INDUSTRIAL WASTE MINIMISATION THROUGH MATERIAL AND ENERGY RECOVERY: THE CASE OF HWANGE POWER STATION, ZIMBABWE

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APPROVAL FORM

The undersigned certify that they have read and recommended to the Midlands State University for acceptance a dissertation entitled: Industrial waste minimisation through material and energy recovery: The case of Hwange Power Station, Zimbabwe.

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Submitted in partial fulfilment of the requirements of a master of science in Safety Health and Environmental management.

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DECLERATION FORM

Student's Declaration

I, Baldwin Anesu Jenya, do hereby declare that this dissertation is of my own research and investigation and research, with the exception of the Acknowledgements, References and it has never been submitted to any institute in part or in full.

Signature…………………………. **Date……………………………..**

DEDICATION

This dissertation is dedicated to the Zimbabwe Power Company and all industries alike who can embrace ideas propounded in this research.

ABSTRACT

The aim of this study was to assess industrial waste minimisation through material and energy recovery at Hwange Power Station, Zimbabwe. This project is significant in that it will divulge the opportunities of boosting power output through the use of industrial waste. Most industries in the country are facing challenges in waste management and the nation at large is suffering from power shortages. A detailed descriptive study was undertaken to unveil the potential of boosting power output whilst sustainably managing industrial waste. Random sampling was employed targeting all employees involved in the power generation activities. Thirty percent of each department was sampled randomly to satisfy a true reflection of the entire population. The research administered 200 questionnaires which is approximately 30% of the entire population directly involved in the core waste generating activities. The 200 questionnaires were distributed to all section at a 30% basis. Out of the 200 questionnaires that were administered, a total of 182 were successfully completed and returned in time for data compilation giving a response rate of 88.5%. The researcher incorporated the qualitative and quantitative research design and used direct field observations, interviews and questionnaires as primary sources of data. Secondary data was acquired from existing literature so as to boost and support the research findings. The main findings of the research divulged the types and quantities of waste from power generation activities, the effectiveness of the current methods of waste management and the definitive degree of waste management through material and energy recovery at Hwange Power Station. The main findings attained from the research revealed that energy and material recovery are essential methods of industrial waste management as well as an opportunity for boosting power output. It is therefore recommended that Hwange Power Station consider investing in energy recovery so as to boost power output at the same time sustainably managing waste.

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LIST OF ACRONYMS

BOD-Biological Oxygen Demand

EMA-Environmental Management Agency of Zimbabwe

GCV-Gross Calorific Value

GMT-Greenwich Meridian

HPS-Hwange Power Station

KWh-kilowatt hour

Kw-Kilowatts

LHV-Lower Heat Value

MoEWC-Ministry of the Environment, Water and Climate

MSW-Municipal Solid Waste

MW-Megawatts

NCV-Net Calorific Values

USA-United States of America

USEPA-United States Environmental Protection Agency

WTE-Waste To Energy

CHAPTER 1 : BACKGROUND

1.1 Study background

Globally, many nations are accepting materials and energy recovery technologies due to their ability to produce useful output from waste at the same time effectively and efficiently managing the waste. The benefits of energy recovery are realised through generation of power, which comes in the form of electricity, gas and oil *inter alia* (Masood 2013). On the other hand materials recovery is paramount in transforming waste materials as raw materials used to make new items. As contended by Ganfer (2011), it is however, noted with great concern that the adoption of Waste To Energy technologies is mainly significant in the developed countries due to the huge financial demands associated with them. As stated by Ganfer (2011) Waste To Energy (WTE) does not only produce energy but also save on space as the cumulative waste produced after energy recovery activities represents approximately 10% of the entire volume of waste produced prior to recovery. An analysis made by the United States Environmental Protection Agency (USEPA) (2014), realised that the problems arising from industrial waste might be mitigated using innovative technologies available.

The harnessing of energy from waste is currently popular in the conversion of municipal waste into energy. To support this assertion Themelis (2006) states that WTE plants consumed approximately 1500 million tons of Municipal Solid Waste (MSW) generated in the European Union in the year 2005 alone whereas the fusion of the same technology in handling industrial waste is still minimal. Table 1.1 represents the breakdown of the total waste conversions in the year 2005.

Table 1.1 Waste to Energy conversions

Nation	Million metric tonnes to WTE
EU 25	48.8
Japan	40.0
USA	26.3
Taiwan	7.0
Singapore	4.0
China	3.0
Switzerland and Norway	3.8
South Korea	1.0
All other	9
Total	143

Source: Themelis (2006)

Deriving from the data presented in Table 1.1 it is realised that Africa is lagging behind in terms of commitment towards waste to energy conversions (energy recovery). Chalmin and Gaillochet (2009) argues that failure to commit in WTE technology represents a huge loss of revenue, employment opportunities and ultimately energy. The arguments brought forward by Themelis (2006) demonstrates that Africa is lacking commitment in the adoption of WTE technologies and thus exerts pressure on the natural resources for energy generation and ultimately struggles with waste management.

According to Shadma, Naaz and Pandey (2010), in the United States of America the amount of hazardous waste generated by manufacturing industries has increased from an estimated 4.5 million tons annually after World War II to some 57 million tons by 1975. By 1990, this total had shot up to approximately 265 million tons. Waste generation is at every stage in the production process, use and disposal of manufactured products (Scheren, Zanting and Lemmens 2000). Challenges in waste management manifest in the inability to prioritise the need to have sound and sustainable waste management systems by industries thus missing opportunities for recovering energy.

Invariably, economic development is at any given time accompanied by increased consumption of materials and a corresponding increase in the generation of waste. This phenomenon is uniform in both the developed and developing nations. As quantified by Themelis (2006), a survey done in 2004 on waste management in the United States of America (USA) showed an increase in waste generation. An increase of up to 353 from 336 million tonnes between 2002 and 2004 was noted thereby depicting a 2.5% increase rate per year.

Table 1.2 Waste use analysis in the United States of America

	MSW Waste generated	Recycled or composted	Waste To Energy (WTE)	Landfilled
2004 (million tons)	352.6	100.4	26.3	226.0
2004 percent	100%	28.5%	7.4%	64.1%
2002, (million tons)	335.8	89.6	25.8	215.3
2002 percent	100%	26.7%	7.7%	65.6%

Source: Themelis (2006).

As presented in Table 1.2 most of the waste generated in the USA during the period under review ended up in the landfills. In the year 2004 alone, 64.1% of waste was ferried to the landfills and hence showing underutilisation of potential energy embedded in waste.

Chandak (2010) postulates that Africa as a whole relies mostly on the conventional waste management methods with most of its waste dumped in open space. He further defined conventional waste management as one that focuses largely on waste collection, treatment (composting and incineration) and disposal (landfills). From the assessment made it is thus realised that only partial attempts are underway to adopt integrated waste management practices. Considering all facets of waste generation (industrial and municipal), it is realised that minimal attempts are being realised to embrace energy recovery. Integrated Waste Management covers but, is not limited to waste reduction at the source, resource recovery and recycling. Masood (2013) is for the argument that the resource value of waste is realised through separation of waste at source for alternative use and hence energy recovery.

The first step towards prevention and control of pollution of industrial wastes is a full understanding of amounts, types and effects of waste generated. This only become operational if there is commitment to harmonise waste management an aspect which most organisations in Africa lacks. According to Musademba, Musiyandaka, Muzinda, Nhemachena and Jambwa (2011), industrial solid waste poses a serious challenge to municipalities and countries, as waste ends up competing with humans for land and financial resources to make it safe. The intrinsic characteristics of industrial waste include occupying land when stock piling, dumping, disposing or storing, having large categories and quantity thus destroying the astatic value of nature and altering the atmospheric composition. In order to have sound waste management system industries need to invest and commit in sustainable waste management. African industries are losing a lot energy embedded in waste due to their failure to embrace WTE technologies.

Inconsistence in waste management also manifest as a result of ignorance demonstrated by most managers on the need to invest in technologies that will enhance sustainable waste management. A study by Scheren, Zanting and Lemmens (2000) on Lake Victoria in East Africa revealed that biological oxygen demand (BOD) load is highest on the Kenyan side of the lake because of the disposal of industrial waste into the lake. From their argument, it is qualified that industrial waste discharged into the water bodies affects BOD. Waste deposited in the lake contains an array of potential energy, which could be harnessed through the adoption of WTE technology at a local scale. The survey realised that BOD loads on the Kenyan side can be reduce by up to 50% through adopting energy recovery technologies.

According to the Environmental Management Agency of Zimbabwe (EMA) (2004), industrial and domestic waste mismanagement presents a topical issue in the country. The failure by industry to invest in WTE technologies has resulted in several environmental problems in and around the country. Investing in sustainable waste management will enhance energy recovery in the various industries, which will also boost energy supply. A survey done by the City of Harare in conjunction with the Environment Management Agency (EMA) in 2011 reviled that "as a result of challenges in industrial waste management over 200 companies in Harare's major industrial sites have been found dumping excessive pollutants in rivers that supply the city with water" (The Standard 26/10/2014). The magnitude of this problem will be reduced if industries embrace WTE technologies and thus managing waste on point of generation. The bulk of the waste deposited into the natural environment can further be absorbed and used for alternative purposes through embracing WTE technologies.

Zimbabwe Power Company is one of the players in the Zimbabwean industries as well as a contributor to industrial waste generation. The challenges experienced by the company in waste management are somewhat a result of its failure to embrace energy recovery options. Having this background, it is therefore the purpose of this research to substantiate how industrial waste presents an opportunity for energy recovery.

1.2 Statement of the problem

A growing population and desired economic recovery in Zimbabwe is resulting in increased energy demand, and a subsequent increase in volumes of waste generated at HPS. The vast amounts of waste generated at HPS is not being effectively managed and thus resulting in environmental problems such as pollution at various levels. Mismanagement of waste generated is subsequently resulting in the underutilization of the potential energy that is embedded in the waste. Magnitude of the environmental problems are magnified by the absence of recycling infrastructure, which will enable separation of waste at source and diversion of waste streams to material recovery. Pressure is being mounted on the natural resources for an increased output in terms of the power generated where as some resources are being thrown away as waste. Waste being generated at various levels can be reintroduced into the energy generation cycle as input in various ways thus energy recovery.

