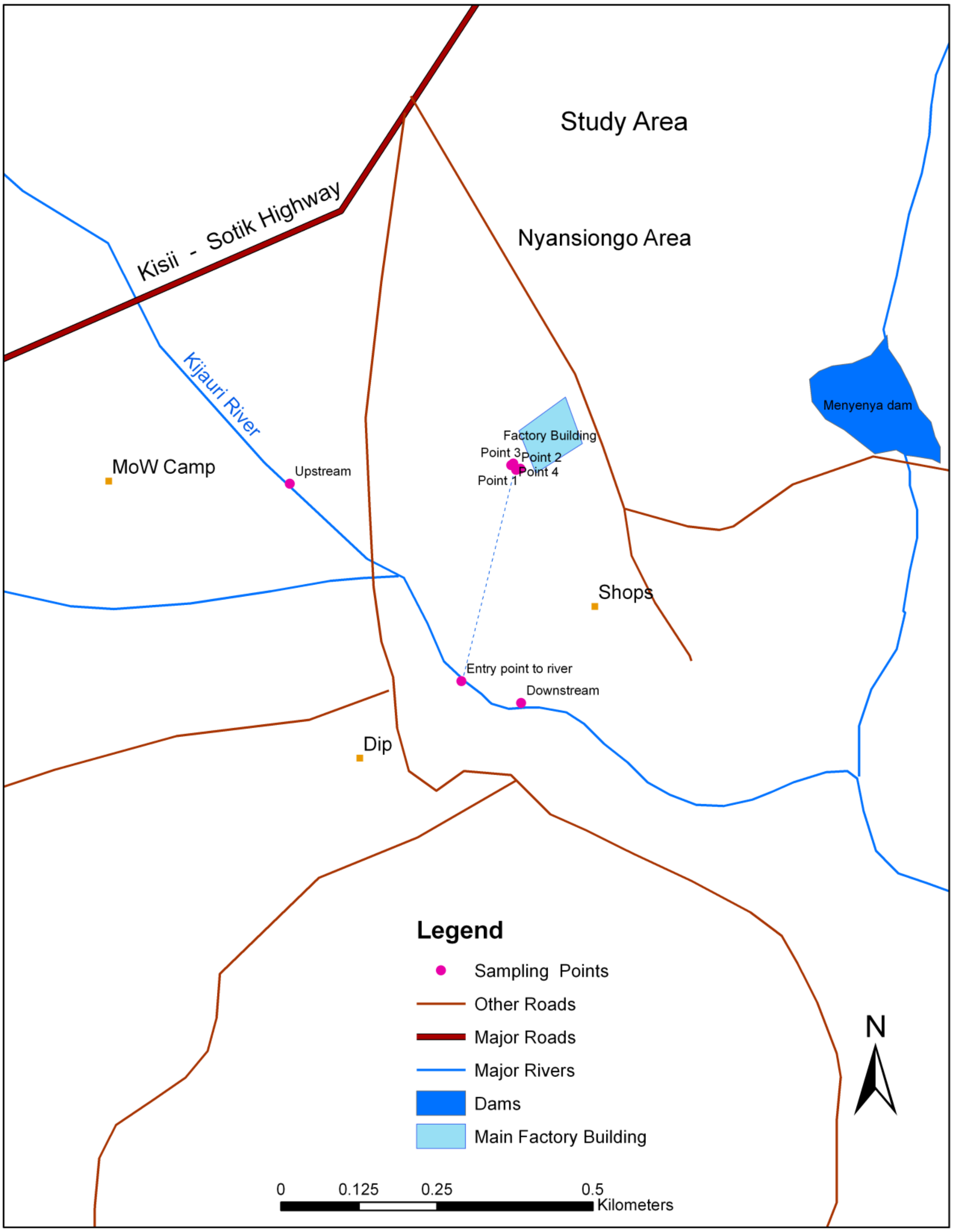


**Figure 4.3: Study location map with sampling points**

## 4.2 Existing Waste Management Systems

Solid waste is generated from tea processing processes. The solid waste is generated from the green leaf inception through withering, cut and curl, drying and packaging. This waste is then collected and disposed in a compost pit with dimensions of 3m by 1.5m by 2.1m. Other waste like scrap has also been dumped next to the compost pit and at times it mixes with the waste in the landfill. At the time of data collection, the pit was filled up with waste. The waste is at times sold as organic manure to farmers.

Wastewater was generated from tea processes and mostly from the cleaning of the factory. There are major cleaning processes, which were done weekly while minor cleaning is done daily. The wastewater is directed to the lagoons for treatment. There were four lagoons in number, which are arranged in series. Wastewater treatment is through naturally aerated lagoons. The lagoons measure 10metres by 5metres with a depth of 5feet.

The factory has two boilers in site; one uses heavy fuel oil while the other uses fire wood. Lately, firewood is the preferred source of fuel in the factory. The boiler has been installed with an economizer to manage waste heat through flue gas.

**Plate 4.1: Lagoons for wastewater**

Plate 4.2: Heap of scrap metal

### 4.3 Classification of Solid Waste Generated

The determination of the types and sources of wastes generated during tea production was done mainly through observations. The following procedure was carried out to help achieve this particular objective.

**Procedure**

Observations and characterization of wastes generated were made at different stages of tea production. The stages were tea collection, withering, leaf maceration (CTC), fermentation, drying and sorting.

The wastes were characterized and classified based on the internationally recognized methodologies. This means the description of the type (composition) of waste present in a waste stream as in table 4.2.

**Table 4.2: Waste characterization**

| Main material waste | Material category |
|---|---|
| Organic waste | • Compostable: Fruit and vegetable<br>• Food preparation waste (cooked) food<br>• Other : Meat, pits of fruit |
| Paper | • Newspaper, magazines, writing paper, packaging paper |
| Cardboard | • Folding boxes, corrugated cartons |
| Carton container | • Drink cartons |
| Plastics | • PET<br>• HDPE<br>• Other plastics; PVC, LDPE, PP, PS, multi resin |
| Glass | • Glass: bottles and jars |
| Metal | • Aluminum cans<br>• Other metals (non-containers) |
| Yard waste | • Leaves, grass, chopped trimmings |
| Textile | Pieces of cloth |
| Wood | Small pieces |
| Rest | Rubber, leather, medical waste, rock, dust, composite, ceramics, leftover of paint in cans, light bulbs |

## 4.4 Determination of Quantities and Qualities of Waste Generated

### 4.4.1 Solid Waste

#### Material and equipment

The following materials were used in waste quantification:

- weighing scale (max. weight 2 kg □ 10gr): to weigh the waste (2002);
- digital scale (max. weight 6 and 10 kg □ 0.1gr): to weigh the waste;
- plastic bags;
- plastic sheets: used to spread waste on this sheets;
- gloves: to handle waste;
- dust masks;
- disinfectant to clean sheet and equipment;
- disinfectant soap to wash hands;

- paper towel;
- forms;
- pencils;
- labels: for coding the measured plastic bags;
- knife;
- scissor;
- safety boots; and
- dustcoat.

**Classifying the waste stream (data collection)**

The following steps were involved in classifying the waste stream:

- Waste was sampled;
- Preparation for collection: the selected units/sections were informed beforehand of the selection (sampling) days. This information was printed on paper;
- The bags were collected on the sampling date; the sampling was done at approximately the same time each day;
- The plastic sheet was spread on the ground and the bags opened and the contents emptied on the plastic sheet;
- The waste was separated into different types on the plastic sheet (see waste categories);
- Each type of waste was weighed separately and the weight was recorded on the data sheet (see appendix 8.5-8.7) ;
- After measuring the waste it is put back into labeled bag and sealed. This label was necessary so as to know that, the particular waste was already measured;
- The team moved to the next unit on the list; and
- These steps were repeated every day for the duration of the study.

### 4.4.2 Liquid Waste Parameters

The amount of wastewater generated during tea processing was approximated using the amount of water used. The readings were obtained from the water meter reading daily for minor cleaning and weekly for major cleaning. The values were recorded for the period of the study (APHA & AWWA, WEF, 2005).

#### 4.4.2.1 pH

*Apparatus*

The following apparatus were used during the study;

a) *pH meter* with temperature compensating device, accurate and reproducible to 0.1 pH unit with a range of 0 to 14;
b) Reference electrode with quartz liquid junction. Following manufacturer's instructions on use and care of the reference electrode. Non-sealed electrodes refilled with correct electrolyte to proper level and junction was properly wetted;
c) *Glass electrode*. Manufacturer's instructions on use and care of electrode followed.

*Reagents*

The following reagents were used during the experiment:

a) *Potassium hydrogen phthalate buffer, 0.05M*, pH 4.00. 10.12 g $KHC_8H_4O_4$ (potassium hydrogen phthalate) dissolved in 1000 mL freshly boiled and cooled distilled water
b) *0.025M Potassium dihydrogen phosphate + 0.025M disodium hydrogen phosphate buffer, pH 6.86*. 3.387 g $KH_2PO_4$ + 3.533 g $Na_2HPO_4$dissolvedin 1000 mL freshly boiled and cooled distilled water
c) *0.01M sodium borate decahydrate (borax buffer), pH = 9.18*. 3.80 g $Na_2B_4O_7.10H_2O$ dissolved in 1000 mL freshly boiled and cooled distilled water.
d) Buffer solutions stored in polyethylene bottles and replaced every 4 weeks.

*Procedure*

The procedure for determining the pH was as follows:

a) Electrodes were removed from the storage solution, rinsed, blot dried with soft tissue, placed in initial buffer solution and standardised pH meter according to manufacturer's instructions.
b) Electrodes were removed from the first buffer, rinsed thoroughly with distilled water, blot dried and immersed in the second buffer of pH within 2 pH units of the pH of the sample. pH was read, which should be within 0.1 unit of the pH of the second buffer.

c) pH of the sample was determined using the same procedure as in (b) after establishing equilibrium between electrodes and sample. For buffered samples this could be done by dipping the electrode into a portion of the sample for 1 min. Blot dry, immerse in a fresh portion of the same sample, and read pH.
d) With diluted poorly buffered solutions, electrodes were equilibrated by immersing in three or four successive portions of the sample. Fresh sample was taken to measure pH.
e) The sample gently stirred while measuring pH to insure homogeneity.

#### 4.4.2.2 Electrical Conductivity

*Apparatus*

The following apparatus were used during the study;

a) *Conductivity meter* capable of measuring conductivity with an error not exceeding 1% or 0.1mS/m.
b) *Conductivity cell*, Pt electrode type. Platinising solution prepared by dissolving 1g chloroplatinic acid, $H_2Pt\ Cl_6.6H_2O$ and 12mg lead acetate in 100 mL distilled water. Electrodes immersed in this solution and connected both to the negative terminal of a 1.5V dry cell battery. The positive terminal connected to a platinum wire and dipped into the solution. Electrolysis continued until both cell electrodes were coated with platinum black.

*Reagent*

The following reagents were used during the experiment:

a) *Conductivity water* - distilled water was boiled shortly before use to minimise $CO_2$ content. Electrical conductivity was maintained at less than 0.01 mS/m (< 0.1 μmho/cm).
b) *Standard potassium chloride solution*, KCl, 0.01*M*, conductivity 141.2 mS/m at 25°C. Dissolved 745.6mg anhydrous KCl (dried 1 hour at 180°C) in conductivity water and diluted to 1000 mL.

*Procedure*

a) The conductivity cell was rinsed with at least three portions of 0.01M KCl solution**.** Resistance of a fourth portion was measured and the temperature noted.

b) In case the instrument indicated conductivity directly, and had internal temperature compensation, after rinsing as above, temperature compensation was adjusted by dialing to 0.0191/ °C and with the probe in standard KCl solution, the meter was adjusted to read 141.2 mS/m (or 1412 µ mho/cm) to continue at step d.

c) The cell constant Kc, was computed according to the formula3.10below:

$$K_c = \frac{1412}{C_{KCl}} \times [0.0191(t-25)+1]$$

**4.1**

Where:

$K_c$ = the cell constant, 1/cm

$C_{KCl}$ = measured conductance, µmho

t = observed temperature of standard KCl solution, °C

The value of temperature correction [0.0191 x (t-25) +1] was read from the correction table (appendix 8.10)

d) The cell was rinsed with one or more portions of the sample. The level of sample was above the vent holes in the cell and no air bubbles were allowed inside the cell. The temperature of sample was adjusted to about 25°C (outside a temperature range of 20 - 30°C, error increases as the sample temperature increasingly deviates from the reporting temperature of 25°C). Sample conductivity was read and temperature noted to nearest 0.1°C.

e) The cell was rinsed thoroughly in distilled water after measurement, kept in distilled water when not in use.

**Calculation**

a) When sample conductivity was measured with instruments having temperature compensation, the readout automatically is corrected to 25°C. If the instrument does not have internal temperature compensation, conductivity at 25$^o$C is:

$$Electical\ Conductivity\left(\frac{mS}{cm}\right) = \frac{C_M \times K_C}{0.0191(t-25)+1}$$

**4.2**

Where:

$K_c$ = the cell constant, 1/cm

$C_M$ = measured conductance of the sample, mS

t = observed temperature of sample, 0C

b) The meter reading, the unit of measurement and the temperature of the sample at the time of reading were recorded. Electrical conductivity was reported at 25°C in mS/m, conversion table in the appendix8.10 was used.

### 4.4.2.3 Chemical Oxygen Demand

*Apparatus*

The following apparatus were used during the study;

a) *Reflux flasks*, consisting of 250 mL flask with flat bottom and with 24/29 ground glass neck
b) *Condensers*, 24/29 and 30 cm jacket Liebig or equivalent with 24/29 ground glass joint, or air cooled condensers, 60 cm long, 18 mm diameter, 24/29 ground glass joint.
c) *Hot plate* or gas burner having sufficient heating surface.

*Reagents*

The following reagents were used during the experiment:

a) *Standard potassium dichromate solution, 0.0417M (0.25N)*: Dissolved 12.259g $K_2Cr_2O_7$, primary standard grade, previously dried at 103°C for 2 hours, in distilled water and diluted to 1L.
b) *Sulphuric acid reagent*: Added 5.5g $Ag_2SO_4$ technical or reagent grade, per kg of conc. $H_2SO_4$, kept for a day or two to dissolve.
c) *Ferroin indicator solution*: Dissolved 1.485g 1, 10-phenanthroline monohydrate and 695 mg $FeSO_4.7H_2O$ in distilled water and diluted to 100 mL. Commercial preparation may also be available.
d) *Standard ferrous ammonium sulphate (FAS), titrant, 0.25M*: Dissolved 98g $Fe(NH_4)_2(SO_4)_2.6H_2O$ in distilled water, add 20 mL conc. $H_2SO_4$, cooled and diluted to 1L, standardised daily as follows.
e) Standardisation: Dilute 10 mL standard $K_2Cr_2O_7$ to about 100 mL, add 30 mL conc $H_2SO_4$, cool. Add 2 drops of ferroin indicator and titrate with FAS.

$$Molarity\ FAS = \frac{Volume\ of\ 0.0417M K_2Cr_2O_7, mL}{Volume\ of\ FAS\ used, mL} \times 0.25 \quad \textbf{4.3}$$

f) *Mercuric Sulphate, $HgSO_4$*, powder

g) *Potassium hydrogen phthalate (KHP) standard*: Lightly crushed and dried potassium hydrogen phthalate ($HOOCC_6H_4COOK$), at 120°C, cool in desiccators, weigh 425 mg in distilled water and dilute to 1L.

<u>*Procedure*</u>

a) 50 mL of sample or an aliquot was diluted to 50 mL, distilled water was added in a 500 mL refluxing flask. 1g $HgSO_4$, few glass beads, and 5 mL sulphuric acid reagent were added, mixed and cooled. 25 mL of 0.0417M $K_2Cr_2O_7$ solution was added and mixed. The flask was connected to the condenser and cooling water was turned on, additional 70 mL of sulphuric acid reagent was added through open end of condenser, with swirling and mixing.

b) Reflux was done for 2 hours; cooled, condenser washed down with distilled water to double the volume of contents and cool.

c) 2 drops of Ferroin indicator were added, the remaining potassium dichromate was titrated with FAS, until a colour change from bluish green to reddish brown. Also reflux and titrate was done to distilled water blank with reagents.

d) Use standard 0.00417M $K_2Cr_2O_7$, and 0.025M FAS, when analysing very low COD samples.

e) The technique and reagents were evaluated by conducting the test on potassium hydrogen phthalate solution.

f) Water was used at the Liebig jacket to prevent jamming

***Calculation***

$$COD, mgO_{2,}/l = \frac{(A-B)\times M\times 8000}{ml\ sample} \qquad \textbf{4.4}$$

Where:

A = FAS used for blank, mL

B = FAS used for sample, mL

M = Molarity of FAS

The procedure was repeated for three samples and the results recorded.

***Note***

- Theoretically the method is suitable for analysing samples containing 1000 mg/L COD without dilution

- In order to economise on quantities of chemicals used in the test, use smaller sample volumes and proportionally reduce quantities of chemicals as given in the following table.

