ASSESSMENT OF WASTE MANAGEMENT STRUCTURES FOR TEA FACTORIES IN KENYA: A CASE STUDY OF NYANSIONGO TEA FACTORY

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Abstract
Waste management is a great challenge in most processing industries in Kenya. This study was specifically carried out to establish 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 and sources of solid, liquid and thermal wastes 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 BOD, COD, PH and electrical conductivity, 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 highest amount of waste was generated from the withering stage due to spillages, while the least amount of waste was generated at the offloading area. Solid waste generated from the factory is poorly disposed; the waste is not segregated (different types of wastes are not disposed separately). Wastewater was generated due to the cleaning processes at the factory. The major cleaning which was done weekly generates about 40 m^3 of wastewater and minor cleaning which is done daily generates about $10m^3$ of wastewater. The wastewater was analysed empirically and the results indicated that BOD_5 levels measured 150 mg/L against the National Environment Management Authority recommended maximum discharge limits of 30 mg/L while the COD levels measured 505.5 mg/L against the NEMA recommended maximum discharge limits of 50 mg/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 76. 83% 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 13.7% and the least amount of heat loss was 0.32% due to moisture in the fuel.

Key words: Energy, solid waste, flue gas, wastewater

1.0 Introduction

Tea in Kenya is grown in high altitude areas between 1800 and 2700 meters 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 (Anon, 2002 and Anon 2006). 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). While poor management of waste is a general problem in Kenya, it is probably worst in Tea industry. 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, 1993 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 (Tipton *et al,*, 1990). 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 in Nyansiongo Tea factory 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. The last identifies which waste categories can be targeted for recycling, reduction or composting programs. 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.

This study will establish that the waste management system in Nyansiongo tea factory is inefficient and will subsequently identify gaps which will help develop an efficient waste management system. Waste management in Nyansiongo tea factory is a great challenge; the current situation is that different types of waste generated is collected in the same area. The biodegradable and non biodegradable waste is collected at the same pit with no clear tracking of the amount of wastes generated. There is a lot of energy lost through waste heat (Rudramoorthy *et al*, 2002 and Palaniappan *et al*., 2006). Steam is a major input in tea production. The steam is produced and released from the boiler at 10 bars; due to losses it reaches at the drying section at 7.8 bars. This study will identify the gaps in the current waste management system and give appropriate recommendations to help develop a more efficient and effective waste management system.

Poor waste management can pose health concerns to the workers and the environment at large. This study will evaluate the effectiveness of the existing waste management system and identify gaps which can be addressed to help design a more efficient and effective waste management. The objective of this study was to evaluate the effectiveness of waste management systems for tea factories in Kenya and the specific objectives were; to classify the generated waste during tea production; to determine the quantities of solid waste and wastewater generated at Nyansiongo Tea Factory; to determine the quality parameters of wastewater generated at Nyansiongo Tea Factory and to assess the effectiveness of the existing solid, liquid and thermal waste management system in Nyansiongo Tea Factory.

1.0 Materials and Methods

2.1 The Study Area

The study was carried out in Nyansiongo Tea Factory in Borabu District, Nyamira County. Nyansiongo Tea Factory is located along Sotik-Kisii on geographical coordinates 0°45'37.39"S and 35°0'58.67"E with an elevation of 1893 metres above sea level.

2.1.1 Classification of Wastes and Amounts

The determination of the types and sources of wastes generated during tea production were done mainly through observations.

2.1.2 Liquid Waste Parameters

pH, Electrical Conductivity and Dissolved Oxygen were measured (IUPAC Recommendations 2002) insitu using a Multi-parameter instrument, while Biochemical Oxygen Demand (5 Days, 27°C) standard method recognized by EPA.

2.1.3 Thermal Waste

Bomb calorimeter experiment was conducted according to the American Society for Testing and materials (ASTM) series of standard methods for testing both solid and liquid fuels in an oxygen bomb calorimeter.