Hwange Power Station is struggling with industrial waste management as most of the waste generated ends up at the open dump (scrape yard) or in the rivers as effluent. This scenario is posing multifaceted adverse impacts on the environment. Current waste management practices at HPS accommodates the discharge of effluent in the nearby stream thereby threatening fauna and flora. This predicament is somewhat amplified by the perceived ideology that investing in sustainable waste management is a liability rather than an asset in industrial governance, (Musademba *et al 2011)*. The composition of effluent discharged into the streams at HPS is composed of all sorts of components, which among them include oils, grease and sewage among others. Effluent discharged in the streams affects water quality and poses a threat to animals. To this end, the problem-identified maybe eliminated through embracing various technologies, which among them include WTE.

An argument put forth by Masood, (2013) reveals that as solid waste decomposes in landfills (open dumpsites or scrape yards); gases with an approximate composition of 50 percent methane (CH_4) and 50 percent carbon dioxide (CO_2), are emitted both of which are Green House Gases (GHGs). This results in a global concern as it ultimately results in global warming. The possibility of eliminating the outlined problem lies within several methods one of which could be the embracing of WTE technologies. The Landfill Gas energy technologies capture CH_4 to prevent it from being emitted to the atmosphere, and can reduce landfill CH_4 emissions by between 60 and 90 percent. The CH_4 gas can thus be used on the firing of boilers and hence energy recovery.

Waste generation at HPS presents hidden opportunities and to this backdrop, it is therefore the intention of this research to analyse industrial waste minimization through material and energy recovery.

1.3 Objectives

1.3.1 General objective

To evaluate the effectiveness of waste minimization through material and energy recovery of industrial waste at Hwange Power Station.

1.3.2 Specific objectives

- To identify the various types of waste generated at Hwange Power Station.
- To quantify the monthly waste generated at Hwange Power Station.
- To assess the efficiency of current waste management strategies at Hwange Power Station.
- To explore the definitive degree of waste management through material and energy recovery at Hwange Power Station.

1.4 Hypothesis

This research was premised on the following hypotheses:

H_0: Waste generation is independent of material and energy recovery.

H_1: Material and energy recovery is dependent on the waste generated.

1.5 Justification of the study

Industrial waste management and energy shortages remains a concern world over whereas little or no research was done on the possibility of transforming waste into energy as a means of recovering energy. To this end, an analysis of how industrial waste presents an opportunity for energy recovery becomes a significant. Importance of this study is realised through establishing whether converting industrial waste into energy recovery will be able to assist in the management of industrial waste as well as allowing a subsequent increase in energy output. The research outcome of the research anticipates benefiting stakeholders in the power generation industries and related disciplines.

The research is significant as it is hoped to benefit the cooperate world in establishing the various opportunities embedded in industrial waste as well as insinuating whether industrial waste can be reduced by means of energy recovery. The study also highlights potential areas of imminent research as it provides a rational elaboration to the basic but more detailed understanding of energy recovery through use of industrial waste. The product of this research maybe used on advisory basis by the Ministry of Energy and Infrastructural development of Zimbabwe for policy formulation.

The domino effect of this research will demonstrate the authenticity of waste conversion as an input for power generation sources to enhance energy recovery and industrial waste management. The outcome of the study will act, as a benchmark for research on which related research may further be reference. The research will also draw a conclusion on whether industrial waste can be reduced though energy recovery and hence aid energy output. The outcome of this research maybe recommended to organisations by EMA and the Ministry of Energy and Infrastructural development on how to reduce industrial waste as well as ensuring energy recovery.

1.6 Study area

Hwange Power Station is located in the North Western part of Zimbabwe approximately 335 Km from the city of Bulawayo, which is the provincial capital for Matabeleland. The power station is situated at approximately 25°45′E to 27°25′E of the Greenwich Meridian (GMT), and 18°53′S to 19°30′S of the equator (DNPWM, 1998). According to DNPWM, (1998) Hwange Power Station lies at about 770 meters (2530 feet) above sea level with fine to medium grained sandy soils, with virtually no clay and silt sized particles. The soils are characterised by very low water holding capacity, and generally agriculturally poor soils.

The region is characterised by hot dry seasons, the cool dry winter extends from May to August (DNPWM, 1998). On average annual rainfall is 650 mm with summer rainy season extending from November to March (DNPWM, 1998. Maximum values for a single month occasionally exceed the average for the whole year (Conybeare, 1991). Fig 1.1 shows the study map.

Hwange is an area of mixed woodland and open savanna (Greaves, 1996; Rogers, 1993) to support this Rushworth, (1975) postulates that woodland occupies about 64%, shrub land 32%, and grassland merely 4%. The dominant vegetation type in Hwange is *Baikiaeaplurijuga* mixed woodland and shrub land, commonly associated with *Combretum*s, *Acacia* and *Terminaliasericea* (Rogers, 1993).

Hwange Power Station is the largest coal-fired power station in Zimbabwe with 920MW-installed capacity, in two stages, four x 120MW units commissioned between 1983 and 1986 and the two x 220MW, commissioned in 1986 and 1987. When all six units are available, the station generates approximately 40% of the country's electricity demand. The power station employs approximately 800 employees housed in company residence and have access to three clinics, pre-schools, two primary schools, a secondary school, as well as a beer hall and sporting facilities for the workforce and its dependents.

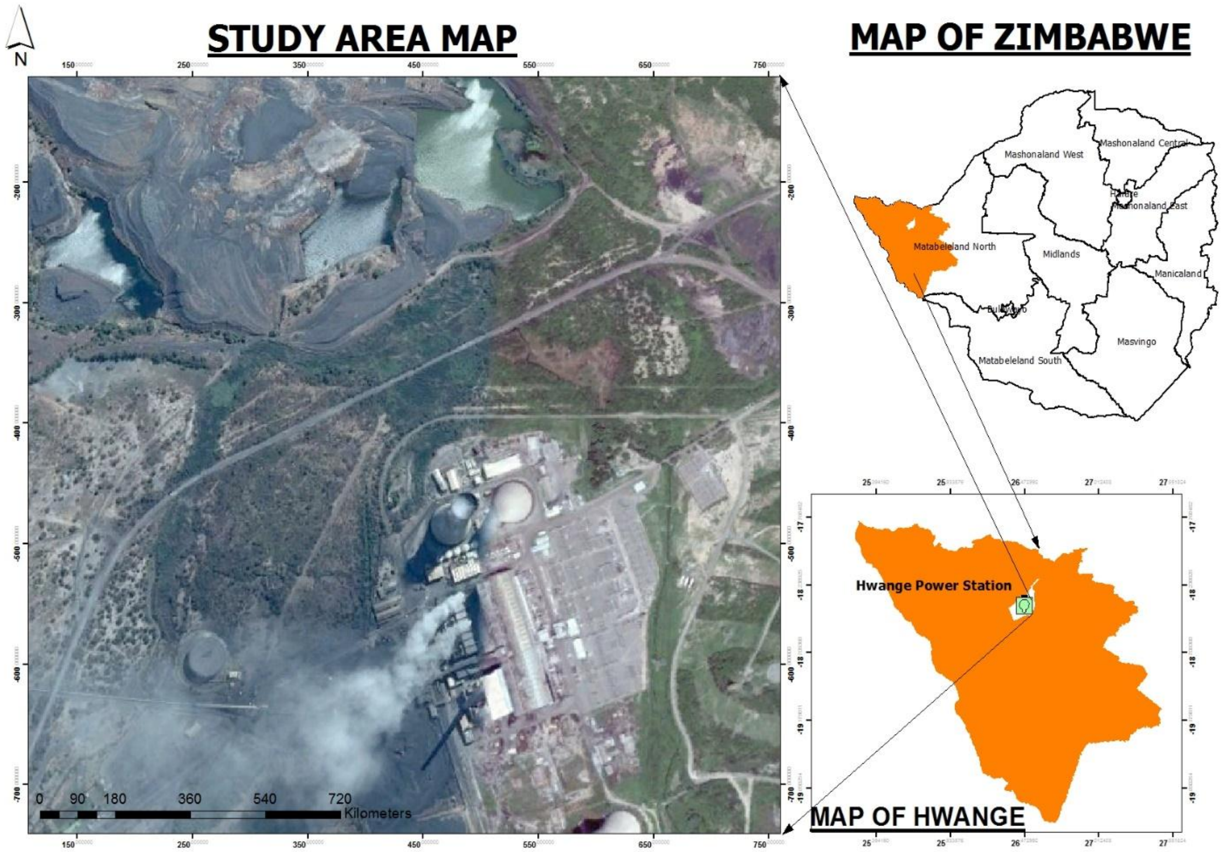

Fig 1.1 Map of study area

Source: Google Earth 2015, DIVA GIS and ArcMap 10.3

CHAPTER 2 : LITERATURE REVIEW

2.1 Industrial waste

Shadma, Naaz and Pandey (2010) define industrial waste as waste generated by manufacturing or any related industrial processes. The types of industrial waste generated include but not limited to dirt and gravel, masonry and concrete, scrap metal, trash, oil, solvents, chemicals, wood and scrap lumber among other waste products. Industrial waste, which may be solid, liquid, or gases held in containers, is subdivided into hazardous and non-hazardous waste. Hazardous waste may result from manufacturing or other industrial processes.

2.2 Zimbabwean framework for environmental management

The government of Zimbabwe is committed to ensure sustainability in environmental management so as to overcome environmental problems. As a facet of environmental management they is strict need to monitor waste generated and the manner in which it is disposed or managed. The structures in place to ensure sustainable environmental management are therefore responsible for spearheading sustainable waste management. The country`s commitment to ensure sustainability in waste management is demonstrated through the establishment of a government wing dedicated for environmental management. As enshrined in the Environmental Management Act Chapter 20:27 of 2003 the structures outlined below are responsible for environmental management.

i. **Ministry of the Environment, Water and Climate** (MoEWC)

Lead by the minister of Environment Water and Climate and is responsible for the development and implementation of national waste management policy. In addition the minister recommends to Government which international and regional conventions on the environmental management the country should become party of as well as securing the incorporation of such conventions into domestic law.

ii. **Environmental Management Agency (EMA)**

The agency is responsible for the collection and processing of waste management data from all facets of the economy. In addition to this the agency acts as the advisor for the minister on policy formulation and implementation. The agency acts as the government arm responsible for the execution of various environmental management actions at all levels. All necessary infrastructure needed to enhance subsequent and sound environmental management at national level is managed by the agency.

iii. Environmental Management Agency Officers

Officers are responsible for environmental monitoring and control through the monitoring of the day to day activities that have a bearing on environmental management. They are also there to issue waste management permits at the regional level and conduct periodic inspections of waste disposal installations. As enshrined in the Environmental Management Act CHAP 2027:2003, EMA officers also shoulder the responsibility of educating the citizens of the country in relation to environmental management. This is achieved through organising education and awareness through various medium of communication.