**Table 4.3: Sample sizes with their respective volumes**

| **Sample size** | **Standard potassium dichromate** | **$H_2SO_4$ with $Ag_2SO_4$** | **$HgSO_4$** | **Ferrous ammonium sulphate** | **Final volume before titration** |
|---|---|---|---|---|---|
| mL | mL | mL | g | mole/L | mL |
| 10.0 | 5.0 | 15 | 0.2 | 0.05 | 70 |
| 20.0 | 10.0 | 30 | 0.4 | 0.10 | 140 |
| 30.0 | 15.0 | 45 | 0.6 | 0.15 | 210 |
| 40.0 | 20.0 | 60 | 0.8 | 0.20 | 280 |
| 50.0 | 25.0 | 75 | 1.0 | 0.25 | 350 |

#### 4.4.2.4 Biochemical Oxygen Demand (5 Days, 20°C)

*Apparatus*

The following apparatus were used during the study;

a) BOD bottles, 300 mL, narrow mouth, flared lip, with tapered and pointed ground glass stoppers.
b) Air incubator or water bath, thermostatically controlled at 20 ± 1°C. Light entry must be prevented in order to avoid photosynthetic oxygen production
c) Accessories: plastic tube, screw-pin and a 5-10 L water container.

*Reagents*

The following reagents were used during the experiment:

a) *Phosphate buffer solution*. Dissolved 8.5 g $KH_2PO_4$, 21.75 g $K_2HPO_4$, 33.4 g $Na_2HPO_4.7H_2O$ and 1.7 g $NH_4Cl$ in 1L distilled water.
b) *Magnesium sulphate solution.* Dissolved 22.5 g $MgSO_4.7H_2O$ in 1L distilled water.
c) *Calcium chloride solution.* Dissolved 27.5 g $CaCl_2$ in 1L distilled water.
d) *Ferric chloride solution.* Dissolve 0.25 g $FeCl_3.6H_2O$ in 1L distilled water.
e) *Acid and alkali solution.* 1*N* NaOH and 1*N* $H_2SO_4$. Used for neutralising samples.
f) *Glucose-glutamic acid solution (prepare fresh).* Dissolved 150 mg dry reagent grade glucose and 150 mg dry reagent grade glutamic acid in 1L distilled water

g) *Sample dilution water*. Add 1 mL each of phosphate buffer, $MgSO_4$, $CaCl_2$ and $FeCl_3$ solutions per litre distilled water.

*Procedure*

a) Required amount of dilution water was prepared at the rate of 1000 to 1200 mL per sample per dilution. The diluted water was brought to a temperature of 20°C. Saturated with air by shaking in a partially filled bottle, by bubbling with organic free filtered air or by storing in cotton-plugged bottles for a day.

b) Some samples do not contain sufficient microbial population (for example, some industrial wastes, high temperature wastes, or wastes with extreme pH values). For such wastes, the dilution water is seeded using effluent from a biological treatment system processing the waste. Where this is not available, supernatant from domestic wastewater after settling for at least 1hour but not more than 36hours was used. Seed from a surface water body receiving the waste may also be suitable. Enough seed volume was added such that the dissolved oxygen (DO) uptake of the seeded dilution water is between 0.6 and 1.0 mg/L. For domestic wastewater seed, usually 4 to 6 mL seed / L of dilution water is required. Surface water samples usually do not require seeding.

c) Dilution of sample. Dilutions must result in a sample with a residual DO (after 5 days of incubation) of at least 1 mg/L and a DO uptake of at least 2 mgl/L several dilutions were made using the table4.5 and experience with the particular sample source.

**Table 4.4: Dilutions for BOD**

| **Using Percent Mixture** | | **By direct pipetting into 300mL bottles** | |
|---|---|---|---|
| Range of BOD | %mixture | Range of BOD | mL Sample |
| 1,000-3,500 | 0.2 | 1,200-4,200 | 0.5 |
| 400-1,400 | 0.5 | 600-2,100 | 1.0 |
| 200-700 | 1.0 | 300-1,050 | 2.0 |
| 100-350 | 2.0 | 120-420 | 5.0 |
| 40-140 | 5.0 | 60-210 | 10.0 |
| 20-70 | 10.0 | 30-105 | 20.0 |
| 10-35 | 20.0 | 12-42 | 50.0 |
| 4-14 | 50.0 | 6-21 | 100.0 |
| 0-7 | 100.0 | 0-7 | 300.0 |

For preparing dilution in graduated cylinders, dilution water was siphoned, into a 1 to 2 litres capacity cylinder. Siphoning should always be done slowly without bubbling; a screw-pin on the tube to regulate the flow was used. The tip of the tube was kept just below the water surface as it rises. Cylinder was half-filled, desired quantity of sample added and diluted to appropriate level, mixed with plunger type mixing rod. Mixed diluted sample was siphoned in three BOD bottles, stopper without entraining any air. Initial DO was determined on one bottle and the other two were incubated at 20°C. Final DO was determined in duplicate after 5days.

For direct pipetting, the desired sample volume was siphoned to individual bottles and filled with enough dilution water. The test was completed as in the earlier case.

d) Dilution water blank. The DO consumption of unseeded dilution water by determining initial and final DO as in c above was found which should not be more than 0.2 mg/L

e) Seed control. The DO uptake by seeding material according to the procedure in *c* above was determined.

***Calculation***

a) When dilution water is not seeded:

$$BOD_{5,}mg.l^{-1} = \frac{D_0 - D_T}{P}$$

**4.5**

b) When dilution water is seeded:

$$BOD_{5,}mg.l^{-1} = \frac{(D_0 - D_T) - f(B_0 - B_T}{P}$$

**4.6**

Where:

$D_0$ = DO of diluted sample initially, mg/L

$D_T$ = DO of diluted sample after 5 day incubation at 27°C, mg/L

P = decimal volumetric fraction of sample used

$B_0$ = DO of seed control initially, mg/L

$B_T$ = DO of seed control after incubation, mg/L

f = ratio of %seed in diluted sample to % seed in seed control

Notes:

- Report average results of duplicates if both dilutions are correct.

- Formula does not correct for BOD of dilution water which is only valid for dilution water meeting the criteria. BOD of dilution water should not be more than 0.2 mg/L, preferably lower than 0.1 mg/L.
- The standard glucose-glutamic acid should have BOD of 198 ± 37 mg/L (BIS3025 (part 44): 1993). Check procedure otherwise.
- Report BOD values lower than 0.5mg/L or 2 times the measured BOD of the dilution water (whichever is lower) as lower than detection limit.

**Plate 4.3: Sample preparation**

**Plate 4.4: Multi parameter meter**

### 4.4.3 Thermal Waste

***Bomb calorimeter experiment***

*Apparatus*

The following apparatus were used during the study;

- Analogue balance
- Ceramic crucible weighing 11.5g
- Stop watch
- Ammeter
- Stirrer
- Oxygen and oxygen cylinder
- Digital thermometer (type K/J/T/E/R0
- Heavy duty battery of 12V
- Firing switch
- Fuse wire
- Cotton wool
- U – Shaped spanner
- Charging system with oxygen cylinder control valve and pressure gauge
- Measuring beaker of 3000 ml
- Measuring cylinder of 100 ml

*Procedure*

The calorimeter was dismantled, cleaned and the crucible dried. The empty crucible was weighed and then with approximately 1gm of furnace oil, the fuse wire was then installed in the form of a coil and a piece of cotton wool was attached to assist in ignition., 10ml of water was added in the bomb to saturate the space inside the bomb and reassembled carefully not to spill the fuel. The bomb was charged with 25 atmospheres of oxygen the leaks checked before immersing it to the water and then drying it.

1750ml of water was added in the calorimeter and the bomb, thermometer and stirrer installed and the stirrer was started and allowed to work for 3minutes to equalize the temperature in the bucket. Then the first 5 readings was taken at 1 minute interval to determine the heat exchange in the jacket

The firing switch was then closed for an instant and then released as soon as the indicator ammeter went back. The temperatures were recorded in 30 seconds till the maximum temperature was reached. The falling temperature was read in every minute for 5 minutes and the procedure repeated for 2 samples. The above data was used to determine the calorific value of the fuel used in tea processing.

## 4.5 Evaluation of the Effectiveness of the Existing System

### 4.5.1 Solid Waste

Disposal methods were observed at the factory and compared with recommended disposal methods nationally/ internationally.

The mass balance for Nyansiongo Tea Factory was compared with existing literature. The data collected from the factory for six months on the following parameters was analysed and compared with available literature:

1. Green leaf collected per month for six months;
2. Made tea per month for six months;
3. Solid waste per month for six months.

Based on the available literature, it is estimated that during black tea manufacture, when the system is efficient, 75% is moisture while 24% is the made tea. The remaining percentage would be solid waste.

These percentages were used to calculate expected made tea, expected solid waste and the expected moisture content in a kilogram of green leaf tea.

To calculate the expected amount of black tea produced each month, the following was done:

The values of expected made tea were compared with the actual made tea while those of expected solid waste were compared with those of the actual solid waste collected.

### 4.5.2 Wastewater

Wastewater samples were collected from the study, they were analysed for biochemical oxygen demand (BOD), pH, chemical oxygen demand (COD) and electrical conductivity (EC). The results were then compared with the available effluent discharge standards by the National Environmental Management Authority.

### 4.5.3 Thermal Waste

The following experiment was done to determine the efficiency of the boiler;
The reference standards for Boiler Testing at site using the indirect method are the *British Standard, BS 845:1987* and the *USA Standard ASME PTC-4-1 Power Test Code Steam Generating Units*.
The indirect method also called the heat loss method was used. The efficiency was calculated by subtracting the heat loss fractions from 100 as follows:
Efficiency of boiler (n) = 100 - (i + ii + iii + iv + v + vi)

**4.7**

Whereby the principle losses that occur in a boiler are loss of heat due to:

1. Dry flue gas
2. Evaporation of water formed due to $H_2$ in fuel
3. Evaporation of moisture in fuel
4. Moisture present in combustion air
5. Radiation and other unaccounted losses
6. Losses due to moisture in fuel and due to combustion of hydrogen are dependent on the fuel, and cannot be controlled by design.

The data required for calculation of boiler efficiency using the indirect method were:

1. Ultimate analysis of fuel ($H_2$, $O_2$, S, C, moisture content, ash content)
2. Percentage of oxygen or $CO_2$ in the flue gas
3. Flue gas temperature in $^{o}$C (Tf)
4. Ambient temperature in $^{o}$C (Ta) and humidity of air in kg/kg of dry air
5. Gross calorific value (GCV) of fuel in kcal/kg

# 5.0 RESULTS AND DISCUSSIONS

## 5.1 Classification of Wastes and Amounts

### 5.1.1 Solid Waste

The types, sources and amounts of waste were identified through measurement and observations in various stages of tea production for a period of six months. These stages were; the offloading bay, withering, processing, firing, sorting and packaging.

**Table 5.1: Type of wastes and amounts generated at every stage of tea production monthly**

| Source | Waste | Type of waste | Amount (Kgs) | Amount (%) |
|---|---|---|---|---|
| Leaf reception | Green leaf | Organic | 67.0 | 13.7 |
| Withering | Green leaf | Organic | 242.3 | 49.7 |
| Maceration (CTC) | Green leaf | Organic | 77.4 | 15.9 |
| Drying | Pekoe dust | Organic | 57.0 | 11.7 |
| Sorting | Fannings | Organic | 22.1 | 4.5 |
| Packing | Paper | Organic | 8.5 | 2.7 |
|  | Polythene Paper and sacks | inorganic | 13.3 | 1.7 |
|  |  | **Total** | **487.7** | **100.0** |

The analysis of the collected data indicates that the highest amount of waste was produced at the withering stage at an average weight of 242.3 kilograms per month due to spillages; this was due to the fact that the troughs were overloaded, followed by offloading bay due to spillages arising from improper handling. Sorting also generated and average of 22.1 kilograms per month from fannings while packaging materials and worn out sacks and papers generated the least amount of solid waste at 21.8 kilograms monthly as indicates in figure 5.1 below. There was a variation of waste generated as a result of season variation throughout the year. During the peak season of tea production the waste generated was high and when the tea production was low, the waste generated was also low.

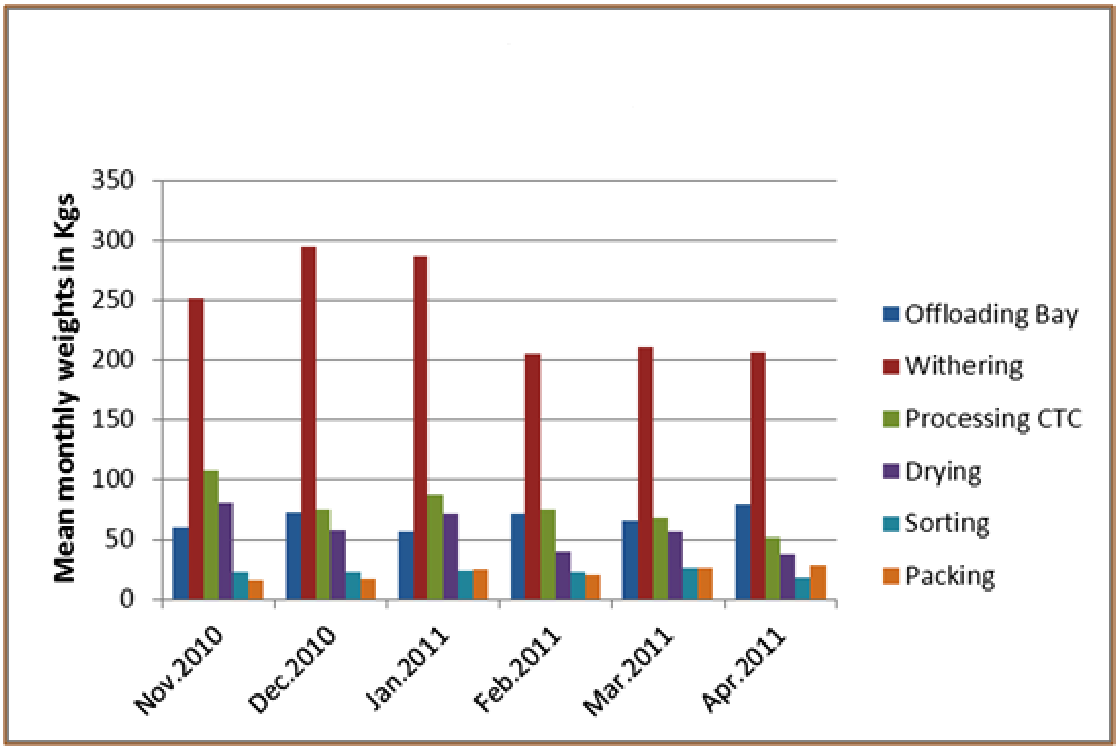


Figure 5.1: Quantities of solid waste at different stages of tea processing

### 5.1.2 Liquid Waste

In tea processing, liquid waste is generated majorly from the cleaning processes in the factory. There are two types of cleaning that are done during tea processing; major and minor cleaning. Major cleaning of the factory is done weekly which involves the entire cleaning of the factory while minor cleaning is done daily and involves the cleaning of various sections like the footbath.

From the data collected, liquid waste generated for a period of six months is illustrated in figure 5.2 below. The amount of wastewater generated from major cleaning at the factory was estimated to be between 100m$^3$ and 140m$^3$as a result of the amount of water used for cleaning. The highest amount of wastewater generated was in the month of April at 140m$^3$(see appendix 8.10).

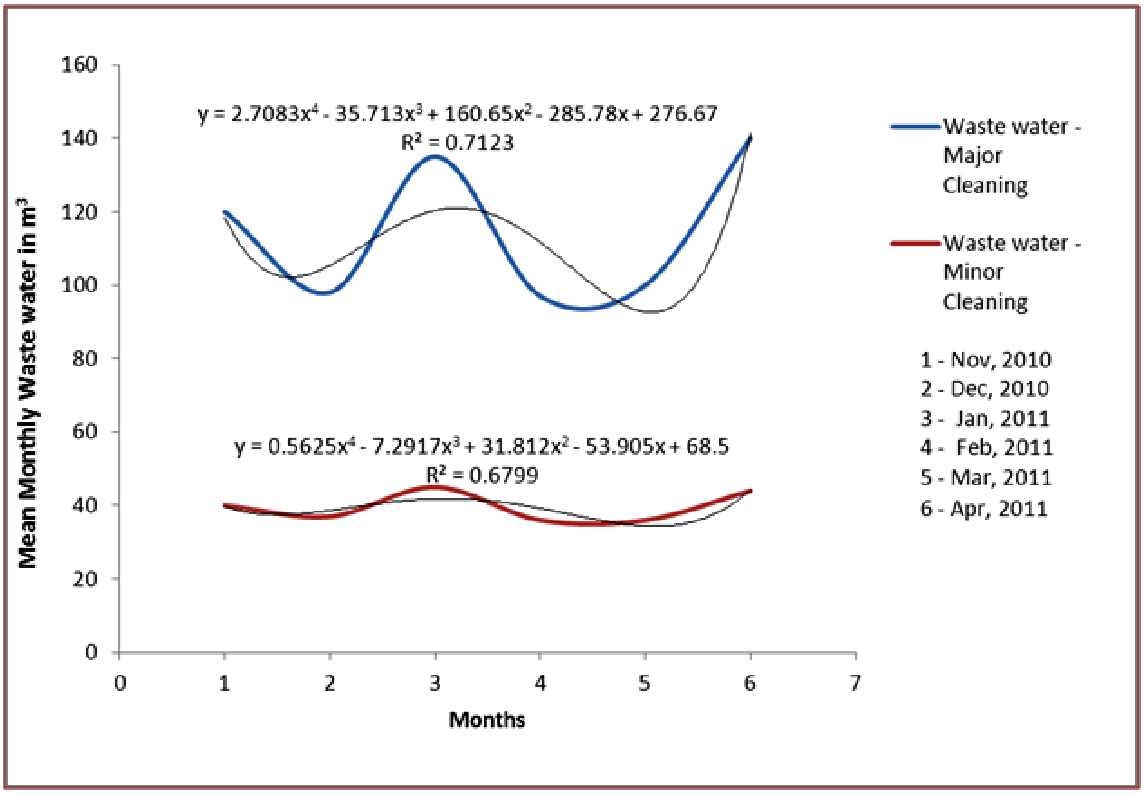


**Figure 5.2: Wastewater generated from tea processing**

### 5.1.3 Thermal Waste

In tea processing, there are various heat losses that occur. These include; loss of heat due to dry flue gas, loss of heat due to hydrogen, heat loss due to moisture in air, heat loss due to moisture in fuel and losses due to radiation. From the data obtained for Nyansiongo tea factory, the above losses have been quantified below. Nyansiongo tea factory uses firewood mostly as their source of fuel. The ultimate analysis of the wood fuel has been given in table 5.2 below.