2.1.4 Evaluation of the Effectiveness of the Existing System

Solid Waste

Secondary data was collected from the factory for six months; the data collected was on the following parameters: Green leaf collected per month for six months; Made tea per month for six months; 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 (Yedla, 2005).

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. Through observations, data was also collected on solid waste disposal methods in the factory.

Wastewater

Wastewater samples were collected from the study, they were analysed for biochemical oxygen demand PH, (BOD), chemical oxygen demand (COD) and electrical conductivity (EC). The procedures have been discussed in discussed in liquid waste parameters. The results were then compared with the available effluent standard by the National Environmental Management Authority.

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 (Yugnus, 2003).

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)

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

i. Dry flue gas
ii. Evaporation of water formed due to H_2 in fuel
iii. Evaporation of moisture in fuel
iv. Moisture present in combustion air
v. Radiation and other unaccounted losses
vi. 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 are:

i. Ultimate analysis of fuel (H2, O_2, S, C, moisture content, ash content)
ii. Percentage of oxygen or CO2 in the flue gas
iii. Flue gas temperature in ^oC (Tf)
iv. Ambient temperature in ^oC (Ta) and humidity of air in kg/kg of dry air
v. GCV of fuel in kcal/kg

2.0 Results and Discussions

3.1 Identification of Types, Sources and Quantities of Waste

3.1.1 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 1: Type of waste generated at every stage of tea production

Source	Waste	Type of waste
Leaf collection	Green leaf	Organic
	Gunny bags	Inorganic
Withering	Green leaf	Organic
Maceration (CTC)	Green leaf	Organic
	Water	Waste water
	Metal chips	Inorganic
Fermentation	Pekoe dust	Organic
	Heat	Thermal
Drying	Pekoe dust	Organic
	Heat	Thermal
Sorting	Pekoe dust	Organic
	Paper	Organic

The analysis of the collected data indicates that the highest amount of waste was produced at the withering stage at an average weight of 63 kilograms per month due to spillages, followed by sorting due to fannings and pekoe dust, packing due to packaging materials and worn out sacks and papers, processing and firing due to spillages and dust and offloading area at 2.83 kilograms as indicates in Figure 2.