2.3 Sustainable management of industrial waste

The art of sustainable waste management is enhanced through the conversion of waste into energy thus energy recovery. Material recovery also entails harnessing the generated waste for alternative uses. The waste aggregates are adopted in their raw state and used for related uses or used for completely different purposes. Industrial waste can be embraced for various uses within the same industry or for completely different operations. Sustainable waste management through material and energy recovery enhances total utilisation of resources. Total utilisation in the event of energy recovery is achieved as latent energy present in its organic fraction is recovered subsequently for gainful utilisation. As insinuated by Shadma, Naaz and Pandey (2010), the recovery of energy from wastes also offers a few additional benefits as follows:

- The total quantity of waste reduces by between 60 and 90%, depending on the waste composition and the adopted technology,
- Demand of land for landfilling is reduced,
- The cost of transportation of waste to landfill sites also reduces proportionately and
- Net reduction in environmental pollution.

The argument put forth by Klein (2002), is vital in elaborating the benefits realised through the adoption of energy recovery and thus it is paramount that the option of WTE be duly examined.

Ganfer, (2011) further argues that wherever feasible, the option of material and energy recovery should be incorporated in the over-all scheme of Waste Management. According to Klein (2002), WTE reduces the amount of materials sent to landfills, prevent pollution, improves recycling rates and lessens the dependence on fossil fuels for power generation.

The adoption of energy recovery at Hwange Power Station will embrace all the aforementioned advantages and thus enable sustainability in environmental management. WTE can be realised in an array of alternatives but Klein (2002) is for the argument that the most commercially viable forms of large scale WTE are combustion and gasification. This argument is anchored on the basis that these methods are relatively cheap to embrace but at the same time harness a subsequent amount of energy from the waste generated. From an overview analysis of the operations at Hwange Power Station the outlined methods maybe adopted to boost the total power generated while reducing total amount of waste ferried to the scrap yard (open dump).

2.4 Energy recovery

Ganfer, (2011) postulates that energy recovery is the best industrial waste management strategy, after recycling and composting. The most common WTE plants involves the burning of industrial waste under controlled conditions and generate steam that is used to turn the turbines for power generation. As propounded by Ganfer, (2011) a typical WTE facility generates between 500 and 700 kWh per ton of waste combusted. The argument put forth also highlight that on average WTE reduces the volume of waste by approximately 90% hence, leaving the remaining 10% as ash. In the event that the boilers are capable of harnessing and separating the ash, fly ash can thus be used in construction for brick moulding or cement production.

Table 2.1 shows the reference values for energy, as depicted on this Table it can be noted that natural gas has the largest electricity equivalent of 1 tonne of fuel as compared to oil and coal in the same quantities. The essence of this argument thus stresses on the potential of harnessing as much energy from waste as possible. The natural gas can be harnessed from the industrial dumpsites and landfills where it generates naturally as a result of decomposition of biodegradable waste. More so arguments put forth by Jean-Guy, Rolf, Tapio, Zoltan, Hans, John and Vasco (2003) illustrates that natural gas can also be harnessed from the sewage inform of biogas. The biogas can also be used for the purpose of power generation and subsequently reduce the pressure exerted on the natural resources as gas acts as a ready substitute which can be harnessed from waste.

Table 2.1 Energy reference values for various components

1 kWh = 0,860 Mcal 1 cal = 4,1868 Joules 1 tonne of Oil = 10 000 Mcal 1 tonne of Coal = 7 000 Mcal 1 tonne of Natural Gas = 10 790 Mcal	Heat equivalent of 1 kWh 1 kWh = 86 gram Oil equivalent 1 kWh = 123 gram Coal equivalent 1 kWh = 79.7 gram Natural Gas equivalent	Electricity equivalent of 1 tonne of Fuel 1 tonne of Oil <> 11 628 kWh 1 tonne of Coal <> 8 140 kWh 1 tonne of Natural Gas <> 12 547 kWh

Source: Jean-Guy et al (2003)

2.5 Basic techniques of energy recovery

Energy maybe recovered from the organic fraction of waste (biodegradable as well as non-biodegradable) through two methods as follows:

a) **Thermo-chemical conversion**: This process entails thermal de-composition of organic matter to produce either heat energy or fuel oil or gas.

The Thermo-chemical conversion processes are useful for wastes containing high percentage of organic non-biodegradable matter and low moisture content. The main technological options under this category include Incineration and Pyrolysis/ Gasification.

b) **Bio-chemical conversion**: This process is based on enzymatic decomposition of organic matter by microbial action to produce methane gas or alcohol.

The bio-chemical conversion processes are preferred for wastes having high percentage of organic bio-degradable (putrescible) matter and high level of moisture/ water content, which aids microbial activity. The main technological options under this category is Anaerobic Digestion, also referred to as Biomethanation.

Parameters affecting Energy Recovery:

The main parameters which determine the potential of Recovery of Energy from Wastes, are:

i. Quantity of waste

ii. Physical and chemical characteristics (quality) of the waste.

The actual production of energy will depend upon specific treatment process employed, the selection of which is also critically dependent upon (apart from certain other factors described below) the above two parameters. Accurate information on the same, including % variations thereof with time (daily/ seasonal) is, therefore, of utmost importance. The important physical parameters requiring consideration include: size of constituents, density and moisture content.

2.6 Waste incineration in power plants

Energy recovery can be attained through incineration of the combustible waste products to retain the energy in waste through the transformation of energy into thermal. As postulated by Furedy, Post, and Baud (2004) waste incineration is a sound technological means that is widely used to produce electricity and heat. It is argued that the strength of this method is realised through the ability to harness energy buried in waste by transforming matter into heat energy. The delineating factor that affects and can compromise the potential for energy recovery is the amount of water in the waste that affects its energy content. If the waste is too wet, the energy that should be added for incineration will be more that the energy that is produced by incineration. In this case, the waste has negative energy value. Therefore, the dry wastes are generally passed to incineration, while the wet wastes go to anaerobic digestion.

According to Furedy *et al*(2004) by the year 2004 there were 29 incinerators in Sweden that burn about 3.82 million tons wastes and produce 13.1 kWh (kilowatt hour) of energy. The incinerator in Borås (Fig 2.1) takes about 300 tons/day wastes and burn it in two 40 MW (megawatts) incinerators and produce both electricity and heat (Furedy *et al* 2004). Energy generated in terms of kWh and MG shows the amount of energy that could be going unaccounted for by failure to embrace energy and material recovery technologies. The wastes are incinerated and make a flue gas with more than 800 ºC temperature. The energy is used to produce high pressure steam, which pass through two turbines and produces electricity. The rest of the energy (from the low pressure steam) is used to heat up warm water that takes the energy to the city by pipelines for heating the houses and also warm water of the households.

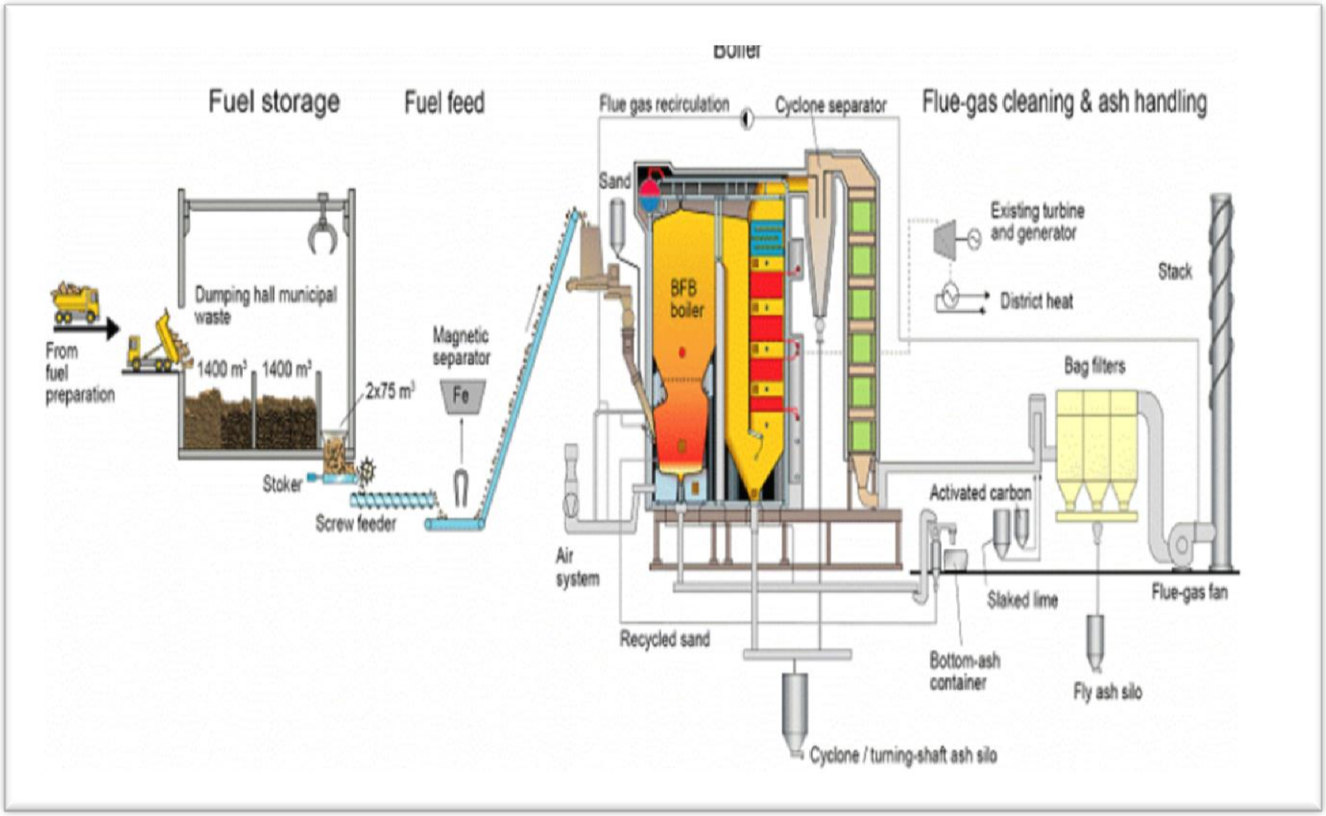

Fig 2.1 Energy recovery through waste incineration

Source: Furedy *et al* (2004)

Fig 2.1 shows the process of harnessing energy from waste through incineration. Energy recovery is achieved through harnessing combustible waste as an input for the boilers for the purpose of power generation. The combustible waste is collected into the stoker which functions as the bunker for boiler input. The collected waste then passes through the magnetic separator where metal aggregates are removed to avoid damaging the conveyors that feed the waste into the boilers. The totality of the waste is used for the firing of the boilers that in turn converts liquid into steam which is used to turn the turbines for power generation.