**Table 5.2: Ultimate analysis of firewood**

| **Ultimate analysis of firewood** | **Percentage (%)** |
|---|---|
| Carbon | 45.60 |
| Hydrogen | 3.96 |
| Sulphur | 0.07 |
| Oxygen | 37.45 |
| Moisture | 9.33 |
| Ash | 3.14 |
| Nitrogen | 0.45 |

Fuel Calorific Value = 6572 kcal/ kg

Percentage of $CO_2$ in flue gas = 10.5 %

Percentage of $O_2$ in flue gas = 10.9 %

Flue gas temperature = 210 °C

Ambient temperature = 22 °C

Moisture content in air = 0.0132 kg / kg of air

$$Theoritical\ air\ requirements = \frac{[(11.43 \times C) + \left\{34.5 \times \left(\frac{H_2 - O_2}{8}\right)\right\} + (4.32 \times S)]}{100}\ kg\ of \frac{air}{kg} of fuel \quad \mathbf{5.1}$$

$$Theoritical\ air\ requirements = \frac{[(11.43 \times 45.6) + \left\{34.5 \times \left(\frac{3.96 - 37.45}{8}\right)\right\} + (4.32 \times 0.07)]}{100}$$

$$= 5.04\ kg\ of \frac{air}{kg} of fuel$$

$$Excess\ air\ supplied(EA) = (O_2 x\ 100) / (21 - O_2) \quad \mathbf{5.2}$$

$$= (10.9\ x\ 100) / 10.1$$

$$= 107\%$$

$$Actual\ Mass\ of\ Air\ Supplied(AAS) = \left[1 + \frac{EA}{100}\right] \times Theoretical\ air \qquad \textbf{5.3}$$

$$= \left[1 + \frac{107}{100}\right] \times 5.04$$

$$= 10.4\ kg\ of \frac{air}{kg} of\ fuel$$

Estimation of all losses

i. Dry flue gas loss

$$\%\ Heat\ loss = \frac{m \times C_p \times (T_F - T_A)}{GCV\ of\ fuel} \times 100 \qquad \textbf{5.4}$$

m= Mass of actual air supplied + mass of fuel supplied

$$m = 10.4 + 1 = 11.4kg$$

Where,

m = mass of dry flue gas in kg/kg of fuel

$C_p$ = Specific heat of flue gas (0.23 kcal/kg )

$$= \frac{11.4 \times 0.23 \times (210 - 22)}{6572} \times 100$$

$$= 7.5\%$$

ii. Percentage heat loss due to evaporation of water formed due to $H_2$ in fuel

$$= \frac{9 \times H_2\{584 + C_p(T_F - T_A)\}}{GCV\ of\ fuel} \qquad \textbf{5.5}$$

Where,

$H_2$ = percentage of $H_2$ in 1 kg of fuel

$C_p$ = specific heat of superheated steam (0.45 kcal/kg)

$$= \frac{9 \times 3.96\{584 + 0.45(210 - 22)\}}{6572}$$

$$= 3.63\%$$

iii. Percentage heat loss due to evaporation of moisture present in fuel

$$= \frac{M\{584 + C_p(T_F - T_A)\}}{GCV\ of\ fuel} \times 100 \qquad \textbf{5.6}$$

Where, M – percent moisture in 1kg of fuel

$C_p$ – Specific heat of superheated steam (0.45 kcal/kg)

$$= \frac{9.33\{584 + 0.45(210 - 22)\}}{6572}$$

$$= 1.10\%$$

iv. Percentage heat loss due to moisture present in air

$$= \frac{AAS\ \times Humidity\ factor\ \times C_p(T_F - T_A)}{GCV\ of\ fuel} \times 100 \qquad \textbf{5.7}$$

Where, $C_p$ – Specific heat of superheated steam (0.45 kcal/kg)

$$= \frac{10.4 \times 0.0132 \times 0.45(210 - 22)}{6572} \times 100$$

$$= 0.177\%$$

v. Surface heat losses

Heat losses due to radiation and other unaccounted losses are estimated at 2.5%

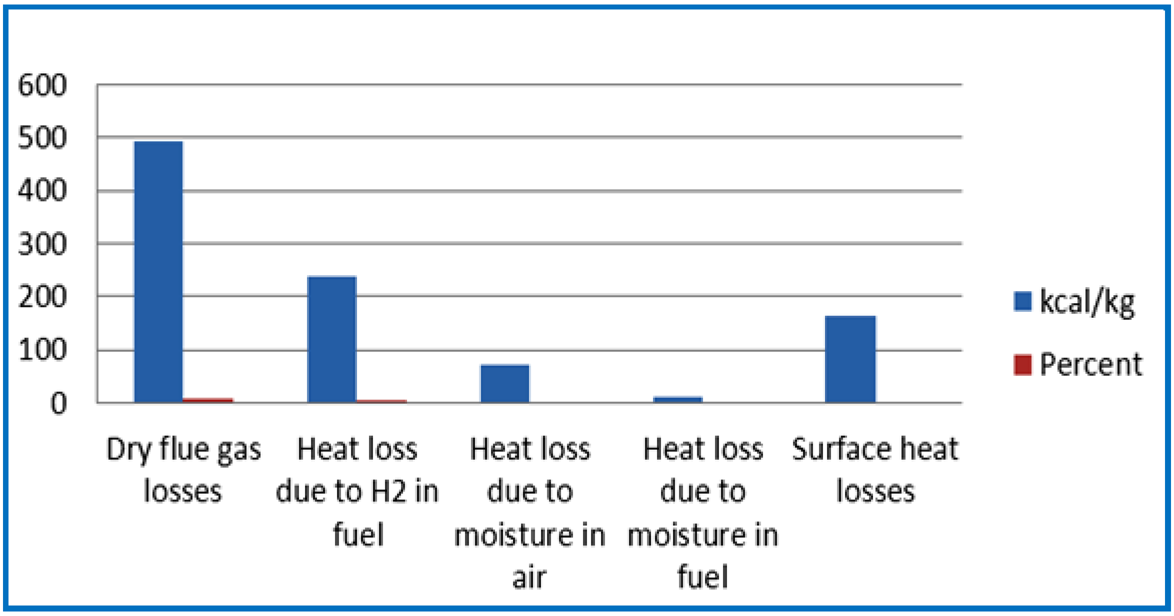


**Figure 5.3: Waste heat generated during tea processing**

The analysis of data obtained indicate that the amount of heat lost during tea processing is lost through the flue gas at 7.5% followed by heat lost due to hydrogen in the fuel at 3.63%. The least amount of heat loss occurs due to the moisture in the fuel at 1.10%. The heat lost through flues gas has been reduced by the installation of an economizer to the boiler.

## 5.2 Determination of Wastewater Quality Parameters

Various physicochemical parameters for the wastewater generated were measured and analysed. These included pH, $BOD_5$, Electrical conductivity and COD. The levels of biochemical oxygen demand and chemical oxygen demand far exceeds the maximum allowable discharge limits of effluent to the environment by NEMA hence the system was ineffective. The results have tabulated in table 5.3 below.

**Table 5.3: Wastewater Analysis Results**

| **Lagoon** | **pH** | **EC** | **COD** | **$BOD_5$** |
|---|---|---|---|---|
| 1 | 6.79 | 318.67 | 608.33 | 196.50 |
| 2 | 6.69 | 298.67 | 631.00 | 188.93 |
| 3 | 6.50 | 204.00 | 443.00 | 113.60 |
| 4 | 6.49 | 150.00 | 340.00 | 101.10 |
| At stream entry | 6.98 | 160.60 | 351.47 | 108.65 |
| Down stream | 7.40 | 154.69 | 308.37 | 102.04 |
| Up stream | 7.29 | 154.42 | 312.30 | 102.25 |
| NEMA standards | 6.5 – 8.5 |  | 50(mg/L) max | 30(mg/L)Max |

## 5.3 Evaluation of the Effectiveness of the Existing System

### 5.3.1 Solid Waste Management

During tea processing, solid waste was generated at various stages which have been discussed previously. Currently at Nyansiongo tea factory, biodegradable wastes are disposed in a landfill/pit which is overflowing. The landfill was of a rectangular shape whose dimensions were 3m by 1.5m by 2.1m which fills up after 3 months. The total amount of biodegradable waste was at an average of 411 kilograms per month. This far outweighs the capacity of the landfill which was found overflowing at the time of data collection.

The scrap metals were generated as another type of waste which was heaped in a yard next to the pit. During the time of the study, waste from the pit got mixed with the wastes from the yard. The amount of scrap metal is not measured at the moment and has no particular benefit.

It was observed that the waste at the factory had not been segregated in terms of the type and amount. All the waste collected was disposed in compost pit. The waste in the pit included the dust that is collected from the packaging and sorting area, the dry leaves from the leaf collection centre and the scrap metals from the broken down machine parts. Figure 5.4 is a mass balance illustration of the quantities produced when a kilogram of green leaf of tea is processed.

Table 5.4 illustrates comparisons between the expected data calculated from the mass balance of tea production and the actual data that was measured in the field.

The amounts of made tea and those of generated waste were higher than those of the expected made tea and waste generated respectively. This indicated that Nyansiongo Tea Factory had minimized their waste generation from tea processing.

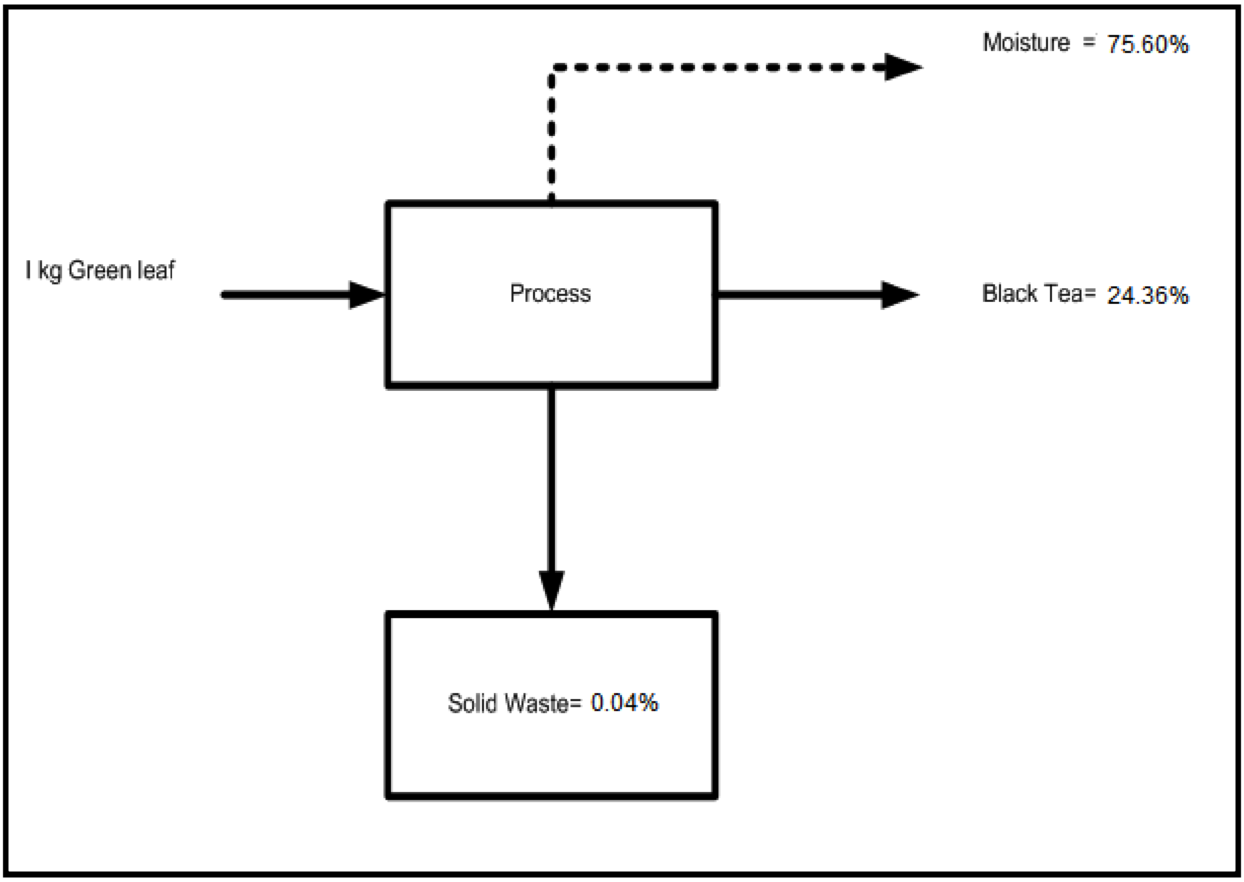


**Figure 5.4: Mass balance of tea production in Nyansiongo tea factory**

**Table 5.4: Nyansiongo Tea factory Mass Balance Data**

| | Green Leaf | Made Tea | Expected Production | Expected Moisture | Expected Solid waste | Solid waste | % Made Tea | Moisture | % Moisture | % Solid waste |
|---|---|---|---|---|---|---|---|---|---|---|
| Nov'10 | 1,457,977 | 362,651 | 320,755 | 1,105,146.57 | 2,915.95 | 411.3 | 25 | 1,095,210 | 75 | 0.03 |
| Dec | 1,159,211 | 280,275 | 255,026 | 878,681.94 | 2,318.42 | 461 | 24 | 878,812 | 76 | 0.04 |
| Jan'11 | 1,432,337 | 356,452 | 315,114 | 1,085,711.45 | 2,864.67 | 448.7 | 25 | 1,075,76 | 75 | 0.03 |
| Feb | 792,098 | 206,325 | 174,262 | 600,410.28 | 1,584.20 | 369.3 | 26 | 585,671 | 74 | 0.05 |
| Mar | 619,906 | 162,527 | 136,379 | 469,888.75 | 1,239.81 | 379.8 | 26 | 457,268 | 74 | 0.06 |
| April | 1,021,319 | 255,883 | 224,690 | 774,159.80 | 2,042.64 | 383.9 | 25 | 765,344 | 75 | 0.04 |

### 5.3.2 Determination of Wastewater Quality Parameters

As discussed in section 5.1 above, the liquid waste is generated during tea production. Various physicochemical parameters were measured and analysed. These included pH, $BOD_5$, Electrical conductivity and COD. The results have tabulated in table 5.5 below.

**Table 5.5: Wastewater analysis results for pH**

| **Lagoon** | **pH** | **NEMA Limits** | |
|---|---|---|---|
| 1 | 6.79 | | |
| 2 | 6.69 | 6.5 – 8.5 | y = -0.109x + 6.89 |
| 3 | 6.50 | | |
| 4 | 6.49 | | |
| At stream entry | 6.98 | | |
| Down stream | 7.40 | | |
| Up stream | 7.29 | | |
| Mean | 6.88 | | |
| C.V | 0.15 | | |
| LSD | 0.02 | | |
| $R^2$ | 0.912 | | |

**Table 5.6: Wastewater analysis results for COD**

| **Lagoon** | **COD** | **NEMA Limits** | |
|---|---|---|---|
| 1 | 608.33 | | |
| 2 | 631.00 | 50 (mg/L) max | y = -99.29x + 753.8 |
| 3 | 443.00 | | |
| 4 | 340.00 | | |
| At stream entry | 351.47 | | |
| Down stream | 308.37 | | |
| Up stream | 312.30 | | |
| Mean | 427.783 | | |
| C.V | 0.19 | | |
| LSD | 1.84 | | |
| $R^2$ | 0.855 | | |

**Table 5.7: Wastewater analysis results for BOD5**

| **Lagoon** | **$BOD_5$** | **NEMA Limits** | |
|---|---|---|---|
| 1 | 196.50 | | |
| 2 | 188.93 | 30(mg/L)Max | y = -36.15x + 240.4 |
| 3 | 113.60 | | |
| 4 | 101.10 | | |
| At stream entry | 108.65 | | |
| Down stream | 102.04 | | |
| Up stream | 102.25 | | |
| Mean | 130.44 | | |
| C.V | 0.60 | | |
| LSD | 1.73 | | |
| $R^2$ | 0.883 | | |

**Table 5.8: Wastewater analysis results for EC**

| **Lagoon** | **EC** | **NEMA Limits** | |
|---|---|---|---|
| 1 | 318.67 | | |
| 2 | 298.67 | | y = -60.06x + 393.0 |
| 3 | 204.00 | | |
| 4 | 150.00 | | |
| At stream entry | 160.60 | | |
| Down stream | 154.69 | | |
| Up stream | 154.42 | | |
| Mean | 205.86 | | |
| C.V | 0.36 | | |
| LSD | 1.69 | | |
| $R^2$ | 0.949 | | |

The results suggest that the treatments undertaken in the different lagoons significantly ($P \leq 0.05$) differed from one another though the results obtained from the analysis of the wastewater when compared with the NEMA standards for the maximum allowable discharge limits to the environment were way above the maximum allowable limits hence the treatment was not effective.