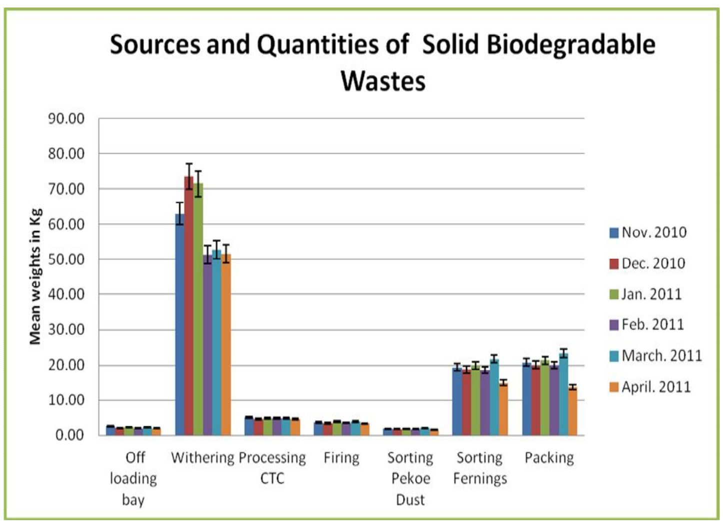

Figure 1: Quantities of solid waste at different stages of tea processing

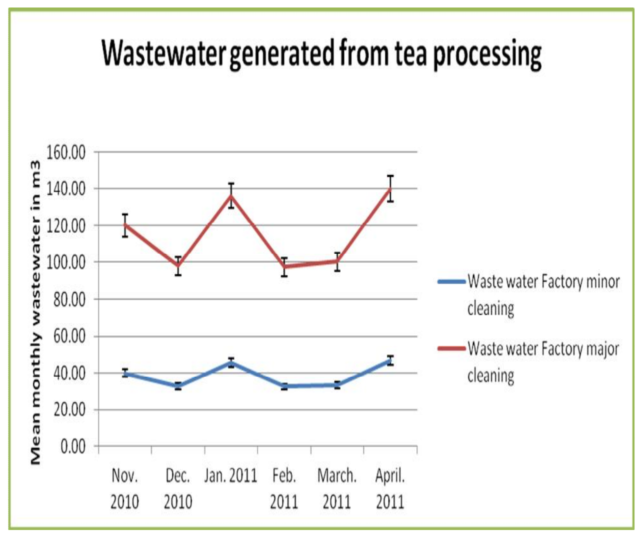

Figure 2: Wastewater generated from tea processing

3.1.2 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 3 above. The amount of waste generated from major cleaning was highest in the month of April at 140m^3.

3.1.3 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 2.

Table 2: Ultimate analysis of firewood

Ultimate analysis of firewood	%
Carbon	45.60
Hydrogen	3.96
Sulphur	0.07
Oxygen	37.45
Moisture	9.33
Ash	3.14
Nitrogen	0.45

Fuel Calorific Value = 3496 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