2.7 Energy recovery model

Waste to Energy conversion is receiving wide spread acceptance world over due to its ability to reduce volumes of waste at the same time harnessing all the energy embedded in the waste for substantial use. As stipulated by Ranade and Geeta (2011) they is a correlation between the total amounts of energy recovered from the waste and the amount of moisture in the waste. To further elaborate on this argument they propounded a model to illustrate how moisture determines the ultimate amount of energy recovered. The models vary depending on the composition of the waste weather it is dry solid waste or wet solid waste and I is only applicable where the waste is used in thermal processes. In explaining these variations Ranade and Geeta (2011) adopted the following models:

i. Waste composition

<u>*Assumptions made:*</u>

a) *Dry solid waste contributes to 30% of the total solid waste*

*Hence, dry solid waste = 0.3 x (W) =**X** Kg*

b) *Wet solid waste contributes to 70% of the total solid waste*

*Hence, wet solid waste = 0.7 x (W) = **X** Kg*

ii. Power generation from dry solid wastes

*Total solid waste generated (W) = **X** Kg*

Net Calorific value (NCV) = 900 kcal / kg

Energy recovery potential (kWh) = NCV x W x1.16 x10 3

Power generation potential (KW) = (1.16 x NCV x Wx10 3) /24

iii. Power generation from wet solid wastes

<u>*Assumptions are made*</u>:

Organic biodegradable fraction (33%) = 2899 Kg

Typical digestion efficiency (60%) = 1739 Kg

Typical biogas efficiency (B) = 0.8 x fraction destroyed= 0.8m^3 /kg of 1739 = 1391 m^3

Net Calorific value (NCV) of biogas = 5000 Kcal/ m^3

Energy recovery potential (KWh) = NCV x B x 1.16 x10^3

Power generation potential = NCV x B x 1.16 x 10^3/24 = 335.92 kW

Total energy generated = (Total Power Generated X 24)

The model demonstrates how various constituents can affect the ultimate output as derived from energy recovery. The model by Ranade and Geeta (2011) is somewhat limited as it is only applicable to energy recovery through incineration and is silent on the other methods that can be employed for energy recovery. The model however demonstrates and brings out the potential energy measured in Kilowatts (Kw) that can be attained from recovering energy embedded in waste.

2.8 Calorific values of fuels

As argued by Jean-Guy *et al* (2003) the solid, liquid and gaseous fuels used in a thermal power plants can be classified as hard coal, lignite, fuel-oils, gasoil and natural gas. These fuels contains various quantities of energy content depending with the structure and composition of components in terms of combustible materials. The combustible materials can also be extracted from decomposing waste through harvesting the gases that are produced. Gases such as methane can be produced from decomposing material as well as sewage systems and are highly combustible such that they can be used as an input in thermal power stations. Furthermore Jean-Guy *et al*(2003) postulates that the approximate Gross Calorific Value (GCV) and the Net Calorific Values (NCV) of the fuels that can be used in thermal power stations are on average as follows:

	GCV	NCV*
Heavy fuel-oil	42.6 MJ/kg (= 10,175 kcal/kg)	40.57 MJ/kg (= 9,690 kcal/kg)
Light fuel-oil	43.3 MJ/kg (= 10,342 kcal/kg)	41.2 MJ/kg (= 9,840 kcal/kg)
Burner-oil	44.1 MJ/kg (= 10,533 kcal/kg)	42.16 MJ/kg (= 10,070 kcal/kg)
Gas-oil	45.7 MJ/kg (= 10,915 kcal/kg)	43.75 MJ/kg (= 10,450 kcal/kg)
Natural gas	42.0 MJ/m^3 (=10,032 kcal/ m^3)	37.9 MJ/m^3 (= 9,052 kcal/m^3)
Hard coal	35.4 MJ/kg (=8,448 kcal/kg)	34.1 MJ/kg (=8,145 kcal/kg)
Lignite	24.0 MJ/kg (=5,732 kcal/kg)	23.0 MJ/kg (=5,493 kcal/kg)

1 calorie = 4.1868 Joules

Table 2.2 Fuel energy calorific content

Source: Jean-Guy *et al* (2003)

As shown in Table 2.2 natural gas has a GCV of 42.0MJ/m^3 which is 6.6MJ more than Hard coal which is the current input for the boilers at Hwange Power Station. The GCV for hard coal stands at approximately 35.4MJ/kg, the difference in GCV between natural gas and hard coal shows that the ability to harness natural gas for thermal power generation process is favorable in the boosting of power generation. As shown in Table 2.2 natural gas has a greater NCV as compared to hard coal and lignite and thus this gives it a leverage over the aforementioned sources of fuel. However there is strict need to have a fusion of the various types of energy so as to boost the cumulative output of power.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Research design

The research adopts a quantitative, cross-sectional design which, as postulated by Bryman and Bell (2007), which involves the collection of data on relevant variables. The independent variable in this case is the generation of waste while the dependent variable is the opportunity for energy recovery. The energy recovered is largely depended on the type and amount of waste generated. The quantitative study sought to substantiate industrial waste generation as an opportunity for energy recovery. An analysis by Babbie and Mouton (2002), values a quantitative study as an inquiry, founded on testing a principle made up of measurable variables. The variables are analyzed with the use of statistical procedures so as to determine authenticity of the predictive simplifications of the theory.

The research adopts data triangulation that is a fusion of qualitative and quantitative approach to describe what exist with respect to variables understudy. Qualitative approach will be used as it enables the researcher to have an in-depth understanding of the phenomenon under study. The research makes use of a survey method utilizing questionnaires, observation check lists and interviews to assess the challenges of industries in waste management and how the generated waste can be transformed into energy. The researcher employees a cross-sectional design, which is a fusion of a case study and experimental approach. The fusion seeks to satisfy the relationship between power generation activities, waste generation and waste reduction through energy recovery. The thrust behind employing case study approach is the desire to address to the limited time available to address various industries in the country.

3.2 Research instruments and data collection methods

3.2.1 Population

The population targeted for this research encompasses all employees directly and indirectly involved in power generation. This decision was reached after a consideration that this population is directly involved in the waste generating activities. Furthermore the identified population is also responsible in carrying out the waste management activities and thus is the source of information pertaining to the efficiency of the current waste management processes. Employees directly involved in power generation under the Operations and Maintenance departments are on the focal point for the questionnaires survey because these departments are the major custodians of waste generation and management. Management representatives such as the Engineering Manager, Section Head Risk and Quality, Chief Risk Officer and Personnel from Environmental Management Agency were also targeted as the key informants for interviews.

3.2.2 Sampling

As insinuated by Fisher (2010), sample size is largely dependent on the margin of error the researcher is willing to accept as well as the entire sample size. The research accepted an error margin of +5% as further amplified by Fisher (2015).

Calculating the Sample Size.

The research is largely reliant on Yamane's (1967) sample size formula, the formula considers two key functions, namely the confidence level and the level of precision in determination of the sample size. The formula assumes a 95% confidence level and a ±5 percent level of precision, the formula is as follows;

$$n = \frac{N}{1 + N(e)^2}$$

Where: n = sample size

N = Population size

e = Level of precision

3.2.3 Sampling Technique

The research adopted the non- probability sampling technique embracing the purposive sampling with a bid of avoiding selecting responses from the same section. As postulated by Cooper and Schindler (2014) non-probability sampling entails a situation where the subjective approach is used and renders the probability of selecting the population element unknown. Non- probability sampling techniques include but is not limited to quota sampling, convenience sampling and purposive sampling. In an endeavor to eliminate repetition and bias in data collection probability sampling was then adopted to sample the individuals for questionnaire distribution. The sampled population is a mirror of the entire phenomenon under study, and thoughtfulness was taken when selecting the population to be sampled so as to avoid at all cost bias in data collection

Sample size reflection

Thirty percent of each department was sampled randomly to satisfy a true reflection of the entire population. The selection of a 30% of the entire populace was based on Glenn and Israel (1992) `s argument that any sample 25% and above gives a true reflection of the scenario under study without ambiguity. The research administered 200 questionnaires which is approximately 30% of the entire population directly involved in the core waste generating activities. The 200 questionnaires were distributed to all section at a 30% basis.

The researcher employed purposive sampling in the distribution of questionnaires across the various sections in order to overcome the problem of distributing questionnaires to workers who work in the same section or same position with similar roles. Purposive sampling was performed with the guidance of the respective forepersons within their respective areas of jurisdictions.

3.3 Data collection methods

The research simultaneously employed the use of primary and secondary data sources, where primary data was harnessed directly from employees using questionnaires, interviews and direct field observations. Secondary data was gathered from already existing literature from related research and research alike. The thrust of using both primary and secondary data sources is to augment research findings and relate the findings to already existing literature pertaining the issue under study.

3.3.1 Primary data sources

Primary data is data that is collected through the use of surveys, meetings, focus group discussions, interviews or other methods that involve direct contact with the respondents (Sechrest 2009). Primary data collection tools used for the purpose of this research were questionnaires, interviews and direct observations. These instruments were used in the collection of data which reflects on the various types and amounts of waste being generated and the efficiency of the current waste management practices.