The results obtained from the lagoons indicate that the levels of biochemical oxygen demand and chemical oxygen demand far exceeded the maximum allowable discharge limits of effluent to the environment by NEMA.

### 5.3.3 Thermal Waste Management

In evaluating the effectiveness of heat waste management, the boiler efficiency of the boiler was calculated using the indirect method also called the heat loss method was used. The heat losses have been calculated in section 5.1 and have been summarised in table 5.9. This efficiency was calculated by subtracting the heat loss fractions from 100.

**Table 5.9: Boiler Heat Losses**

| | **Heat Balance (per kg fuel basis)** | **kcal/kg** | **Percent** |
|---|---|---|---|
| | Total energy input | 6572 | 100 |
| L1 | Dry flue gas losses | 492.90 | 7.5 |
| L2 | Heat loss due to $H_2$ in fuel | 238.56 | 3.63 |
| L3 | Heat loss due to moisture in air | 72.29 | 1.10 |
| L4 | Heat loss due to moisture in fuel | 11.83 | 0.18 |
| L5 | Surface heat losses | 164.3 | 2.5 |

$Boiler\ Efficiency\ (\eta) = 100 - (L1 + L2 + L3 + L4 + L5)$

$Boiler\ Efficiency\ (\eta) = 100 - (14.9)$

$$Boiler\ Efficiency\ (\eta) = \mathbf{85.1}\%$$

The boiler efficiency was found to be 85.1%. The highest amount of heat loss was from the dry flue gas at 7.5% whilst the minimum was found to be that from heat loss due to moisture in the fuel. The boiler efficiency was found to be higher than the recommended efficiency of 80% by American Council for an Energy-Efficient Economy (ACEEE). This is due to the fact that the tea factory boiler has been installed with an economizer.

# 6.0 CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Conclusions

The largest amount of waste generated during the period of study was organic at 95.6% while inorganic waste is only 4.4%. This waste was generated from the withering stage due to spillages from overloaded troughs and poor handling of green leaf during loading of troughs. It was also found that 0.01% of total tea produced amounted to waste; this can be applied to other factories to determine the amount of waste generated in relation to the amount of tea they produce.

The highest amount of wastewater was generated from major cleaning operations in the factory at an average capacity of 115$m^3$per month while the lowest amount of wastewater generated was due to minor cleaning operations at an average capacity of 40$m^3$ per month.

The wastewater being discharged to the environment was found to have high levels of BOD5 and COD when compared with the NEMA standards. The $BOD_5$ levels measured 101.1mg/L against the NEMA recommended maximum discharge limits of 30mg/L while the COD levels measured 340.0mg/L against the NEMA recommended maximum discharge limits of 50mg/L indicating that the wastewater treatment system of the factory was not effective.

Dry flue gas generated the highest amount of thermal waste at 7.5% and the least was 0.18% due to heat loss from moisture in the fuel. An economizer has been installed on the boiler to increase its efficiency which is commendable. The efficiency was found to be at 85.1%

This study found out that the waste management systems in Nyansiongo tea factory did not fully comply with the recommended standards nationally and could be improved.

## 6.2 Recommendations

The highest source of solid waste was from the offloading bay due to spillages. The factory management in Kenyan tea factories should evaluate whether there is need for re-designing the withering troughs as they appeared overloaded at the time of this research. The factory management should consider employing cleaner production techniques such as waste segregation and reduction at source; waste recycling and reuse to manage their waste.

The design parameters of the current wastewater treatment lagoons should be re-evaluated to ascertain the cause of its ineffectiveness. Subsequently, different wastewater treatment methods should be considered which can recover and treat the wastewater for recycling at the factory.

The management should improve on steam distribution and utilization by lagging the steam pipes and eliminating steam leakages to improve the energy utilization in the factory.

The waste management system for tea factories in Kenya is partially effective which raises an important concern regarding their contribution towards a sustainable environment. Kenyan factories should develop and implement an Environment Management Systems (EMS). To achieve an effective EMS, the factory management should develop policies with measurable objectives and targets that can be reviewed periodically. This will also require that the factory management set aside resources for its implementation.

## 7.0 REFERENCES

1. ACEEE (2012): "**Heating, Ventilating, and Air Conditioning (HVAC)**" http://www.aceee.org/consumer/heating (Accessed 25.04.2012)
2. ADF (2013): "**Health Manual**" Vol 20, Part8, Chp2, pp. 1
3. AGAMUTHU, P. (2002): "**Solid Waste: Principles and Management**" with Malaysian case studies. Inst. of Biological Sciences, University of Malaya. Kuala Lumpur. pp. 2, pp. 153.
4. ANON, "**Solid Waste Management**" (accessed on 13th August 2013) http://www.cyen.org/innovaeditor/assets/Solid%20waste%20management.pdf
5. APHA, AWWA and WEF (2005): "**Standard Methods for Examination of Water and Wastewater**" American Public Health Association, *American Water Works Association*, NW Washington, DC pp 5-2, 2-34-95, 4-111,2-26, 2-36, 4-49, 3-66.
6. ARCHANA, S. (2009): "**Municipal Solid Waste Management**" (accessed on 15th October 2013.) http://mahenvis.nic.in/Pdf/MSW_.pdf
7. ASABE (2010): "**Design of Anaerobic Lagoons for Animal Waste Management**". ASABE Standards 2010 pp. 814-818.
8. COINTREAU-LEVINE, S. (1994): "**Private Sector Participation in Municipal Solid Waste Services in Developing Countries (Vol. 1)**". Washington DC: World Bank. pp7-8, 14.
9. COWI CONSULTING ENGINEERS AND PLANNERS, (2000): "**Cleaner Production Assessment in Meat Processing**". Denmark for UNEP and Danish Environment Protection Agency, pp. 1-5
10. CPCB (2008): **"The Environment Protection Act",** Guidelines for water quality management in India, pp. 10.
11. DAS, S. K., (2006): "**Further Increasing the Capacity of Tea Leaf Withering Troughs".** Agricultural Engineering International: the CIGR Journal. Manuscript FP 05 012. Vol. VIII. January,pp. 1-2.
12. FAO (1992): "**Wastewater Treatment and Use in Agriculture**" - FAO Irrigation and Drainage Paper 47.

13. FRANKE, M., and GARMENDIA, A. M. (1999): **Application of Experience in European Integrated Waste Management to Latin American Conditions**. In Memorias Congreso AIDIS (pp. 1-15).

14. GOK (1999): "**The Environment Management and Coordination Act, 1999".** Government printers.

15. GOK (2006): **"Water Resources Management (Water) Rules."** Government printers, pp. 65

16. GOK (2011): **The Tea (Amendment) Act No**. 4 of 2011

17. HEIMLICH, J. E., HUGHES, K. L. and CHRISTY, A. D. (1992). "**Integrated Solid Waste Management."** Publication-Louisiana Cooperative Extension Service (USA), pp 2-5.

18. HILTON, P. J. (1973): "**Encyclopedia of Industrial Chemical Analysis."** vol. 18, pp. 453 – 516, New York, USA: John Willey.

19. IKIARA, M. M., KARANJA, A. M., and DAVIES, T. C. (2004): "**Solid Waste Management and Recycling"** (pp. 61-91). Springer Netherlands.

20. ISO, N. (2004). "**Solid Mineral Fuels"** - Determination of gross calorific value by the bomb calorimetric method, and calculation of net calorific value. ICS.

21. JONES, D. D. (1999): **Extension Publications: Cooperative Extension Services**. http://www.extension.purdue.edu/extmedia/ID/I_D-120.html Accessed 7th October, 2010.

22. MATSUTO, T., TANAKA, N., & LAGERKVIST, A. (2000): "**State-of-the-Art Treatment Processes for Municipal Solid Waste Incineration Residues in Japan"**. Waste Management and Research, 18(1), 41-51.

23. MAUSKAR, J.M (2007): "**Comprehensive Industry Document on Tea Processing Industry"** Published By: Dr. B. Sengupta, Member Secretary, Central Pollution Control Board, Delhi — 32. Printing Supervision & Layout: P.K. Mahendru, Anamika Sagar and Satish Kumar Composing & Laser Typesetting: Suresh Chander Sharma. DSIDC, New Dellhi.

24. MIDDLEBROOKS, E.J. (1979): "**Industrial Pollution Control. Volume 1: Agro-Industries".** Wiley-Interscience publication, John Wiley & Sons, New-York.

25. MILLER, R., MAJOR, J. AND TRINCA, P. (2011)**: "How a Lagoon Works."** Extension Publications: Cooperative Extension Services.pp1-4.

26. MINISTRY OF ENERGY AND MINERAL DEVELOPMENT UGANDA, (2008): "**Energy Management Manual for Tea Industry.**"

27. MURUNGA, S.I.R. (2011): "**An Efficient and Cleaner Production System for Tea Processing Industry in Kenya (A Case Study of; Mudete Tea Factory)**" Master of Science thesis in environment and biosystems engineering, University of Nairobi.

28. NORRINGTON-DAVIES, G and THORNTON, N (2011): "**Climate Change Financing and Aid Effectiveness, Kenya Case Study**". OECD, ADB.

29. OMOSA, I. (2004): "**Assessment of the Biological Treatability of Black Tea Processing Effluent.**" Master of Science thesis in civil engineering, University of Nairobi.

30. OWOUR, P. O. and J. E. ORCHARD (1989): "**Changes in the Biochemical Constituents of Green Leaf and Black Tea to Withering**": a review. Tea 10(1): pp. 53-59.

31. OWUOR, P.O; OBANDA M; NYIRENDA H. E; and MANDALA W. L. (2008): "**Influence of Region of Production on Clonal Black Tea Characteristics**". Food Chemistry Vol 108, pp. 27.

32. PARR INSTRUMENT COMPANY (1960): "**Oxygen bomb calorimetry and combustion methods (No. 130)**". Technical manual.

33. PEAVY, H.S., ROWE, D. R, and TCHOBANOGLOUS, G. (1985); "**Environmental Engineering**", McGraw Hills, New York 1985

34. PRASERTSAN P, PRASERTSAN S and KITTIKUN A (2006): "**Recycling of Agro-Industrial Wastes through Cleaner Technology**" Prince of Songkla University, Hat Yai, Thailand, pp.1-3.

35. RUDRAMOORTHY, R., SUNIL KUMAR, C. P., VELAVAN, R., & SIVASUBRAMANIAM, S. (2000). "**Innovative Measures for Energy Management in Tea Industry**". In proceedings of the 42nd National Convention of Indian Institute of Industrial Engineering, pp. 29-30.

36. STOCKHOLM ENVIRONMENT INSTITUTE, (2009): "**Economics of Climate Change Kenya Project Report**" http://www.sei-international.org/mediamanager/documents/Publications/Climate-mitigation-adaptation/kenya-climatechange.pdf (Accessed on 6th February 2013)

37. TBK(2008): **“National Survey on Processing Capacity Needs for the tea Industry Report”** pp. 1,15.
38. TBK, (2006): “**Tea Board of Kenya Statistics annual report”,** pp8-11
39. TIPTON, T.V, YOKOYAMA, K.M, WANITPRAPHA K, and NAKAMOTO, S.T. (1990): “**Tea Economic Fact Sheet no. 8”**, Univ. of Hawaii, College of Tropical Agriculture and Human Resources, pp. 4.
40. TRFK (2011): “**Strategic Plan 2010-20152nd Edition”**, pp.1-2, 3.
41. TRFK, (2002): “**The Tea Growers Hand Book.5th Edition”,** the Tea Research Foundation of Kenya Printing Services.
42. UNEP(1996): “**Environmentally Sound Technologies (ESTs) for Municipal Solid Waste Management (MSWM)”**
43. UNEP and UNIDO (2000): **Mini-Guide to Cleaner Production**. Vietnam cleaner production centre.
44. US-EPA (2004): “**Primer for Municipal Wastewater Treatment Systems”** Office of Water and Wastewater Management, Washington DC 20460.
45. VAN BEUKERING, P., SEHKER, M., GERLAGH, R., and KUMAR, V. (1999): “**Analysing Urban Solid Waste in Developing Countries: A Perspective on Bangalore, India.”** Collaborative Research in the Economics of Environment and Development.
46. YEDLA, S. (2005): “**Modified Landfill Design for Sustainable Waste Management”**, Int. J. Global Energy Issues, Vol. 23, No. 1, pp.93.105.
47. YUGNUS, A C (2004): “**Heat Transfer-A Practical Approach2nd ed.”** Publisher McGraw Hill Professional, p26 by ISBN 0072458933, 9780072458930, Google Book Search. Accessed 20-04.-09
48. ZHANG, R. (2001): “**Biology and Engineering of Animal Wastewater Lagoons**. Biological and Agricultural Engineering Department University of California, Davis, pp.211-213.

# 8.0 APPENDICES

## 8.1 Characteristics of Pollution Control Problems in Various Agro-Industries

| Industry | Pollution Control Problems | | |
|---|---|---|---|
| | **Water** | **Solid Waste** | **Air** |
| Canning,Frozen and dehydrated fruits and vegetables, soup,potato chips,speciality, baby food, etc | Large seasonal volumes. Variation in effluent strength and volume. High bioegradable effluents. Some soluble organics difficult to remove chemically. water colouration by strong pigments in raw products.Liquid wastes highly putrescible and can not be stored for long periods of time. | Highly putrescible waste from peeling and triming which can not be stored for long peroids of time | Odours from food processing wastewater treatment and solid waste disposal. visible moisture (steam plumes). Entrained material losses (particulates). |
| Edible oils | High concentrations of oil fats and greases; $BOD_5$, suspended solids; dispersed organics and dissolved solids.Fats, oils and greases difficult to remove to acceptable level for direct discharge to waterways. Highly biodegradable effluents. Relatively large | Production of large quantities of solid material as by-product recovered as fertilzer or fee Highly putrescible waste which can not be stored for long peroids of time. | Odours from processing operations if not properly operated and maintained.Odours from wastewater treatment and solid waste disposal visible moisture (steam plumes).Particulate emissions. ocassional toxin or allergen discharge specific to raw |

| Industry | Pollution Control Problems | | |
|---|---|---|---|
| | Water | Solid Waste | Air |
| | volumes of wastewater | | product |
| Dairy | Highly biodegradable effluents. Variation in flow rates and characteristics. Whey from cheese production | | |
| Pickle | Brine, high dissolved, solids in effluents | | |
| Peanuts | | Disposition of peaut shells and hulls | Roasting odour |
| Tea | Evaporation effluent | Tea-chest and spent tea disposal | |
| Coffee | Evaporation and Other effluents | Coffee grounds | Roasting odour |
| Chocolates | Suspended fats in effluents | Cocoa shells | Roasting odour |
| Fish and sea food | Liquid wastes highly putrescible and can not be stored for long peroids of time. Waste have water colouring properties | Processing wastes suchs crabs, shrimps and other shells. | Smoke from processing, visible moisture (steam plumes), Odours from waste disposal. |
| Red meat | Highly biodegradable effluents. Liquid wastes highly putrescible and can not be | Highly putrescible waste from screening operations | Odours from waste disposal. Visible moisture (steam plumes |

| Industry | Pollution Control Problems | | |
|---|---|---|---|
| | Water | Solid Waste | Air |
| | stored for long peroids of time. Relatively large volumes of wastewater | which can not be stored for long periods of time | |
| Poultry | Highly organic effluent, high in suspended solids and floating materials such as grease. Relatively large volumes of wastewater.Highly biodegradable effluent. Fat and grease in high concentration. | Highly putrescible waste from screening operations which can not be stored for long periods of time. Production of large quantities of solids such as entrails, offal, feathers,etc which are used to make animal feed | Odours from waste disposal. |