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

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

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

$$Excess\ air\ supplied(EA) = (O_2 x\ 100)\ /\ (21 - O_2)$$

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

$$= 107\%$$

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

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

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

Estimation of all losses

i. Dry flue gas loss

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

Where,

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

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

$$= \frac{11.4 \times 0.23 \times (210 - 22)}{3598} \times 100$$

$$= 14.52\ \%$$

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

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

Where,

H_2 = percentage of H_2 in 1 kg of fuel

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

$$= \frac{9 \times 3.96\{584 + 0.45\,(210 - 22)\}}{3598}$$

$$= 6.62\ \%$$

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

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

Where, M – percent moisture in 1kg of fuel

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

$$= \frac{9.33\{584 + 0.45\,(210 - 22)\}}{3598}$$

$$= 1.73\ \%$$

iv. Percentage heat loss due to moisture present in air

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

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

$$= \frac{10.4 \times 0.0132 \times 0.45(210 - 22)}{3598} \times 100$$

$$= 0.32\ \%$$

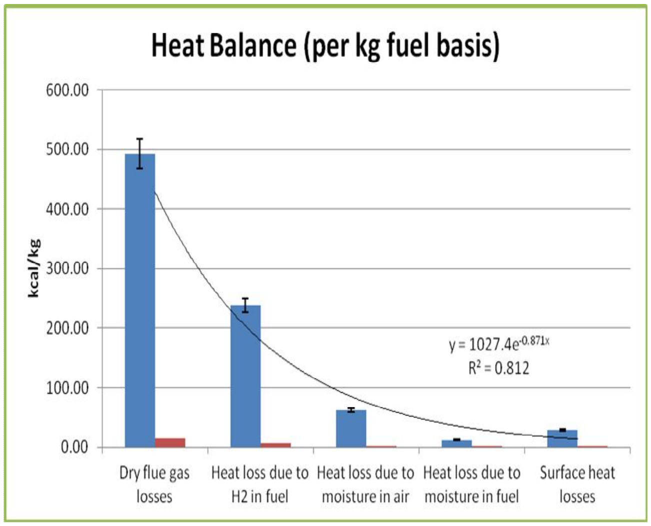

Figure 3: Waste heat generated during tea processing

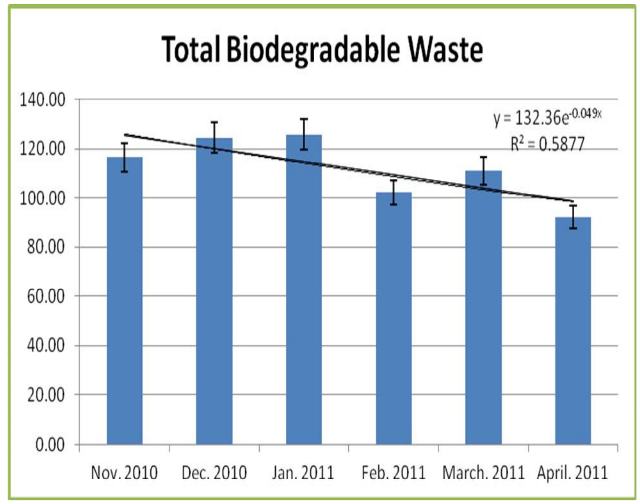

Figure 4: Total biodegradable waste generated

The analysis of data obtained indicate that the amount of heat lost during tea processing is lost through the flue gas at 14.52% followed by heat lost due to hydrogen in the fuel at 6.62%. The least amount of heat loss occurs due to the moisture in the fuel at 1.72%.

3.2 Evaluation of the Effectiveness of the Existing System

3.2.1 Solid Waste Management

During tea processing, solid waste was generated at various stages which have been discussed in classification of wastes and amounts above. Currently at Nyansiongo tea factory, biodegradable wastes are disposed in a landfill 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 112 kilograms per month. This far outweighs the capacity of the landfill which was found overflowing at the time of data collection. The total biodegradable waste is depicted in Figure 5.

The scrap metals were generated as another type of waste which was heaped in a yard next to the pit. At some point the wastes from the yard and the pit got mixed. 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 has 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. According to figure 5, the highest amount of waste was generated in the month of January while the least amount was generated in the month of April. This was due to the climatic changes in the year of study. Figure 6 is a mass balance illustration of the quantities produced when a kilogram of green leaf of tea is processed. Table 3 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 expected made tea were lower than the actual made tea and the amounts of expected solid waste were higher than the actual amounts collected.