3.3.2 Questionnaires surveys

Questionnaires were used to gather information from both the technical and non-technical personnel to amass information on the various types of waste being generated in the various sections. The same data collection tool was also used to query the adequacy and efficiency of the current waste management practices. The research used a fusion of open ended and closed ended questions as illustrated on the questionnaire, *Appendix 1*.

The researcher self-administered questionnaires with the help of the research assistant targeting all employees, since there is no variation for waste generated in the various departments. Self-administering questionnaires was essential since it allowed employees to respond without consultation thus avoiding bias in responding.

3.3.3 Interviews

Interviews were targeted to the key informants on the waste management process and the various management personnel within the Power Station. The interview guide in *Appendix 2* was used for this research. The interview guide was structured in a way that augments the gathering of information on the challenges being faced by the organisation in industrial waste management as to identify the gap for energy recovering option. The interview was also used to gather information on the possibility and the sustainability of energy recovery through the use of waste generated.

Table 3.2: Personnel interviewed and justification for interviewing

Personnel interviewed	Justification
Engineering manager	Has information pertaining to the various challenges in waste management and also how best energy can be recovered given the available technology.
Section Head Risk	Is the custodian of environmental issues and hence will furnish the

and Quality	research with the waste status as well as the possible solutions that will enhance energy recovery.
Forepersons	These are the people responsible for the day to day running of the plant and hence are at par with the various forms of waste found within the power station.
Chief Risk Officer	Is the custodian responsible for environmental issues on a day to day basis and hence will furnish the research with possible solutions that will enhance energy recovery.
District EMA inspector.	Has an overview on the types of waste being generated at the Power Station and hence assumes an advisory role on the possibility of managing waste through energy recovery. Also furnishes with information on energy recovery.

3.3.4 Direct observations

Spring (1997) acclaims that structured observation are a fundamental way of actively finding out about the world around us. For the purpose of this study, observations were carried out so as to have a glimpse on the existing ways of waste management and the current methods of enhancing energy recovery if any exists. Observations also helped in the identification of the various types of waste being generated at Hwange Power Station. The structured observation checklist *(appendix 3)* was used to guide the researcher as well as recording the findings. To augment observations where necessary photographs were captured for presentation of evidence.

3.3.5 Secondary data sources

Secondary data as defined by Sechrest (2009) is data collected for other purposes which can be analysed and interpreted to suite the current research. Sources of this data include government records, unpublished reports, company records and government departments among others. For the purpose of this research the main source for secondary data is literature, information relevant for research alike was gathered from already existing work so as to augment the research.

3.4 Data Analysis

The scope of the research was more of a quantitative nature thus rendering the Statistical Package for Social Sciences (SPSS) the best tool for data analysis. The package is flexible as it enabled the researcher to execute various data analysis procedures. The data analysis activities performed include but were not limited to validity and reliability test, normality test and hypothesis testing.

3.4.1 Validity and Reliability Test

Internal validity is the extent to which inferences from the study can be attributed to the interventions rather than any flows in the research design (Trochim 2004; Saunders *et al*. 2009). To ensure internal validity, the questionnaire was derived from validated items derived from available literature. Nonetheless, a pilot test was also conducted to ensure that the respondents fully comprehend questionnaire in line with the study objectives.

Saunders *et al*. (2009) defines reliability as the extent to which data collection techniques or analysis procedures will yield consistent findings. Reliability in this study was measured by the Cronbach's Alpha which Trochim (2004) notes must have a coefficient greater than 0.6 to be accepTable. This test was done in line with Yin's (2009) assertion that testing reliability makes sure that if a later researcher followed the same procedures as done by an earlier researcher repeatedly, the later researcher must be able to reach the same conclusion and findings. As a result, the reliability of the items in this study was tested to ensure that they were consistently measuring the same constructs.

3.4.2 Normality Test

The Kolmogorov-Smirnov test was done on all variables under study in order to test for normality. As argued by Ghasemi & Zahediasl (2012) on a Kolmogorov-Smirnov test, a p-value greater than 0.05 shows data that is normally distributed suggesting that the sample nominated does not differ expressively from the populace under study and parametric tests can be done using the data. They further argued that on the, conversely, if the $p\text{-value} < 0.05$, then it suggests that the data is not normally. Given such scenarios the sample differs considerably from the population and this calls for the performance of non-parametric tests.

3.5 Research Limitations

The researcher encountered some hurdles as some respondents were rather uneasy and uncomforTable to release information. This predicament was realised due to the nature of business in which the industry is. With the Power Station being regarded as a national asset much of the information was considered to be confidential in their operations. The hurdle was circumvented by assuring and elaborating to respondents the fact that all information gathered was strictly for academic purposes. To further earn the respondents confidence and trust the research also elaborated that all information obtained would be treated with confidentiality and on an anonymous basis (no form of identification would be revealed).

3.6 Research Ethics and Data Credibility

According to Saunders *et al*. (2009), ethics in research ensures that no individual is harmed or suffers adverse consequences as a result of any activity during the research. The researcher accepted liability to protect the rights of the respondents by abiding to use and disseminate data collected specifically and meticulously for academic purposes only. The research was carried out in full honesty and total avoidance of deception following the research code of ethics. To satisfy the entirety on the scope and purpose of the research was disclosed so as to ensure voluntary participation in data collection. Coupled to this, the researcher worked to their best ability to ensure that the research did not cause any harm, embarrassment, stress, discomfort or pain to any of the respondents. Furthermore the researcher respected the participants' right to refuse to partake at any given stage of the research study. Guided by the research ethics the researcher ensured that all participated at the basis of anonymity and confidentiality was respected.

CHAPTER 4: PRESENTATION OF RESULTS

4.0 Introduction

The chapter is a representation of the various research findings which are presented in graphical, tabular and photographic information for easy of interpretation. The findings are however not divorced from the existing literature and hence they is a cordial relationships between the findings and what is already known.

4.1 Questionnaire response rate

Out of the 200 questionnaires that were administered, a total of 182 were successfully completed and returned in time for data compilation. However, of the 185, a sum of 5 were rendered unimportant during the data cleaning process. The 5 were rejected basing on the fact that some were half-completed, and others constituted significant outliers thus their inclusion in the analysis would somewhat compromise the authenticity of the outcomes. Resultantly the sum of the operative questionnaires for analysis purposes stood at 177.

$$\therefore \text{Responce Rate} = \frac{177}{200} = 88.5\%$$

As argued by Kiess & Bloomquist (1985), the standard acceptable response rate is 60% and above, and hence the 88.5% response rate falls within range.

4.2 Demographic Analysis

The importance of understanding the background statistics for the respondents is overemphasized by several theorists, a case in point, Cooper and Schindler (2014), who hints that demographic data can unearth salient relationships that may be present in data. Basing on this argument, it was thus found imperative to explore on a personal level, the highest level of education attained, years employed in/working with the organisation and position in organisation of the respondents. Due to the nature of the industry under study no particular attention was given to gender issues in the distribution of questionnaires as there is no correlation between gender and material and energy recovery. Furthermore the industry is generally male dominated and thus striking a balance anchoring on gender would yield biased results for the research.

4.2.1 Highest Level of education

The respondents were asked to identify their highest level of education. The outcome from the analysis is presented in Figure 4.1 below.

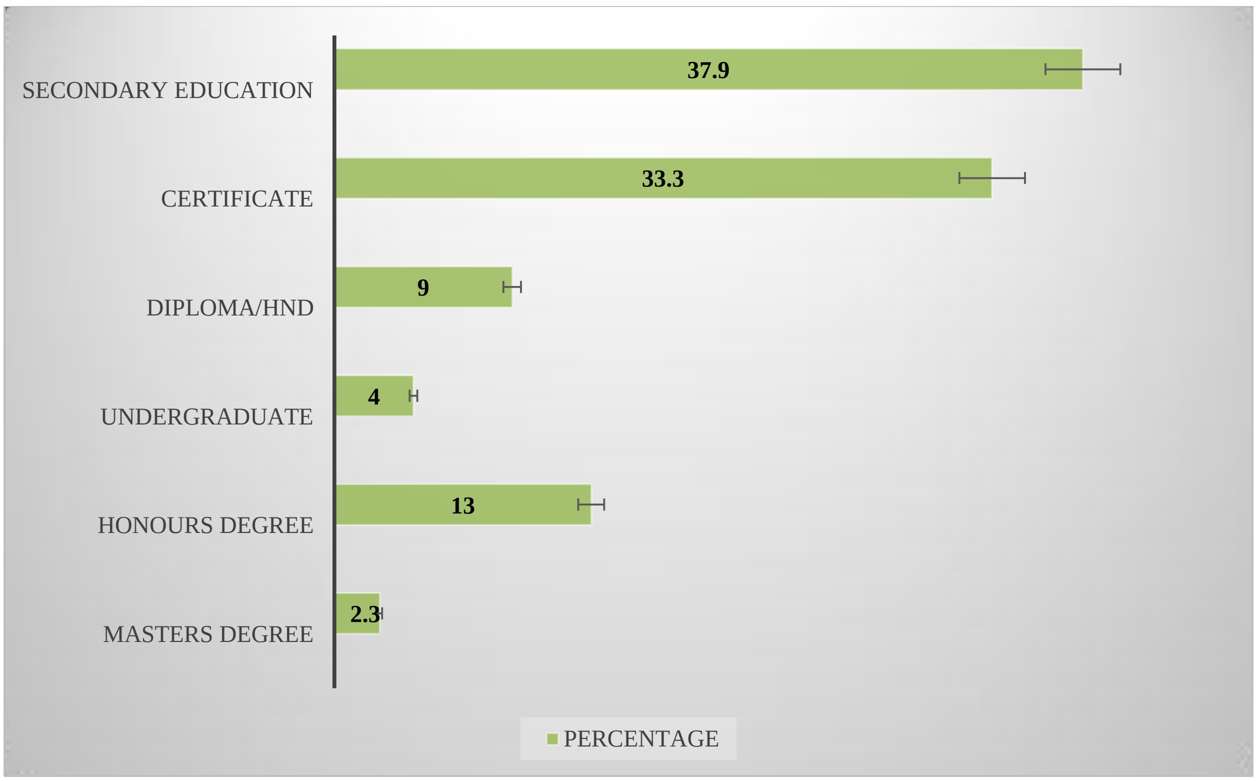

Fig 4.1: Highest Level of education attained

As depicted on the above graph the bulk of the respondents (37.9%) attained secondary education as their highest level of education, while 33.3% attained the certificate as their highest level of education. The third significant category constituted 13%, who were honors degree holders. A mere 9% of the respondents had either a Diploma or a Higher National Diploma, while 4% are undergraduates, with an insubstantial 2.3%, being holders of Masters degrees as their highest level of education. This information is paramount in determining on a generalized scope the potential of reducing waste through material and energy recovery. Sustainable waste management is largely reliant on the level of education of the proponent as education affects in a positive way the effects of waste on both the individuals and the environment. In a broad sense the majority of the respondents expressed a lot of dissatisfaction in current the methods being employed by the company in waste management. The ability to analyse the efficiency of the current methods of waste management is largely reliant on the level of education.