Source:Middlebrooks 1979

## 8.2 Sources of Waste, Waste Generators & Solid Waste Contents

| Source | Typical waste generators | Solid waste contents |
|---|---|---|
| Residential | Single and multifamily dwellings | Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ashes, special wastes (e.g., bulky items, consumer electronics, batteries, oil, tires), and household hazardous wastes. |
| Industrial | Light and heavy manufacturing, fabrication, construction sites, power and chemical plants. | Housekeeping wastes, packaging, food wastes, construction and demolition materials, hazardous wastes, ashes, special wastes. |
| Commercial | Stores, hotels, restaurants, markets, office buildings, etc. | Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes. |
| Institutional | Schools, hospitals, prisons, government centers. | Paper, cardboards, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes. |
| Construction and demolition | New construction sites, road repair, renovation sites, | Wood, steel, concrete, dirt, etc. |

| Source | Typical waste generators | Solid waste contents |
|---|---|---|
|  | demolition of buildings |  |
| Municipal services | Street cleaning, landscaping, parks, beaches, other recreational areas, water and wastewater treatment plants. | Street sweepings; landscape and tree trimmings; general wastes from parks, beaches, and other recreational areas; sludge. |
| Process (manufacturing, etc.) | Heavy and light manufacturing, refineries, chemical plants, power plants, mineral extraction and processing. | Industrial process wastes, scrap materials, off-specification products, slay tailings. |
| Agriculture | Crops, orchards, vineyards, dairies, feedlots, farms. | Spoiled food wastes, agricultural wastes, hazardous wastes (e.g., pesticides). |

(Source: Shirke, 2009)

## 8.3 World Production of Tea (metric tons) and Percent Share

| Country | Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2007 | | 2008 | | 2009 | | 2010 | |
| | Prod. | % Vol. | Prod. | % Vol. | Prod. | % Vol. | Prod. | % Vol. |
| China | 1,140,000 | 30.0 | 1,200,000 | 32.5 | 1,358,642 | 34.5 | 1,370,000 | 33.7 |
| India | 944,678 | 25.9 | 980,818 | 25.4 | 978,999 | 24.9 | 966,403 | 23.8 |
| Kenya | 369,606 | 9.7 | 345,817 | 8.9 | 314,198 | 8.0 | 399,382 | 9.8 |
| Sri Lanka | 304,6138 | 8.0 | 318,697 | 8.2 | 289,774 | 7.4 | 329,382 | 8.1 |
| Indonesia | 137,248 | 3.6 | 137,499 | 3.6 | 136,481 | 3.5 | 129,200 | 3.2 |
| Others Africa | 189,845 | 5.1 | 172,022 | 4.5 | 201,767 | 5.1 | 207,967 | 5.1 |
| Others | 664,904 | 17.7 | 649,337 | 16.9 | 656,235 | 16.6 | 664,638 | 16.3 |
| **World Totals** | **3,750,894** | **100.0** | **3,804,190** | **100.0** | **3,936,096** | **100.0** | **4,066,596** | **100.0** |

*Source: Tea Research Foundation of Kenya: 2010 – 2015 Strategic Plan*

## 8.4 World Exports of Tea (metric tons) and Percent Share

| Country | Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2007 | | 2008 | | 2009 | | 2010 | |
| | Amount | % Vol. | Amount | % Vol. | Amount | % Vol. | Amount | % Vol. |
| China | 289,431 | 18.4 | 296935 | 18.1 | 302949 | 19.2 | 302419 | 17.5 |
| India | 175,454 | 11.2 | 200070 | 12.2 | 193000 | 12.3 | 189000 | 10.9 |
| Kenya | 343,703 | 21.9 | 383444 | 23.4 | 342482 | 21.8 | 441021 | 25.5 |
| Sri Lanka | 294,254 | 18.7 | 298821 | 18.2 | 279839 | 17.8 | 298587 | 17.3 |
| Indonesia | 836,59 | 5.3 | 96210 | 5.9 | 92304 | 5.9 | 87101 | 5.0 |
| Others Africa | 163,183 | 10.4 | 151022 | 9.2 | 162886 | 10.3 | 173927 | 10.1 |
| Others | 223,041 | 14.2 | 211433 | 12.9 | 200968 | 12.8 | 236921 | 13.7 |
| **World Totals** | **1,572,725** | **100.0** | **1,637,935** | **100.0** | **1,574,428** | **100.0** | **1,728,976** | **100.0** |

*Source: Tea Research Foundation of Kenya: 2010 – 2015 Strategic Plan*

## 8.5 Waste from Beds in Kilograms

**Waste from Beds in Kg**

| | **W1** | **W2** | **W3** | **W4** | **Min** | **Max** | **Count** | **Average** | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Nov. 2010 | 56 | 66 | 62 | 68 | 56 | 68 | 4 | 63 | 252 |
| Dec. 2010 | 66 | 64 | 68 | 96 | 64 | 96 | 4 | 73.5 | 294 |
| Jan. 2011 | 92 | 80 | 55 | 59 | 55 | 92 | 4 | 71.5 | 286 |
| Feb. 2011 | 50 | 48 | 54 | 53 | 48 | 54 | 4 | 51.25 | 205 |
| March. 2011 | 54 | 56 | 55 | 46 | 46 | 56 | 4 | 52.75 | 211 |
| April. 2011 | 50 | 57 | 51 | 48 | 48 | 57 | 4 | 51.5 | 206 |
| **Min** | 50 | 48 | 51 | 46 | | | | | |
| **Max** | 92 | 80 | 68 | 96 | | | | | |
| **Count** | 6 | 6 | 6 | 6 | | | | | |
| **Average** | 61.3333 | 61.8333 | 57.5 | 61.6667 | | | | **60.5833** | |
| **Total** | 368 | 371 | 345 | 370 | | | | | |

## 8.6 Waste Weight from Offloading Area

**Waste Weight from Offloading Area**

| Day | Apr-11 | Mar-11 | Feb-11 | Jan-11 | Dec-10 | Nov-10 |
|---|---|---|---|---|---|---|
| 1 | 0 | 4 | 3 | 0 | 3 | 0 |
| 2 | 2 | 4 | 2 | 3 | 2 | 5 |
| 3 | 0 | 3 | 3 | 3 | 3 | 3 |
| 4 | 4 | 2 | 3 | 2 | 2 | 2 |
| 5 | 3 | 2 | 3 | 4 | 0 | 3 |
| 6 | 4 | 0 | 2 | 3 | 4 | 3 |
| 7 | 3 | 2 | 3 | 3 | 3 | 0 |
| 8 | 3 | 4 | 2 | 2 | 3 | 0 |
| 9 | 2 | 3 | 2 | 0 | 4 | 4 |
| 10 | 2 | 2 | 2 | 4 | 3 | 3 |
| 11 | 4 | 2 | 2 | 4 | 3 | 4 |
| 12 | 4 | 2 | 2 | 3 | 0 | 3 |
| 13 | 3 | 0 | 0 | 2 | 4 | 3 |
| 14 | 3 | 3 | 0 | 2 | 4 | 0 |
| 15 | 2 | 3 | 4 | 2 | 3 | 0 |
| 16 | 2 | 3 | 3 | 0 | 3 | 5 |
| 17 | 0 | 2 | 2 | 3 | 2 | 3 |
| 18 | 4 | 2 | 2 | 3 | 2 | 4 |
| 19 | 4 | 2 | 2 | 2 | 0 | 2 |
| 20 | 2 | 0 | 0 | 2 | 4 | 3 |
| 21 | 3 | 0 | 0 | 2 | 3 | 0 |
| 22 | 2 | 4 | 4 | 2 | 3 | 6 |
| 23 | 0 | 4 | 3 | 0 | 3 | 4 |
| 24 | 0 | 3 | 2 | 4 | 2 | 3 |
| 25 | 0 | 2 | 2 | 3 | 0 | 4 |
| 26 | 3 | 2 | 3 | 3 | 0 | 3 |
| 27 | 0 | 0 | 0 | 2 | 2 | 2 |
| 28 | 0 | 4 | 0 | 3 | 0 | 0 |
| 29 | 0 | 3 |  | 2 | 0 | 4 |
| 30 | 0 | 3 |  | 0 | 0 | 3 |
| 31 |  | 2 |  | 3 | 0 |  |
| Min | 0 | 0 | 0 | 0 | 0 | 0 |
| Max | 4 | 4 | 4 | 4 | 4 | 6 |
| Count | 30 | 31 | 28 | 31 | 31 | 30 |
| Average | 1.96667 | 2.32258 | 2 | 2.29032 | 2.09677 | 2.63333 |
| Total | 59 | 72 | 56 | 71 | 65 | 79 |
| Month | Apr-11 | Mar-11 | Feb-11 | Jan-11 | Dec-10 | Nov-10 |

## 8.7 Waste Pekoe Dust

**Waste Pekoe Dust**

| date | time cleaned | weight (kgs) |
|---|---|---|
| 03.11.2010 | 4.45pm | 2 |
| 04.11.2010 | 3.13pm | 1.3 |
| 05.11.2010 | 4.04pm | 2.5 |
| 06.11.2010 | 4.36pm | 2 |
| 07.11.2010 | 3.49pm | 1 |
| 10.11.2010 | 4.29pm | 2 |
| 11.11.2010 | 4.30pm | 2.5 |
| 12.11.2010 | 3.43pm | 2 |
| 13.11.2010 | 3.54pm | 1.5 |
| 14.11.2010 | 3.30pm | 2 |
| 16.11.2010 | 4.03pm | 2.3 |
| 17.11.2010 | 3.00pm | 1 |
| 18.11.2010 | 3.43pm | 1 |
| 19.11.2010 | 3.39pm | 2 |
| 20.11.2010 | 4.14pm | 1 |
| 23.11.2010 | 2.43pm | 2.4 |
| 24.11.2010 | 4.30pm | 1.5 |
| 25.11.2010 | 4.26pm | 1 |
| 26.11.2010 | 2.56pm | 1 |
| 27.11.2010 | 4.30pm | 2 |
| 28.11.2010 | 4.06pm | 2.3 |
| 30.11.2010 | 4.00pm | 2 |
|  |  | 38.3 |
| 03.12.2010 | 3.40pm | 1 |
| 04.12.2010 | 4.36pom | 1.5 |
| 08.12.2010 | 4.10pm | 1.5 |
| 09.12.2010 | 4.00pm | 2.8 |

|  |  |  |
|---|---|---|
| 10.12.2010 | 3.10pm | 2.4 |
| 11.12.2010 | 4.40pm | 2 |
| 15.12.2010 | 4.36pm | 2.5 |
| 16.12.2010. | 3.46pm | 2 |
| 17.12.2010 | 3.43pm | 2.5 |
| 18.12.2010 | 4.31pm | 1.5 |
| 22.12.2010 | 4.30pm | 1 |
| 23.12.2010 | 4.00pm | 2 |
| 24.12.2010 | 2.40pm | 2.5 |
| 29.12.2010 | 4.46pm | 2 |
| 30.12.2010 | 4.39pm | 1 |
|  |  | 28.2 |
| 05.01.2011 | 12.40pm | 2 |
| 06.01.2011 | 3.17pm | 1.5 |
| 07.01.2011 | 2.10pm | 2 |
| 08.01.2011 | 3.25pm | 2 |
| 12.01.2011 | 4.00pm | 1.2 |
| 13.01.2011 | 2.26pm | 2 |
| 14.01.2011 | 4.49pm | 2.5 |
| 15.01.2011 | 2.24pm | 1.5 |
| 19.01.2011 | 3.45pm | 1 |
| 20.01.2011 | 4.46pm | 2 |
| 21.01.2011 | 2.29pm | 2.5 |
| 22.01.2011 | 2.49pm | 2 |
| 26.01.2011 | 4.30pm | 1 |
| 27.01.2011 | 11.00pm | 1 |
| 28.01.2011 | 4.00pm | 2 |
| 29.01.2011 | 3.00pom | 2 |
| 30.01.2011 | 2.34pm | 3 |
| 31.01.2011 | 3.36pm | 2.5 |
|  |  | 33.7 |
| 03.02.2011 | 1.57pm | 1 |

| | | |
|---|---|---|
| 04.02.2011 | 4.41pm | 2 |
| 05.02.2011 | 4.00pm | 1 |
| 08.02.2011 | 2.36pm | 1.4 |
| 09.02.2011 | 4.00pm | 2.5 |
| 10.02.2011 | 4.30pm | 1 |
| 11.02.2011 | 4.26pm | 1.5 |
| 12.02.2011 | 3.14pm | 1.8 |
| 16.02.2011 | 4.09pm | 3.6 |
| 17.02.2011 | 4.45pm | 2 |
| 18.02.2011 | 4.00pm | 2 |
| 19.02.2011 | 2.14pm | 1 |
| 23.02.2011 | 2.13pm | 2.5 |
| 25.02.2011 | 3.40pm | 2 |
| 28.02.2011 | 2.30pm | 1 |
| | | 26.3 |
| 02.03.2011 | 4.24pm | 2.5 |
| 03.03.2011 | 11.50pm | 2 |
| 05.03.2011 | 1.04pm | 2.5 |
| 08.03.2011 | 3.22pm | 1.5 |
| 10.03.2011 | 2.00pm | 1 |
| 12.03.2011 | 3.30pm | 2 |
| 16.03.2011 | 1.57pm | 2.5 |
| 17.03.2011 | 2.47pm | 2 |
| 19.03.2011 | 3.47pm | 2.3 |
| 23.03.2011 | 12.06pm | 2 |
| 24.03.2011 | 3.00pm | 2 |
| 26.03.2011 | 3.15pm | 2.5 |
| 30.03.2011 | 3.25pm | 2.8 |
| 31.03.2011 | 2.20pm | 1 |
| | | 28.6 |
| 06.04.2011 | 3.46pm | 2.6 |
| 08.04.2011 | 3.00pm | 1 |

| | | |
|---|---|---|
| 09.04.2011 | 4.13pm | 2.5 |
| 13.04.2011 | 4.03pm | 1 |
| 14.04.2011 | 4.10pm | 1.5 |
| 15.04.2011 | 3.21pm | 2 |
| 16.04.2011 | 2.47pm | 2 |
| 19.04.2011 | 2.00pm | 0.5 |
| 20.04.2011 | 4.00pm | 2 |
| 21.04.2011 | 3.24pm | 2 |
| 22.04.2011 | 2.46pm | 1 |
| | | 18.1 |
| **Total** | | **328.3** |
| Average | | 3.283 |
| Max | | 38.3 |
| Min | | 0.5 |
| Count | | 100 |

| | |
|---|---|
| Nov. 2010 | 38.3 |
| Dec. 2010 | 28.2 |
| Jan. 2011 | 33.7 |
| Feb. 2011 | 26.3 |
| March. 2011 | 28.6 |
| April. 2011 | 18.1 |
| **Min** | 18.1 |
| **Max** | 38.3 |
| **Count** | 6 |
| **Average** | 28.86667 |
| **Total** | 173.2 |

### 8.8 Solid Waste Data (Weight in Kgs)

| **Section** | **Nov.2010** | **Dec.2010** | **Jan.2011** | **Feb.2011** | **Mar.2011** | **Apr.2011** | **Total** | **Mean** |
|---|---|---|---|---|---|---|---|---|
| Offloading Bay | 59 | 72 | 56 | 71 | 65 | 79 | 402 | 67.0 |
| Withering | 252 | 294 | 286 | 205 | 211 | 206 | 1454 | 242.3 |
| Processing CTC | 25 | 24.5 | 22 | 24 | 25.6 | 27.8 | 148.9 | 24.8 |
| Drying | 38.3 | 28.2 | 33.7 | 26.3 | 28.6 | 18.1 | 173.2 | 28.9 |
| Sorting | 22 | 25.3 | 26 | 23 | 24 | 25 | 145.3 | 24.2 |
| Packing | 15 | 17 | 25 | 20 | 25.6 | 28 | 130.6 | 21.8 |