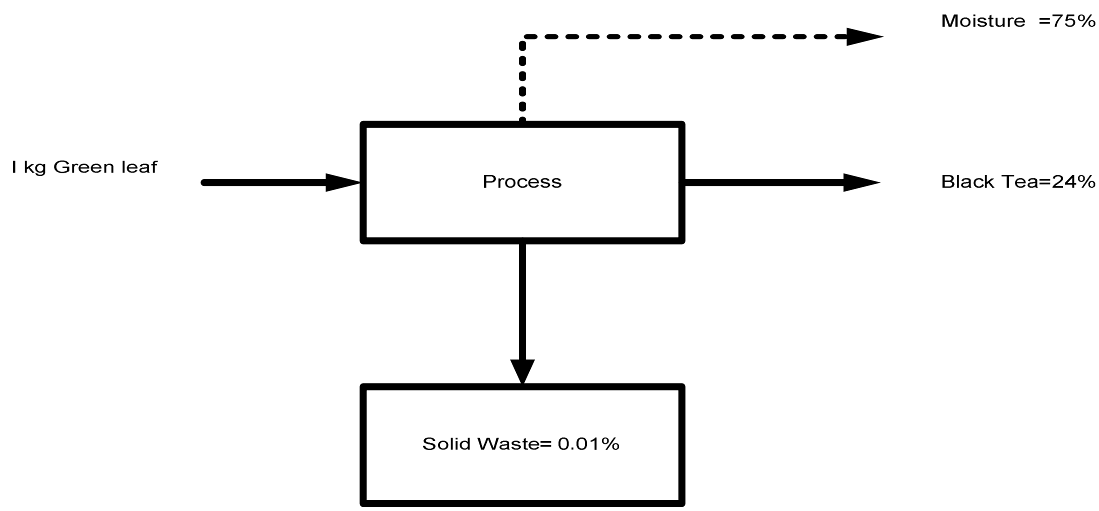

Figure 5: Mass balance of tea production in Nyansiongo

Table 3: 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	1,457,977	362,651	320,755	1,105,146.57	2,915.95	116.59	25	1,095,210	75	0.01
Dec	1,159,211	280,275	255,026	878,681.94	2,318.42	124.43	24	878,812	76	0.01
Jan	1,432,337	356,452	315,114	1,085,711.45	2,864.67	125.78	25	1,075,76	75	0.01
Feb	792,098	206,325	174,262	600,410.28	1,584.20	102.27	26	585,671	74	0.01
Mar	619,906	162,527	136,379	469,888.75	1,239.81	111.02	26	457,268	74	0.02
April	1,021,319	255,883	224,690	774,159.80	2,042.64	92.13	25	765,344	75	0.01

3.2.2 Liquid Waste Management

Various physicochemical parameters were measured and analysed. These included pH, BOD_5, Electrical conductivity and COD. The results have tabulated in Table 4.

Table 4: 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
Mean	6.60	242.83	505.58	150.03
C.V	0.15	0.36	0.19	0.60
LSD	0.02	1.69	1.84	1.73

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 NEMA maximum allowable discharge limits have been presented in Table 5.

Table 5: NEMA effluent discharge limits

No	Parameter	Guide value(maximum allowable
	pH	6.5 – 8.5
2	Biochemical Oxygen Demand $(BOD)_5$@ 20^0C mg/l	30(mg/L)Max
3	Chemical Oxygen Demand (COD) mg/l	50 (mg/L) max

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

2.2.3 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 and summarised in table 6. This efficiency was calculated by subtracting the heat loss fractions from 100.

$$Boiler\ Efficiency\ (\eta) = 100 - (L1 + L2 + L3 + L4 + L5)$$
$$Boiler\ Efficiency\ (\eta) = 100 - (23.17)$$
$$Boiler\ Efficiency\ (\eta) = 76.83\%$$

Table 6: Boiler heat losses

	Heat Balance (per kg fuel basis)	kcal/kg	Percent
L1	Dry flue gas losses	492.93	13.70
L2	Heat loss due to H_2 in fuel	238.19	6.62
L3	Heat loss due to moisture in air	62.25	1.73
L4	Heat loss due to moisture in fuel	11.51	0.32
L5	Surface heat losses	28.78	0.80
	Total	3598.00	100.00

The boiler efficiency was found to be 76.83%. The highest amount of heat loss was from the dry flue gas at 13.7% whilst the minimum was found to be that from heat loss due to moisture in the fuel. Though in Nyansiongo tea factory, they have installed an economizer, they still experience large amount of heat energy loss during their operation.

3.0 Conclusions

Solid waste in Nyansiongo tea factory was found to be minimal at 0.01% of the total tea production. The highest amount of waste was generated from the withering stage due to spillages at.63 kilograms per month while the least was generated at the offloading area at 2.83kilograms per month. The solid waste is majorly disposed in an open landfill which gets filled up after every three months; the solid waste is not segregated at source so that it can be disposed effectively hence making the system ineffective.

The wastewater is currently treated in lagoon with open channels. It was noted that the levels of BOD and COD far exceeded the maximum allowable discharge limits by NEMA standards. This indicates that the wastewater treatment is not effective and should be improved. Dry flue gas generated the highest amount of thermal waste at 13.7% and the least was 0.32% due to heat loss from moisture in the fuel. The boiler efficiency was found to be 76.8% which could be improved to 80%.

5.0 Recommendations

Solid waste should be segregated at the source before disposal. The management should consider installing a garbage grinder to manage the solid waste as it will eliminate landfilling. The management should consider collecting all the biodegradable waste including the waste generated by their staff to utilise it in a biogas plant. This will help in reducing the COD and BOD levels as well as generating their own electricity to use for the factory and other domestic uses. The management should enhance the boiler efficiency by ensuring proper steam distribution and utilization.

Acknowledgment

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