4.2.2 Position in organisation

The research aimed all personnel across the industry as they poses almost equal information pertaining to types of waste generated by the various operations. The outcome and the distribution of responses according to the position held within the organisation is as shown in Figure 4.2 below.

Fig 4.2: Position in organisation

As illustrated on the graph in Fig 4.2 the bulk of the questionnaires were administered to the shop floor workers which realised 138 questioners being successfully completed and responded. The trainees in their totality also responded to 23 questionnaires. The large number of trainees is also a reflection of how the organisation relies largely on the use of trainees as a ready source of labor. Top management and middle management responded to 13 and 3 questionnaires respectively. The composition of the positions held within the organisation as a reflection of the questionnaire responses presented in Fig 4.2 is paramount in identify the various types of waste generated, quantifying the monthly waste generated as well as determining the efficiency of the current waste management strategies at Hwange Power Station. The bulk of the waste is generated in the actual power generation process and thus this justifies having these as the largest representation.

4.2.3 Time served within the organisation

In order to analyse the efficiency of the current waste management practices it is paramount to have an appreciation of the number of years the respondents had been employed by the organisation. This enhanced the potential to further query on the effectiveness and efficiency of the waste management practices aboard. The findings denoting time served within the organisation are presented in Figure 4.3 below.

Fig 4.3: Years in organisation

From the above figure, it can be depicted that 31% of the respondents had been employed in the organisation for a period of between 16 and 20 years, while a comprehensive 22% has been in the organisation for 21+ years. A total of 19% of the entirety of the questionnaire responses has been within the organisation for less than 5years. Only 15% had been employed for between 11 and 15 years whilst 13% has been saving the organisation for a period of between 6 and 10 years. The time served within the organisation is paramount in determining the trends in material and energy recovery at Hwange Power Station. This information is essential in querying the efficiency of the methods being employed in waste management as well as to understand the level of understanding of material and energy recovery by the populace.

4.3 Process flow for the power generation

Fig 4.4 is a diagrammatic representation of the various processes involved in the entirety of the power generation process within the Power Station. The essence of having a glimpse of the power generation process is to give an insight of the core business and the major activities responsible for the generation of waste. The entirety of the power generation process as illustrated has several complex and minute inputs which culminates into extensive outputs. The whole process will also result in the generation of various unwanted material which Shadma, Naaz and Pandey (2010) defined as industrial waste.

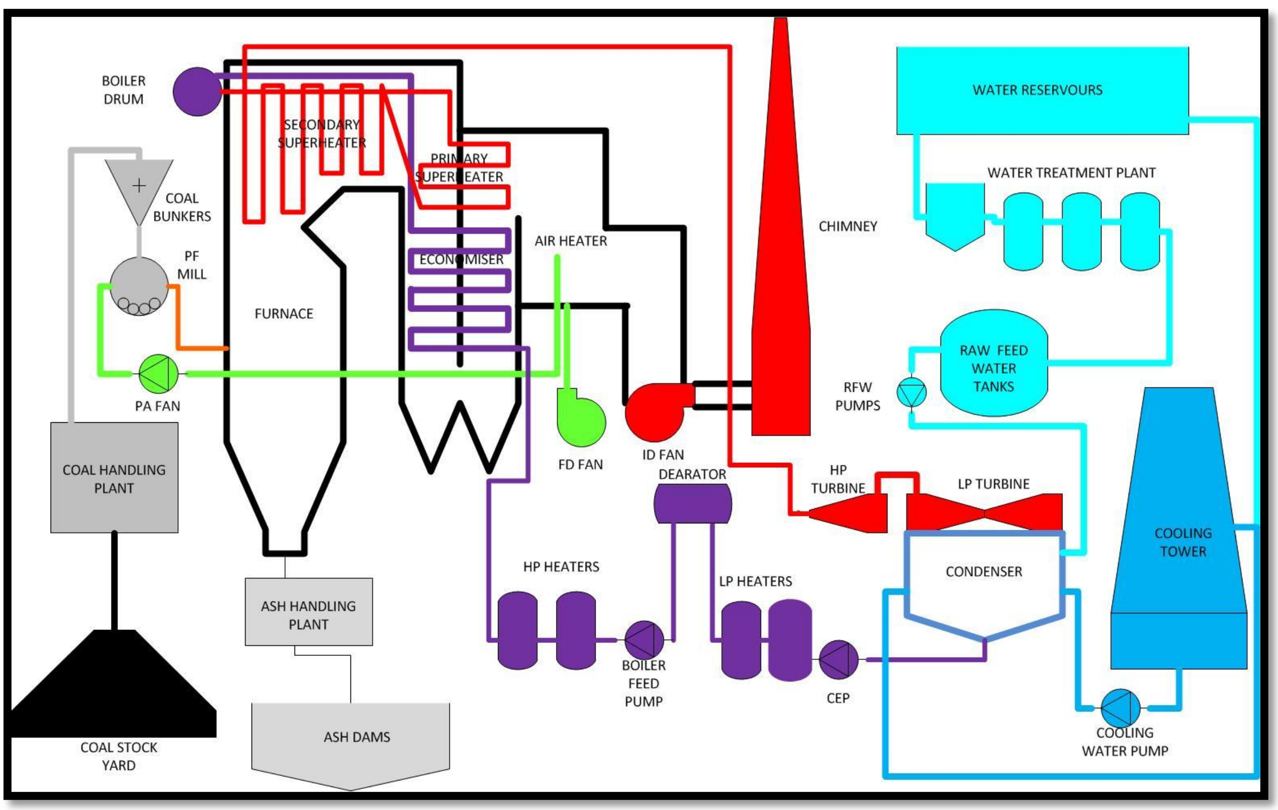

Fig. 4.4 Process flow chart for Hwange Power Station

Source: Visio (2010)

As shown in Fig 4.4 the major input for the boilers is coal and this results in the generation of ash as a byproduct of combustion. A close analysis of the entirety of the power generation process and considering the age of the plant it is also worthwhile mentioning that there is constant maintenance of the plant to ensure continuity and continual improvement. The noted cause results in the generation of high volumes of disused and decommissioned components which can be used for material recovery. The process as shown in Fig 4.4 is also responsible for the generation of liquid waste (effluent) from the boiler discharge as well as the various operations that uses water either for cooling or for cleanup. Regardless of the fact that the power generation process is more of a closed system with minor losses and leakages there is constantly replacement and lubrication of components which results in the generation of waste at various levels. Apart from the power generation process there are also activities that support but not directly involved in the power generation process. Supporting activities such as vehicle maintenance, material fabrication in workshops and the canteen works among others are also involved in the generation of large quantities of waste. The totally of the waste is quantified as industrial waste as it is generated solely as a function of the industrial activities.

4.4 The various types of waste generated

As illustrate on the process flow chart for the power generation the major input is the coal used to fire the boilers as well as water used in turning the turbines. The wholeness of the processes involved requires the use of grease and oil for lubrication and thus results in the use of a multiple number of lubricants. The processes highlighted in Fig 4.4 subsequently result in the generation of waste as classified below.

4.4.1 Effluent

Operations as highlighted in Fig 4.4 are highly mechanized and uses a lot of steam and various lubricants as earlier highlighted. The unwanted liquid waste from the power generation processes is termed effluent. Effluent at Hwange Power Station is composed of various components including but not limited to boiler effluent from the blow down activities, grease from surface cleaning and slurry from the various activities. The effluent mainly comes from the following operations:

- Boiler cleaning.

- Boiler blown down.
- Surface water wash.
- General water cleaning of plant and equipment.
- Sewage.

4.4.2 Waste oil

Waste oil is also realised in its bulkiness at Hwange power station, this goes along with Furedy Post and Baud (2004) who argues that thermal power stations makes use of various forms of oils. In their argument they further highlighted how these oils may end up polluting the environment. The bulk of the waste oil at Hwange Power Station comes from the garage since the power station runs a large fleet of vehicles and earth moving equipment. In addition oils also comes from contaminated lubrication oil which would have surpassed its live and lost its viscosity.

4.4.3 Scrape (electrical cables and metal)

As a result of wear and tear and the upgrading of structures to conform to technological upgrade Hwange Power Station ends up with large volumes of scrape. The composition of scrape is composed of metal aggregates and electrical cables harnessed from rewiring activities. The bulk of the scrape is dumped at the scrape yard (open dump)

4.4.4 Solid waste-paper, electronic waste and plastic

For the purpose of this research minute aggregates of waste were grouped together under the name of solid waste. The solid waste is composed of paper, pet bottles, plastic, polythene and kitchen waste from the canteens. All solid waste generated in the Power Station is dumped at the Hwange Collier Company dumpsite.

4.4.5 Wood aggregates and construction rubble

The bulk of the wood aggregates comes from crating and pallets used in the packaging of spares and other substances procured within the Power Station. The disposal method for these wood aggregates is mainly deposition at the local scrape yard where the wood will be exposed to all weather conditions. Little or no energy is being recovered from the wood aggregates found within the Power Station.

4.4.6 Ash

The largest amount of waste generated is found in the form of ash amassed from combustion in the boilers. The ash is dumped at the Ash dams without any alternative uses. Both bottom and fly ash is mixed and transported by water to the Ash Dams (open dumping).