## 8.9 Boiler Data

| **Date** | **Time** | **F/ wood used** | **Accumulated fuel used** | **Hot $H_2O$ metre reading** | **Amount of $H_2O$ used** | **Wood Pac Pressure** | **Feed Tank Temp** | **Hot Air ºC** | **Drier** |
|---|---|---|---|---|---|---|---|---|---|
| 01.07.2011 | 1am | 2 | 2 | 11631 | 3 | 9.8 | 90°C | 100 | 2 |
| | 2am | 2.5 | 4.5 | 11634 | 3 | 9.6 | 90°C | 100 | 2 |
| | 3am | 2 | 6.5 | 11639 | 5 | 9.6 | 90°C | 100 | 2 |
| | 4am | 2 | 8.5 | 11644 | 5 | 9.8 | 90°C | 100 | 2 |
| | 5am | 2.5 | 11 | 11649 | 5 | 9.6 | 90°C | 100 | 2 |
| | 6am | 2 | 13 | 11654 | 5 | 9.8 | 90°C | 100 | 1 |
| | 7am | 2 | 15 | 11659 | 5 | 9.8 | 90°C | 100 | |
| | 8am | 2 | 17 | 11663 | 4 | 8.8 | 90°C | 100 | 2 |
| | 9am | 2 | 19 | 11667 | 4 | 9 | 90°C | 100 | 2 |
| | 10am | 2 | 21 | 11671 | 4 | 9.6 | 90°C | 100 | 2 |
| | 11am | 2 | 23 | 11676 | 5 | 9.6 | 90°C | 100 | 2 |
| | 12noon | 2 | 25 | 11680 | 5 | 9.8 | 90°C | 100 | 2 |
| | 1pm | 2 | 27 | 11684 | 4 | 9.6 | 90°C | 100 | 2 |
| | 2pm | 2 | 29 | 11688 | 4 | 9.8 | 90°C | 100 | 2 |
| | 3pm | 2.5 | 31.5 | 11690 | 3 | 9.6 | 90°C | 100 | 2 |
| | 4pm | 2.5 | 34 | 11693 | 3 | 9.8 | 90°C | 100 | 2 |

| **Date** | **Time** | **F/ wood used** | **Accumulated fuel used** | **Hot $H_2O$ metre reading** | **Amount of $H_2O$ used** | **Wood Pac Pressure** | **Feed Tank Temp** | **Hot Air ºC** | **Drier** |
|---|---|---|---|---|---|---|---|---|---|
| | 5pm | 2.5 | 36.5 | 11696 | 3 | 9.8 | 90°C | 100 | 2 |
| | 6pm | 2 | 38.5 | 11701 | 4 | 9.8 | 90°C | 100 | 2 |
| | 7pm | 2.5 | 41 | 11705 | 4 | 9.8 | 90°C | 100 | 2 |
| | 8pm | 2 | 43 | 11708 | 3 | 9.8 | 90°C | 100 | 2 |
| | 9pm | 2.5 | 45.5 | 11718 | 5 | 9.8 | 90°C | 100 | 2 |
| | 10pm | 2 | 47.5 | 11717 | 3 | 9.8 | 90°C | 100 | 2 |
| | 11pm | 2.5 | 5 | 11721 | 4 | 9.8 | 90°C | 100 | 2 |
| | 12midnight | 2 | 52 | 11725 | 4 | 9.8 | 90°C | 100 | 2 |
| | | | | | | | | | |
| | | | | 52M3 | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| 02.07.2011 | 1am | 2 | 2 | 11728 | 3 | 9.8 | 90°C | 100 | |
| | 2am | 2 | 4 | 11731 | 3 | 9.8 | 90°C | 100 | |
| | 3am | 0.5 | 5.5 | 11735 | 4 | 9.8 | 90°C | 100 | |
| | 4am | | 5.5 | 11736 | 1 | 9.8 | 90°C | 100 | |
| | 5am | 2.5 | 8 | 11740 | 4 | 9.8 | 90°C | 100 | 2 |
| | 6am | 2 | | 11742 | 3 | 9.8 | 90°C | 100 | 2 |

| **Date** | **Time** | **F/ wood used** | **Accumulated fuel used** | **Hot $H_2O$ metre reading** | **Amount of $H_2O$ used** | **Wood Pac Pressure** | **Feed Tank Temp** | **Hot Air °C** | **Drier** |
|---|---|---|---|---|---|---|---|---|---|
| | 7am | 2 | 12 | 11745 | 3 | 9.6 | 90°C | 100 | 2 |
| | 8am | 2 | 14 | 11749 | 4 | 9.8 | 90°C | 100 | 2 |
| | 9am | 2.5 | 16.5 | 11755 | 4 | 9.8 | 90°C | 100 | 2 |
| | 10am | 2 | 18.5 | 11757 | 4 | 9.8 | 90°C | 100 | 2 |
| | 11am | 2.5 | 21 | 11761 | 4 | 9.8 | 90°C | 100 | 2 |
| | 12noon | 2 | 23 | 11765 | 4 | 700 | 90°C | 100 | 1 |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | 7pm | 2 | 2 | 11837 | 3 | 9.8 | 90°C | 100 | |
| | 8pm | 2 | 4 | 11840 | 3 | 9.8 | 90°C | 100 | |
| | 9pm | 2 | 6 | 11843 | 3 | 9.6 | 90°C | 100 | |
| | 10pm | 2 | 8 | 11846 | 3 | 9.8 | 90°C | 100 | |
| | 11pm | 2 | 10 | 11849 | 3 | 9.8 | 90°C | 100 | |
| | 12midnight | 2 | 12 | 11852 | 3 | 9.8 | 90°C | 100 | |
| 03.07.2011 | 1am | 2 | 14 | 11856 | 4 | 9.8 | 90°C | 100 | |
| | 2am | 1 | 15 | 11859 | 3 | 9.8 | 90°C | 100 | |

| **Date** | **Time** | **F/ wood used** | **Accumulated fuel used** | **Hot $H_2O$ metre reading** | **Amount of $H_2O$ used** | **Wood Pac Pressure** | **Feed Tank Temp** | **Hot Air ºC** | **Drier** |
|---|---|---|---|---|---|---|---|---|---|
| | 3am | | 15 | 11862 | 3 | 9.6 | 90°C | 100 | |
| | 4am | 2 | 17 | 11866 | 4 | 9.8 | 90°C | 100 | 2 |
| | 5am | 2 | 19 | 11870 | 4 | 9.8 | 90°C | 100 | 2 |
| | 6am | 2 | 21 | 11873 | 3 | 9.6 | 90°C | 100 | 2 |
| | 7am | 2 | 23 | 11876 | 3 | 9.8 | 90°C | 100 | 2 |
| | 8am | 2 | 25 | 11893 | 3 | 8.5 | 90°C | 100 | 2 |
| | 9am | 2 | 27 | 11882 | 3 | 8.5 | 90°C | 100 | 2 |
| | 10am | 2 | 29 | 11886 | 4 | 8.5 | 90°C | 100 | 2 |
| | 11am | 2 | 31 | 11890 | 4 | 9 | 90°C | 100 | 2 |
| | 12noon | 2 | 34 | 11893 | 3 | 9 | 90°C | 100 | 2 |
| | 1pm | 2 | 36 | 11897 | 4 | 9 | 90°C | 100 | 2 |
| | 2pm | 2 | 38 | 11900 | 3 | 9.4 | 90°C | 100 | 2 |
| | 3pm | 2 | 40 | 11903 | 3 | 9.6 | 90°C | 100 | 2 |
| | 4pm | 2 | 42 | 11905 | 2 | 9.8 | 90°C | 100 | 1 |
| | 5pm | 1.5 | 42.5 | 11907 | 2 | 8.6 | 90°C | 100 | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

| **Date** | **Time** | **F/ wood used** | **Accumulated fuel used** | **Hot $H_2O$ metre reading** | **Amount of $H_2O$ used** | **Wood Pac Pressure** | **Feed Tank Temp** | **Hot Air °C** | **Drier** |
|---|---|---|---|---|---|---|---|---|---|
|  | 7pm | 2 | 2 | 11908 | 1 | 4.5 | 65°C | 100 |  |
|  | 8pm | 2 | 4 | 11909 | 1 | 8.8 | 70°C | 100 |  |
|  | 9pm | 2 | 6 | 11911 | 2 | 9.8 | 85°C | 100 |  |
|  | 10pm | 1.5 | 7.5 | 11913 | 2 | 9.8 | 90°C | 100 |  |
|  | 11pm | 2 | 9.5 | 11916 | 3 | 9.8 | 90°C | 100 |  |
|  | 12md | 2 | 11.5 | 11919 | 3 | 9 | 90°C | 100 |  |
| 04.07.2011 | 1am | 2 | 13.5 | 11922 | 3 | 9.4 | 90°C | 100 |  |
|  | 2am | 2 | 15.5 | 11926 | 4 | 9.6 | 90°C | 100 |  |
|  | 3am | 2.5 | 18 | 11929 | 3 | 9.8 | 90°C | 100 | 2 |
|  | 4am | 2 | 20 | 11933 | 4 | 9.8 | 90°C | 100 | 2 |
|  | 5am | 2 | 22 | 11937 | 4 | 9.6 | 90°C | 100 | 2 |
|  | 6am | 2 | 24 | 11941 | 4 | 9.8 | 90°C | 100 | 2 |
|  | 7am | 2 | 26 | 11945 | 4 | 9.6 | 90°C | 100 | 2 |
|  | 8am | 2 | 28 | 11948 | 4 | 9 | 85°C | 100 | 2 |
|  | 9am | 2 | 30 | 11952 | 4 | 9 | 88°C | 100 | 2 |
|  | 10am | 2 | 32 | 11956 | 4 | 9.4 | 90°C | 100 | 2 |
|  | 11am | 2 | 34 | 11960 | 4 | 9.4 | 90°C | 100 | 2 |

| **Date** | **Time** | **F/ wood used** | **Accumulated fuel used** | **Hot $H_2O$ metre reading** | **Amount of $H_2O$ used** | **Wood Pac Pressure** | **Feed Tank Temp** | **Hot Air ºC** | **Drier** |
|---|---|---|---|---|---|---|---|---|---|
| | 12noon | 2 | 36 | 11964 | 4 | 9 | 90°C | 100 | 2 |
| | 1pm | 2 | 38 | 11968 | 4 | 8.8 | 90°C | 100 | 2 |
| | 2pm | 2 | 40 | 11972 | 4 | 8.8 | 90°C | 100 | 2 |
| | 3pm | 2 | 42 | 11976 | 4 | 8 | 90°C | 100 | 2 |
| | 4pm | 2 | 44 | 11980 | 4 | 8.2 | 90°C | 100 | 2 |
| | 5pm | 0.5 | 44.5 | 11982 | 2 | 8 | 90°C | 100 | 2 |
| | | | | | | | | | |
| | 6pm | 2 | 2 | 11984 | 2 | 5.6 | 90°C | 100 | |
| | 7pm | 2 | 4 | 11985 | 1 | 8.8 | 90°C | 100 | |
| | 8pm | 1.5 | 5.5 | 11986 | 1 | 9.2 | 90°C | 100 | |
| | 9pm | 2 | 7.5 | 11988 | 2 | 9.6 | 90°C | 100 | |
| | 10pm | 2 | 9.5 | 11991 | 2 | 9.8 | 90°C | 100 | |
| | 11pm | 2 | 11.5 | 11994 | 3 | 9.6 | 90°C | 100 | |
| | 12mn | 2 | 13.5 | 11997 | 3 | 9.6 | 90°C | 100 | |
| 05.07.2011 | 1am | 2 | 15.5 | 12000 | 3 | 9.8 | 90°C | 100 | |
| | 2am | 1.5 | 17 | 12004 | 4 | 9.8 | 90°C | 100 | |
| | 3am | 2 | 19 | 12007 | 3 | 9.8 | 90°C | 100 | |

| **Date** | **Time** | **F/ wood used** | **Accumulated fuel used** | **Hot $H_2O$ metre reading** | **Amount of $H_2O$ used** | **Wood Pac Pressure** | **Feed Tank Temp** | **Hot Air °C** | **Drier** |
|---|---|---|---|---|---|---|---|---|---|
| | 4am | 2 | 21 | 12011 | 4 | 9.8 | 90°C | 100 | 2 |
| | 5am | 2 | 23 | 12014 | 3 | 9.8 | 90°C | 100 | 2 |
| | 6am | 2 | 25 | 12018 | 4 | 9.8 | 90°C | 100 | 2 |
| | 7am | 2 | 27 | 12021 | 3 | 9.8 | 90°C | 100 | 2 |
| | 8am | 2 | 29 | 12025 | 4 | 9.4 | 90°C | 100 | 2 |
| | 9am | 2 | 31 | 12028 | 4 | 9.4 | 90°C | 100 | 2 |
| | 10am | 2 | 33 | 12032 | 4 | 9.4 | 90°C | 100 | 2 |
| | 11am | 2 | 25 | 12036 | 4 | 9.8 | 85°C | 100 | 2 |
| | 12md | 2 | 37 | 12040 | 4 | 9.4 | 88°C | 100 | 2 |
| | 1pm | 2 | 39 | 12044 | 4 | 9.6 | 88°C | 100 | 2 |
| | 2pm | 2 | 41 | 12048 | 4 | 9.8 | 90°C | 100 | 2 |
| | 3pm | 2 | 43 | 12052 | 4 | 9.8 | 90°C | 100 | 2 |
| | 4pm | 2 | 45 | 12056 | 4 | 9.8 | 90°C | 100 | 2 |
| | | | | | | | | | |
| | | | | | | | | | |
| | 5pm | 2 | 2 | 12.05 | 4 | 9.8 | 90°C | 100 | |
| | 6pm | 2 | 4 | 12064 | 4 | 9.6 | 90°C | 100 | |

| **Date** | **Time** | **F/ wood used** | **Accumulated fuel used** | **Hot $H_2O$ metre reading** | **Amount of $H_2O$ used** | **Wood Pac Pressure** | **Feed Tank Temp** | **Hot Air °C** | **Drier** |
|---|---|---|---|---|---|---|---|---|---|
|  | 7pm | 2 | 6 | 12068 | 4 | 9.6 | 90°C | 100 |  |
|  | 8pm | 2 | 8 | 12071 | 3 | 9.8 | 90°C | 100 |  |
|  | 9pm | 2 | 10 | 12073 | 2 | 9.8 | 90°C | 100 |  |
|  | 10pm | 2 | 12 | 12076 | 3 | 9.8 | 90°C | 100 |  |
|  | 11pm | 2 | 14 | 12079 | 3 | 9.8 | 90°C | 100 |  |
|  | 12mn | 2 | 16 | 12083 | 4 | 9.8 | 90°C | 100 | 2 |
| 06.07.2011 | 1am | 2.5 | 18.5 | 12086 | 3 | 9.8 | 90°C | 100 | 2 |
|  | 2am | 2 | 80.5 | 12090 | 4 | 9.8 | 90°C | 100 | 2 |
|  | 3am | 2 | 22.5 | 12093 | 3 | 9.6 | 90°C | 100 | 2 |
|  | 4am | 2.5 | 25 | 12096 | 3 | 9.6 | 90°C | 100 | 2 |
|  | 5am | 2 | 27 | 12100 | 4 | 9.8 | 90°C | 100 | 2 |
|  | 6am | 2 | 29 | 12105 | 5 | 9.8 | 90°C | 100 | 2 |
|  | 7am | 2 | 31 | 12110 | 5 | 9.8 | 90°C | 100 | 2 |
|  | 8am | 2 | 33 | 12115 | 5 | 9.6 | 90°C | 100 | 2 |
|  | 9am | 2 | 35 | 12120 | 5 | 9.6 | 90°C | 100 | 2 |
|  | 10am | 2.5 | 37.5 | 12125 | 5 | 9.6 | 90°C | 100 | 2 |
|  | 11am | 2 | 39.5 | 12130 | 5 | 9.8 | 90°C | 100 | 2 |

| Date | Time | F/ wood used | Accumulated fuel used | Hot $H_2O$ metre reading | Amount of $H_2O$ used | Wood Pac Pressure | Feed Tank Temp | Hot Air $^{o}C$ | Drier |
|---|---|---|---|---|---|---|---|---|---|
|  | 12md | 2.5 | 42 | 12135 | 5 | 9 | 90°C | 100 | 2 |
|  | 1pm | 2 | 44 | 12140 | 5 | 8.6 | 90°C | 100 | 2 |
|  | 3pm | PREPARATION |  |  |  |  |  |  |  |
|  | 4pm | 2 | 2 | 12144 | 4 |  | 30°C | 100 |  |
|  | 6pm | 2 | 4 | 12145 | 1 | 300 | 65°C | 100 |  |
|  | 7pm | 1.5 | 5.5 | 12146 | 1 | 8.6 | 70°C | 100 |  |
|  | 7pm | 2 | 7.5 | 12148 | 2 | 9.8 | 90°C | 100 |  |
|  | 8pm | 1.5 | 9 | 12150 | 2 | 9.6 | 90°C | 100 |  |
|  | 9pm | 2 | 11 | 12153 | 3 | 9.6 | 90°C | 100 |  |
|  | 10pm | 2 | 13 | 12156 | 3 | 9.8 | 90°C | 100 |  |
|  | 11pm | 2 | 15 | 12160 | 4 | 9.8 | 90°C | 100 |  |
|  | 12md | 2 | 17 | 12163 | 3 | 9.8 | 90°C | 100 |  |
| 07.07.2011 | 1am | 2.5 | 19 | 12166 | 3 | 9.8 | 90°C | 100 | 2 |
|  | 2am | 2 | 21.5 | 12170 | 4 | 9.8 | 90°C | 100 | 2 |
|  | 3am | 2 | 23.5 | 12173 | 3 | 9.8 | 90°C | 100 | 1 |
|  | 4am | 2 | 25.5 | 12176 | 3 | 9.8 | 90°C | 100 | 1 |
|  | 5am | 2.5 | 28 | 12180 | 4 | 9.6 | 90°C | 100 | 2 |

| **Date** | **Time** | **F/ wood used** | **Accumulated fuel used** | **Hot $H_2O$ metre reading** | **Amount of $H_2O$ used** | **Wood Pac Pressure** | **Feed Tank Temp** | **Hot Air ºC** | **Drier** |
|---|---|---|---|---|---|---|---|---|---|
| | 6am | 2 | 30 | 12185 | 5 | 9.8 | 90°C | 100 | 2 |
| | 7am | 2 | 32 | 12189 | 4 | 9.6 | 90°C | 100 | 2 |
| | 8am | 2 | 34 | 12193 | 4 | 9.4 | 90°C | 100 | 2 |
| | 9am | 2 | 36 | 12197 | 4 | 9.6 | 90°C | 100 | 2 |
| | 10am | 2.5 | 38.5 | 12201 | 4 | 9.8 | 90°C | 100 | 2 |
| | 11am | 2.5 | 41 | 12205 | 4 | 9.4 | 85°C | 100 | 2 |
| | 12noon | 2.5 | 43.5 | 12209 | 4 | 9.4 | 85°C | 100 | 2 |
| | 1pm | 2.5 | 46 | 12213 | 4 | 8.8 | 88°C | 100 | 2 |
| | 2pm | 2.5 | 48.5 | 12217 | 4 | 8.6 | 90°C | 100 | 2 |
| | 3pm | 2.5 | 51 | 12220 | 3 | 9 | 90°C | 100 | 2 |
| | 4pm | 2.5 | 53.5 | 12223 | 3 | 9 | 90°C | 100 | 2 |
| | 5pm | 4.5 | 58 | 12227 | 4 | 9.2 | 90°C | 100 | 2 |
| | 6pm | 4.5 | 62.5 | 12231 | 4 | 8.8 | 90°C | 100 | 2 |
| | 7pm | 4.5 | 67 | 12236 | 5 | 8.8 | 90°C | 100 | 2 |
| | 8pm | 4.5 | 71.5 | 12240 | 4 | 9 | 90°C | 100 | 2 |
| | 9pm | 4.5 | 76 | 12245 | 5 | 8.8 | 90°C | 100 | 2 |
| | 10pm | 4.5 | 80.5 | 12250 | 5 | 8.8 | 90°C | 100 | 2 |

| **Date** | **Time** | **F/ wood used** | **Accumulated fuel used** | **Hot $H_2O$ metre reading** | **Amount of $H_2O$ used** | **Wood Pac Pressure** | **Feed Tank Temp** | **Hot Air °C** | **Drier** |
|---|---|---|---|---|---|---|---|---|---|
|  | 11pm | 4.5 | 85 | 12255 | 5 | 9 | 90°C | 100 | 1 |
|  | 12mn | 2m3 | 2 | 12259 | 4 | 9.6 | 90°C | 100 |  |
| 08.07.2011 | 1am | 2.5 | 4.5 | 12263 | 4 | 9.8 | 90°C | 100 | 2 |
|  | 2am | 2.5 | 7 | 12266 | 3 | 9.8 | 90°C | 100 | 2 |
|  | 3am | 2 | 9 | 12271 | 5 | 9.8 | 90°C | 100 | 2 |
|  | 4am | 2 | 11 | 12275 | 4 | 9.6 | 90°C | 100 | 2 |
|  | 5am | 2.5 | 13.5 | 12279 | 4 | 9.6 | 90°C | 100 | 2 |
|  | 6am | 2.5 | 16 | 12284 | 5 | 9.8 | 90°C | 100 | 2 |
|  | 7am | 2 | 18 | 12288 | 4 | 9.6 | 90°C | 100 | 2 |
|  | 8am | 2.5 | 20.5 | 12292 | 4 | 9.8 | 90°C | 100 | 1 |
|  | 9am | 2 | 22.5 | 12295 | 3 | 9.6 | 90°C | 100 | 1 |
|  | 10am | 2 | 24.5 | 12298 | 3 | 9.8 | 90°C | 100 | 1 |
|  | 11am | 2 | 26.5 | 12301 | 3 | 9.8 | 90°C | 100 | 2 |
|  | 12noon | 2.5 | 29 | 12303 | 3 | 9.8 | 90°C | 100 | 2 |
|  | 1pm | 2.5 | 32 | 12307 | 4 | 9.8 | 90°C | 100 | 2 |
|  | 2pm | 2 | 34 | 12311 | 4 | 9.4 | 90°C | 100 | 2 |
|  | 3pm | 2.5 | 36.5 | 12312 | 4 | 9.4 | 90°C | 100 | 2 |

| **Date** | **Time** | **F/ wood used** | **Accumulated fuel used** | **Hot $H_2O$ metre reading** | **Amount of $H_2O$ used** | **Wood Pac Pressure** | **Feed Tank Temp** | **Hot Air ºC** | **Drier** |
|---|---|---|---|---|---|---|---|---|---|
| | 4pm | 2.5 | 39 | 12317 | 3 | 9.4 | 90°C | 100 | 2 |
| | 5pm | 4 | 43 | 12321 | 4 | 9.8 | 90°C | 100 | 2 |
| | 6pm | 4 | 47 | 12324 | 3 | 8.2 | 90°C | 100 | 2 |
| | 7pm | 4 | 51 | 12328 | 4 | 8.2 | 90°C | 100 | 2 |
| | 8pm | 4 | 55 | 12332 | 4 | 8.4 | 90°C | 100 | 2 |
| | 9pm | 4 | 59 | 12335 | 3 | 8.4 | 90°C | 100 | 2 |
| | 10pm | 3.5 | 62.5 | 12340 | 5 | 8.4 | 90°C | 100 | 2 |
| | 11pm | 3.5 | 66 | 12345 | 5 | 8.6 | 90°C | 100 | 2 |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | 12mn | 2 | 2 | 12347 | 3 | 8.6 | 90°C | 100 | |
| 09.07.2011 | 1am | 2 | 4 | 12350 | 3 | 8.7 | 90°C | 100 | |
| | 2am | 2 | 6 | 12354 | 4 | 9.6 | 90°C | 100 | 2 |
| | 3am | 2.5 | 8.5 | 12358 | 4 | 9.6 | 90°C | 100 | 2 |
| | 4am | 2 | 10.5 | 12362 | 4 | 9.8 | 90°C | 100 | 2 |
| | 5am | 2.5 | 13 | 12365 | 3 | 9.8 | 90°C | 100 | 2 |
| | 6am | 2 | 15 | 12369 | 4 | 9.6 | 90°C | 100 | 2 |

| Date | Time | F/ wood used | Accumulated fuel used | Hot $H_2O$ metre reading | Amount of $H_2O$ used | Wood Pac Pressure | Feed Tank Temp | Hot Air ºC | Drier |
|---|---|---|---|---|---|---|---|---|---|
| | 7am | 2 | 17 | 12374 | 5 | 9.6 | 90°C | 100 | 2 |
| | 8am | 2 | 19 | 12378 | 4 | 9.8 | 90°C | 100 | 2 |
| | 9am | 2.5 | 21.5 | 12382 | 4 | 9.6 | 90°C | 100 | 2 |
| | 10am | 2.5 | 24 | 12386 | 4 | 8.8 | 90°C | 100 | 2 |
| | 11am | 2 | 28 | 12390 | 4 | 8.8 | 90°C | 100 | 2 |
| | 12noon | 2.5 | 31.5 | 12394 | 4 | 9 | 90°C | 100 | 2 |
| | 1pm | 2 | 32.5 | 12398 | 4 | 9 | 90°C | 100 | 2 |
| | 2pm | 2.5 | 35 | 12402 | 4 | 8.8 | 90°C | 100 | 2 |
| | 3pm | 2.5 | 37.5 | 12406 | 4 | 9 | 90°C | 100 | 2 |
| | 4pm | 2 | 39.5 | 12410 | 4 | 8.8 | 90°C | 100 | 2 |
| | 5pm | 2.5 | 42 | 12413 | 3 | 9 | 90°C | 100 | 2 |
| | 6pm | 2 | 44 | 12417 | 4 | | 90°C | 100 | 2 |
| | 7pm | 2 | 2 | 12421 | 4 | 9 | 90°C | 100 | |
| | 8pm | 1.5 | 3.5 | 12424 | 3 | 9 | 90°C | 100 | |
| | 9pm | 1.5 | 5 | 12426 | 2 | 9 | 90°C | 100 | |
| | 10pm | 2 | 7 | 12429 | 3 | 9 | 90°C | 100 | |
| | 11pm | 2 | 7 | 12432 | 3 | 9.2 | 90°C | 100 | |

| **Date** | **Time** | **F/ wood used** | **Accumulated fuel used** | **Hot $H_2O$ metre reading** | **Amount of $H_2O$ used** | **Wood Pac Pressure** | **Feed Tank Temp** | **Hot Air °C** | **Drier** |
|---|---|---|---|---|---|---|---|---|---|
| | 12md | 1.5 | 10.5 | 12436 | 4 | 9 | 90°C | 100 | |
| 10.07.2011 | 1am | 2 | 12.5 | 12439 | 3 | 9.2 | 90°C | 100 | |
| | 2am | 1 | 13.5 | 12443 | 4 | 9.6 | 90°C | 100 | |
| | 3am | 2.5 | 16 | 12446 | 3 | 9.8 | 90°C | 100 | |
| | 4am | 2 | 18 | 12449 | 4 | 9.6 | 90°C | 100 | |
| | 5am | 2.5 | 20.5 | 12452 | 3 | 9.6 | 90°C | 100 | |
| | 6am | 2.5 | 23 | 12455 | 3 | 9.8 | 90°C | 100 | |
| | 7am | 2 | 25 | 12458 | 3 | 9.6 | 90°C | 100 | |
| | 8am | 2 | 27 | 12461 | 3 | 9.8 | 90°C | 100 | |
| | 9am | 2 | 29 | 12465 | 4 | 9.8 | 90°C | 100 | |
| | 10am | 2.5 | 31 | 12469 | 4 | 9.5 | | 100 | |
| | 11am | 2 | 33 | 12473 | 4 | 9 | 90°C | 100 | |
| | 12noon | 2 | 35 | 12477 | 4 | 9 | 90°C | 100 | |
| | 1pm | 2.5 | 38 | 12481 | 4 | 9.8 | 90°C | 100 | |
| | 2pm | 2 | 40 | 12485 | 4 | 9.8 | 90°C | 100 | |
| | 3pm | 2 | 42 | 12488 | 3 | 9.8 | 90°C | 100 | |
| | 4pm | 2.5 | 42.5 | 12491 | 3 | 9.6 | 90°C | 100 | |

| **Date** | **Time** | **F/ wood used** | **Accumulated fuel used** | **Hot $H_2O$ metre reading** | **Amount of $H_2O$ used** | **Wood Pac Pressure** | **Feed Tank Temp** | **Hot Air °C** | **Drier** |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| | | | | | | | | | |
| | 5pm | 2 | 2 | 12494 | 3 | 9.6 | 90°C | 100 | |
| | 6pm | 2 | 4 | 12496 | 2 | 9.4 | 90°C | 100 | |
| | 7pm | 1.5 | 5.5 | 12499 | 3 | 9.2 | 90°C | 100 | |
| | 8pm | 1.5 | 7 | 12502 | 3 | 9.2 | 90°C | 100 | |
| | 9pm | 2 | 9 | 12504 | 2 | 9.2 | 90°C | 100 | |
| | 10pm | 2 | 11 | 12506 | 2 | 9.4 | 90°C | 100 | |
| | 11pm | | | | | | | | |
| | 12md | 2.5 | 15.5 | 12512 | 3 | 9.6 | 90°C | 100 | |

## 8.10 Wastewater Data

Amount of wastewater generated

| **Months** | **Major cleaning ($m^3$)** | **Minor cleaning ($m^3$)** |
|---|---|---|
| November‘10’ | 120 | 40 |
| December ‘10’ | 100 | 39 |
| January ‘11’ | 138 | 42 |
| February ‘11’ | 109 | 40 |
| March ‘11’ | 112 | 41 |
| April ‘11’ | 140 | 43 |

**Sampling locations**

| Sampling points | Coordinates | Elevation |
|---|---|---|
| Main factory building | 0°45'37.58"S<br>35° 0'58.60"E | 1898m |
| Point 1 Entry | 0°45'38.88"S<br>35° 0'57.43"E | 1889m |
| Point 2 | 0°45'38.61"S<br>35° 0'57.07"E | 1889m |
| Point 3 | 0°45'38.70"S<br>35° 0'56.96"E | 1889m |
| Point 4 | 0°45'38.94"S<br>35° 0'57.21"E | 1889m |
| Landfill | 0°45'37.29"S<br>35° 0'56.47"E | 1890m |
| Upstream | 0°45'42.66"S<br>35° 0'45.34"E | 1870m |
| Entry point to river | 0°45'49.93"S<br>35° 0'54.37"E | 1864m |
| Point after entry | 0°45'52.11"S<br>35° 0'55.40"E | 1868m |

| | | | |
|---|---|---|---|
| pH | Lagoon 1 | | |
| | | Rep 1 | 6.71 |
| | | Rep 2 | 6.82 |
| | | Rep 3 | 6.62 |
| | Lagoon 2 | | |
| | | Rep 1 | 6.61 |
| | | Rep 2 | 6.69 |
| | | Rep 3 | 7.09 |
| | Lagoon 3 | | |
| | | Rep 1 | 6.50 |
| | | Rep 2 | 6.51 |
| | | Rep 3 | 6.40 |
| | Lagoon 4 | | |
| | | Rep 1 | 6.48 |
| | | Rep 2 | 6.59 |
| | | Rep 3 | 6.49 |
| | At stream entry | | |
| | | Rep 1 | 6.99 |
| | | Rep 2 | 6.98 |
| | | Rep 3 | 6.99 |
| | Up stream | | |
| | | Rep 1 | 7.30 |
| | | Rep 2 | 7.50 |
| | | Rep 3 | 7.40 |
| | Down stream | | |
| | | Rep 1 | 7.36 |
| | | Rep 2 | 7.19 |
| | | Rep 3 | 7.32 |
| EC | Lagoon 1 | | |
| | | Rep 1 | 318.78 |
| | | Rep 2 | 400.67 |

| | | | |
|---|---|---|---|
| | | Rep 3 | 307.60 |
| | Lagoon 2 | | |
| | | Rep 1 | 298.67 |
| | | Rep 2 | 299.66 |
| | | Rep 3 | 298.66 |
| | Lagoon 3 | | |
| | | Rep 1 | 204.00 |
| | | Rep 2 | 202.11 |
| | | Rep 3 | 205.68 |
| | Lagoon 4 | | |
| | | Rep 1 | 149.173 |
| | | Rep 2 | 150.000 |
| | | Rep 3 | 149.997 |
| | At stream entry | | |
| | | Rep 1 | 30.80 |
| | | Rep 2 | 30.70 |
| | | Rep 3 | 30.40 |
| | Up stream | | |
| | | Rep 1 | 23.95 |
| | | Rep 2 | 24.74 |
| | | Rep 3 | 25.39 |
| | Down stream | | |
| | | Rep 1 | 21.78 |
| | | Rep 2 | 23.09 |
| | | Rep 3 | 22.38 |
| COD | Lagoon 1 | | |
| | | Rep 1 | 607.358 |
| | | Rep 2 | 608.556 |
| | | Rep 3 | 609.103 |
| | Lagoon 2 | | |
| | | Rep 1 | 630.674 |

| | | | |
|---|---|---|---|
| | | Rep 2 | 631.846 |
| | | Rep 3 | 632.870 |
| | Lagoon 3 | | |
| | | Rep 1 | 442.921 |
| | | Rep 2 | 443.000 |
| | | Rep 3 | 444.001 |
| | Lagoon 4 | | |
| | | Rep 1 | 351.679 |
| | | Rep 2 | 339.643 |
| | | Rep 3 | 340.002 |
| | At stream entry | | |
| | | Rep 1 | 87.43 |
| | | Rep 2 | 89.32 |
| | | Rep 3 | 88.66 |
| | Up stream | | |
| | | Rep 1 | 80.02 |
| | | Rep 2 | 81.09 |
| | | Rep 3 | 80.01 |
| | Down stream | | |
| | | Rep 1 | 84.50 |
| | | Rep 2 | 85.60 |
| | | Rep 3 | 85.90 |
| $BOD_5$ | Lagoon 1 | | |
| | | Rep 1 | 197.512 |
| | | Rep 2 | 195.450 |
| | | Rep 3 | 196.500 |
| | Lagoon 2 | | |
| | | Rep 1 | 188.084 |
| | | Rep 2 | 188.864 |
| | | Rep 3 | 188.933 |
| | Lagoon 3 | | |

|  |  |  |
|---|---|---|
|  | Rep 1 | 109.991 |
|  | Rep 2 | 113.997 |
|  | Rep 3 | 113.600 |
| Lagoon 4 |  |  |
|  | Rep 1 | 100.998 |
|  | Rep 2 | 102.001 |
|  | Rep 3 | 101.100 |
| At stream entry |  |  |
|  | Rep 1 | 106.98 |
|  | Rep 2 | 109.97 |
|  | Rep 3 | 108.99 |
| Up stream |  |  |
|  | Rep 1 | 60.12 |
|  | Rep 2 | 63.01 |
|  | Rep 3 | 63.00 |
| Down stream |  |  |
|  | Rep 1 | 60.86 |
|  | Rep 2 | 63.23 |
|  | Rep 3 | 62.65 |

## 8.11 Waste Water Analysis

Function: FACTOR

Experiment Model Number 7:

One Factor Randomized Complete Block Design

Data case no. 1 to 12.