4.5 Average quantity of monthly waste generated

Table 4.1 shows the average waste generated in a period of a month within Hwange Power Station. Variations may exist as depending on the activities underway, for instance during a unit outage the amount of average waste is bound to be on a high owing to an increase in the replacement of worn out material such as scrape metal. The information in Table 4.1 is an approximate generalized average volume of the monthly total volume of waste generated as due to the nature of the operation it is difficult to have precise volumes of total waste generated. The power generation activities and the maintenance of plant and equipment adopts a skewed and rather undefined paths and the activities are not routine. Furthermore some activities do not have a defined time frame and thus quantifying the waste generated to a particular month becomes difficult. Maintenance jobs can overlap thus making it rather difficult to account for the monthly waste generated.

Table 4.1 Monthly waste generated.

Type of waste	**Quantity**
Sewage.	996 000 liters
Effluent.	891 000 liters
Waste oil.	2 000 liters
Solid waste.	24 tones.
Scrape.	18 355 kilograms

Wood aggregates.	7 tones.
Construction rubble.	10 Tones.

4.5.1 Association between types of waste and energy and or material recovery.

Chi- square test was computed to query the hypothesis so as to determine the association between types of waste and energy and or material recovery from industrial waste. The formula for calculating Chi-square test is stated below;

$$X^2 = \frac{(O - E)^2}{E}$$

Where: ***O*** is the Observed Frequency in each category

E is the Expected Frequency in the corresponding category

X^2 is Chi Square

H_0 - There is no association between waste generation and energy/ material recovery.

H_1 - There is an association between waste generation and energy/ material recovery.

Table 4.2 Association between energy recovery and waste generation

Material and energy recovery	Types of waste being generated							
	Sewage	Effluent	Waste oil	Solid waste	scrape	Wood aggregates	Rubble	**Total**
Volume disposed.	996 000	891 000	2 000	24 000	18 355	7 000	10 000	1051 955
Potential recovery %	75	55	90	88	97	80	95	580
Total	996 075	89 155	2 090	24 088	18 452	7 080	10 095	**1147 035**

$$\textbf{Expected value } (E) = \frac{\textbf{row total} \times \textbf{column total}}{\textbf{Grand total}}$$

Chi-test X^2= 233.13

Degrees of freedom (df) = (no of rows -1) (number of columns -1)

= (7-1) (2-1)

df = 6

Hopkins (2002) argues that an error margin of 5% is acceptable in Social Sciences and hence 5% was considered for critical level in this research.

Critical level at 5% is 14.07

Where 3.13<14.07

If X^2 value is less than critical value accept H_1 and reject $H_{0.}$

In short there is a positive correlation between energy recovery and waste generation.

4.6 Efficiency of the current waste management strategies

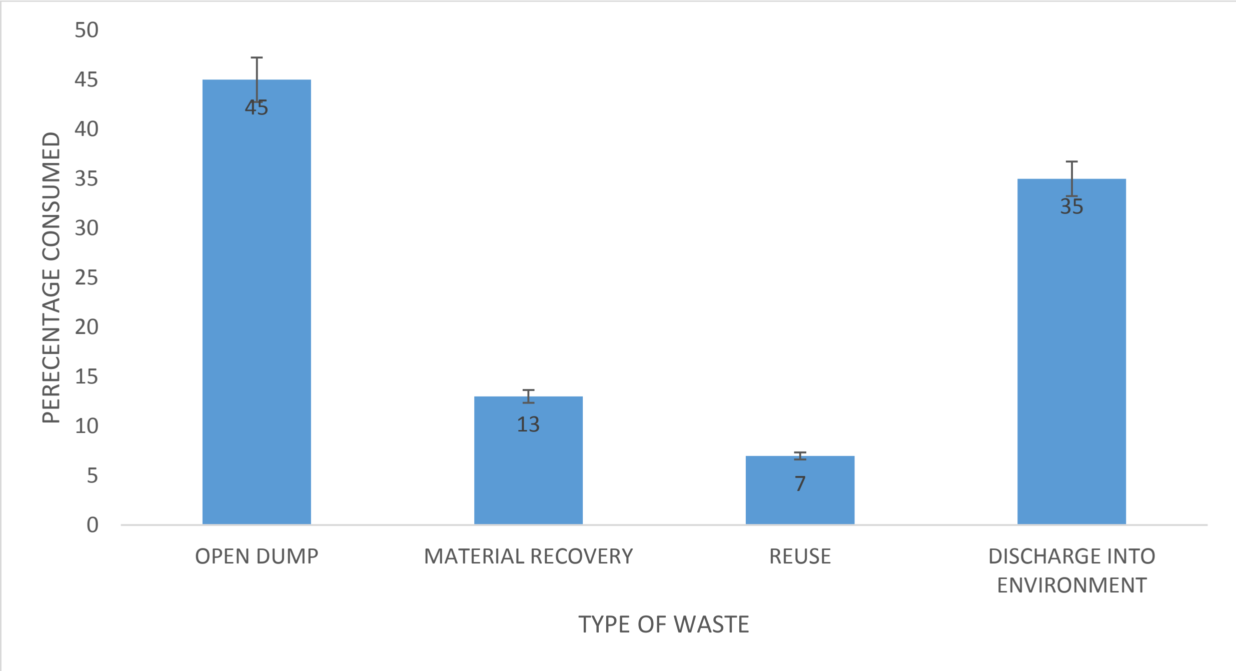

Fig. 4.5 Efficiency of current waste management strategies

As highlighted in Fig 4.5, 45% of the total waste generated at Hwange Power Station is being ferried to the open dump where no energy is recovered. Material recovery constitutes approximately 13% and this is realised from scavenging of components from the waste dump. Of the total waste generated a subsequent 35% is dumped into the natural environment either as effluent or in its solid state. The amount being reused only accounts for 7% of the totality.

The current practices somehow conflicts with what is already known in literature, as Jean-Guy *et al* (2003) pointed out the amount of energy buried in waste. As on Fig 4.5 the totality of the waste being ferried to the open dump demonstrates a gap in energy loss. From their argument natural gas accounts for approximately a GCV of 42.0MJ/m^3. The methods being employed at the Hwange Power Station does not harness any energy from the waste and only 13% is being account for as material recovery. Cumulatively of the average total waste generated at the Power Station only 13% is being put to good use through energy recovery with the remaining 87% going unaccounted for. This thus demonstrates that the methods at Hwange Power Station are ineffective in dealing with the waste generated.

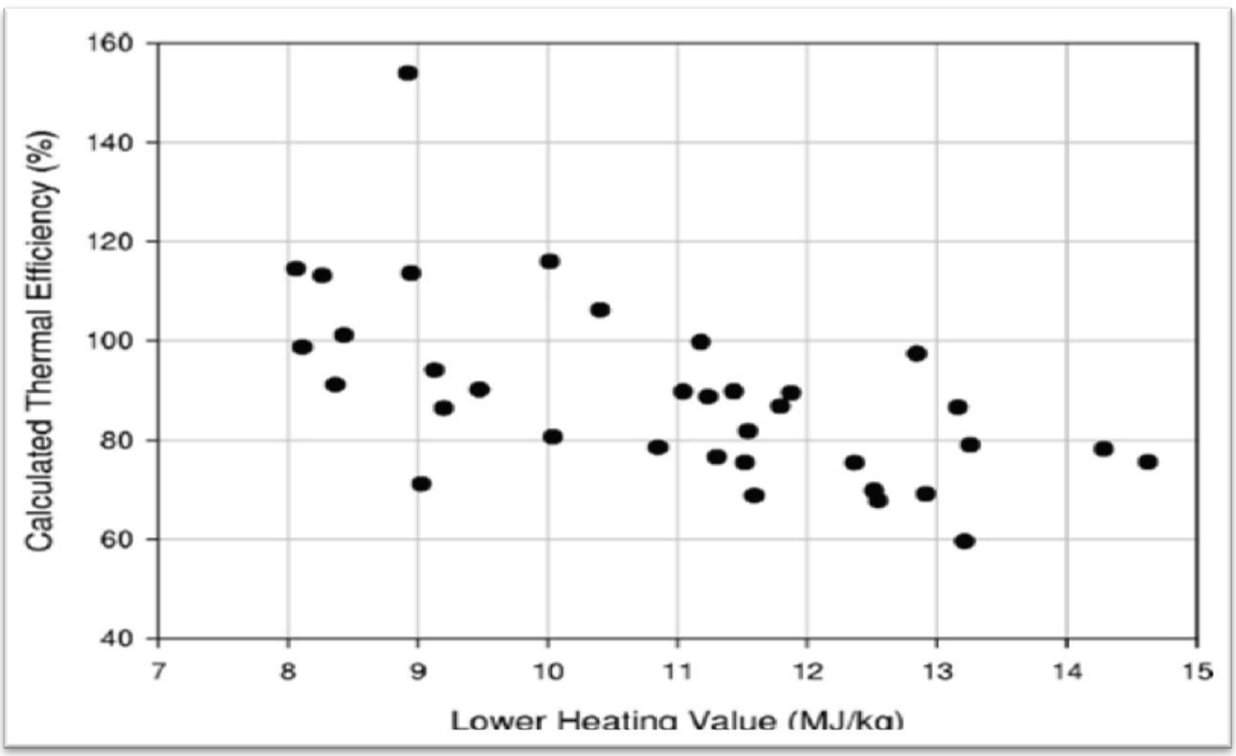

Fig 4.6 Fuel efficiencies for steam production versus Lower Heat Value in incineration
Source: Jean-Guy *et al* (2003)

As illustrated in fig 4.6 the combustion of waste converts chemical energy Lower Heat Value (LHV) into thermal energy of combustion gas at high efficiencies. The current practice at Hwange Power Station results in the emission of CH_4 from landfills (dumpsite and scrape yard), spontaneous combustion at the dumpsite releases the fossil carbon in the fuel into CO_2 and biogenic carbon. The release of these gases has a potential of causing global warming through the release of greenhouse gases into the atmosphere.

As shown in Fig 4.6 the least efficient value that can be attained from the waste conversions is approximately 60% that is harnessed from 13 MJ/Kg of LHV. The variations can be subjected to moisture contained in the waste which thus compromise on the ability to harness a higher note in thermal efficiency. The practice at Hwange Power Station does not cultivate by any means energy embedded in the waste and thus attains zero thermal efficiency. On average thermal efficiency ranges between 80 and 120 % and thus harnessing the potential energy from the waste. With the current waste management practices at Hwange Power Station, the company is missing out in potential energy buried in waste.