Factorial ANOVA for the factors:

Replication (Var 1: REP) with values from 1 to 3

Factor A (Var 2: SITE(1 = Lagoon 1, 2 = Lagoon 2, 3 = Lagoon 3, 4 = Lagoon 4)) with values from 1 to 4

Variable 3: pH

Grand Mean = 6.601   Grand Sum = 79.214   Total Count = 12

```
        T A B L E   O F   M E A N S

 1  2         3          Total
-------------------------------------------------
 1  *         6.601        26.404
 2  *         6.597        26.388
 3  *         6.606        26.422
-------------------------------------------------
 *  1         6.718        20.153
 *  2         6.694        20.082
 *  3         6.499        19.497
 *  4         6.494        19.482
-------------------------------------------------
```

```
        A N A L Y S I S   O F   V A R I A N C E   T A B L E

 K              Degrees of   Sum of        Mean         F
Value    Source       Freedom    Squares      Square       Value     Prob
---------------------------------------------------------------------------
  1    Replication     2        0.000        0.000      0.7138
  2    Factor A        3        0.132        0.044    435.3264   0.0000
 -3    Error           6        0.001        0.000
---------------------------------------------------------------------------
       Total          11        0.133
---------------------------------------------------------------------------


    Coefficient of Variation: 0.15%


s_ for means group 1:     0.0050       Number of Observations: 4
y

s_ for means group 2:     0.0058       Number of Observations: 3
y


    Variable 4: EC (S/cm)


    Grand Mean = 242.833   Grand Sum = 2914.000   Total Count = 12
```

```
              T A B L E   O F   M E A N S

      1   2            4            Total
    -------------------------------------------------
      1   *          243.000          972.000
      2   *          242.000          968.000
      3   *          243.500          974.000
    -------------------------------------------------
      *   1          318.667          956.000
      *   2          298.667          896.000
      *   3          204.000          612.000
      *   4          150.000          450.000
    -------------------------------------------------


        A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K               Degrees of   Sum of        Mean         F
Value    Source       Freedom    Squares       Square       Value     Prob
-----------------------------------------------------------------------------
  1     Replication      2         4.667         2.333      3.0000   0.1250
  2     Factor A         3     56982.333     18994.111  24421.0000   0.0000
 -3     Error            6         4.667         0.778
-----------------------------------------------------------------------------
        Total           11     56991.667
-----------------------------------------------------------------------------

    Coefficient of Variation: 0.36%

s_ for means group 1:     0.4410       Number of Observations: 4
y

s_ for means group 2:     0.5092       Number of Observations: 3
y
    Variable 5: COD (mg/L)


Grand Mean = 505.583   Grand Sum = 6067.000   Total Count = 12
```

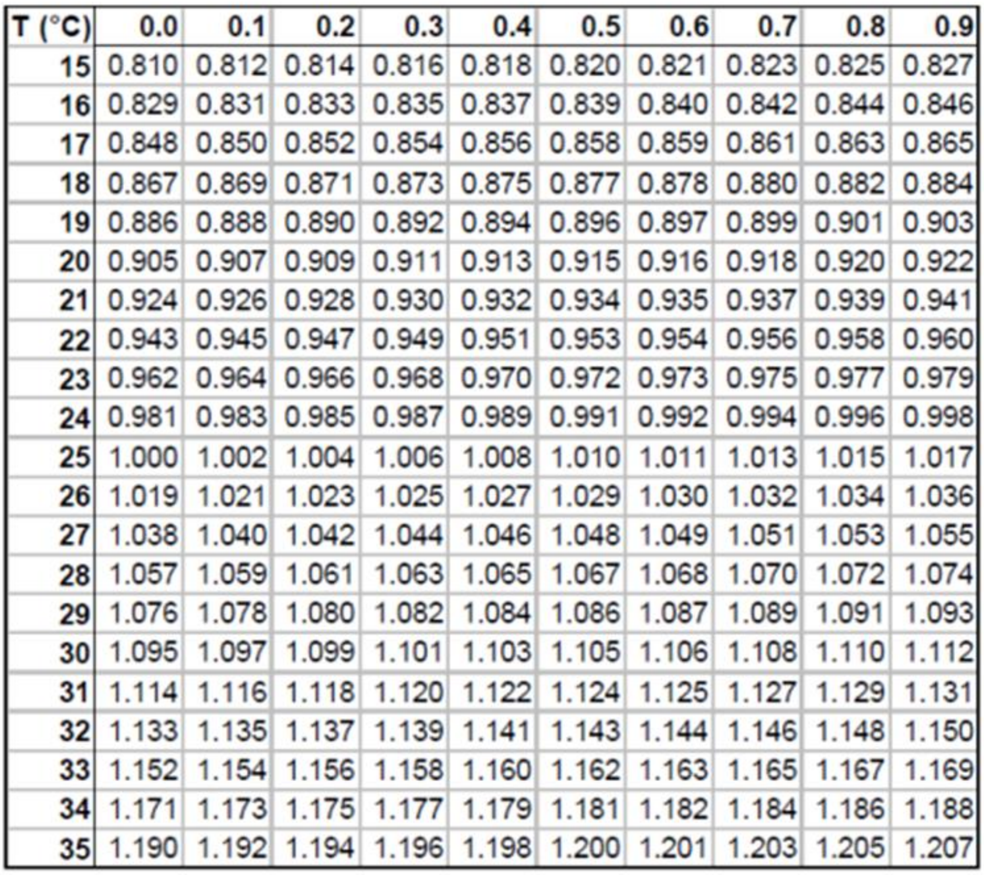
```
              T A B L E   O F   M E A N S

   1   2           5           Total
 -------------------------------------------------
   1   *        506.000       2024.000
   2   *        505.250       2021.000
   3   *        505.500       2022.000
 -------------------------------------------------
   *   1        608.333       1825.000
   *   2        631.000       1893.000
   *   3        443.000       1329.000
   *   4        340.000       1020.000
 -------------------------------------------------


          A N A L Y S I S   O F   V A R I A N C E   T A B L E

   K               Degrees of   Sum of        Mean         F
 Value   Source       Freedom    Squares      Square       Value    Prob
 ----------------------------------------------------------------------------
   1    Replication     2        1.167        0.583      0.6364
   2    Factor A        3    172864.250    57621.417   62859.7273   0.0000
  -3    Error           6        5.500        0.917
 ----------------------------------------------------------------------------
        Total          11    172870.917
 ----------------------------------------------------------------------------

     Coefficient of Variation: 0.19%

 s_ for means group 1:     0.4787       Number of Observations: 4
 y

 s_ for means group 2:     0.5528       Number of Observations: 3
 y
```

## Variable 6: BOD5 (mg/L)

```
    Grand Mean = 150.033   Grand Sum = 1800.400   Total Count = 12
```

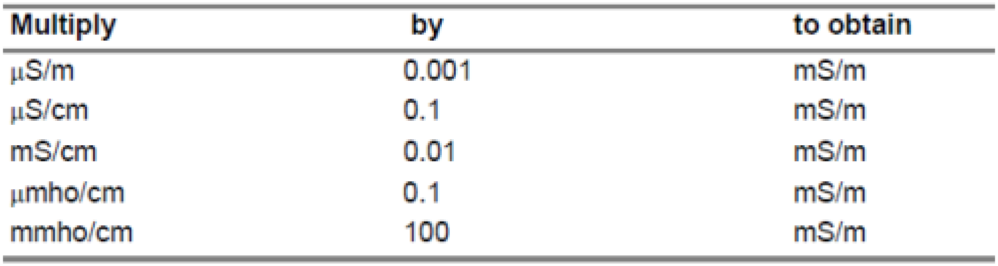
```
                    T A B L E   O F   M E A N S

      1   2           6           Total
    -----------------------------------------------
      1   *        149.900        599.600
      2   *        149.500        598.000
      3   *        150.700        602.800
    -----------------------------------------------
      *   1        196.500        589.500
      *   2        188.933        566.800
      *   3        113.600        340.800
      *   4        101.100        303.300
    -----------------------------------------------


          A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K              Degrees of   Sum of        Mean         F
Value    Source       Freedom    Squares       Square      Value Prob
-------------------------------------------------------------------
1     Replication     2       2.987        1.493      1.8361   0.2387
  2     Factor A        3     22182.660      7394.220   9091.2955   0.0000
 -3     Error           6       4.880        0.813
-------------------------------------------------------------------
       Total          11     22190.526
-------------------------------------------------------------------


    Coefficient of Variation: 0.60%


s_ for means group 1:     0.4509       Number of Observations: 4
y

s_ for means group 2:     0.5207       Number of Observations: 3
y
```

Value of [0.0191× (t-25)+1] for Temperature Correction of EC Measurement



| T (°C) | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 0.810 | 0.812 | 0.814 | 0.816 | 0.818 | 0.820 | 0.821 | 0.823 | 0.825 | 0.827 |
| 16 | 0.829 | 0.831 | 0.833 | 0.835 | 0.837 | 0.839 | 0.840 | 0.842 | 0.844 | 0.846 |
| 17 | 0.848 | 0.850 | 0.852 | 0.854 | 0.856 | 0.858 | 0.859 | 0.861 | 0.863 | 0.865 |
| 18 | 0.867 | 0.869 | 0.871 | 0.873 | 0.875 | 0.877 | 0.878 | 0.880 | 0.882 | 0.884 |
| 19 | 0.886 | 0.888 | 0.890 | 0.892 | 0.894 | 0.896 | 0.897 | 0.899 | 0.901 | 0.903 |
| 20 | 0.905 | 0.907 | 0.909 | 0.911 | 0.913 | 0.915 | 0.916 | 0.918 | 0.920 | 0.922 |
| 21 | 0.924 | 0.926 | 0.928 | 0.930 | 0.932 | 0.934 | 0.935 | 0.937 | 0.939 | 0.941 |
| 22 | 0.943 | 0.945 | 0.947 | 0.949 | 0.951 | 0.953 | 0.954 | 0.956 | 0.958 | 0.960 |
| 23 | 0.962 | 0.964 | 0.966 | 0.968 | 0.970 | 0.972 | 0.973 | 0.975 | 0.977 | 0.979 |
| 24 | 0.981 | 0.983 | 0.985 | 0.987 | 0.989 | 0.991 | 0.992 | 0.994 | 0.996 | 0.998 |
| 25 | 1.000 | 1.002 | 1.004 | 1.006 | 1.008 | 1.010 | 1.011 | 1.013 | 1.015 | 1.017 |
| 26 | 1.019 | 1.021 | 1.023 | 1.025 | 1.027 | 1.029 | 1.030 | 1.032 | 1.034 | 1.036 |
| 27 | 1.038 | 1.040 | 1.042 | 1.044 | 1.046 | 1.048 | 1.049 | 1.051 | 1.053 | 1.055 |
| 28 | 1.057 | 1.059 | 1.061 | 1.063 | 1.065 | 1.067 | 1.068 | 1.070 | 1.072 | 1.074 |
| 29 | 1.076 | 1.078 | 1.080 | 1.082 | 1.084 | 1.086 | 1.087 | 1.089 | 1.091 | 1.093 |
| 30 | 1.095 | 1.097 | 1.099 | 1.101 | 1.103 | 1.105 | 1.106 | 1.108 | 1.110 | 1.112 |
| 31 | 1.114 | 1.116 | 1.118 | 1.120 | 1.122 | 1.124 | 1.125 | 1.127 | 1.129 | 1.131 |
| 32 | 1.133 | 1.135 | 1.137 | 1.139 | 1.141 | 1.143 | 1.144 | 1.146 | 1.148 | 1.150 |
| 33 | 1.152 | 1.154 | 1.156 | 1.158 | 1.160 | 1.162 | 1.163 | 1.165 | 1.167 | 1.169 |
| 34 | 1.171 | 1.173 | 1.175 | 1.177 | 1.179 | 1.181 | 1.182 | 1.184 | 1.186 | 1.188 |
| 35 | 1.190 | 1.192 | 1.194 | 1.196 | 1.198 | 1.200 | 1.201 | 1.203 | 1.205 | 1.207 |

Conversion table



| Multiply | by | to obtain |
|---|---|---|
| μS/m | 0.001 | mS/m |
| μS/cm | 0.1 | mS/m |
| mS/cm | 0.01 | mS/m |
| μmho/cm | 0.1 | mS/m |
| mmho/cm | 100 | mS/m |

## 8.12 Bomb Calorimeter Data and Calculations

| | |
|---|---|
| Mass of empty crucible | 11.5gm |
| Mass of crucible + fuel | 12.5gm |
| Mass of fuel | 1.0gm |
| Volume of water in calorimeter in | 1750gm |
| Water equivalent of bomb | 520gm |
| Total equivalent of water | 2270gm |

| **Test Sample (Diesel)** | | **Sample 1** | |
|---|---|---|---|
| Time in Minutes | Temperature $^{o}$C | Time in Minutes | Temperature $^{o}$C |
| 0 | 25.2 | 0 | 23.50 |
| 1 | 25.3 | 1 | 23.52 |
| 2 | 25.3 | 2 | 23.52 |
| 3 | 25.4 | 3 | 23.57 |
| 4 | 25.4 | 4 | 23.57 |
| 5 | 25.4 | 5 | 23.58 |
| 5.5 | 25.4 | 5.5 | 24.62 |
| 6 | 25.5 | 6 | 25.70 |
| 6.5 | 26.7 | 6.5 | 26.10 |
| 7 | 27.9 | 7 | 26.34 |
| 7.5 | 28.8 | 7.5 | 26.57 |
| 8 | 29.4 | 8 | 26.62 |
| 8.5 | 30.0 | 8.5 | 27.04 |
| 9 | 30.5 | 9 | 27.06 |
| 9.5 | 30.9 | 9.5 | 27.10 |
| 10 | 31.2 | 10 | 27.12 |
| 10.5 | 31.4 | 10.5 | 27.15 |
| 11 | 31.5 | 11 | 27.20 |

| | | | |
|---|---|---|---|
| 11.5 | 31.6 | 11.5 | 27.80 |
| 12 | 31.7 | 12 | 27.90 |
| 12.5 | 31.7 | 12.5 | 27.90 |
| 13 | 31.7 | 13 | 27.90 |
| 14 | 31.7 | 13.5 | 27.90 |
| 15 | 31.7 | 14 | 27.90 |
| 16 | 31.6 | 14.5 | 27.82 |
| 17 | 31.6 | 15 | 27.80 |
| 18 | 31.6 | 15.5 | 27.75 |
| 19 | 31.5 | 16 | 27.72 |
| 20 | 31.5 | 16.5 | 27.72 |

| **Sample 2** | | **Sample 3** | |
|---|---|---|---|
| Time in Minutes | Temperature $^{o}$C | Time in Minutes | Temperature $^{o}$C |
| 0 | 26.23 | 0 | 23.50 |
| 1 | 26.23 | 1 | 23.52 |
| 2 | 26.23 | 2 | 23.52 |
| 3 | 26.23 | 3 | 23.57 |
| 4 | 26.23 | 4 | 23.57 |
| 5 | 26.23 | 5 | 23.58 |
| 5.5 | 27.04 | 5.5 | 24.62 |
| 6 | 28.19 | 6 | 25.70 |
| 6.5 | 30.30 | 6.5 | 26.20 |
| 7 | 30.35 | 7 | 26.54 |
| 7.5 | 30.45 | 7.5 | 26.59 |

| **Sample 2** | | **Sample 3** | |
|---|---|---|---|
| 8 | 30.64 | 8 | 26.62 |
| 8.5 | 30.68 | 8.5 | 26.68 |
| 9 | 30.70 | 9 | 26.74 |
| 9.5 | 30.82 | 9.5 | 26.79 |
| 10 | 30.85 | 10 | 26.82 |
| 10.5 | 31.02 | 10.5 | 26.88 |
| 11 | 31.10 | 11 | 26.91 |
| 11.5 | 31.20 | 11.5 | 26.93 |
| 12 | 31.30 | 12 | 26.94 |
| 12.5 | 31.30 | 12.5 | 26.94 |
| 13 | 31.30 | 13 | 26.94 |
| 14 | 31.30 | 14 | 26.94 |
| 15 | 31.20 | 15 | 26.90 |
| 16 | 31.10 | 16 | 26.75 |
| 17 | 31.10 | 17 | 26.67 |
| 18 | 30.90 | 18 | 26.55 |
| 19 | 30.90 | 19 | 26.50 |
| 20 | 30.80 | 20 | 26.50 |

Gross Calorific value of Diesel is 44800KJ/Kg

Temperature rise$= 6.5℃$

Total equivalent weight = 2.27kg

Weight of fuel = 1×10-3kg

$$\text{Energy liberated by diesel} = 6.5 \times 2.27 \times 4.1861\text{kJ}$$

$$\text{Gross calorific valueof diesel} = \frac{6.5 \times 2.27 \times 4.1861\text{kJ}}{1 \times 10^{-3}} = 61776\text{kJ/Kg}$$

Correction factor = 1.38

Gross Calorific Value (GCV) of wood fuel Calculation

$$\text{Temperature Rise} = \frac{\Delta 1 + \Delta 2 + \Delta 3}{3}$$

$$\text{Temperature Rise} = \frac{3.44 + 5.00 + 3.44}{3} = 4.58℃$$

$$\text{GCV} = \frac{3.99 \times 2.27 \times 4.1861}{1 \times 10^{-3}} = 27497.4\text{kJ/kg}$$

$$\text{GCV} = \frac{27497.4}{4.184} = 6572\text{kcal/kg}$$

## 8.13 Selected Images of Nyansiongo Tea Factory

**Plate 8.1: Factory entrance**

**Plate 8.2: Factory vehicles parking**

**Plate 8.3: Withering bed**

**Plate 8.4: Withering process**

Plate 8.5: Firewood storage area

Plate 8.6: CTC process

Plate 8.7: CTC equipment

Plate 8.8: Fermentation bed

Plate 8.9: Dying process

Plate 8.10: Sorting

Plate 8.11: Packaging

Plate 8.12: Lagoons for wastewater

**Plate 8.13:Heap of scrap metals** **Plate 8.14: Labeled samples**

**Plate 8.15: Sample preparation**