CHAPTER 5 : DISCUSSION OF RESULTS

5.1 Efficiency of current waste management strategies and the definitive degree of energy recovery.

Hypothesis testing was performed to determine the applicability and authenticity of the obtained results through querying the relationship between the variables under study. Broadly hypothesis testing was done to assess the efficiency of current waste management strategies at Hwange Power Station. In addition hypothesis testing was also undertaken to explore the definitive degree of waste management through material and energy recovery at Hwange Power Station.

5.1.1 Correlations

The study employed Pearson`s product moment correlation in SPSS to ascertain the strength of the relationship between the variables under study. Establishing the strength of relationship between the variables is paramount in assess the efficiency of current waste management strategies as well as exploring the definitive degree of waste management through material and energy recovery at Hwange Power Station.

Table 5.1 Pearson`s product moment correlation

		Waste generated	*Potential recovery*
Recorded	Pearson Correlation	1	.954**
	Sig. (2-tailed)		.003
	N	7	6
Potential recovery	Pearson Correlation	.954**	1
	Sig. (2-tailed)	.003	
	N	6	6

**. Correlation is significant at the 0.01 level (2-tailed).

Model Description

Model Name	MOD_1

Dependent Variable	1	Energy recovery
Equation	1	Linear
Independent Variable		Recorded
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified

Model Summary and Parameter Estimates

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Linear	.954	54.151	1	5	.001	2.971	.764

- Independent variable is total waste generated.
- Dependent Variable is energy and material recovery.

As illustrated in Table 5.1 there is a strong relationship between total waste generated and material and energy recovery with correlation significant at 0.9. As depicted from the analysis there is a strong positive correlation between the waste generated and the potential energy and material that can be recovered. Deriving from the analysis energy and material recovery is suffering as there is no attempts being made to harness energy from the waste available.

As yielded from the interviews the key informants demonstrated that the Power Station is not in any way harvesting energy embedded in waste. It was also highlighted that a lot of revenue is being lost through the inability to recover materials as the process of procuring waste goes through a cumbersome process which in turn affects the potential for material recovery

5.1.2 Regression Analysis

Table 5.2: Correlation

	Energy/ material recovery	Waste generation

Energy recovery	Pearson Correlation	1	.566**
	Sig. (2-tailed)		.000
	N	119	119
Waste generation	Pearson Correlation	.566**	1
	Sig. (2-tailed)	.000	
	N	119	119
**. Correlation is significant at the 0.01 level (2-tailed).			

The above analysis realized a correlation coefficient of 0.566, the correlation depicted was significant at the 0.000 level. According to Bryman and Bell (2007), correlation coefficients beyond 0.5 implies a high positive correlation and thus there is a strong positive correlation between energy recovery and waste generation. Therefore, it follows that there was a high correlation coefficient that was established to exist between energy recovery and waste generation.

Having established the existence of a significant correlation between waste generation and energy recovery (the dependent and independent variable), simple regression was computed so as to determine the outcome of the potential embracing of the energy recovery technology. Results of the simple regression are thus presented in Table 4.4 below.

Table 5.3: Regression Analysis of the Recovery Model Summary

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.566	.320	.328	.41361
a. Predictors: (Constant), Energy Recovery.				

Table 5.4: ANOVA analysis of the Recovery Model

Model	Sum of Squares	df	Mean Square	F	Sig.

1	Regression	4.608	2	2.304	13.468	.000[b]
	Residual	19.844	116	.171		
	Total	24.452	118			

a. Dependent Variable: Energy recovery

b. Forecasters: (Constant), Waste generation

As depicted from Tables 5.3 and 5.4, the regression coefficient for the relationship between waste generation and energy/material recovery stood at 0.566, and the corresponding r-square statistic was 0.18. The derived 18% is as a result of the material recovery being practiced at the Power Station and thus satisfy the essence of material recovery. The high residual of 87% is attributed to the failure to attain both material and energy recovery which has subsequently resulting in missing out in terms of power generation. The analysis done thus demonstrates that the company is losing a subsequent volume of potential energy as a result of failing to invest in energy and material recovery.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Energy and material recovery is crucial in industrial waste management as it has the ability to reduce waste as well as improve production in terms of power generated. Hwange Power Station is missing out on the potential to boost power output through embracing energy recovery. In addition an extended consideration of the material recovery option at Hwange Power Station will broaden the income base for the company. The income and resource base can be broadened through the adoption of material recovery which will allow for the selling useful waste to potential users and thus material recovery.

Hwange Power Station is missing out in terms of energy opportunities due to the failure to embrace material and energy recovery options. Regardless of the fact that the energy and material recovery options are not on the apex of the waste control hierarchy, these options remain vital in reducing waste as well as boosting output. More so the current practice of waste management being employed at Hwange Power Station are detrimental to the natural environment as they have a potential to cause environmental pollution. Environmental pollution is being realized from the direct disposal of effluent into Deka River. Environmental pollution is also being realized as a result of open dumping of the industrial waste. Open dumping of waste at the scrape yard as well as the open dumpsite results in the release of greenhouse gases released during decomposition.

Failure to invest in material and energy recovery by the Zimbabwe Power Company is consequently resulting in the loss of revenue by the Company. Subsequent amounts of cash are being remitted to the Environmental Management Agency (EMA) in the payment of fines for environmental pollution. The paying of vast amounts of fines for polluting the environment could be circumvented through the recovery of all the waste generated through various processes. The bulk of the fines being paid to the Environmental Management Agency are as a result of direct discharge of waste (effluent) into the natural streams and the improper handling of waste being practiced under the current waste management methods.

6.2 Recommendations

The research revealed that energy and material recovery are paramount methods of dealing with industrial waste. The aforementioned methods are capable of reducing waste as well as edifying the total output in terms of power. Energy/ material recovery is also capable of reducing the total costs incurred by the organization through the payment pollution fines. Having observed this the following is therefore being recommended:

- The management at Zimbabwe Power Company should consider investing in sustainable waste management through embracing energy and material recovery so as to circumvent costs associated with poor waste management.

- Hwange Power Station should consider adopting environmental management systems such as ISO 14001. This will go a mile in disseminating information pertaining to the effects of industrial waste at a broader scope. Environmental management systems will also help transform employee attitude towards environmental management.

- Zimbabwe Power Company should consider investing in energy recovery technology so as to boost power output from the power stations. Technologies such as the biogas power plants can be adopted so as to utilize waste from the sewages and effluent.

- The Zimbabwe Power Company should consider diversifying their line of business rather than limiting only to coal fired boilers. Diversifying in the type of input for the boilers will lessen pressure on the natural resources as waste can be used an input.

- The Environmental Management Agency should encourage sustainable industrial waste management through issuing of incentives to companies that excel in sustainable waste management.

- The Zimbabwe Power Company should also consider venturing into the establishment of Power Stations that make use of energy from the municipal waste. This will go a mile in boosting power output whilst sustainably managing both industrial and municipal waste.

Appendix 1: Questionnaire for technical and non-technical personnel

Dear Sirs

My name is Baldwin Anesu Jenya a student undertaking a MSC in Safety Health and Environmental management with the Midlands State University. This research is aimed at evaluating the effectiveness of waste minimization through material and energy recovery of industrial waste at Hwange Power Station. For this study to be a success you are being kindly requested to respond honestly and truthfully to this questionnaire. Your cooperation will be greatly appreciated and information gathered on this questionnaire will be kept confidential and used only for academic purposes.

NB. No form of identification is required on this form.

(Put ticks in the gaps provided and fill details in the spaces provided.)

Section A: Personal information

Sex: Female ☐ Male ☐

Age of Interviewee

18-20yrs		21-30yrs		31-40yrs		41-50		50+	

Marital status________________________

Level of education:

Grade 7 ☐ Advanced level ☐

Zimbabwe Junior Certificate ☐ University Graduate ☐

Ordinary Level ☐ Other ☐

Nature of occupation? ____

Section B: Waste management information

Which types of waste does your section generate as a result of the various activities you undertake?____

____

____

How does your section/department deal with the different types of waste generated from your routine activities?

____

____

____

Do you understand the impacts of this type of waste on the environment as well as on employee wellbeing?

____

____

____

Is there anyone responsible for quantifying the waste generated by either your section or the department? Yes ☐ No ☐

How frequently is the waste being quantified?

Daily ☐

Weekly ☐

Every fortnight ☐

Monthly ☐

Never ☐

If yes in question (9), do you understand the purpose of quantifying the waste generated?____

____

____

Have you partake in any waste handling training course(s) ever since you joined this company?

Yes ☐ No ☐

If yes specify____

Do you understand the purpose of the course(s)? Yes ☐ No ☐

Has the course(s) changed your attitude towards waste management in any way?

____

____

____

Do you think it is your responsibility to sustainably manage waste in your section?

Yes ☐ No ☐

Give reasons, ____

____

____

What do you thing are the challenges being faced by the organisation in ensuring sustainable (proper) waste management?

____

____

____

Do you think the waste generated by your section/department can in any way be used for energy generation? Yes ☐ No ☐

If yes to (15) which types of waste do you think can be used for this purpose?

____

____

____

In what ways do you think the organisation can benefit from the waste being generated by the various operations?

____

____

____

____

____

THANK YOU!!!

Appendix 2: Interview guide

Briefly explain the level of awareness in line with sustainable (proper) waste management?

Is there any commitment shown by the organisation to enhance sustainable (proper) waste management?

How often do you carry out environmental audits?

Are there any systems in place to ensure the achievement of sustainable waste management and energy/material recovery?

Of all the systems in place is there any system that relies on the waste output of one process as an input to the other?

Basing on your own experiences how best can be the various types of waste generated at the Power Station be used in enhancing energy and material recovery?

____
____
____
____

Additional information

____
____
____
____
____
____

Appendix 3: Observation checklist

Date: ...../…../2015 Area/Section………………….

ACTIVITY		SATISFACTORY	UNSUSTAINABLE	COMMENT
Handling of waste oil				
Disposal of waste oil				
Waste separation at source				
Waste reduction				
Reuse of waste output as input for other processes				
Waste categorisation	Hazardous			
	Non-hazardous			
	Bio-accumulative			
	Bio-degradable			
Procedure in place for waste disposal				
Waste monitoring systems.				
Evidence for sustainable waste				

management.			

Additional information

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